ANTENTOP

ANTENTOP 01 2004 # 005

ANTENTOP is *FREE* e-magazine devoted to ANTENnas Theory, Operation, and Practice

1-2004

Edited by hams for hams

In the Issue:

Practical design of HF Antennas!

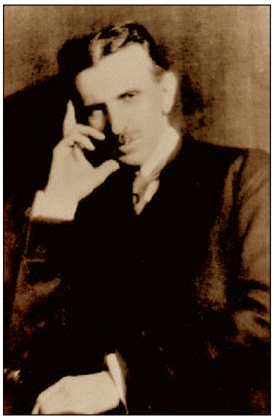
Antennas Theory!

Tesla's Life!

QRP!

And More….

Nicola Tesla



Thanks to our authors:

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And others…..

UA9JKW Helical Loop Antenna

EDITORIAL:

Well, my friends, new ANTENTOP – 01 -2004 come in! ANTENTOP is just authors' opinions in the world of amateur radio. I do not correct and re-edit yours articles, the articles are printed "as are". A little note, I am not a native English, so, of course, there are some sentence and grammatical mistakes there… Please, be indulgent!

Now ANTENTOP is sponsored by microHAM, please, visit to microHAM's site at http://www.microham.com/

I believe, you find many interesting there!

ANTENTOP 01 –2004 contains huge antenna articles, and several historical articles. Hope, you will like it. Our pages opened for all amateurs, so, you are welcome always, or as a reader or as a writer.

73! Igor Grigorov, RK3ZK

ex: UA3-117-386, UA3ZNW, UA3ZNW/UA1N, UZ3ZK
op: UK3ZAM, UK5LAP, EN1NWB, EN5QRP, EN100GM

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Welcome to ANTENTOP, FREE e - magazine!

ANTENTOP is ***FREE e- magazine***, made in **PDF**, devoted to antennas and amateur radio. Everyone may share his experience with others hams on the pages. Your opinions and articles are published without any changes, as I know, every your word has the mean.

Every issue of ANTENTOP is going to have 100 pages and this one will be paste in whole on the site. Preview's files will be removed in this case. I do not know what a term for one issue will need, may be 2-3 month or so. As I have counted, a whole issue of ANTENTOP will hold nearly 10 - 20 MB .

A little note, I am not a native English, so, of course, there are some sentence and grammatical mistakes there… Please, be indulgent!

Preview: Some articles from "cooking" issue will be pasted for preview on this site, others no. Because, as I think, it must be something mysterious in every issue.

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73! ***Igor Grigorov***, RK3ZK

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A Five Bands Vertical Trap Antenna

M. Chirkov, UL7GCC

The classical **W3DZZ** antenna in vertical installation designed by UL7GCC and shown at the **Reference 1** is well known in Russia. **Figure 1** shows the antenna. Diameter of sections A and B is 40- 50-mm. How is it work?

40-m band: The trap LC cut out the upper section B from the antenna. So only section A works as a radiator, and the section A has length in 10.1 meters, i.e. has electrical length in 1/4λ. Vertical radiator having with the length of 1/4λ has a quarter- wave resonance and works in very effectively way. At the band the circuit LC works as a **trap**.

80-m band: On the 80-m band the antenna has summary physical length of this two sections A+B a little less than 1/4λ. A + B = 16.47 meters, less then 20 meters OF quarter wave length for the 80-m band. A short vertical radiator has a capacity part in its input impedance. But the circuit LC at the 80-m range has an inductance part in its impedance. The inductance part compensates capacity part of the electrically short vertical, and the antenna has a low SWR at the 80-m range too. In other words, the inductor of the LC works as a usual lengthening spool.

10-, 15- and 20-m ranges: Visa versa, at the 10-, 15-, and 20-m the LC has a capacity part at its impedance that goes the electrical length of the antenna to 1.75λ at 10-m, to 1.25λ at 15-m and to 0.75λ at 20-m.

Do not forget, verticals like counterpoises, so use several 1/4λ counterpoises for each bands.

Reference

M. Chirkov, UL7GCC: Multi range vertical // Radio #12, 1991, p. 21.

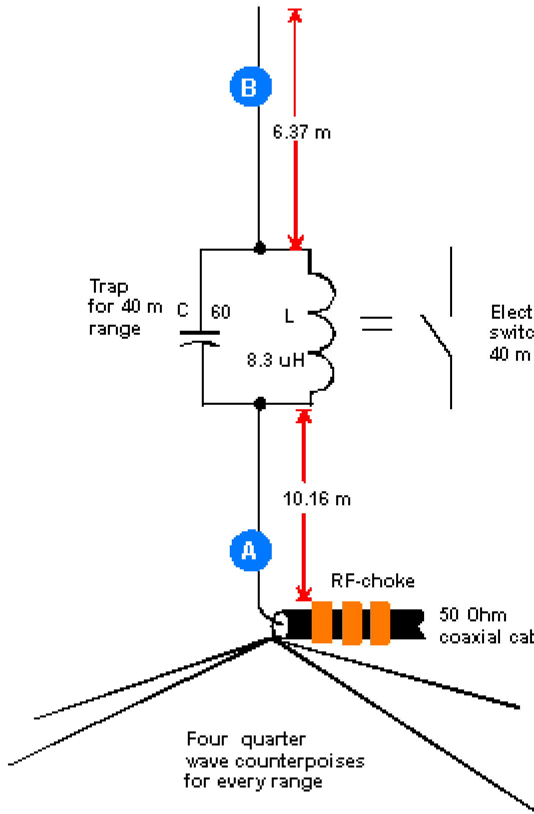


Figure 1

Feel Yourself a Student!

Dear friends, I would like to give to you an interesting and reliable antenna theory. Hours searching in the web gave me lots theoretical information about antennas. Really, at first I did not know what information to chose for ANTENTOP. Finally, I stopped on lectures “Modern Antennas in Wireless Telecommunications” written by Prof. Natalia K. Nikolova from McMaster University, Hamilton, Canada.

You ask me: Why?

Well, I have read many textbooks on Antennas, both, as in Russian as in English. So, I have the possibility to compare different textbook, and I think, that the lectures give knowledge in antenna field in great way. Here first lecture “Introduction into Antenna Study” is here. Next issues of ANTENTOP will contain some other lectures.

So, feel yourself a student! Go to Antenna Studies!

I.G.

My Friends, the above placed Intro was given at ANTENTOP- 01- 2003 to Antennas Lectures.

Now I know, that the Lecture is one of popular topics of ANTENTOP. Every Antenna Lecture was downloaded more than 1000 times!

Now I want to present to you one more very interesting Lecture - it is a Lecture about Basic Methods in Antenna Measurements. I believe, you cannot find such info anywhere for free! Very interesting and very useful info for every ham, for every radio- engineer.

So, feel yourself a student! Go to Antenna Studies!

I.G.

McMaster University Hall

Prof. Natalia K. Nikolova

Basic Methods in Antenna Measurements

The basic concepts in antenna measurements are presented in this module. First, a brief description of antenna ranges and anechoic chambers is given. Second, the basic methods for measuring the far-field patterns, the gain, the directivity, the radiation efficiency, the impedance and the polarization are discussed.

by Prof. Natalia K. Nikolova

Basic Methods in Antenna Measurements

The basic concepts in antenna measurements are presented in this module. First, a brief description of antenna ranges and anechoic chambers is given. Second, the basic methods for measuring the far-field patterns, the gain, the directivity, the radiation efficiency, the impedance and the polarization are discussed.

1. Introduction

1.1. Most of the methodology for measuring the characteristics of antennas was developed before and during World War II. The basic methods for the measurement of antenna far field patterns, antenna polarization, antenna input impedance, gain and directivity were developed during the above period in conjunction with the design of novel radiating structures, which were needed in the rapidly expanding telecommunication and radar technology.

1.2. However, it was soon understood that antenna metrology requires not only sound theoretical background to develop efficient measurement techniques but also sophisticated (and very expensive) equipment capable of providing the necessary accuracy and purity of the measured data. Commercial equipment specifically designed for antenna measurements was introduced much later (in the 1960s) due, in part, to the requirements of aerospace, space and defence industry.

1.3. The equipment specifically designed for antenna measurements includes: antenna ranges, antenna positioners, pattern recorders, signal generators, antenna gain standards, etc. Later on, sophisticated computer systems were developed to provide automated control of pattern measurements, and fast calculations related to antenna directivity, 2-D to 3-D pattern conversion, near-to-far field transformations (in compact antenna ranges), etc.

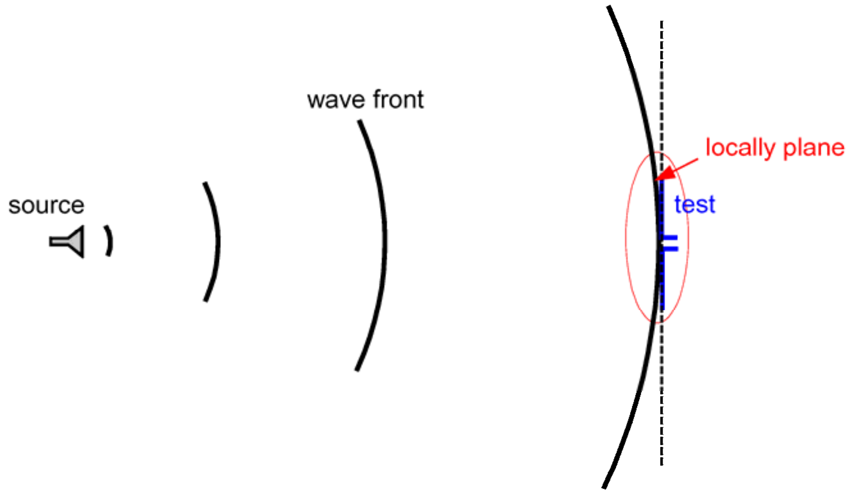
2. General requirements for antenna measurement procedures

2.1. The ideal condition for measuring the far-field characteristics of an antenna is its illumination by a *uniform plane wave*. This is a wave, which has a plane wave front with the field vectors being constant across it. For example, the electric field vector $\vec{E}$ of a uniform (non-attenuating) plane wave propagating in the $+z$ -direction is described by the general 1-D wave expression:

$$\vec{E}(z,t) = \hat{u}_e \; E_m \; f(t - z/v) \tag{1}$$

Here, $\hat{u}_e(z,t)$ describes the polarization of the $\vec{E}$ -vector, and, generally, it may depend on time and position. Notice that the $\vec{E}$ -vector does not depend on the x and y coordinates, i.e. its magnitude E_m is constant across any $x-y$ plane. The field vectors depend only on the z coordinate through the argument of the waveform $f(t-z/v)$.

2.2. In practice, antennas in 3-D space generate far fields, which are closely approximated by spherical wave fronts when the observation point is sufficiently far away from the source. However, at large distances from the source antenna, the curvature of the phase front is small over the aperture of the test antenna, and it is well approximated by a uniform plane wave.



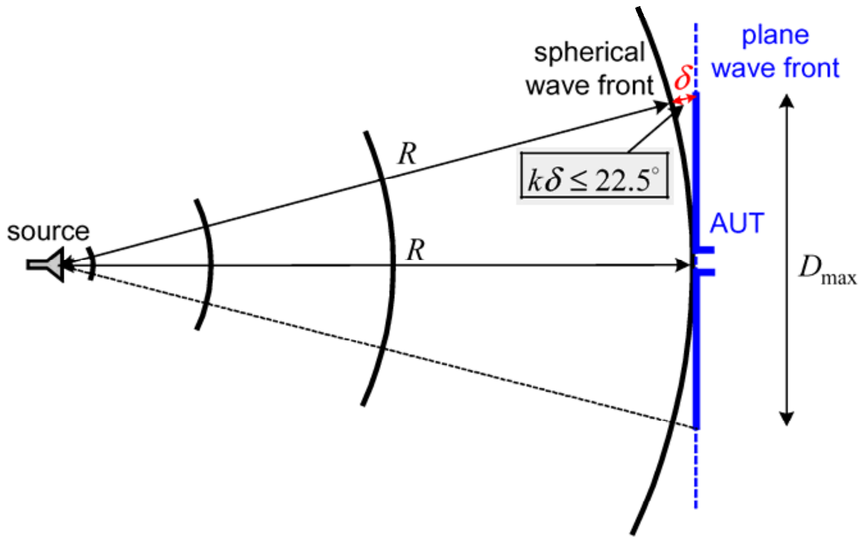
2.3. It was already shown in LO6 (6.1.6) that if the distance from the source is equal to the inner boundary of the far field region of that source, $R_{\min}^{far} = 2D_{\max}^2 / \lambda$, then the maximum phase error of the incident field from the ideal plane wave is about $e_{\max} \simeq 22.5^\circ = \pi/8$ rad. Here, $D_{\max}$ is the maximum dimension of the source antenna.

2.4. We will now show that if $D_{\max}$ is the maximum dimension of the antenna under test (AUT), a distance $R_{\min}$ from the source of a spherical wave given by

$$R_{\min} = 2D_{\max}^2 / \lambda \qquad (2)$$

will ensure that the maximum phase difference between a plane wave and the spherical wave at the aperture of the AUT is $e_{\max} \simeq 22.5^\circ = \pi/8$ rad.

2.5. Consider a source of a spherical wave and an AUT located at a distance R away from it.



The largest phase difference between the spherical wave and the plane wave appears at the edges of the AUT, which corresponds to the difference in the wave paths, δ. This phase difference must fulfil the requirement:

$$k\delta \le \pi/8 \qquad (3)$$

2.6. The difference in the wave paths, δ, is determined by noticing that

$$(R+\delta)^2 = R^2 + (D_{\max}/2)^2 \tag{4}$$

The only physical solution of the above quadratic equation for δ is:

$$\delta = \sqrt{R^2 + (D_{\max}/2)^2} - R \tag{5}$$

The above is approximated by the use of the binomial expansion (the first two terms only) as:

$$\delta = R\left[\sqrt{1+\left(\frac{D_{\max}}{2R}\right)^2} - 1\right] \simeq R\left[1+\frac{1}{2}\left(\frac{D_{\max}}{2R}\right)^2 - 1\right] = \frac{D_{\max}^2}{4R} \tag{6}$$

2.7. The minimum distance from the source of the spherical wave is now determined from the requirement in (3).

$$k\frac{D_{\max}^2}{4R} = \frac{2\pi}{\lambda}\frac{D_{\max}^2}{4R} \le \frac{\pi}{8} \tag{7}$$

Thus,

$$\boxed{R_{\min} = 2D_{\max}^2/\lambda} \tag{8}$$

2.8. The requirement for a very small wave front curvature leads to a major difficulty in antenna measurements: large separation distances are required between the source antenna and the AUT. Thus, the larger the AUT, the larger measurement site is required. While the size of the site may not be a problem, securing its reflection-free, noise-free, and EM interference-free environment is extremely difficult.

2.9. Special attention must be paid to minimizing unwanted reflections from nearby objects (equipment, personnel, buildings), from the ground or the walls of the site. This makes the open sites for antenna measurements (open ranges) a very rare commodity since they have to provide free-space propagation. Such ideal conditions are found only in unpopulated (desert) areas of predominantly flat terrain. The other alternative is offered by indoor chambers, which minimize reflections by special wall lining with RF/microwave absorbing material. They are very much preferred to open ranges because of their clean and controlled environment. Unfortunately, they are very expensive and often they cannot accommodate large antennas.

2.10. There are cases in which the antenna operates in a very specific environment (mounted on an aircraft, mobile system, etc.). In such cases, it is better to measure the antenna as it is mounted, i.e., in its own environment. Such measurements are very specific and often cannot be performed in indoor chambers (anechoic chambers).

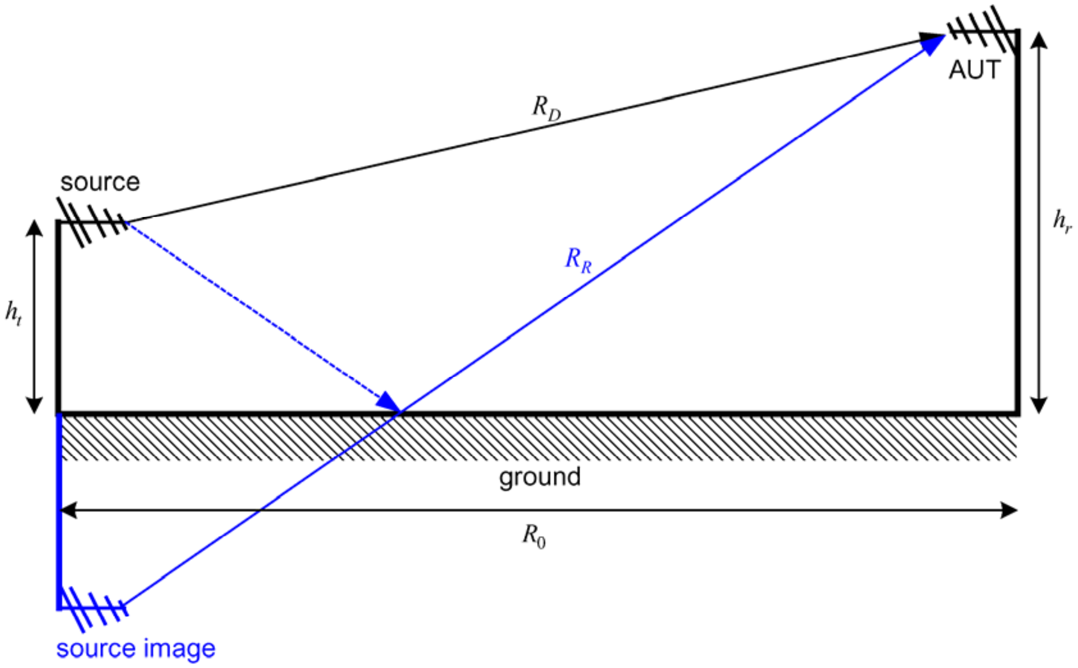
2.11. Here is a summary of the drawbacks associated with experimental antenna investigations (antenna measurements).

- They are affected by unwanted reflections.
- Often, they require too large separation distances.
- They are very complicated when a whole antenna system (on-craft mounted antenna) is to be measured.
- Outdoor measuring sites provide uncontrollable EM environment, which besides all depends on the weather.
- Indoor measuring sites cannot accommodate large antenna systems.
- Antenna measurement technology is very expensive.

3. Antenna ranges (AR)

3.1. The facilities for antenna measurements are called *antenna ranges* (AR). They can be categorized as outdoor ranges and indoor ranges (anechoic chambers). According to the principle of measurement, they can be also categorized as: reflection ranges, free-space ranges, and compact ranges.

3.2. The reflection ranges are designed so that the reflection (usually from ground) is used to create constructive interference and a uniform wave front in the region of the AUT. Such a region is called the “quite zone”. Reflection ranges are usually of the outdoor type. They are used to measure antennas of moderately broad patterns operating in the UHF frequency bands (500-1000 MHz).



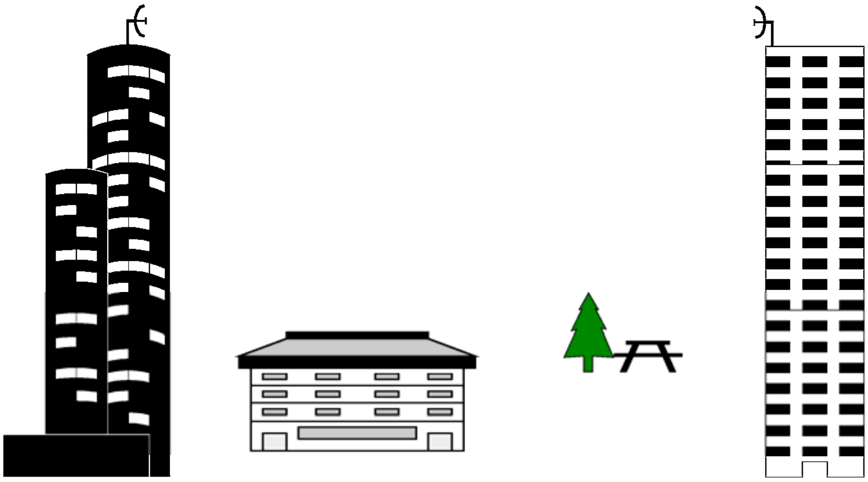
3.3. The design of reflection ranges is rather complicated and depends on the reflection coefficient of the ground (the range's surface), its smoothness, as well as the pattern of the source antenna. The main parameter to be determined is the height of the mast, on which the AUT is to be mounted h_r, provided that the height of the transmitting antenna h_t is known. Detailed information is provided in

L.H. Hemming and R.A. Heaton, "Antenna gain calibration on a ground reflection range," *IEEE Trans. on Antennas and Propagation*, vol. AP-21, pp. 532-537, July 1977.

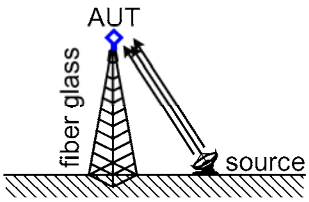
3.4. The free-space ranges provide reflection-free propagation of the EM waves. They can be outdoor or indoor. ***Outdoor free-space ranges*** are carefully built in such a way that reflections from buildings and other objects are minimized. Outdoor free-space ranges can be realized as *elevated ranges* and *slant ranges*. ***Indoor ranges*** suppress reflections (echoes) by lining the walls, the floor and the ceiling with special RF/microwave absorbers. The indoor free-space ranges are called *anechoic chambers*.

3.5. The elevated ranges are characterized by the following features:

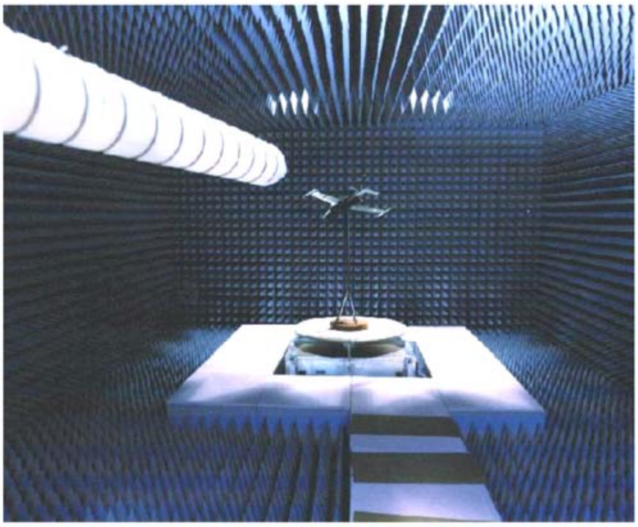
- Both antennas (the transmitting and the receiving) are mounted on high towers or buildings.
- The terrain beneath is smooth.
- The source antenna has very low side lobes so that practically there is no energy directed toward the surface below (the ground) or the buildings behind.
- The line-of-sight is always clear.



3.6. The slant ranges use up less space than the elevated ranges. The test antenna is mounted at a fixed height on a non-conducting tower (e.g. made of fiber glass), while the source antenna is mounted near the ground. The source antenna must have its pattern null pointed toward ground. It is desirable that it has very low side lobes, too. Slant ranges still require wide open space to minimize reflections from surrounding buildings.



3.7. The anechoic chambers are the most popular antenna measurement sites especially in the microwave frequency range. They provide convenience and controlled EM environment. However, they are very expensive and complex facilities. An anechoic chamber is typically a large room whose walls, floor and ceiling are first EM isolated by steel sheets. In effect, it is a huge Faraday cage, which provides ideal security against outer EM noise and interference. Besides, all inner surfaces of the chamber are lined with RF/microwave absorbers. An anechoic chamber is shown in the figure below.

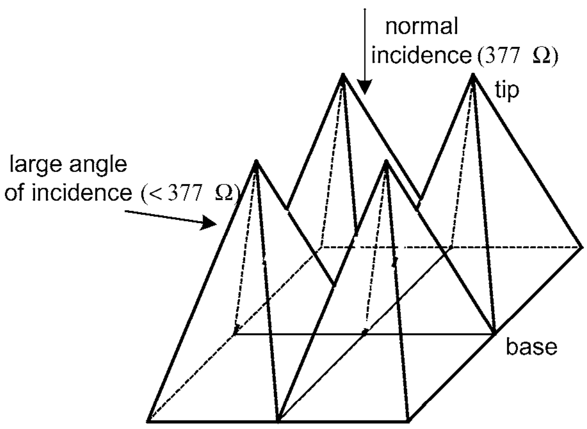


3.8. The first EM wave absorbers were developed during World War II in both US and German laboratories. The manufacturing of anechoic chambers became possible after RF/microwave absorbing materials with improved characteristics had become commercially available. The first broad band absorbers were made of a material called hairflex. Hairflex was made of animal fibres sprayed with (or dipped in) conducting carbon in neoprene. A historical summary of the development of EM wave absorbing materials is given by Emerson in his paper:

W.H. Emerson, "Electromagnetic wave absorbers and anechoic chambers through the years," *IEEE Trans. on Antennas and Propagation*, vol. AP-21, pp. 484-489, July 1973.

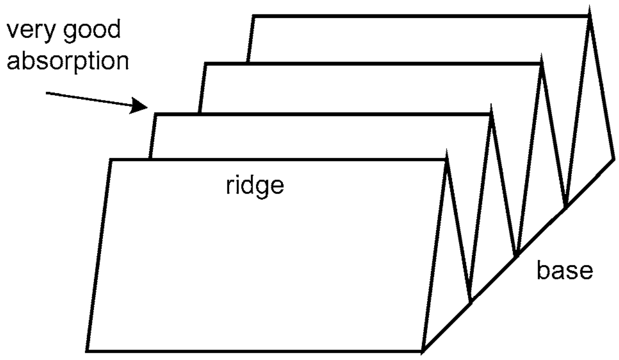
3.9. Nowadays, absorbing elements are with much improved characteristics providing reflection coefficients as low as –50 dB at normal incidence for a thickness of about four wavelengths. Reflection increases as the angle of incidence increases. For example, a typical reflection of –25 dB is related to an angle of incidence of about 70 degrees.

3.10. A typical absorbing element has the form of a pyramid or a wedge. Pyramids are designed to absorb best the waves at normal (nose-on) incidence, while they do not perform very well at large angles of incidence. They act, in effect, as a tapered impedance transition for normal incidence of the EM wave from the intrinsic impedance of 377 Ω to the short of the chamber's wall. Their resistance gradually decreases as the pyramid's cross-section increases.



Pyramids

3.11. Wedges, on the other hand, perform much better than pyramids for waves, which travel nearly parallel to their ridges.



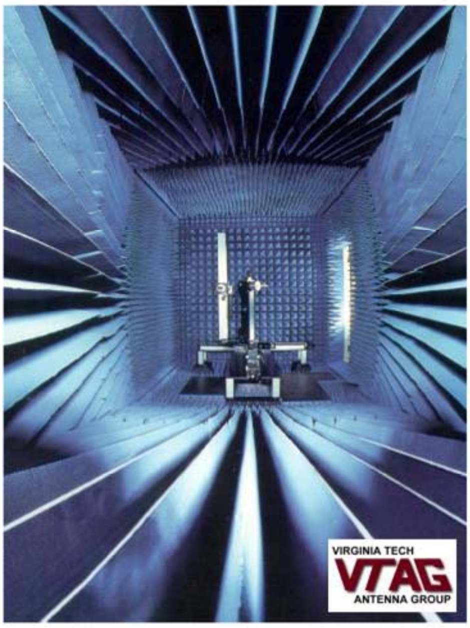
Wedges

For more detailed information on absorbing materials and shapes see:

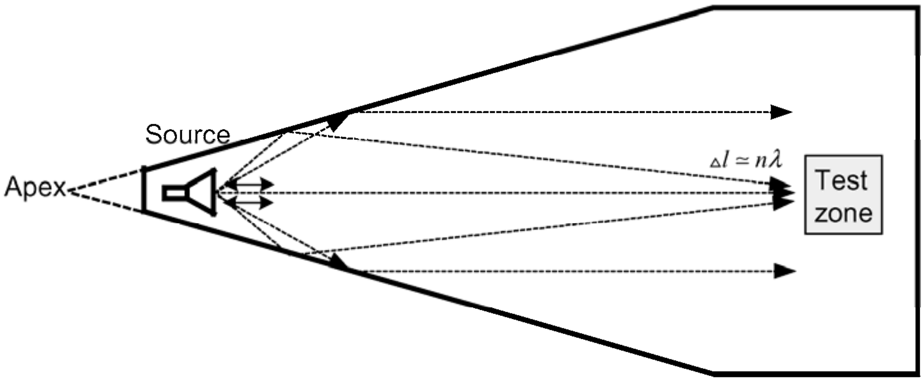
John Kraus, *Antennas*, 2nd edition, McGraw-Hill, Inc.

B.T. DeWitt and W.D. Burnside, "Electromagnetic scattering by pyramidal and wedge absorber," *IEEE Trans. on Antennas and Propagation*, 1988.

An anechoic chamber lined with both types of absorbing shapes is shown below.

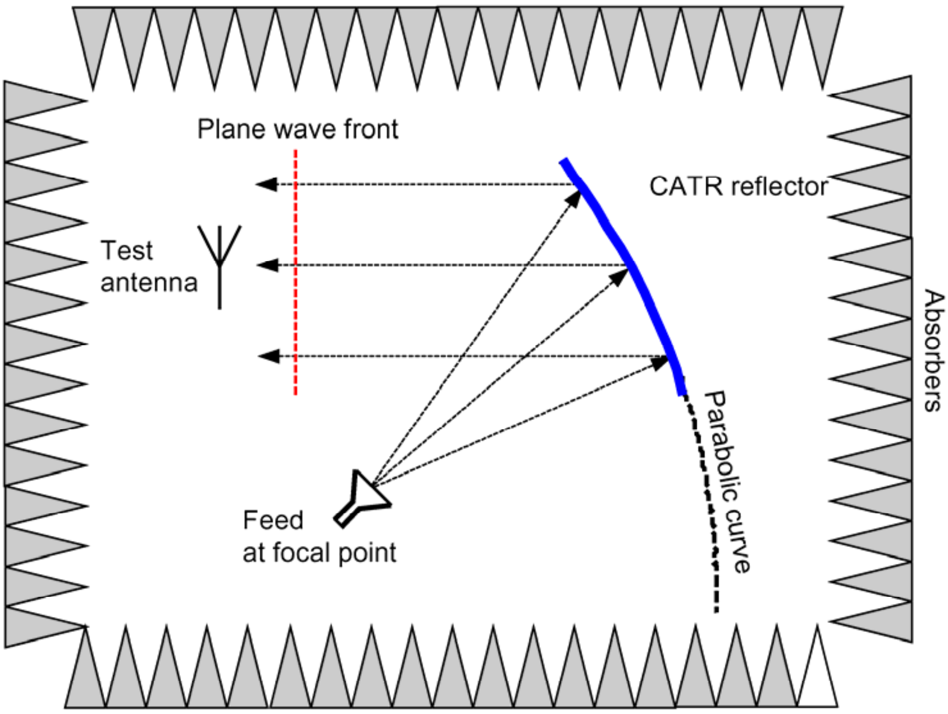


3.12. There are two types of anechoic chamber designs: rectangular chambers and tapered chambers. The design of both chamber types is based on geometrical optics considerations, whose goal is to minimize the amplitude and phase ripples in the test zone (the quiet zone), which are due to the imperfect absorption by the wall lining. The tapered chamber has the advantage of tuning by moving the source antenna closer to (at higher frequencies) or further from (at lower frequencies) the apex of the taper. Thus, the reflected rays are adjusted to produce nearly constructive interference with the direct rays at the test location.



3.13. Simple anechoic chambers are limited by the distance requirements of the far-field measurements of large antennas or scatterers. There are two basic approaches to overcome this limitation. One is presented by the Compact Antenna Test Ranges (CATRs), which produce a nearly uniform plane wave in a very short distance via a system of reflectors (or a single paraboloidal reflector). Another approach is presented by techniques based on near-to-far field transformation, where the measurements are performed in the near-field zone or in the Frennel zone of the AUT.

3.14. The Compact Antenna Test Range (CATR) utilizes a precision paraboloidal antenna to collimate the energy of a primary feed antenna in a short distance (about 10 to 20 m). Typical arrangement of a compact range is as shown below.



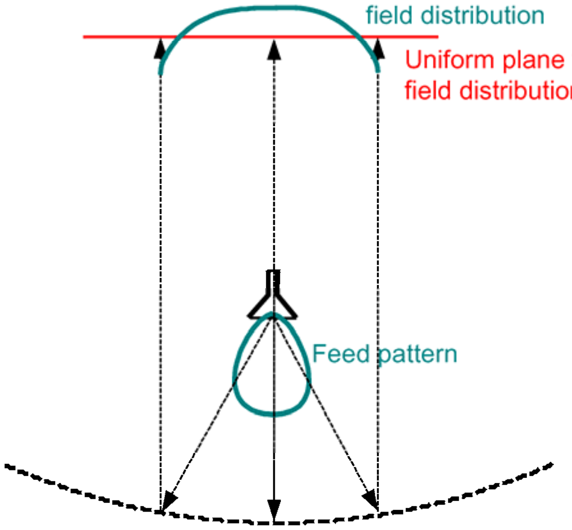
3.15. The linear dimensions of the reflector must be at least three to four times those of the test antenna in order the illumination of the test antenna to sufficiently approximate a uniform plane wave. An offset feed is used for the reflector to prevent aperture blockage and to reduce the diffraction from the primary feed structure. The paraboloidal reflector surface must be fabricated with very high precision to obtain fairly uniform amplitude distribution of the incident field at the test antenna.

3.16. A perfect plane wave is produced by the CATR if the paraboloidal reflector has a perfect surface, infinite size, and if the feed is a point source with a pattern to ideally compensate for the space attenuation. Of course, such ideal conditions cannot be achieved, and the field distribution in a real

CATR deviates from the uniform plane wave. However, it is within acceptable parameters in the so called “quite zone”, which is also the test zone, where the AUT is positioned.

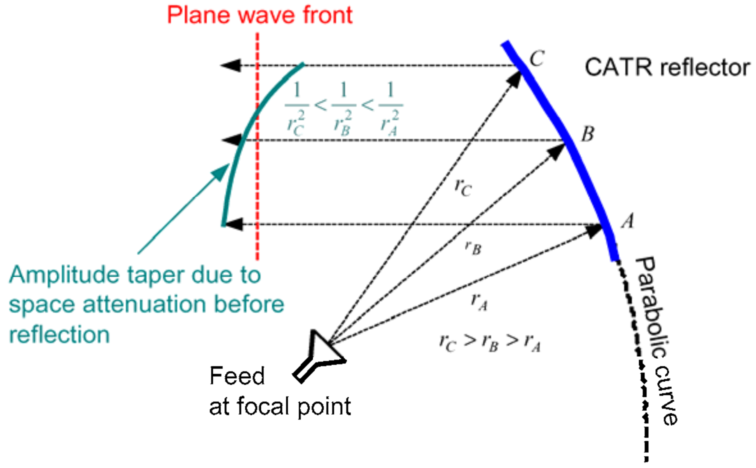
3.17. The quiet zone is typically 50-60% the size of the reflector. The imperfections of the field in the quiet zone are measured in terms of phase errors, ripple amplitude deviations, and taper amplitude deviations. Acceptable deviations for most CATRs are: less than 10% phase error, less than 1dB ripple and taper amplitude deviations.

3.18. Amplitude taper in the quiet zone is attributed to two sources: the primary feed pattern and the space attenuation. The primary feed is not isotropic; therefore, its pattern has certain variation with direction. Usually, the pattern gradually decreases as the directional angles point away from the antenna’s axis. This is called the feed amplitude taper. That portion of the feed pattern, which illuminates the CATR surface, is directly transferred into the quiet zone, thus contributing to the field amplitude taper deviation from the ideal uniform plane wave.

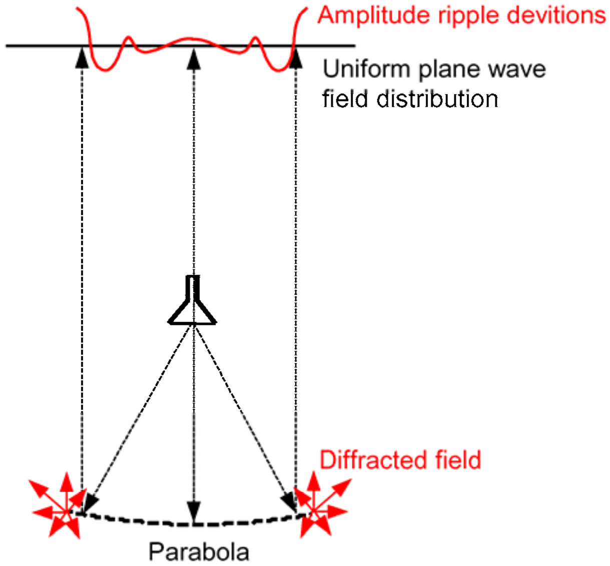


3.19. It is obvious that if the feed pattern is nearly isotropic for the angles illuminating the reflector, the feed amplitude taper will be very small. That is why low-directivity antennas are preferred as feeds. However, the feed cannot be omnidirectional because direct illumination of the AUT by the primary feed is unacceptable. The careful choice of the feed antenna and its location is of paramount importance for the CATR design.

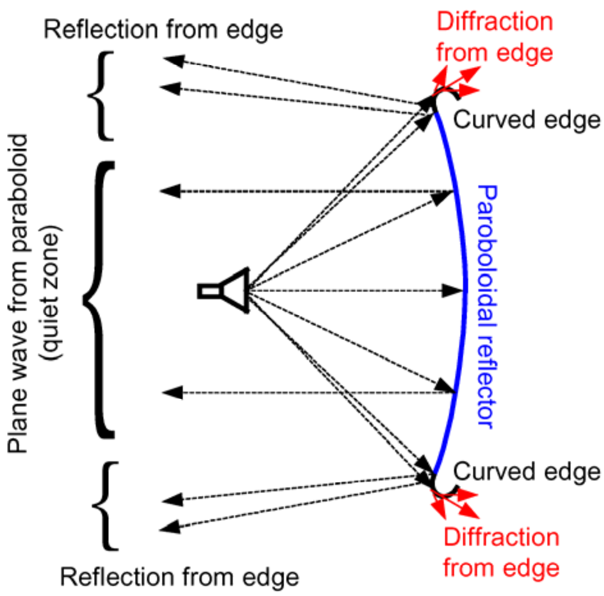
3.20. The $1/r^2$ space attenuation occurs with the spherical spreading of the uncollimated energy radiated by the primary feed towards the reflector. The paths of these primary EM rays from the feed to the reflector are of different lengths, which results in different amplitude across the front of the reflected collimated EM wave. This is yet another reason for amplitude taper deviations in the quiet zone.



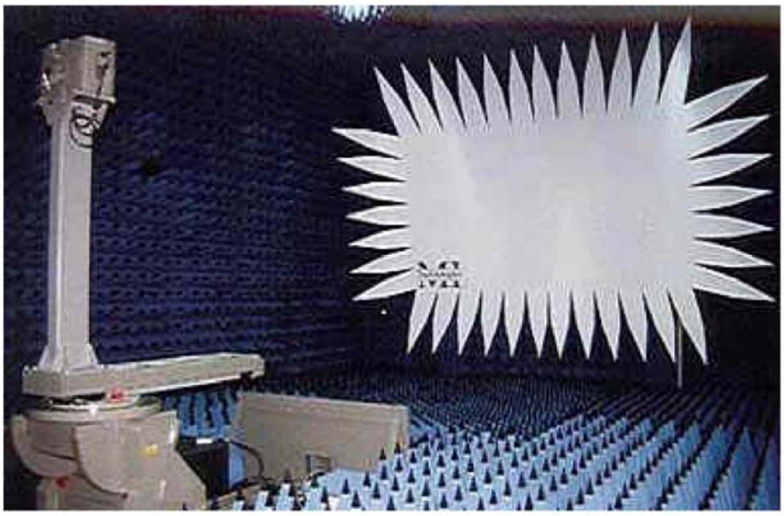
3.21. Amplitude and phase ripples in the quiet zone are primarily caused by diffraction from the edges of the reflector. The diffracted field is spread in all directions interfering with the major reflected field in constructive and destructive patterns. The result is the appearance of maxima and minima of the field amplitude across the plane wave front in the quiet zone. Diffraction from edges causes deviation of the phase of the plane wave, too.



3.22. There are two popular ways to reduce diffraction from reflector edges: serrated-edge reflectors and rolled-edge reflectors. Rolled-edge modifications at the edge of the reflector are introduced to direct the diffracted field mainly to the side and the back of the reflector.



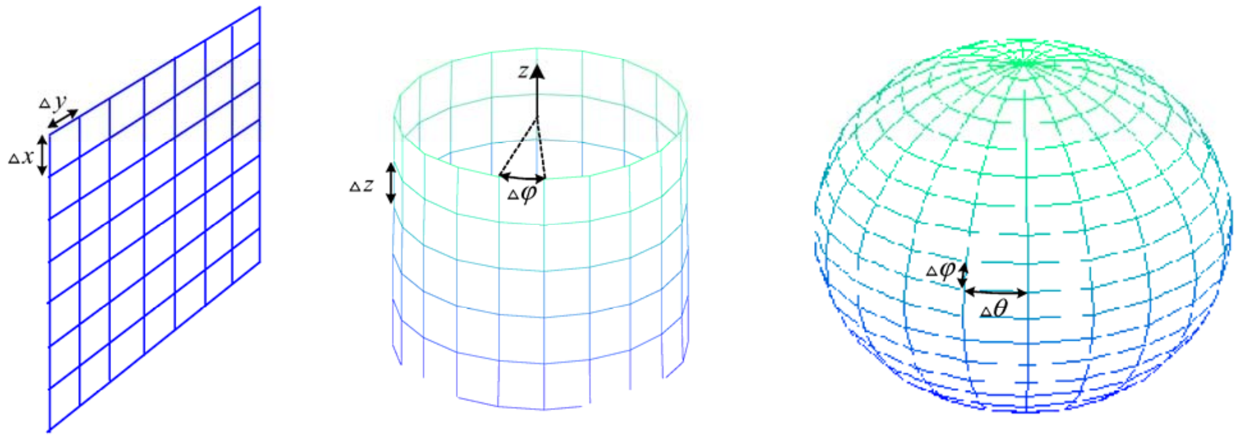
3.23. Serrated edges of reflectors produce multiple low-amplitude diffractions, which are randomized in amplitude, phase and polarization. That is why the probability of their cancellation in any point of the quiet zone is high. Serrations are typically of irregular triangular shape. To further reduce the diffraction in the direction of the test zone, the serrated edges may be also rolled backwards. A photograph of a compact range whose reflector has serrated edges is shown below.



3.24. Another modern approach for measuring far-field patterns, which allows for the most compact chambers, is the near-field/far-field (NF/FF) method. The field amplitude, phase and polarization are measured in the near field of the AUT, which is in radiating mode. The near-field data is transformed to far-field patterns via analytical techniques implemented in the sophisticated software run by an automated computer system, which controls the measurement procedure.

3.25. The magnitude and phase of the tangential electric field are measured at regular intervals over a well-defined surface: a plane, a cylinder, or a sphere, located close to the AUT. The sampled E-field data is used to calculate the angular spectrum of plane, cylindrical or spherical waves, which matches closely the radiated field angular distribution. This is called ***modal expansion*** of the radiated field.

3.26. In principle, the measurement can be done over a surface, which can be defined in any of the six orthogonal-vector coordinate systems: rectangular, cylindrical (circular-cylindrical), spherical, elliptic-cylindrical, parabolic-cylindrical, and conical. However, only the first three are deemed convenient for data acquisition, and of them, of course, the simplest one from technological point of view is the planar surface. The field is measured at the nodes of the mesh of the respective surface (see the figure below).



3.27. Here, we will consider the simplest data acquisition over a planar surface and its modal expansion. At this point, we will not discuss in detail Fourier transforms in antenna theory. It should suffice to state that ***the far-field radiation pattern of any aperture (surface) is the Fourier transform of the aperture field distribution***. We will now show the formulas associated with this statement in the simplest case of a planar aperture.

3.28. Assume that in the near-field measurements, the E-vector is being measured over a planar surface, which is our aperture. According to the ***equivalence principle***, we can now assume that the field behind the surface (on the side of the antenna) is equal to zero, and its impact on the field on the other side of the surface is due to equivalent surface currents defined at the surface as:

$$\vec{J}_s = \hat{n}\times\vec{H}_a$$
$$\vec{M}_s = -\hat{n}\times\vec{E}_a \qquad (9)$$

Here, $\vec{E}_a$ and $\vec{H}_a$ represent the field vectors at the aperture (the surface) created by the antenna behind it. $\vec{J}_s$ is the equivalent electric current density, $\vec{M}_s$ is the equivalent magnetic current density, and $\hat{n}$ is the surface unit normal pointing toward the region of observation (away from the antenna).

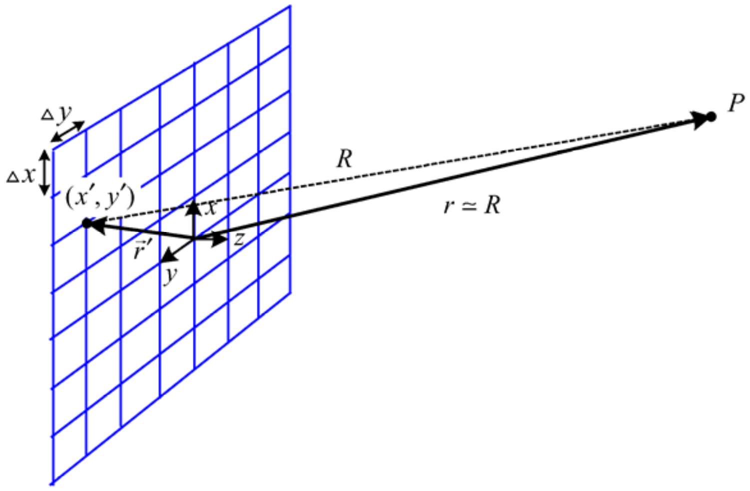
3.28. Since the field behind the plane surface is now set to zero, we can as well assume that the medium behind the surface is a perfect conductor. In the case of a flat surface, whose size is much larger than a wavelength, the image theory can be applied. Now, the equivalent surface sources become:

$$\vec{J}_s = 0;\ \vec{M}_s = -\hat{n}\times(2\vec{E}_a) \qquad (10)$$

3.29. The equivalent surface magnetic currents $\vec{M}_s$ create an electric vector potential $\vec{F}$, which, in the far zone, is calculated as:

$$\vec{F}(P) \simeq -\varepsilon\frac{e^{-jkr}}{4\pi r}\hat{n}\times\iint_{S_a} 2\vec{E}_a(\vec{r}')e^{j\vec{k}\cdot\vec{r}'}ds' = -\varepsilon\frac{e^{-jkr}}{2\pi r}\hat{n}\times\iint_{S_a}\vec{E}_a(\vec{r}')e^{j\vec{k}\cdot\vec{r}'}ds' \qquad (11)$$

Here, $\vec{r}' = \hat{x}\ x' + \hat{y}\ y'$ is the position vector of the integration point, and r is the distance from the observation point P to the origin.



3.30. Note that the far-field approximations have been applied (see module LO6) to the amplitude and the phase term of the vector potential integral. The propagation vector $\vec{k} = k\hat{r}$ shows the direction of propagation, and has a magnitude equal to the wave number $k = \omega\sqrt{\mu\varepsilon}$. The scalar product $\vec{k}\cdot\vec{r}'$ yields the familiar phase term $\vec{k}\cdot\vec{r}' = kr'\cos\theta$, which in the case of z -oriented wire antennas becomes $\vec{k}\cdot\vec{r}' = kz'\cos\theta$ (see LO6).

3.31. We now remember that the far-field E-vector is related to the far-field electric vector potential as (see Module 3, equation (3.60)):

$$\vec{E}^{far} = -j\omega\eta\vec{F}\times\hat{r} \tag{12}$$

Here, $\eta = \sqrt{\mu/\varepsilon}$ is the intrinsic impedance of the medium of propagation. Substituting (11) in (12) yields:

$$\vec{E}^{far} \simeq -jk\frac{e^{-jkr}}{2\pi r}\hat{r}\times\iint_{S_a}(\hat{n}\times\vec{E}_a)e^{j\vec{k}\cdot\vec{r}'}dx'dy' \tag{13}$$

3.32. In the case of a planar surface, its unit normal is constant, and we can assume that $\hat{n}\equiv\hat{z}$. Having in mind that the radial unit vector in rectangular coordinates is:

$$\hat{r} = \hat{x}\sin\theta\cos\varphi + \hat{y}\sin\theta\sin\varphi + \hat{z}\cos\theta \text{ ,} \tag{14}$$

one can calculate the x and y components of $\vec{E}^{far}$ as:

$$E_x^{far} \simeq jk\frac{e^{-jkr}}{2\pi r}\cdot\cos\theta\cdot\iint_{S_a}E_{xa}(x',y')e^{j(k_x x'+k_y y')}dx'dy' \tag{15}$$

$$E_y^{far} \simeq jk\frac{e^{-jkr}}{2\pi r}\cdot\cos\theta\cdot\iint_{S_a}E_{ya}(x',y')e^{j(k_x x'+k_y y')}dx'dy' \tag{16}$$

3.33. The z -component of the far E-field is found as:

$$E_z^{far} \simeq -jk\frac{e^{-jkr}}{2\pi r}\cdot\sin\theta\cdot\left[\cos\varphi\iint_{S_a}E_{xa}(x',y')e^{j(k_x x'+k_y y')}dx'dy' + \sin\varphi\iint_{S_a}E_{ya}(x',y')e^{j(k_x x'+k_y y')}dx'dy'\right] \tag{17}$$

It is obvious from (15), (16) and (17) that if the components E_x^{far} and E_y^{far} are known, the E_z^{far} component can be calculated from them as:

$$E_z^{far} = -\tan\theta\left[E_x^{far}\cos\varphi + E_y^{far}\sin\varphi\right] \tag{18}$$

3.34. Let us pay more attention to the integrals appearing in equations (15) and (16):

$$f_x(k_x,k_y) = \iint_S E_{xa}(x',y')e^{j(k_x x'+k_y y')}dx'dy' \tag{19}$$

$$f_y(k_x,k_y) = \iint_{S_a} E_{ya}(x',y') e^{j(k_x x' + k_y y')} dx'dy' \qquad (20)$$

These integrals are nothing else but the double Fourier transforms of the field components' distribution over the area of the surface S_a, where the tangential E-field components are being measured. The surface is assumed infinite ($-\infty < x' < +\infty$, $-\infty < y' < +\infty$) although the field components may have zero values outside a given aperture.

3.35. The functions f_x and f_y depend on the spectral variables k_x and k_y, which are the components of the propagation vector $\vec{k} = k\hat{r}$ in the x - y plane:

$$\begin{aligned} k_x &= k\sin\theta\cos\varphi \\ k_y &= k\sin\theta\sin\varphi \end{aligned} \qquad (21)$$

where $k = \omega\sqrt{\mu\varepsilon} = 2\pi/\lambda$ is the wave number of the medium.

3.36. Note that the functions $f_x(k_x,k_y)$ and $f_y(k_x,k_y)$ give the far-field pattern in terms of x and y components for small θ when $\cos\theta \approx 1$ because they become almost identical with the normalized far-field E-components.

$$\left.\begin{aligned} \overline{E}_x^{far} &\approx f_x(k_x,k_y) \\ \overline{E}_y^{far} &\approx f_y(k_x,k_y) \end{aligned}\right\}, \quad \cos\theta \simeq 1 \qquad (22)$$

This finally clarifies the statement made in 3.27.

3.37. The far-field z-component can be also expressed by its spectral counterpart $f_z(k_x,k_y)$ in the same manner as the x and y components:

$$E_z^{far} = jk\frac{e^{-jkr}}{r}\cdot\cos\theta\cdot f_z(k_x,k_y) \qquad (23)$$

Having in mind (17) and (18), it becomes clear that $f_z(k_x,k_y)$ is not an independent function but is related to the other two spectral components as:

$$\boxed{f_z(k_x,k_y) = -\tan\theta\left[f_x(k_x,k_y)\cos\varphi + f_y(k_x,k_y)\sin\varphi\right]} \qquad (24)$$

3.38. We can now define the vector plane wave spectral function:

$$\vec{f}(k_x,k_y) = \hat{x}f_x(k_x,k_y) + \hat{y}f_y(k_x,k_y) + \hat{z}f_z(k_x,k_y) \qquad (25)$$

whose spatial components are calculated via (19), (20) and (24). The far-field E-vector can be calculated from the spectral function as:

$$\boxed{\vec{E}(r,\theta,\varphi) \simeq jk\frac{e^{-jkr}}{2\pi r}\cos\theta\cdot\vec{f}(k_x,k_y)} \qquad (26)$$

3.39. One can express the vector equation (26) in terms of the θ and φ components of the far-field E-vector:

$$\begin{aligned} E_\theta(r,\theta,\varphi) &\simeq jk\frac{e^{-jkr}}{2\pi r}\cos\theta\cdot f_\theta(k_x,k_y) \\ E_\varphi(r,\theta,\varphi) &\simeq jk\frac{e^{-jkr}}{2\pi r}\cos\theta\cdot f_\varphi(k_x,k_y) \end{aligned} \qquad (27)$$

Since the spectral function $\vec{f}$ is derived via its rectangular components during the data acquisition over a planar surface, it is desirable to convert f_θ and f_φ to f_x and f_y.

3.40. Following the standard transformation from spherical to rectangular components, one obtains:

$$f_\theta \cos\theta = \cos\theta\left(f_x\cos\theta\cos\varphi + f_y\cos\theta\sin\varphi - f_z\sin\theta\right) \qquad (28)$$

After substituting f_z with its equivalent expression (24), one arrives at:

$$f_\theta\cos\theta = f_x\cos\varphi + f_y\sin\varphi \qquad (29)$$

In analogous manner, it can be shown that

$$f_\varphi\cos\theta = -f_x\sin\varphi + f_y\cos\varphi \qquad (30)$$

3.41. The substitution of (29) and (30) into (27) finally yields:

$$E_\theta(r,\theta,\varphi) \simeq jk\frac{e^{-jkr}}{2\pi r}(f_x\cos\varphi + f_y\sin\varphi)$$
$$E_\varphi(r,\theta,\varphi) \simeq jk\frac{e^{-jkr}}{2\pi r}(-f_x\sin\varphi + f_y\cos\varphi) \quad (31)$$

3.42. We can now summarize the procedure of the NF/FF pattern measurement in three basic steps:

- Measure the tangential E-field components $E_{ax}(x',y',z'=0)$ and $E_{ay}(x',y',z'=0)$ over the near-field aperture (data acquisition).
- Calculate the plane wave spectral functions $f_x(k_x,k_y)$ and $f_y(k_x,k_y)$ using (19) and (20).
- Calculate the normalized far-field components using

$$\overline{E}_\theta(\theta,\varphi) \simeq f_x\cos\varphi + f_y\sin\varphi$$
$$\overline{E}_\varphi(\theta,\varphi) \simeq -f_x\sin\varphi + f_y\cos\varphi, \quad (32)$$

or, the total normalized field patterns using

$$\overline{E}(\theta,\varphi) = \sqrt{\overline{E}_\theta^2(\theta,\varphi) + \overline{E}_\varphi^2(\theta,\varphi)} = \sqrt{f_x^2(k_x,k_y) + f_y^2(k_x,k_y)} \quad (33)$$

3.43. In the actual experimental procedure, a planar surface is chosen a distance z_0 away from the test antenna, which is in radiating mode. We will call this surface the measurement aperture. The distance z_0 must be at least three wavelengths away from the antenna, so that the measurement is carried out in the radiating near field region (Frennel zone) rather than in the reactive near-field region.

3.44. The measurement aperture is rectangular of dimensions $a \times b$. The measurement aperture is divided into M×N points spaced evenly $\vartriangle x$ and $\vartriangle y$ apart. The relation between the number of points and the respective spacing is then:

$$M = \frac{a}{\vartriangle x} + 1$$
$$N = \frac{b}{\vartriangle y} + 1 \quad (34)$$

3.45. Thus, the sampling points are located at coordinates $(m\vartriangle x, n\vartriangle y, 0)$, where $0 \le m \le M-1$ and $0 \le n \le N-1$. The separation distances $\vartriangle x$ and $\vartriangle y$ must be less than half a wavelength in order to satisfy Nyquist's sampling criterion, and such that the equations in (34) yield integer numbers. The measurement aperture must be large enough so that the signal at its edges is at least 45 dB down from the maximum measured signal over the entire surface.

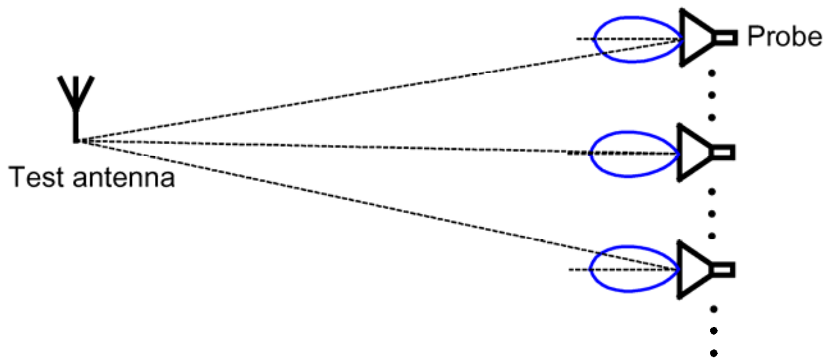
3.46. The plane wave spectral function $\vec{f}(k_x,k_y)$ can be evaluated at a discrete set of wave numbers as dictated by the discrete Fourier transform:

$$k_x = m\frac{2\pi}{a} = m\frac{2\pi}{(M-1)\vartriangle x}$$
$$k_y = n\frac{2\pi}{b} = n\frac{2\pi}{(N-1)\vartriangle x} \quad (35)$$

Conventional two-dimensional FFT (Fast Fourier Transform) techniques are used to perform this transformation.

3.47. The acquisition of the planar near-field data is done by a computer-controlled probe antenna (typically a waveguide horn or an open waveguide), which is moved to each grid node over the measurement aperture by a high-precision positioning system (positioner). The probe's axis is held stationary and normal to the measurement aperture. The probe must be linearly polarized so that separate measurements of the two tangential field components E_x and E_y become possible.

3.48. As the probe location changes, its pattern orientation with respect to the AUT changes, too, as shown below. The probe's partial directivities in the direction of the test antenna must be taken into account using probe compensation techniques.



3.49. The principal advantage of the planar NF/FF transformation over the cylindrical and the spherical one is its mathematical simplicity. Its major disadvantage is that it cannot cover all directional angles. In the ideal case of infinite planar measurement surface, only one hemisphere of the antenna pattern can be measured. Thus, the back lobes and the side lobes of the antenna cannot be measured together with the main beam. Of course, the AUT can be rotated in different positions, so that the overall pattern can be constructed.

The reader interested in the subject of NF/FF transforms and measurements is referred to the following popular sources:

R.C. Johnson, H.A. Ecker, and J.S. Hollis, "Determination of far-field antenna patterns from near-field measurements," *Proc. IEEE*, vol. 61, No. 12, pp. 1668-1694, Dec. 1973.

D.T. Paris, W.M. Leach, Jr., and E.B. Joy, "Basic theory of probe compensated near-field measurements," *IEEE Trans. on Antennas and Propagation*, vol. AP-26, No. 3, pp. 373-379, May 1978.

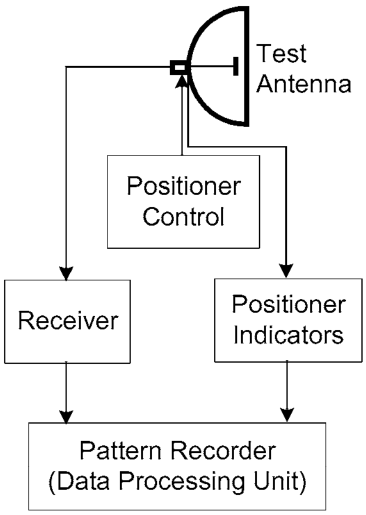
E.B. Joy, W.M. Leach, Jr., G.P. Rodrigue, and D.T. Paris, "Applications of probe compensated near-field measurements," *IEEE Trans. on Antennas and Propagation*, vol. AP-26, No. 3, pp. 379-389, May 1978.

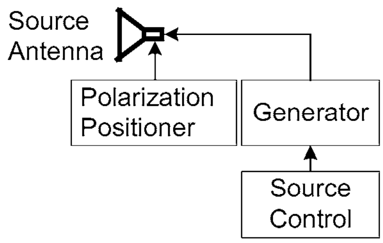
A.D. Yaghjian, "An overview of near-field antenna measurements," *IEEE Trans. on Antennas and Propagation*, vol. AP-34, pp. 30-45, January 1986.

4. Far-field pattern measurements

4.1. The far-field patterns are measured on the surface of a sphere of constant radius. Any position on the sphere is identified by the standard directional angles θ and φ of the spherical coordinate system. In general, the pattern of an antenna is 3-dimensional. However, 3-dimensional pattern acquisition is impractical, and a number of 2-D pattern measurements are performed. The minimal number of 2-dimensional patterns is two, and these two patterns must be in two orthogonal planes.

4.2. The pattern measurements are performed in 2-D pattern cuts. A simplified block diagram of a pattern measurement system is given below.





4.3. The total ***amplitude pattern*** is described by the vector sum of the two orthogonally polarized radiated field components, e.g.:

$$|\vec{E}| = \sqrt{|E_\theta|^2 + |E_\varphi|^2} \quad (36)$$

Rarely, the separate patterns for both components are needed. In this case, the polarization of the test antenna must be measured, too.

4.4. The entire 3-D pattern of the antenna can be approximated making use of the 2-D pattern acquisitions. Generally, for antennas of low directivity, at least three 2-D pattern cuts (in the three principal planes (e.g., $\varphi = 0^\circ$, $\varphi = 90^\circ$ and $\theta = 90^\circ$) are necessary in order to obtain good 3-D pattern approximation. For high-directivity antennas, only two orthogonal 2-D patterns will suffice. Assuming that the antenna axis is along the z-axis, these are the patterns at $\varphi = 0^\circ$ and $\varphi = 90^\circ$.

4.5. High-directivity antennas such as aperture antennas (horn antennas, reflector antennas), have their far field components expressed as:

$$E_\theta(\theta,\varphi) = jk\frac{e^{-jkr}}{4\pi r}[\mathcal{J}_x^E \cos\varphi + \mathcal{J}_y^E \sin\varphi + \eta\cos\theta(\mathcal{J}_y^H \cos\varphi - \mathcal{J}_x^H \sin\varphi)] \quad (37)$$

$$E_\varphi(\theta,\varphi) = jk\frac{e^{-jkr}}{4\pi r}[-\eta(\mathcal{J}_x^H \cos\varphi + \mathcal{J}_y^H \sin\varphi) + \cos\theta(\mathcal{J}_y^E \cos\varphi - \mathcal{J}_x^E \sin\varphi)] \quad (38)$$

Here, $\mathcal{J}_x^E$, $\mathcal{J}_y^E$, $\mathcal{J}_x^H$ and $\mathcal{J}_y^H$ are the familiar plane wave spectral functions:

$$\mathcal{J}_x^E(\theta,\varphi) = \iint_{S_A} E_{a_x}(x',y')e^{jk(x'\sin\theta\cos\varphi + y'\sin\theta\sin\varphi)}dx'dy' \quad (39)$$

$$\mathcal{J}_y^E(\theta,\varphi) = \iint_{S_A} E_{a_y}(x',y')e^{jk(x'\sin\theta\cos\varphi + y'\sin\theta\sin\varphi)}dx'dy' \quad (40)$$

$$\mathcal{J}_x^H(\theta,\varphi) = \iint_{S_A} H_{a_x}(x',y')e^{jk(x'\sin\theta\cos\varphi + y'\sin\theta\sin\varphi)}dx'dy' \quad (41)$$

$$\mathcal{J}_y^H(\theta,\varphi) = \iint_{S_A} H_{a_y}(x',y')e^{jk(x'\sin\theta\cos\varphi + y'\sin\theta\sin\varphi)}dx'dy' \quad (42)$$

4.6. From equations (37) and (38) it follows that the field components in the principal planes are:

$$E_\theta(\theta,\varphi = 0^\circ) = E_\theta(0) = jk\frac{e^{-jkr}}{4\pi r}[\mathcal{J}_x^E + \mathcal{J}_y^H \eta\cos\theta] \quad (43)$$

$$E_\theta(\theta,\varphi = 90^\circ) = E_\theta(90) = jk\frac{e^{-jkr}}{4\pi r}[\mathcal{J}_y^E - \mathcal{J}_x^H \eta\cos\theta] \quad (44)$$

$$E_\varphi(\theta,\varphi=0^\circ)=E_\varphi(0)=jk\frac{e^{-jkr}}{4\pi r}[-\eta\mathcal{J}_x^H+\mathcal{J}_y^E\cos\theta] \tag{45}$$

$$E_\varphi(\theta,\varphi=90^\circ)=E_\varphi(90)=jk\frac{e^{-jkr}}{4\pi r}[-\eta\mathcal{J}_y^H-\mathcal{J}_x^E\cos\theta] \tag{46}$$

4.7. It is, therefore, clear that the 3-D field dependence on the directional angles can be derived from the 2-D dependences in the equations (43) through (46) as:

$$\vec{E}(\theta,\varphi)=jk\frac{e^{-jkr}}{4\pi r}[\cos\varphi\,\vec{E}(\theta,\varphi=0^\circ)+\sin\varphi\,\vec{E}(\theta,\varphi=90^\circ)], \tag{47}$$

where:

$$\vec{E}(\theta,\varphi=0^\circ)=\hat{\theta}\,E_\theta(0)+\hat{\varphi}\,E_\varphi(0);$$

$$\vec{E}(\theta,\varphi=90^\circ)=\hat{\theta}\,E_\theta(90)+\hat{\varphi}\,E_\varphi(90)$$

4.8. The total 3-D amplitude pattern of the field defined in (47) is obtained as:

$$|\vec{E}(\theta,\varphi)|=\sqrt{\cos^2\varphi\,\underbrace{[E_\theta^2(0)+E_\varphi^2(0)]}_{|\vec{E}(\theta,0^\circ)|^2}+\sin^2\varphi\,\underbrace{[E_\theta^2(90)+E_\varphi^2(90)]}_{|\vec{E}(\theta,90^\circ)|^2}+\sin2\varphi[E_\theta(0)E_\theta(90)+E_\varphi(0)E_\varphi(90)]} \tag{48}$$

In the pattern considerations, we will drop the factor $jk\frac{e^{-jkr}}{4\pi r}$.

It is easy to show that the last term in (48) is equal to:

$$E_\theta(0)E_\theta(90)+E_\varphi(0)E_\varphi(90)=(1-\cos^2\theta)(\mathcal{J}_x^E\mathcal{J}_y^E+\eta^2\mathcal{J}_x^H\mathcal{J}_y^H) \tag{49}$$

4.9. For high-directivity antennas, the angles θ, at which the antenna has significant pattern values, are small, and the term given in (49) can be neglected. Thus, the approximation of the 3-D pattern in terms of two orthogonal 2-D patterns reduces to the simple expression:

$$|\vec{E}(\theta,\varphi)|\approx\sqrt{\cos^2\varphi\;|\vec{E}(\theta,0^\circ)|^2+\sin^2\varphi\;|\vec{E}(\theta,90^\circ)|^2} \tag{50}$$

4.10. Sometimes, the ***phase pattern*** of the far field is also measured. This requires special equipment, which includes phase measuring circuits.

5. Gain measurements

5.1. The gain measurements require essentially the same environment as the pattern measurements, although they are not so very much sensitive to reflections and EM interference. To measure the gain of antennas operating above 1 GHz, usually, free-space ranges are used. Between 0.1 GHz and 1 GHz, ground-reflection ranges are used.

5.2. Below 0.1 GHz, directive antennas are very large and the ground effects become increasingly pronounced. Usually the gain at these frequencies is measured directly in the environment of operation. Same holds for high-frequency antennas operating in a complicated environment (mounted on vehicles or aircrafts).

5.3. We will consider three gain-measurement techniques. The first two belong to the so-called *absolute-gain measurements*, and they are: the ***two-antenna method***, and the ***three-antenna method***. The third method is called the ***gain-transfer*** (or ***gain-comparison***) ***method***.

5.4. The ***two-antenna method*** is based on Friis transmission equation and it needs two identical samples of the tested antenna. One of the identical samples is the radiating antenna, and the other one is the receiving antenna. Assuming that the antennas are well matched in terms of impedance and polarization (mutual alignment must be sufficiently good), the Friis transmission equation is:

$$\frac{P_r}{P_t}=\left(\frac{\lambda}{4\pi R}\right)^2G_tG_r,\quad\text{where }G_t=G_r=G \tag{51}$$

5.5. The formula for the calculation of the gain in dB obtained from (51) is:

$$\boxed{G_{\text{dB}}=\frac{1}{2}\left[20\log_{10}\left(\frac{4\pi R}{\lambda}\right)+10\log_{10}\left(\frac{P_r}{P_t}\right)\right]} \tag{52}$$

One needs to measure accurately the distance between the two antennas R , the received power P_r , the transmitted power P_t , and the frequency $f = c/\lambda$, which would allow the calculation of the wavelength λ .

5.6. The ***three-antenna method*** is used when only one sample of the test antenna is available. Then, any other two antennas can be used to perform three measurements, which allow the calculation of the gains of all three antennas. All three measurements are made at a fixed known distance between the radiating and the transmitting antennas, R .

5.7. It does not matter whether an antenna is in a transmitting or in a receiving mode. What matters is that the three measurements involve all three possible pairs of antennas: antenna #1 and antenna #2; antenna #1 and antenna #3; and, antenna #2 and antenna #3. The calculations are again based on Friis transmission equation, which in the case of two different antennas (antenna # i and antenna # j) measured during experiment # k ($k = 1,2,3$) becomes:

$$G_{i\ \mathrm{dB}} + G_{j\ \mathrm{dB}} = 20\log_{10}\left(\frac{4\pi R}{\lambda}\right) + 10\log_{10}\left(\frac{P_r}{P_t}\right)^{(k)} \tag{53}$$

5.8. The system of equations describing all three experiments is:

$$\begin{aligned} G_{1\ \mathrm{dB}} + G_{2\ \mathrm{dB}} &= 20\log_{10}\left(\frac{4\pi R}{\lambda}\right) + 10\log_{10}\left(\frac{P_r}{P_t}\right)^{(1)} \\ G_{1\ \mathrm{dB}} + G_{3\ \mathrm{dB}} &= 20\log_{10}\left(\frac{4\pi R}{\lambda}\right) + 10\log_{10}\left(\frac{P_r}{P_t}\right)^{(2)} \\ G_{2\ \mathrm{dB}} + G_{3\ \mathrm{dB}} &= 20\log_{10}\left(\frac{4\pi R}{\lambda}\right) + 10\log_{10}\left(\frac{P_r}{P_t}\right)^{(3)} \end{aligned} \tag{54}$$

5.9. The right-hand side of the equations in (54) is known after an accurate measurement is performed on the distance R , and the ratios received-power/transmitted-power. Thus, the following system of three equations with three unknowns is obtained:

$$\begin{aligned} G_{1\ \mathrm{dB}} + G_{2\ \mathrm{dB}} &= A \\ G_{1\ \mathrm{dB}} + G_{3\ \mathrm{dB}} &= B \\ G_{2\ \mathrm{dB}} + G_{3\ \mathrm{dB}} &= C \end{aligned} \tag{55}$$

5.10. The solution to the system of equations in (55) is easily found to be:

$$\boxed{\begin{aligned} G_{1\ \mathrm{dB}} &= \frac{A+B-C}{2} \\ G_{2\ \mathrm{dB}} &= \frac{A-B+C}{2} \\ G_{3\ \mathrm{dB}} &= \frac{-A+B+C}{2} \end{aligned}} \tag{56}$$

5.11. The ***gain-transfer (or gain-comparison) method*** requires an antenna whose gain is exactly known. This antenna is called ***gain standard***. Two sets of measurements are performed.

1) The test antenna is in receiving mode, and its received power P_T is measured;
2) The gain standard is in receiving mode in exactly the same arrangement (the distance R and the transmitted power P_0 are kept the same), and its received power P_S is measured.

In both measurements, the receiving antennas must be matched to their loads (the receiver).

5.12. The calculation of the test antenna gain in dB is based on Friis transmission equation. Both experiments described above lead to the following system of equations:

$$G_{T\,\text{dB}} + G_{0\,\text{dB}} = 20\log_{10}\left(\frac{4\pi R}{\lambda}\right) + 10\log_{10}\left(\frac{P_T}{P_0}\right)^{(1)}$$
$$G_{S\,\text{dB}} + G_{0\,\text{dB}} = 20\log_{10}\left(\frac{4\pi R}{\lambda}\right) + 10\log_{10}\left(\frac{P_S}{P_0}\right)^{(2)} \quad (57)$$

Here,

$G_{T\,\text{dB}}$ is the gain of the test antenna;

$G_{S\,\text{dB}}$ is the gain of the gain standard; and

$G_{0\,\text{dB}}$ is the gain of the transmitting antenna.

5.13. From (57), one can derive the expression for the calculation of the gain of the test antenna:

$$\boxed{G_{T\,\text{dB}} = G_{S\,\text{dB}} + 10\log_{10}\left(\frac{P_T}{P_S}\right)} \quad (58)$$

5.14. If the test antenna is circularly or elliptically polarized, two orthogonal linearly polarized gain standards must be used in order to obtain the partial gains corresponding to each linearly polarized component. The total gain of the test antenna is:

$$G_{T\,\text{dB}} = 10\log_{10}(G_{Tv} + G_{Th}), \quad (59)$$

where:

G_{Tv} is the dimensionless gain of the test antenna measured with the vertically polarized gain standard; and

G_{Th} is the dimensionless gain of the test antenna measured with the horizontally polarized gain standard.

6. Directivity measurements

6.1. The directivity measurements are directly related to the pattern measurements. Once the pattern is well defined in the 3-D space, the directivity can be determined using its definition as:

$$D_0 = 4\pi \frac{F_{\max}(\theta_0, \varphi_0)}{\int_0^{2\pi}\int_0^{\pi} F(\theta,\varphi)\sin\theta\, d\theta\, d\varphi}, \quad (60)$$

where $F(\theta,\varphi)$ is the radiation pattern of the test antenna.

6.2. Generally, the radiation pattern $F(\theta,\varphi)$ is measured by sampling the field over a sphere of constant radius R. The spacing between the sampling points depends on the directive properties of the antenna and on the desired accuracy. As discussed in LO3 and LO4, the far-field pattern can be measured directly or via NF/FF transformations. It may also be approximated by making use of the 2-D patterns measured in the three (or two) principal planes.

6.3. The integral:

$$\Pi = \int_0^{2\pi}\int_0^{\pi} F(\theta,\varphi)\sin\theta\, d\theta\, d\varphi \quad (61)$$

is usually solved numerically, e.g.:

$$\Pi \simeq \frac{\pi}{N}\frac{2\pi}{M}\sum_{j=1}^{M}\left[\sum_{i=1}^{N} F(\theta_i,\varphi_j)\sin\theta_i\right] \quad (62)$$

6.4. If the antenna is circularly or elliptically polarized, two measurements of the above type must be carried out in order to determine the partial directivities, D_θ and D_φ. Then, the total directivity is calculated as:

$$D_0 = D_\theta + D_\varphi \quad (63)$$

where the partial directivities are defined as:

$$D_\theta = 4\pi \frac{F_{\theta \max}}{\Pi_\theta + \Pi_\varphi}; \qquad (64)$$

$$D_\varphi = 4\pi \frac{F_{\varphi \max}}{\Pi_\theta + \Pi_\varphi}; \qquad (65)$$

7. Radiation efficiency, e_{cd}

7.1. In order to calculate the radiation efficiency, the gain and the directivity must be measured first. Factors like impedance mismatch and polarization mismatch have to be minimized during those measurements. The radiation efficiency is then calculated using its definition:

$$e_{cd} = \frac{\text{Gain}}{\text{Directivity}} \qquad (66)$$

8. Impedance measurements

8.1. The input impedance of an antenna is calculated via the reflection coefficient at its terminals Γ, which are connected to a transmission line of known characteristic impedance Z_c. If the magnitude and the phase of Γ are known, then, the antenna input impedance is calculated as:

$$\boxed{Z_A = Z_c \frac{1+\Gamma}{1-\Gamma}}, \ \Omega \qquad (67)$$

8.2. The magnitude of the reflection coefficient $|\Gamma|$ is found from the measurement of the SWR (Standing Wave Ratio) in the transmission line:

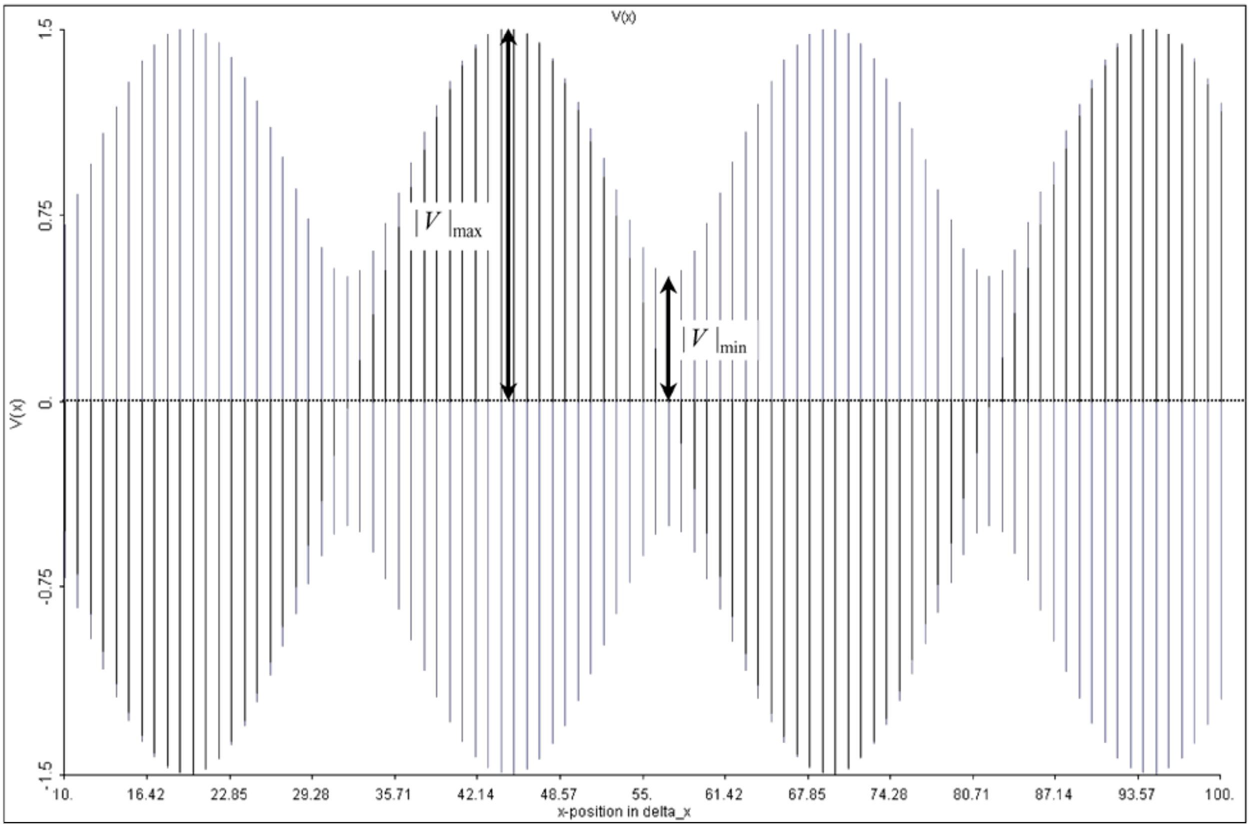
$$\boxed{|\Gamma| = \frac{SWR-1}{SWR+1}} \qquad (68)$$

From transmission-line theory, it is known that the SWR is defined as the ratio of the maximum value to the minimum value measured along the transmission line terminated with a certain load.

8.3. The envelope of the voltage along a transmission line terminated with an unmatched load is shown below. The minima and the maxima of the voltage along the line can be clearly identified. The SWR is defined as:

$$SWR = \frac{|V|_{\max}}{|V|_{\min}} \qquad (69)$$

The SWR is a number between 1 and infinity. When $SWR = 1$, a pure traveling wave exists in the transmission line, and the signal envelope is constant along the line. This mode is achieved when perfect impedance match is in place. When $SWR \to \infty$, then a pure standing wave is established in the line with the minima of the wave being exactly zero. This happens when the line is terminated with a short circuit or an open circuit.



8.4. The phase of $\Gamma = |\Gamma| e^{j\gamma}$ can be determined by locating a voltage maximum or a voltage minimum in the transmission line at a certain distance x away from the antenna. The ratio of this distance and the wavelength in the line λ_g is used to calculate the phase of Γ:

$$\gamma = 2k_g x_n \pm (2n-1)\pi = \frac{4\pi}{\lambda_g} x_n \pm (2n-1)\pi \quad (70)$$

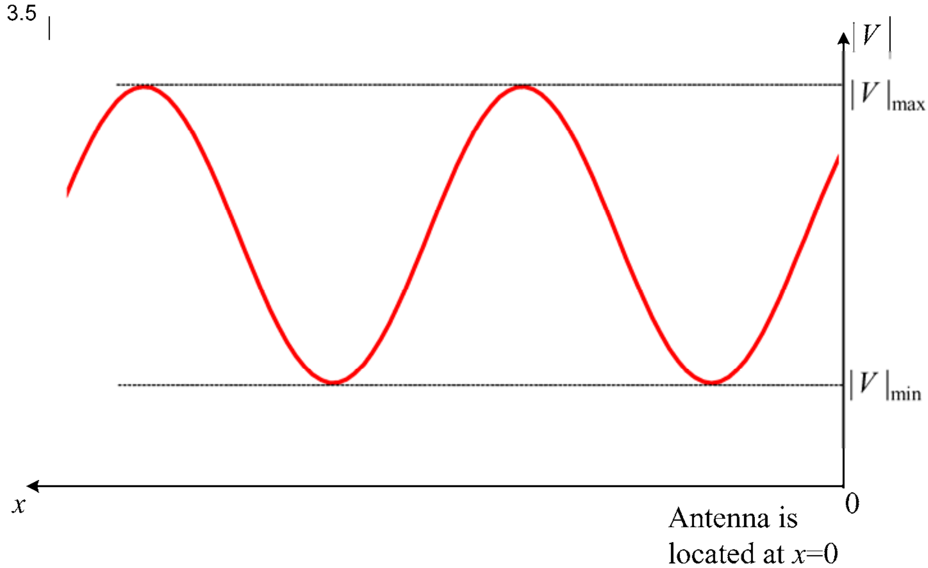
Here:

n is the number of the voltage minimum as counted from the antenna terminals;

x_n is the distance from the antenna terminals to the n-th voltage minimum;

$k_g = 2\pi / \lambda_g$ is the guide (transmission line) phase constant.

8.5. Equation (70) is found by deriving the minima of the total field in the transmission line as a function of the distance from the antenna terminals x. The voltage magnitude distribution is shown in the figure below.



8.6. First, we have to determine the magnitude of the total voltage as a function of x. Assuming that the incident voltage is represented by the phasor:

$$\tilde{V}^i(x) = \tilde{V}^i(0)e^{+jk_g x}, \tag{71}$$

one obtains the reflected voltage as:

$$\tilde{V}^r(x) = \Gamma\tilde{V}^i(0)e^{-jk_g x} \tag{72}$$

8.7. The total voltage in the transmission line is the superposition of the incident and the reflected waves:

$$\begin{aligned}&\tilde{V}(x) = \tilde{V}^i(x) + \tilde{V}^r(x)\\&\tilde{V}(x) = \tilde{V}^i(0)[e^{+jk_g x} + \Gamma e^{-jk_g x}] = \tilde{V}^i(0)[e^{+jk_g x} + |\Gamma|\, e^{-j(k_g x-\gamma)}]\end{aligned} \tag{73}$$

The magnitude of the voltage is determined as:

$$|\tilde{V}(x)|^2 = |\tilde{V}^i(0)|^2 \{[\cos(k_g x) + |\Gamma|\cos(k_g x-\gamma)]^2 + [\sin(k_g x) - |\Gamma|\sin(k_g x-\gamma)]^2\} \tag{74}$$

8.8. To obtain all extrema of the function $|\tilde{V}(x)|^2$, one has to find the roots of the equation:

$$\frac{\partial |\tilde{V}(x)|^2}{\partial x} = 0 \tag{75}$$

Equations (74) and (75) lead to the equation:

$$\sin(2k_g x - \gamma) = 0, \tag{76}$$

whose solutions give all values of x, at which the function's extrema are found:

$$2k_g x_n = \gamma + n\pi, \quad n = 0, \pm 1, \pm 2, \ldots \tag{77}$$

8.9. The odd values of $n = \pm 1, \pm 3, \pm 5, \ldots$ in (77) correspond to the minima of the function $|\tilde{V}(x)|^2$. Thus, one can formulate the equation for the calculation of γ via the location of the minima as:

$$\boxed{\gamma = 2k_g x_n \pm (2n-1)\pi, \quad n = 1, 2, 3, \ldots} \tag{78}$$

The value of n in (78) shows the number of the respective minimum as counting from the antenna (load) terminals.

9. Polarization measurements

9.1. A complete description of the antenna polarization requires an accurate description of the polarization ellipse (the axial ratio and the tilt angle), as well as the sense of rotation (clockwise, or counter-clockwise). All these concepts have already been defined in LO9.

9.2. It must be pointed out that, in general, the polarization of an antenna is not the same in every direction, i.e., it depends on the observation angle. That is why, often, a number of measurements are required according to the desired degree of polarization description.

9.3. The polarization measurement methods are classified into three general categories.

- Partial methods: they give incomplete information about the polarization but are simple and require conventional equipment.
- Comparison methods: they yield complete polarization information; however, they require a polarization standard.
- Absolute methods: they yield complete polarization information; and, they do not require a polarization standard.

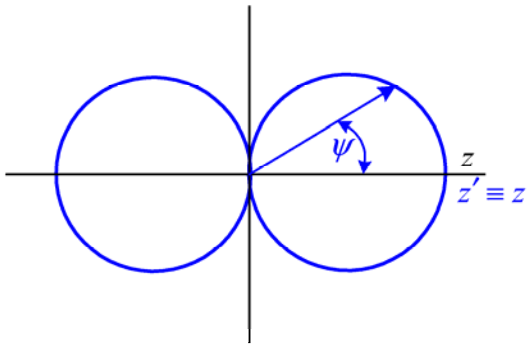
9.4. One of the popular partial methods is the ***polarization-pattern method***. It produces the polarization ellipse parameters (the axial ratio and the tilt angle) in a given direction of radiation. It cannot determine however the sense of rotation. The AUT can be either in transmitting or in receiving mode. The other antenna (the probe) must be linearly polarized, e.g. a dipole, and its pattern must be accurately known.

9.5. A typical arrangement for the polarization-pattern measurement is given below.

The direction of radiation is specified by the angles (θ,φ).

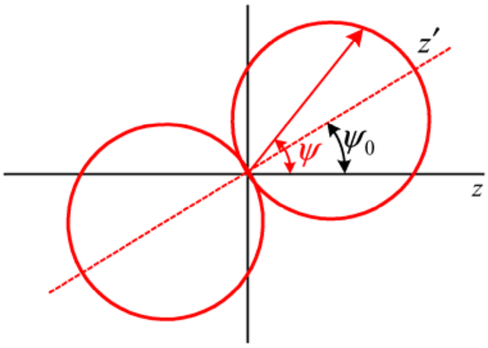
9.6. The signal at the output of the probe depends on two factors: the test antenna's polarization and the angle of the probe's rotation. The signal's level is recorded and plotted versus the angle of rotation. Thus, the polarization pattern is obtained for the considered direction of radiation. There are three typical contours that can be observed: the linear polarization pattern, the circular polarization pattern, and the most general pattern of the elliptical polarization.

9.7. Let us assume that the probe is initially in such a position that it is polarized along the z-axis. If the AUT is linearly polarized along the z'-axis, where $z' \equiv z$, then the polarization pattern is a $\cos\psi$ function of the rotation angle ψ with respect to the z-axis.

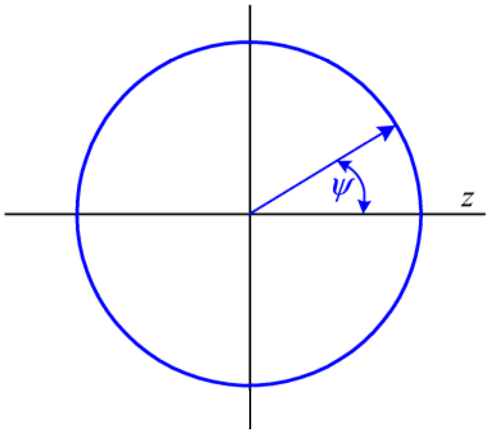


This is obvious from the fact that the PLF of two linearly polarized antennas is determined by the dot product of their polarization vectors, $PLF = |\hat{\rho}_t \cdot \hat{\rho}_r|^2$, as discussed in LO9.

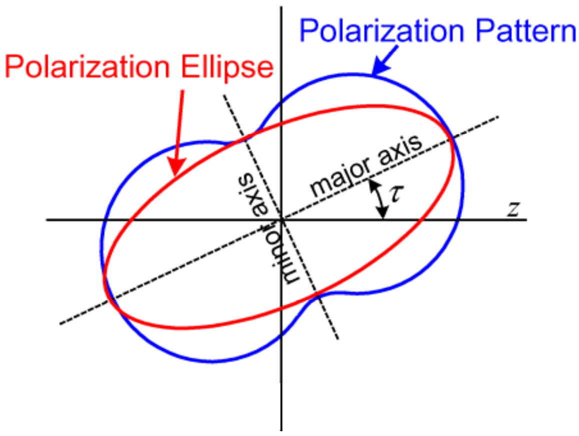
9.8. Obviously, in the general linear polarization case, the polarization pattern will be tilted with respect to the polarization axis of the probe. The polarization pattern then will be $\cos(\psi-\psi_0)$, where ψ_0 is the angle between the polarization axes of both antennas for the initial orientation of the probe. However, the shape of the pattern will remain the same, indicating the linear polarization of the AUT.



9.9. If the AUT is circularly polarized, the polarization pattern is a circle regardless of the initial mutual orientation of the probe and the AUT.

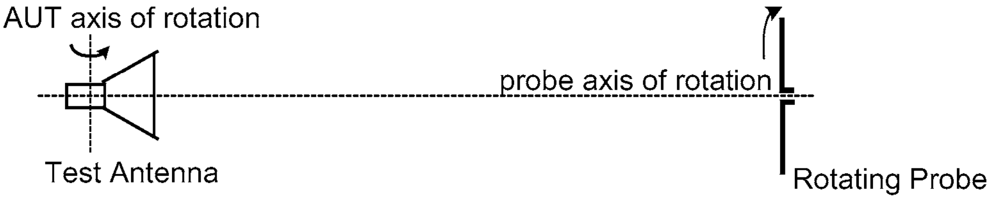


9.10. In the general case of elliptically polarized test antenna, a typical dumb-bell contour is obtained, which allows the direct calculation of the axial ratio and the tilt angle τ of the polarization ellipse as it is shown in the figure below.



9.11. The polarization-pattern method cannot provide information about the sense of rotation of the field of circularly or elliptically polarized antennas. However, this parameter can be easily established by the use of circularly polarized probes (e.g. spiral antennas): one of a clockwise polarization, and the other one of a counter-clockwise polarization. Whichever receives a stronger signal will determine the sense of rotation.

9.12. Another partial method is the ***axial-ratio pattern method***. The arrangement is very similar to that of the polarization-pattern method. The only difference is that now the test antenna (which operates in a receiving mode, usually) is rotated in a desired plane by the antenna positioning mechanism. The probe must rotate with much larger angular frequency than the test antenna because it should complete one full turn at approximately every degree of rotation of the test antenna.



9.13. As a result of the measurement described above, a 2-D pattern is obtained, which allows the calculation of the axial ratio of the polarization at any direction of the measured 2-D pattern. Such a pattern (in dB) of a nearly circularly polarized antenna is shown below.

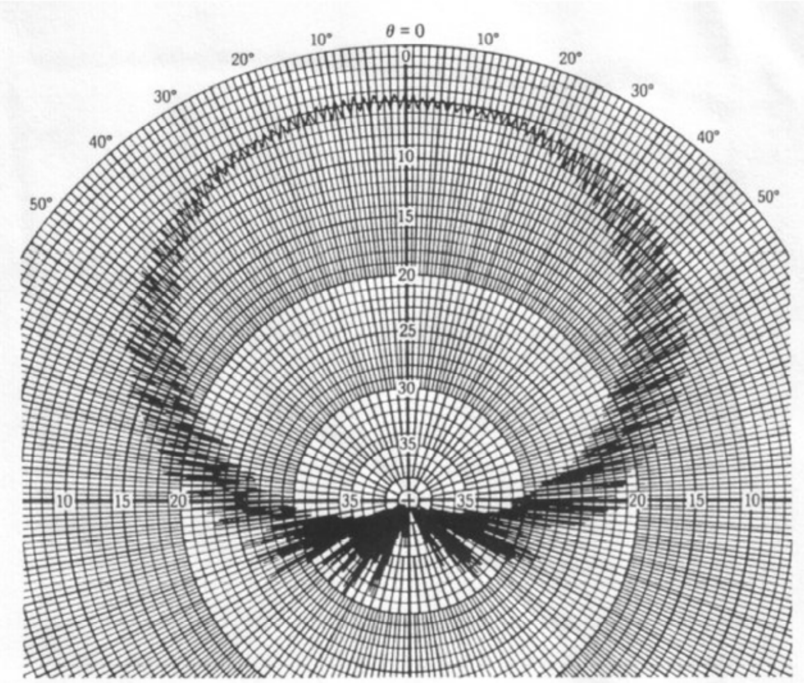


Figure 16.26 Pattern of a circularly polarized test antenna taken with a rotating, linearly polarized, source antenna [E. S. Gillespie, "Measurement of Antenna Radiation Characteristics on Far-Field Ranges," in *Antenna Handbook* (Y. T. Lo & S. W. Lee, eds.), 1988, © Van Nostrand Reinhold Co., Inc.]

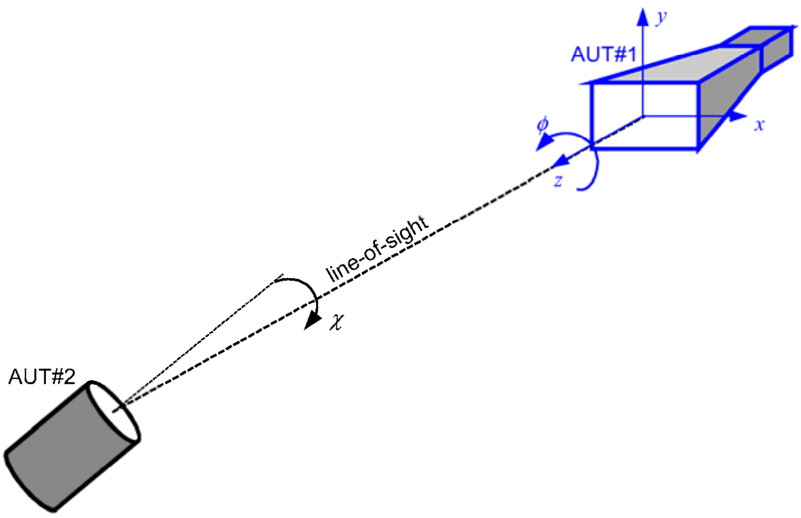
9.14. From the example pattern above, it is obvious that the axial ratio pattern has an inner envelope and an outer envelope. The ratio of the outer envelope to the inner one for a given angle gives the axial ratio of the E-field polarization in this direction. For example, the pattern above shows that the test antenna is nearly circularly polarized along its axis, i.e. its axial ratio is closed to one. At greater observation angles, however, its polarization becomes elliptical of increasingly large axial ratio.
9.15. The axial ratio pattern method yields only the axial ratio of the polarization ellipse. It does not give information about the tilt angle and the sense of rotation. However, it is very fast and convenient to

implement in any antenna test range. The tilt angle at selected directional angles can be always clarified later with the polarization-pattern method.

9.16. A powerful absolute polarization measurement method, which is often used in practice, is the ***three-antenna method***. The method will not be described in detail here since it involves more advanced knowledge on monochromatic EM wave polarization. The interested reader is referred to the existing extensive technical references given at the end of this module. The three-antenna method yields full polarization information for all three antennas. The only *a-priori* knowledge required is the approximate tilt angle of one of the three antennas.

9.17. The method requires the measurement of the amplitude and the phase of the normalized received voltage in three experiments, which involve: 1) antenna #1 and antenna #2; 2) antenna #1 and antenna #3; and 3) antenna #2 and antenna #3. All three experiments must use the same measurement set-up. The three complex voltage phasors are measured as a function of the angles φ and χ, which are the angles of rotation of the antennas about the antenna-range axis (usually, this is the line-of-sight between them).

9.18. The angles φ and χ show the clockwise rotation of each antenna as one looks from it towards the other antenna. An example set-up is shown in the figure below. First, the AUT#1 is scanned for $\phi \in [0^\circ, 360^\circ]$ usually with a step of $\Delta\phi = 1^\circ$. Then, the angle of AUT#2 is incremented by $\Delta\chi$ (usually, $\Delta\chi \approx 15^\circ$), and AUT#1 is scanned again. This is repeated until the angle χ sweeps the whole range from 0° to 360°.



9.19. Three complex quantities M_{mn} are then calculated from the double Fourier transform of the voltage phasor patterns:

$$M_{mn} = \frac{\int_0^{2\pi}\int_0^{2\pi} \tilde{V}_{mn}(\phi,\chi) e^{+j(\phi+\chi)} d\phi d\chi}{\int_0^{2\pi}\int_0^{2\pi} \tilde{V}_{mn}(\phi,\chi) e^{-j(\varphi+\chi)} d\phi d\chi}, \quad mn = 12, \text{ or } 13, \text{ or } 23 \tag{79}$$

9.20. It can be shown (see references [6],[7],[8]) that M_{mn} are equal to the dot products of the circular polarization ratios (see reference [3]) of the two antennas used in the respective measurement:

$$\begin{aligned} \hat{\rho}_{c1} \cdot \hat{\rho}_{c2} &= M_{12} \\ \hat{\rho}_{c1} \cdot \hat{\rho}_{c3} &= M_{13} \\ \hat{\rho}_{c2} \cdot \hat{\rho}_{c3} &= M_{23} \end{aligned} \tag{80}$$

9.21. The system in (80) is used to solve for the three circular polarization ratios:

$$\hat{\rho}_{c1} = \sqrt{\frac{M_{12}M_{13}}{M_{23}}};\ \hat{\rho}_{c2} = \sqrt{\frac{M_{12}M_{23}}{M_{13}}};\ \hat{\rho}_{c3} = \sqrt{\frac{M_{23}M_{13}}{M_{12}}} \quad (81)$$

The square root of a complex number implies ambiguity in the phase calculations for the polarization vectors. Here, it becomes necessary to have an approximate knowledge of the tilt angle of one of the antennas. The circular polarization ratios are directly related to the polarization ellipse, as described in [2] and in [3].

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Modern Military HF - Antennas of Communication Cars

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I have a small collection of information about old and modern military HF antennas used over the World. Presently, two modern automobile HF antennas are described at the article. The antennas are written "as it is," i.e., I give all information, that I have had. I know, the information is not complete at all, but, nevertheless, the information is interesting and it can help somebody to make own 'car antennas.'

The basic types of military *antennas, which for a long time were used on communication cars, were construed during and before the World War II. After WW-II researches for new antennas for communication cars was renewed. Below we shall consider two new type of car antennas which have appeared in army after the World War-II still are in use on modern communication car. There are magnet antennas and DDRR antennas, that began to be used for communication cars (under my information) rather recently - in the middle of 70s years of the 20 century.*

Mag Loop antennas of communication cars for 150-80 meters

As usual a magnet antenna of the range is installed on a communication car as it is shown in **Figure 1**. The magnet antenna ensures sure communication in radius of 200 kms at the daylight time and up to 400 kilometers at the night time.

Figure 1 Magnet antenna on a communication car

The magnet antenna at marching condition is installed parallel to the car roof (see. **Figure 1a**) and does not hinder to ride the car under low bridges or under trees in forests. The magnet antenna stands in operating position with the help of an electric motor or by operator hand. **Figure 1b** shows the zenith magnet antenna in the operating position.

The magnet antenna (item 2, **Figure 1b**) is tuned in resonance on the operating frequency with the help of variable capacitor (item 3, **Figure 1b**), which is weatherproofed by hermetic box (item 4, **Figure 1b**). The variable capacitor is turned with the help of an electric motor. The magnet antenna is drove by a small loop (item 1, **Figure 1b**) that is installed in corner of the magnet antenna. Driven loop is coupled to the transmitter with the help of a coaxial cable by characteristic impedance of100 Ohm. The sizes of the army magnet antenna for operation in 150 - 80 meters are exhibited in **Figure 1b**.

Mag Loop antennas of *communication cars* for meters

Also magnet antennas are used for operation in HF ra
60 meters. Such magnet antenna has smaller
contrasted to magnet antenna intended for operation
meters. Magnet antenna for 90-60 meters owing to
sizes is installed or above the roof of the cabin of comn

car (see **Figure 2**) or at back edge of the car (see **Figure 3**). At this installation of mag loop the roof of the car is free to place other antennas or some more electronic equipment. The sizes of the magnet antenna for operation in 90 - 60 meters are exhibited in **Figure 2** and **Figure 3.**

Figure 2 Magnet antenna above the roof of the car cabin

Figure 3 Magnet antenna on the back edge of the car

The magnet antennas shown in **Figures 1-3** usually are made of an aluminum bent tube in 20- 40 millimeters in OD and 2-3 millimeters thick.

Magnet antennas for 150 -90 meters is not intended for operation when a communication car is moving. But Magnet antennas for 90 - 60 meters can be used when a communication car is moving.

Magnet antenna on a communication car

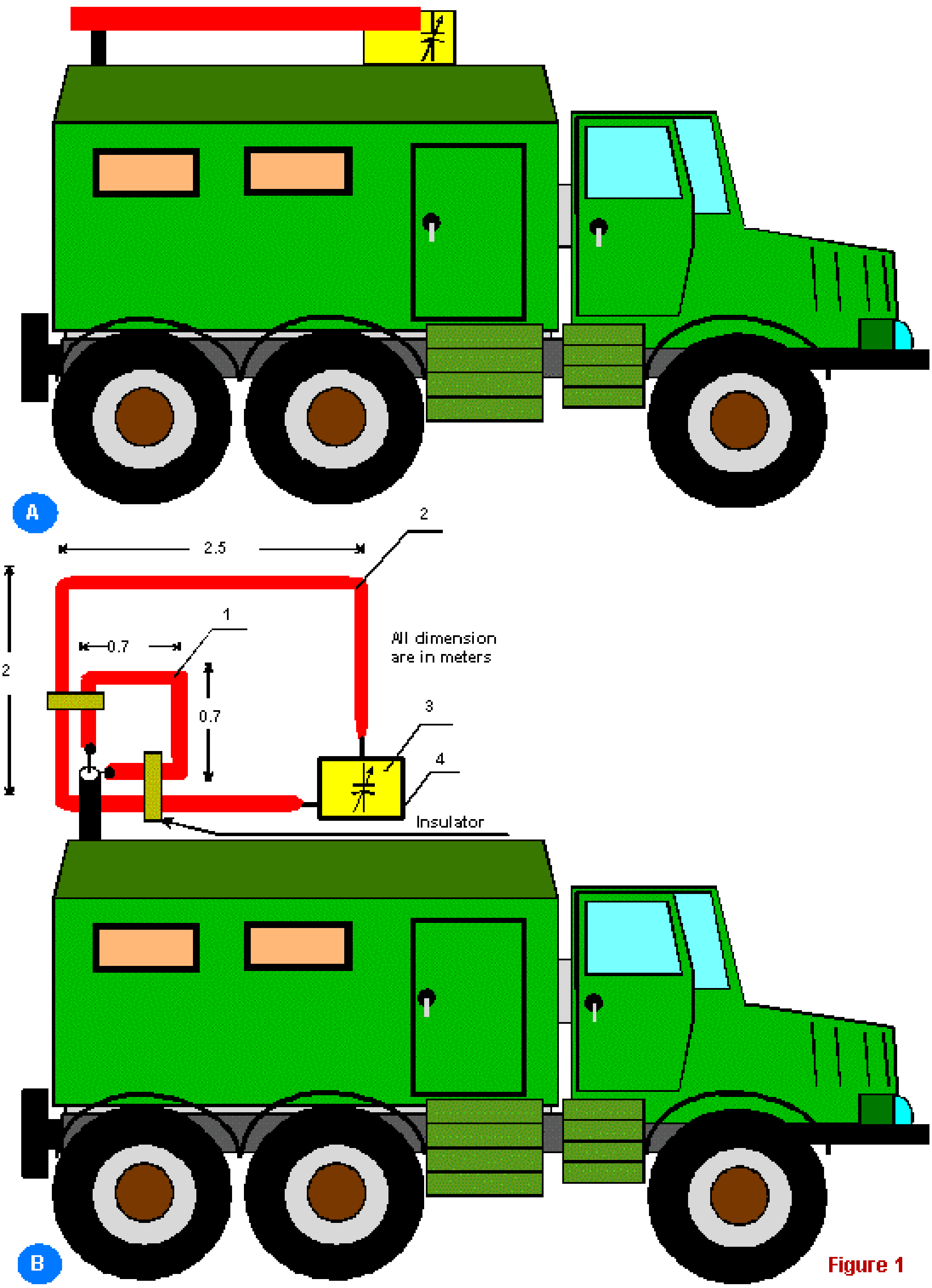


Figure 1

Antennas DDRR in military communication

Antennas DDRR are used in military communication of many countries. **Figure 4** shows the schematic of antenna DDRR. Say simple the antenna represents a tube bent in shape of letter “L”. The length of the ‘L’ Is little smaller the quarter wave of the high lower range of the antenna, but the length ‘L’ not less the lower operation range of the antenna. Antenna DDRI to resonance by the variable capacitor C which is dri electric motor M. Antenna DDRR, as usual, is mad aluminum tube in 20-40 millimeters OD.

Figure 4 Schematic of Antenna DDRR of communicati

Magnet antenna above the roof of the car cabin

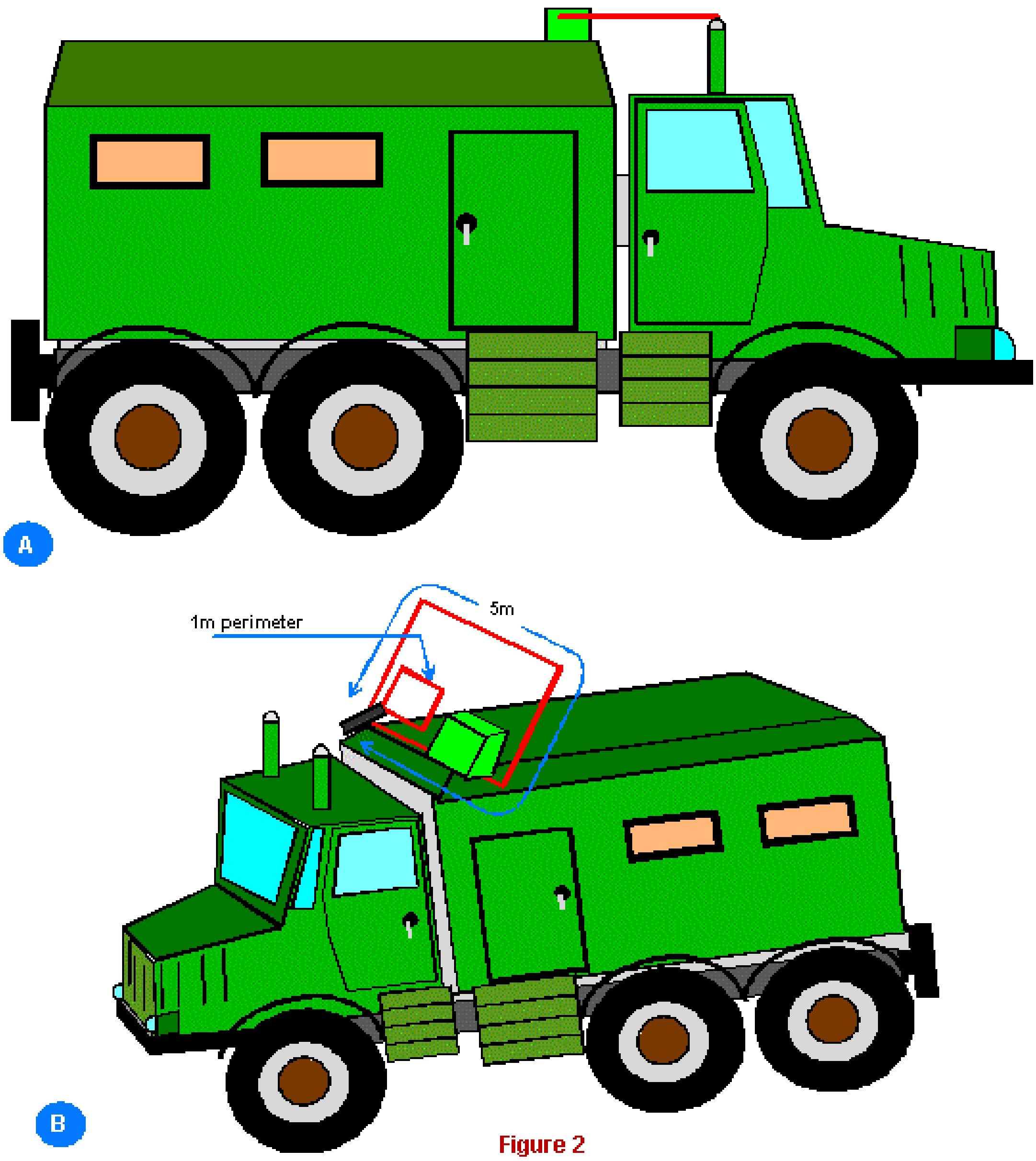


Figure 2

On military vehicles an antenna DDRR usually places on one of edges as it is shown in **Figure 5**. It allows to install other antennas on the roof of the communication car. Antennas DDRR often serve as enclosure of the roof.

Figure 5 Antenna DDRR on military vehicle

Antennas DDRR also are used on some heavy tanks or BMI (battle machine of infantry). On this military vehicle the antenna DDRR serves as a rail for other hand. Antenna DDRR has mechanically strong design, so it is difficult to damage an antenna DDRR in battle.

Seldom use two antennas DDRR that fed with some phase shift to create special diagram directivity. **Figure 6** shows such antenna array.

Figure 6 Array of antennas DDRR

Antenna DDRR is very strong and allows to do comr when the car is moving. Radio amateurs also can us DDRR for the operation in ether at installation on the r car.

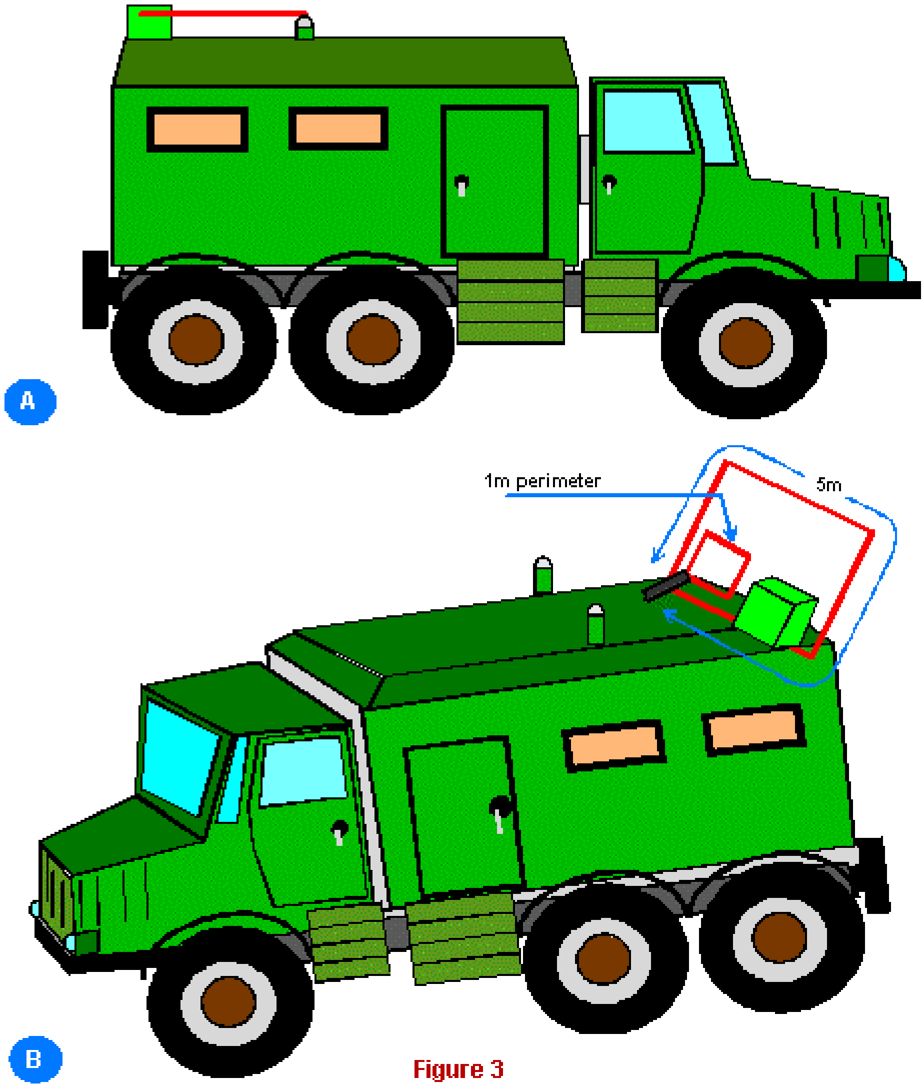


Figure 3

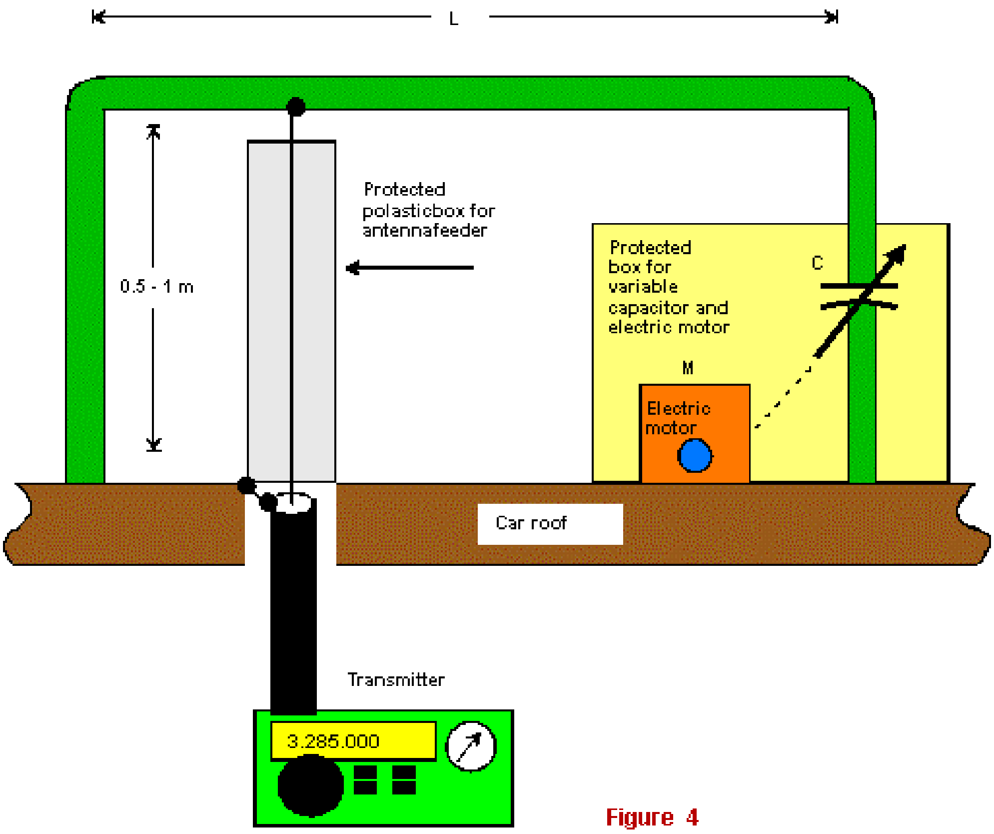


Figure 4

Antenna DDRR on military vehicle

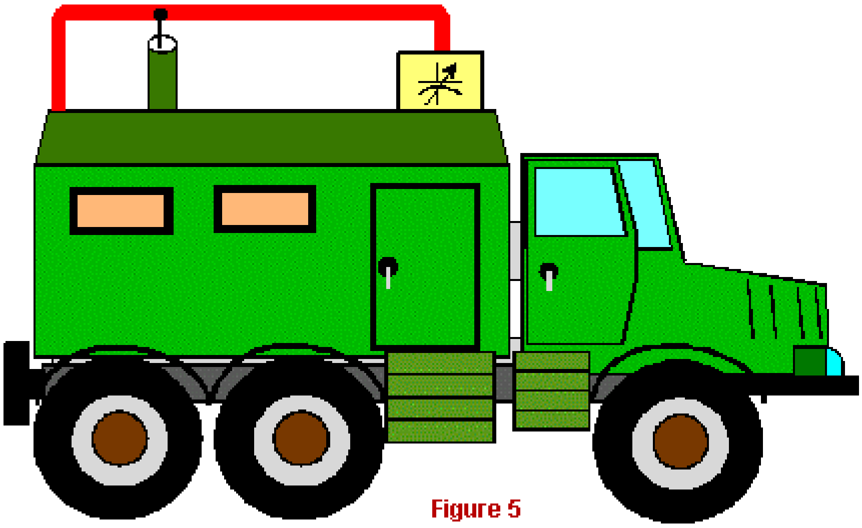


Figure 5

Array of antennas DDRR

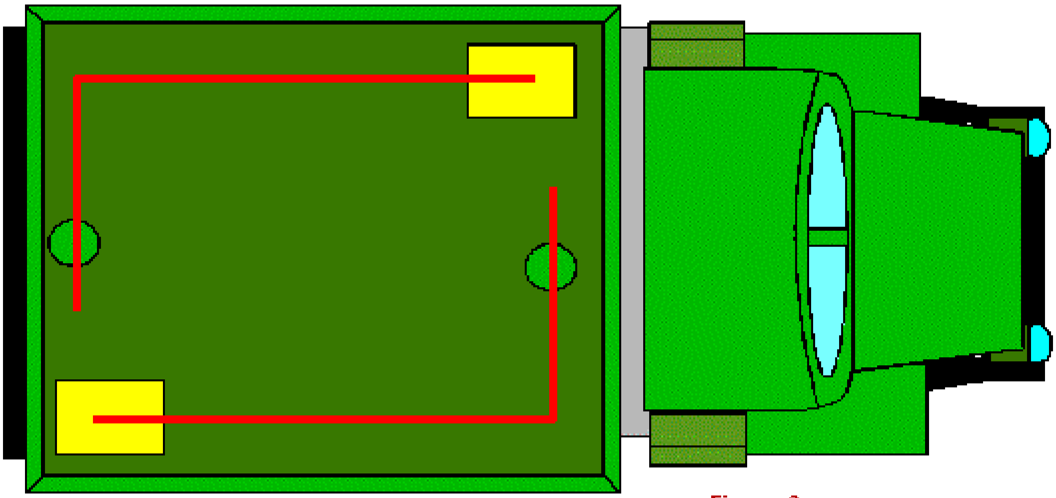
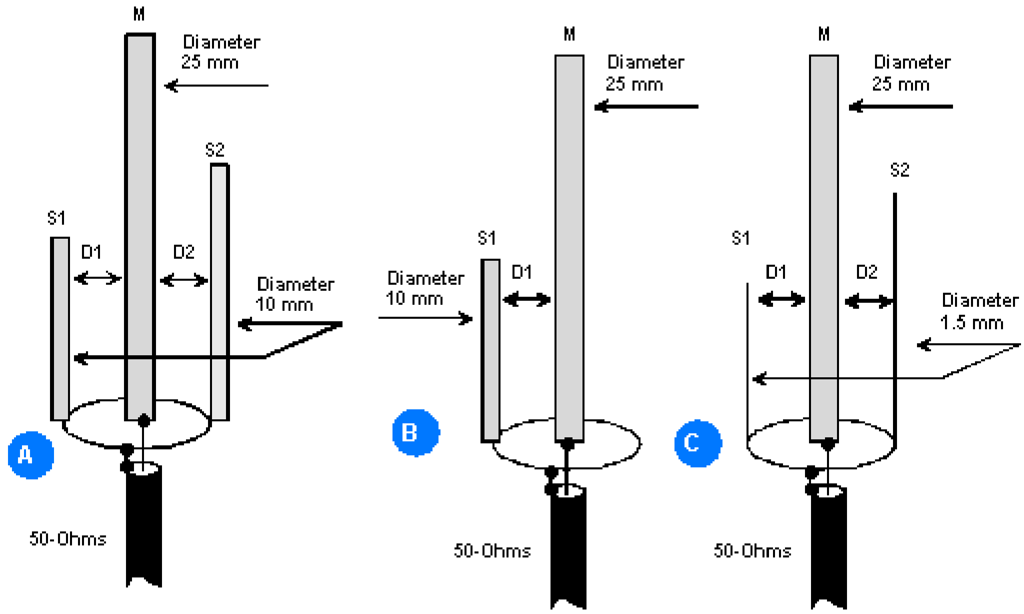


Figure 6

Practical Design of Open - Sleeve Antennas for Upper Amateur HF - Ranges

By Dmitry Fedorov, UA3AVR



Open Sleeve antennas presented at this article were designed by UA3AVR (Reference: Dmitry Fedorov (UA3AVR).: Multi-range vertical Open Sleeve.- Radiomir. HF and VHF, 2001, #8, pp. 34-36). **Table 1** shows data for the Open Sleeve **Figure 1** shows the design of the antennas

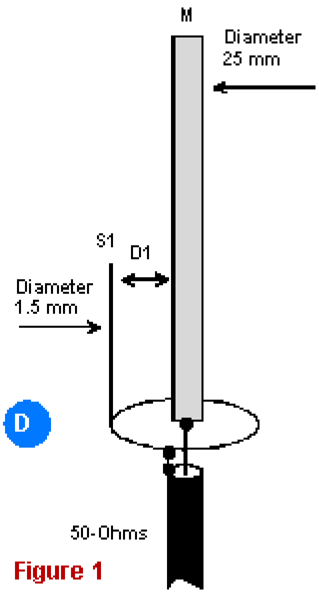


Figure 1

Band, m	Length M, mm	Length S1, mm	Distance D1, mm	Length S2, mm	Distance D2, mm	Figure 1
20; 14; 10	5168	3407	220	2573	200	A
14; 10	3630	2527	220	-	-	B
20; 14; 10	5149	3451	220	2601	200	C
14; 10	3432	2567	210	-	-	D

Something about Antenna Tuning Units

By Igor Grigorov, RK3ZK
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What an ATU does?

You should not think that an Antenna Tuning Unit (ATU) is a magic thing to do any antenna work well with your transceiver. At installation between the transmitter and feeder the ATU only does matching of output impedance of your transmitter with input impedance of your antenna - feeder system. It means that ATU allows to the transmitter with output of 50 Ohm to work normally with antenna plus feeder having any input impedance. But probably SWR would be enough high in the feeder. If the ATU is installed between antenna and feeder it does low SWR in feeder and provides good operation for the transmitter. But probably the antenna would work not in good way.

So, an ATU provides safe operation for transmitters end stage, if the ATU is between the transmitter and the feeder, additionally an ATU does low SWR in feeder, if the ATU is installed between antenna and feeder.

As usual modern transceivers and military equipment have inner ATU that does matching end stage with feeder or antenna. Below we take close look to ATU design.

ATU Design

Fig. 1 shows schematic of a "classical" ATU. Such ATU has:

- a Matching Unit, that provides the matching of end stage of the transmitter with antenna - feeder system. Matching Unit is the "heart" of any ATU;
- A SWR mater or HF-bridge, that shows how the matching is done;

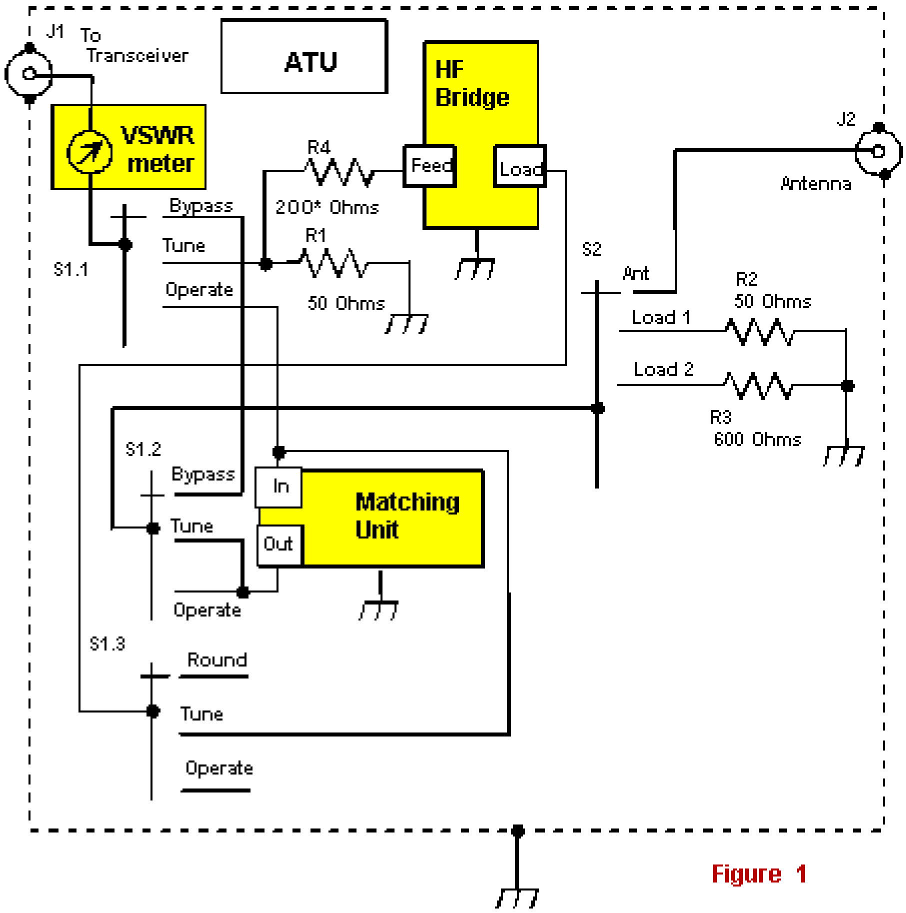

Figure 1

- Dummy loads R1, R2 and R3, that help us to monitor how Matching Unit and SWR – meter (HF-bridge) do work:
- S1 and S2 for proper connection of the above mentioned parts;
- J1 and J2 for transmitter and antenna connection.

So, how the ATU does work?

S1 at “Bypass” position does connection of the transmitter to S2. S2 does connection or to antenna, or to Dummy Loads R2 (50 Ohms) or R3 (600 Ohms). So, at good 50-Ohms antenna the transmitter works straight on the antenna, also is possibility to load the transmitter on 50-Ohms Dummy Load for a tuning of the transmitter or checking of the SWR- meter.

S1 at “Tune” position does connection of the transmitter through inner HF-bridge and Matching Unit to S2. So, it is possible to tune the Matching Unit or on to real antenna (S2 in position Ant) or check how the Matching Unit can tune to 50-Ohms (S2 in position Load 1) or 600-Ohms (S2 in position Load 2) load. When you have your antenna tuned, switch S1 in position “Operate” and just work in the ether.

You can see, it is possible to use or SWR- meter or HF-bridge for tuning the MU on to real load.

As it is visible from this scheme the degree of the matching of the transmitter with used antenna depends only on used Matching Unit. Let’s see what our Matching Unit can contain.

Classical Matching Unit

One of most effective Matching Units is shown on **Fig. 2**. This scheme was widely used by the radio amateurs from early 30s till recently days. As it is visible from **Fig. 2**, the end stage of the transmitter is connected through coupling coil L1 and coupling capacitor C1. L2 and C2 is tuned to resonance to input signal. C3 does coupling with the load (antenna).

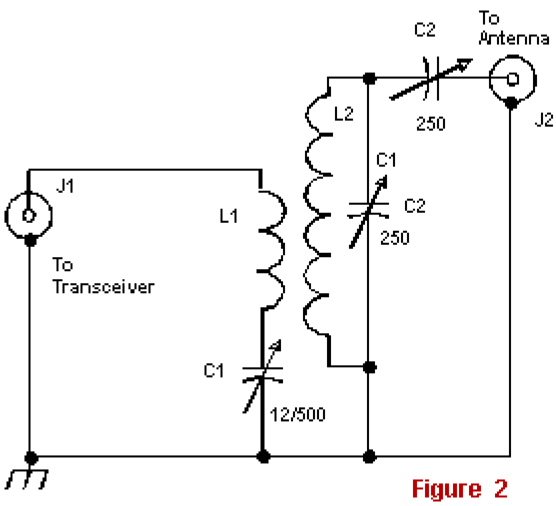

Figure 2

As usual, L1 has from ¼ to 1/6 from amount of turns of L2. L1 is winded in lower part of L2. L1 should be unbound from L2 by any qualitative isolation. In some designs of the MU, L1 is isolated by means of air. The transmitter is coupled to the antenna only by magnetic field, so the end stage of the transmitter is protected from a lightning. Resonance circuit kills harmonics. The Classical Matching Unit does well match a load from 10 to 1000 Ohms with end stage of transmitter in 50 or 75-Ohm impedance.

C1 should have maximum of capacity up to 1500-pF at operation through 1,8- 28 MHz, and 500-pF would be enough for operation through 3.5- 28 MHz. If L1 has optimal number of turns the C1 is not necessary at all. C2 and C3 should have the greatest possible clearance between their plates.

At constant parameters of L1 and L2 the Classical Matching Unit works with high efficiency only in two multiple amateur HF - ranges, for example, 1,8 and 3,5 MHz, 7 and 14 MHz and so on. At others ranges efficiency is dropped. Old Classical Matching Unit had plug-in coils for all amateur range for keeping the efficiency at high level. L2 should be placed as far as possible from metal walls of the cabinet of the ATU.

To tune the MU is very simple. At first, C1 has the maximum capacity, C2 and C3 have minimum capacity. Then, with help of C2 do tune resonance circuit L2C2 in the resonance to working frequency, then C3 does optima matching with the antenna. After that once more time do tuning C2 and C1. It is necessary to say, that after final tuning of the MU C3 has to have the greatest capacity as it is possible.

Advantages of the MU are following. It does not require too careful manufacture of L1 and L2. The system ensures high efficiency, up to 80 percents. Tuning is done with two capacitors C2 and C3. The lacks are that for high efficiency in the matching unit it is necessary to use one spool to two multiple ranges, and one variable capacitor insulated from case of an ATU.

Classical Matching Unit with a symmetrical output

Recently symmetrical antennas with a symmetrical feeder are applied seldom, but some decades ago it was a usual matter. Classical Matching Unit with symmetrical output is shown on **Fig. 3**. In scheme shown in **Fig. 3** a RF- voltage for antenna - feeder system is removed symmetrically from both ends of L2, and it is only difference from the scheme shown in **Fig. 2**. In practical design L1 should be disposed symmetrically concerning resonance spool L2. Twins capacitors C2.1 and C2.2 should have one axe. It is as well as to C3.1 and C3.2.

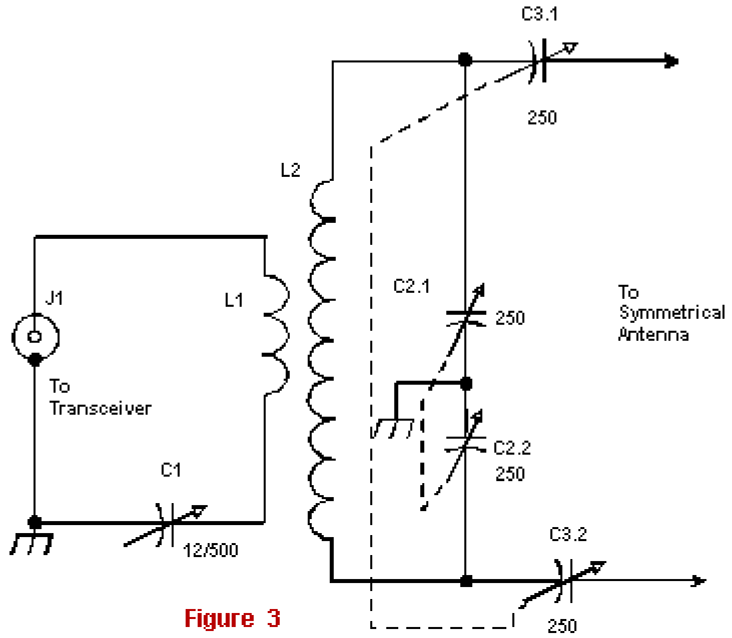

Figure 3

Classical Matching Unit with taps

You can see that C3 is isolated from metal cabinet of the ATU. It is not convenient for practical design of an ATU, so amateurs often use Classical Matching Unit with taps.

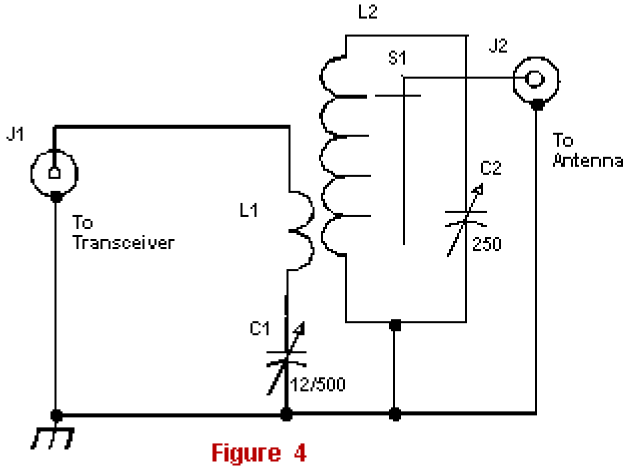

Figure 4

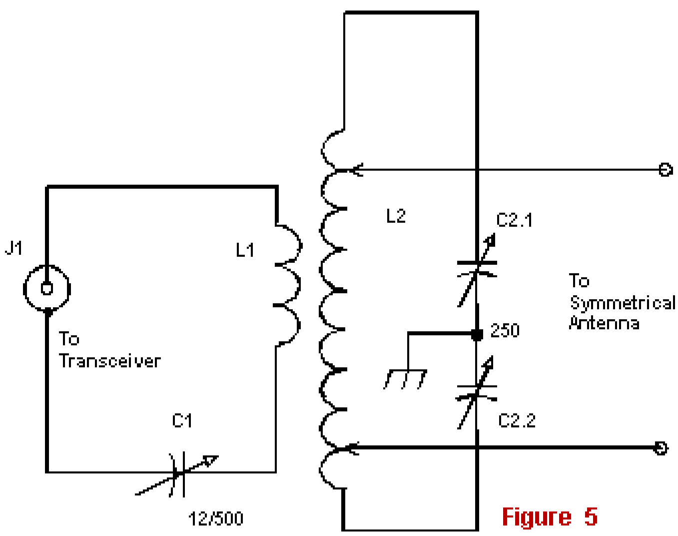

Figure 5

Fig. 4 shows such MU with asymmetrical output, **Fig. 5** shows Classical Matching Unit with taps with symmetrical output. These schemes (**Fig. 4 and 5**) cannot give such careful matching, as shown in **Fig. 2** or **Fig. 3** have provided. But in case if it is need to minimize dimensions of an ATU the schemes can be used.

Multi-range Matching Unit with taps

So, if you want to build an ATU having minimum sizes and parts try the schematic shown in **Fig. 6**. However, the Matching Unit has not high efficiency at upper amateur ranges because of lowering of the Q-factor of L2 and because of not optimal selection of taps from L2. But usage of such simplified multi-range Matching Unit at amateur HF - ranges 1,8-10-MHz is quite acceptable.

T - Matching Unit

Classical Matching Unit is very effective in the work. However, among radio amateurs and military T-Matching Unit has more popularity then one shown in **Fig. 2**. It takes place because T- Matching Unit have high efficiency at very wide frequency ranges and T-Matching Unit allows to do easy automatic tuning (that very likely to the military!). Also, T- Matching Unit works very well with for asymmetrical coaxial cables feeding modern antennas. **Fig. 7** shows schematic of T- Matching Unit. The MU has rather good parameters. It is possible to do matching a 50–Ohms transmitter to 10- 1000-Ohms antenna. It is possible overlap all HF- amateur bands from 3,5 up to 30 MHz using only one variable inductor at 0.5-30-µH and two variable capacitor at 10- 250-pF. The MU does matching at 1.8-MHz if to bridge C1 and C2 to connect fixed capacitors at 200-pF.

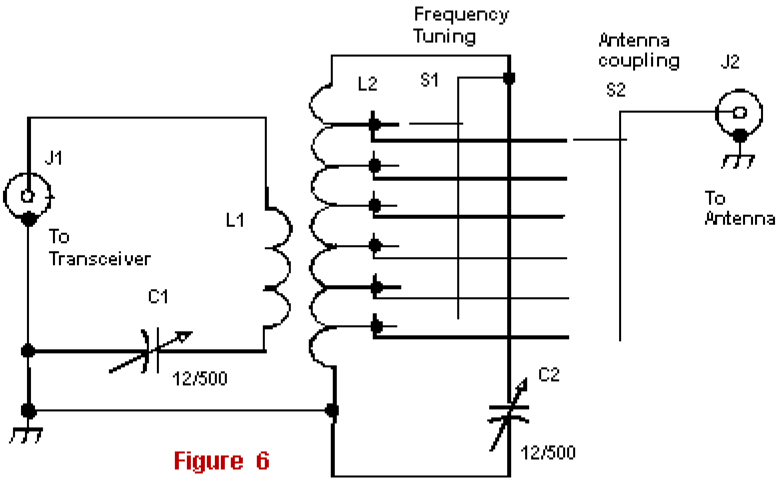

Figure 6

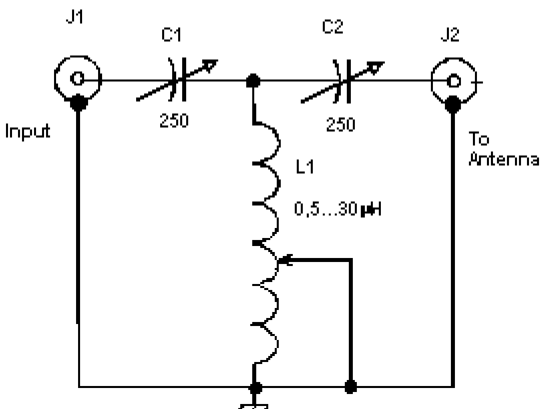

Figure 7

The "cold" end of L1 should be grounded or isolated carefully from the metal case of ATU. Otherwise you probably will have strong arc between the ungrounded end of L1 and a wall of the ATU, as it is shown in **Fig. 8**. C1 and C1 should be very qualitative with aerial or vacuum dielectric. The clearance between plates of capacitors should be not less than 2-mm/ to 200-W bypass power. Stray capacitance of C1 and C2 to the metal case of ATU should be no more than 25-pF, otherwise the efficiency at 24-28-MHz drop.

Figure 8 Arcing inductor

If you want to connect symmetrical antennas feeding through symmetrical ladder lines to the T- Matching Unit, use symmetrical transformer 1:4 or 1:6. BTW, many of symmetrical antennas, feeding through ladder lines have large reactive component, which bad to transformation by simple transformers 1:4 or 1:6. The T - Matching Unit suppress harmonics up to 10-15 dB.

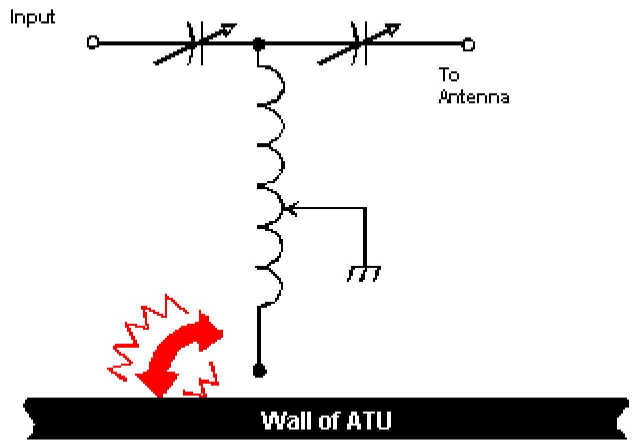

Figure 8

T - Matching Unit with a "digital" inductor

L1 has to have slide contact to operate the MU in proper way. Sometimes, even extra half of a turn influences to the matching. It restricts usage of an inductor with taps, or demands personal selection taps for real antenna, that certainly, restricts possibilities "tap" MU. Simple decision on this problem by W3TS made, he offered a "digital" inductor that **Fig. 9** shows. Really, it is possible with the help of several switches very fine to tune needed inductance. Electronic relays with special chips allow realize automatic ATU. Military also use the method at their automatic ATU.

T - Matching Unit with mirror parts

For practical design of any ATU it is not conveniently to have two capacitors insulated from the ground. AEA corporation (USA) does the MU as **Fig. 10** shows. You can see that they changed C to L. Really, schemes of MU figured in **Fig. 7** and **Fig. 10** are equivalent.

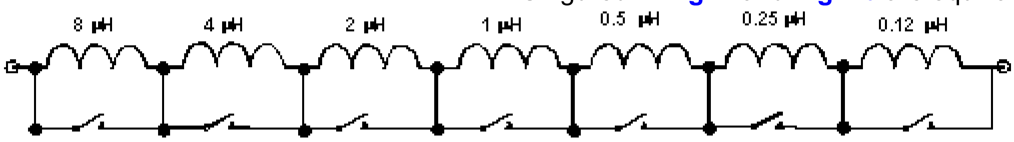

Figure 9

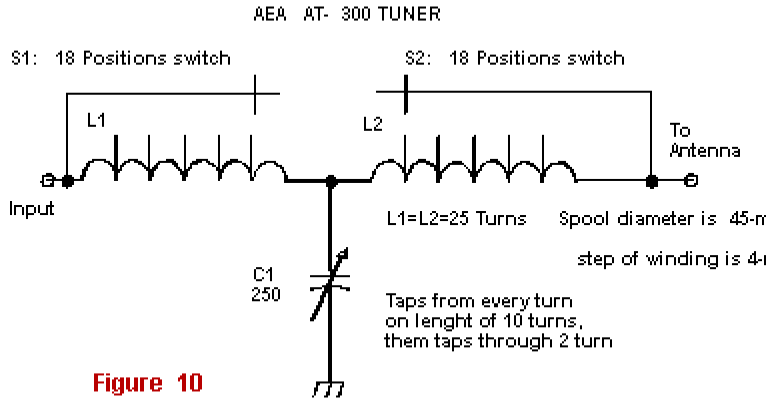

Figure 10

But scheme in **Fig. 10** has advantages. At first, it is much easier to use only one grounded high-quality capacitor instead of two ones but insulated from metal cabinet. Secondly, it is wise to substitute expensive inductor with slide control to two cheapie spools with taps.

The MU made by me at home conditions worked well on all amateur ranges from 1,8 up to 30 MHz and did matching to 50-Ohms transmitter to antenna with resistance from 15 up to 500-Ohms.

The inductors were made as **Fig. 11** shows. Form of inductors is made of PC – board with slots for turns. On the plate switch for taps is installed. The plate is disposed not in center of the inductor but little sideways as **Fig. 12** shows.

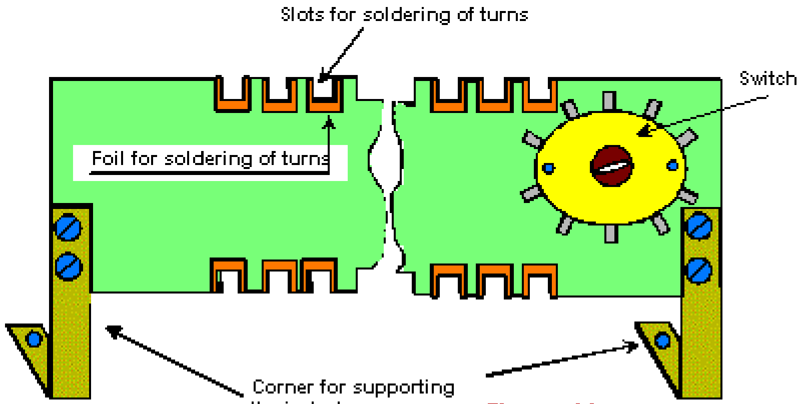

Figure 11

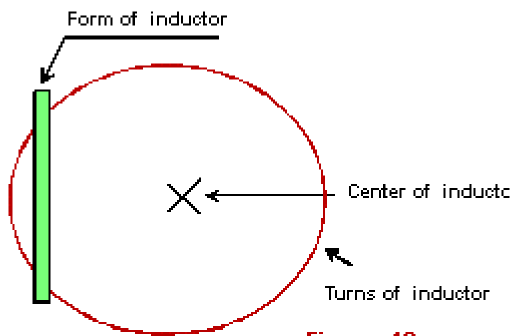

Figure 12

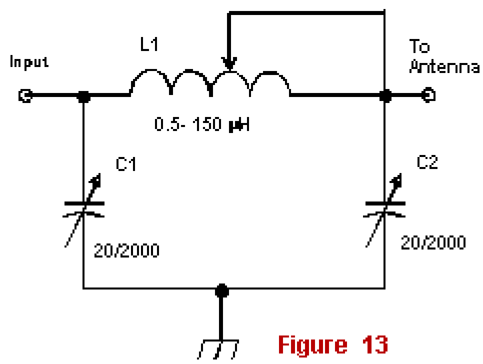

Figure 13

Pi- Matching Unit

Pi - MU is used in radio amateur practice for a long time. It is possible to find Pi - MU and disputes on this subject at radio amateur journals issued on 20s of the 20 century till our time in the Internet. **Fig. 13** shows Pi– MU. As usual Pi – MU is used at inner MU at tube and transistor PA or straight at antenna clips..

Pi – MU seldom is used at separate ATU. For matching in a wide frequency ranges loads with resistance 10-1000- Ohms it need to change C and L at Pi – MU too greatly. So, it is impossible to do universal Pi – MU.

It is desirable to use slider inductor because. In case if an inductor with fixed taps is used you can carefully to select the tap for real antenna.

L- Matching Unit

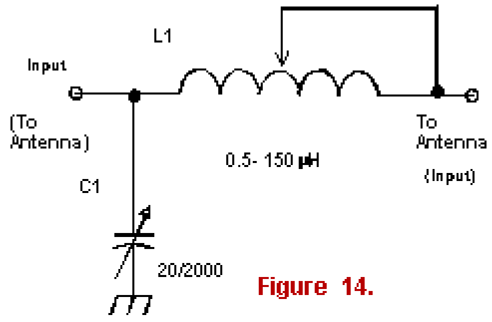

Figure 14.

Fig. 14 shows L- MU. This one is a simplified version of Pi – MU. ATU, keeping L- MU often is used for operation with simple tube and transistor transceivers and for matching simple multi- range antennas, which do not contain large reactive component.

Parts for the ATU

The data of spools for the MU exhibited on **Fig. 2** are shown in **Tab. 1**, for the MU exhibited on **Fig. 3** are shown in **Tab. 2**.

Table 1 Data for MU exhibited on Fig. 2

Frequency band, MHz	1,9	3,5-3,8	7	10	18	14	21	24	27-30
Diameter of spool, mm	50	30	25	25	25	25	25	25	25
Length of winding, mm	50	30	40	40	40	40	30	30	30
Number of turns	100	30	20	15	10	11,5	8,5	7,5	6,5

Table 2 Data for MU exhibited on **Fig. 3**

Frequency band, MHz	1,9	3,5-3,8	7	10	14	18	21	24	27-30
Diameter of spool, mm	50	40	25	25	25	25	25	25	25
Length of winding, mm	60	40	40	50	40	40	40	40	35
Number of turns, n	130	35	28	20	15	11,5	11	9,5	8,5

Tab. 3 Data for digital inductor shown in **Fig. 9**

Inductance, µH	8	4	2	1	0,5	0,25	0,12
Diameter of spool, mm	30	20	20	20	25	10	10
Length of winding, mm	30	20	25	20	20	10	10
Number of turns, mm	20	18	12	8,5	5	6	4

It is possible to use for T –MU any variometer, which is possible to get. Variometer has to have maximum inductance not less than 30-µH and minimum close to zero. If the maximum of the inductance of the variometer is less, for expansion of frequency range of the ATU to include in serial with the variometer a fixed inductor. If the minimum inductance of the variometer does not reach zero, it is essentially cut off the upper range of operation of the ATU.

The design data for spools for digital inductor shown on **Fig. 9** are shown in **Tab. 3**. Significant RF-currents flow through parts of MU - capacitors, inductors, and switches. So all of the parts should be qualitative.

73! I.G.

ANTENNA TUNING UNIT FOR 6-METERS

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For experimental operation on the 6-meters range some antennas for others bands with ATU can be used, especially if a radio amateur only starts to work on the "magic" band. Schematic for such ATU that does match any antenna of 10-20 meters to 6-meters is shown on **Fig. 1**.

The ATU allows match a load of 15 to 1000 Ohms with 50- Ohms coaxial cable or with end stage of the transceiver. Efficiency is not less than 70 %. The ATU has L2C1 resonant circuit that kills TVI very well.

Of course, to install the ATU between the antenna and the coaxial cable is the best way for the RF power going to the antenna. In this case you can connect the antenna to J3 and the coaxial cable to J1. Of course, the situation is impossible at many cases, because it requires install the ATU straight by the antenna terminals. So, more often we have only one way - connect the coaxial cable going from the antenna to J2 and the transceiver to J1. The coaxial cable going from the antenna will work with high SWR and maybe, with large losses. But we will have possibility work in the ether at 6-meters.

Some words about parts of the ATU. L2 consist of 8 turns of copper wire of 2.0-mm or #12AWG. The coil is air wound, OD is 16-mm diameter, the length is 24-mm. L1 consists of 3 turns of copper wire of 1.0-mm or #18AWG. L1 is wound above "cold" end of L2. The length of L1 is approximately 5-mm. R1 serves for removal of static voltage accumulated by the antenna. J1 is intended for coaxial cable going to the transceiver. J2 is intended for coaxial cable feeding antennas. J3 is intended connection to the antenna terminals or for feeding the antenna through a ladder line. J3 is just two screws of diameter of 3-mm.

ATU is tuned with help of a Neon bulb VL1. You can use any small neon bulb. One clip of the bulb is connected to the antenna a piece of wire of length of 3- 10-cm (depends on the transceiver power) is connected to other clip. Tune the ATU to the maxima of glow of the bulb. If you use a QRP- transceiver you can use a FSM (Field Strength Meter) for the tuning.

Do tuning in this way. Firstly C2 stands to minimum. Secondly, with the help of C1 do tune the L2C1 to the resonance (by the neon bulb VL1). Then gradually do augment capacity of C2 to maxima of glow of the neon bulb VL1. C1 and C2 can be aerial dielectric, and plate clearance should be 0.5-mm to 30 watts bypass power. .

The ATU is assembled inside a box soldered from PC – board. Box has dimensions 100*70*50 mm.

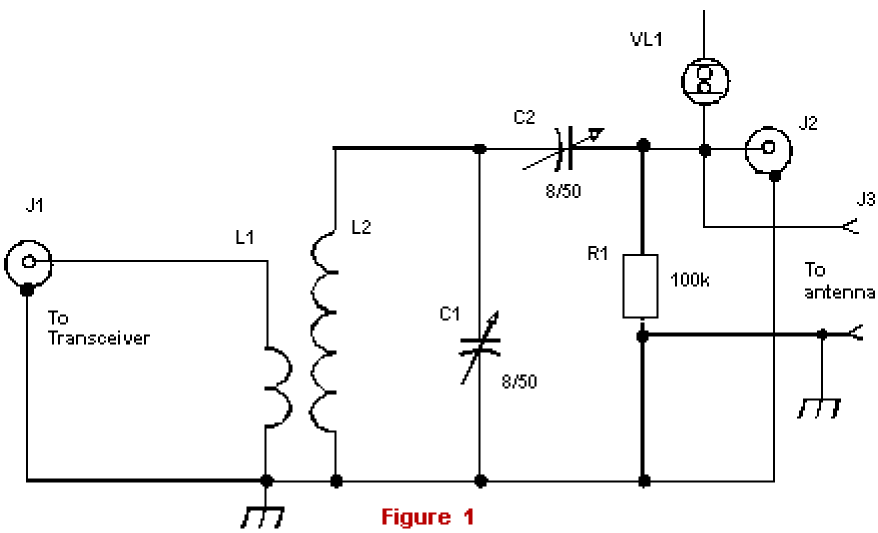


Figure 1

UR5LCV'S YAGI FOR HAMS

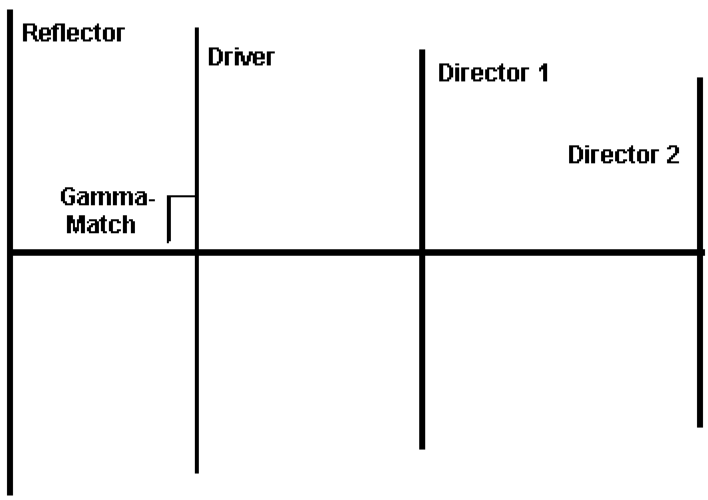
Antennas from here were designed and optimized by Igor Zel'din, UR5LCV, and design of the antennas were wrote in the book: HF- Antennas- 3, by I. Beketov, UR4LTX, I. Zel'din, UR5LCV, Kharkov, 1994.

10 years has gone from the publishing of the book, for this time lots of these antennas became well-known to hams of the CIS. Lots of these antennas are practically made and have shown full conformity to the theoretical parameters.

The antennas are designed for tubes of 25-mm diameter. If for tubes with different OD are used for elements of antennas do correcting of antenna sizes by modern Antenna Simulation Program. Input resistance of the antenna is much lower the 50 Ohms so it need to use a gamma match feed the antenna. You may calculate a gamma – match using programs given at Appendix to ARRL-Antenna Book, 19 or 20 Edition.

UR5LCV's YAGI FOR 28-MHz

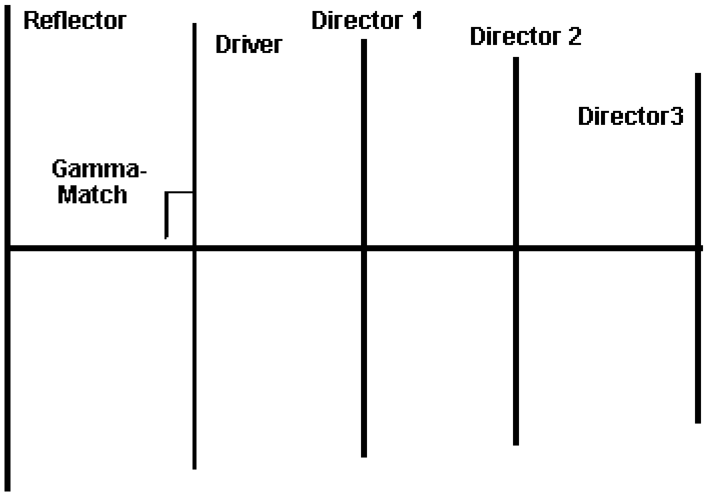
4-el YAGI for 28-MHz



F, MHz	28.0	28.35	28.7
G, dBd	7.16	7.49	7.87
F/B, dB	20.35	28.36	20.27
Z, Ohm	30.4-j7	26.4+j1.6	20.4+j.14.3
SWR	1:1.63	1:1.14	1:1.6

OD 25-mm	Reflector	Driver	Director 1	Director 2
Length, cm	535	503	479	448
Spacing to Reflector, cm	0	168	368	683

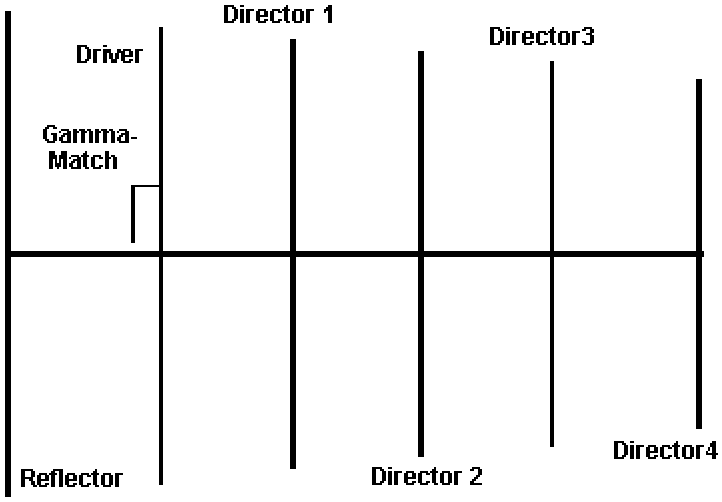
5-el YAGI for 28-MHz



F, MHz	28.0	28.35	28.7
G, dBd	8.17	8.41	8.46
F/B, dB	20.46	38.03	20.74
Z, Ohm	28.9-j9.8	29.5+j0.3	35+j2.9
SWR	1:1.3	1:1.09	1:1.29

OD 25-mm	Reflector	Driver	Director 1	Director 2	Director 3
Length, cm	524	509	488	482	466
Spacing to Reflector, cm	0	149	253	478	736

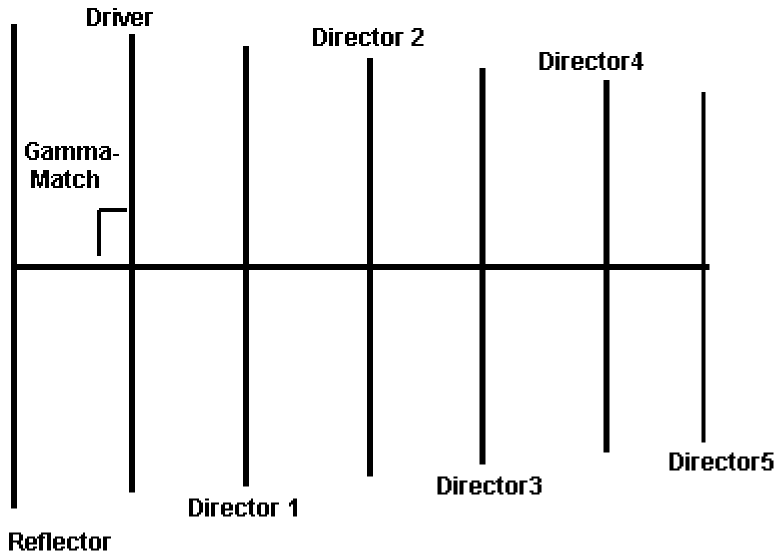
6-el YAGI for 28-MHz



F, MHz	28.0	28.35	28.7
G, dBd	9.39	9.62	9.49
F/B, dB	17.1	26.7	18.1
Z, Ohm	29.2-j8.8	24.6+j1	21.4+j21.7
SWR	1:1.95	1:1.3	1:1.94

OD 25-mm	Reflector	Driver	Director 1	Director 2	Director 3	Director 4
Length, cm	530	502	481	480	477	464
Spacing to Reflector, cm	0	160	308	500	781	1084

7-el YAGI for 28-MHz

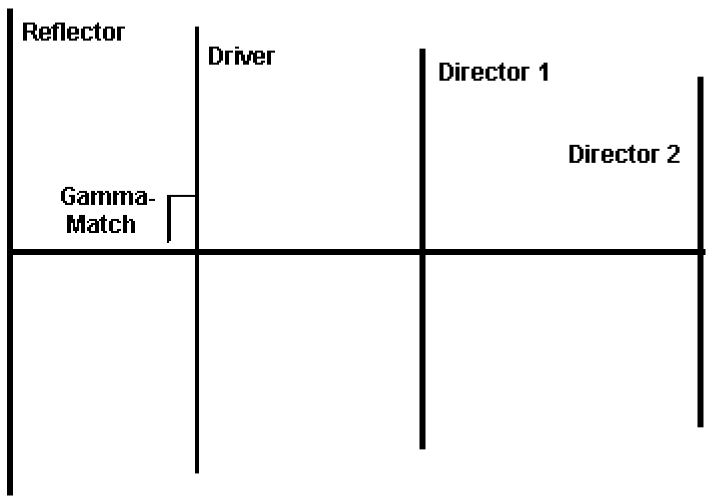


F, MHz	28.0	28.35	28.7
G, dBd	9.74	10.1	10.2
F/B, dB	20.48	23.75	18.15
Z, Ohm	30.2-11.1	30.6+j0.8	33.8+j10.9
SWR	1:1.48	1:1	1:1.39

OD 25-mm	Reflector	Driver	Director 1	Director 2	Director 3	Director 4	Director 5
Length, cm	520	501	486	479	473	470	458
Spacing to Reflector, cm	0	205	348	541	779	1058	1343

UR5LCV's YAGI FOR 21-MHz

4-el YAGI for 21-MHz



F, MHz	21.0	21.175	21.35
G, dBd	6.88	7.03	7.16
F/B, dB	20.83	21.36	20.83
Z, Ohm	26.7-j3.8	23.3+j1.4	18.3+j8.6
SWR	1:1.4	1:1.09	1:1.4

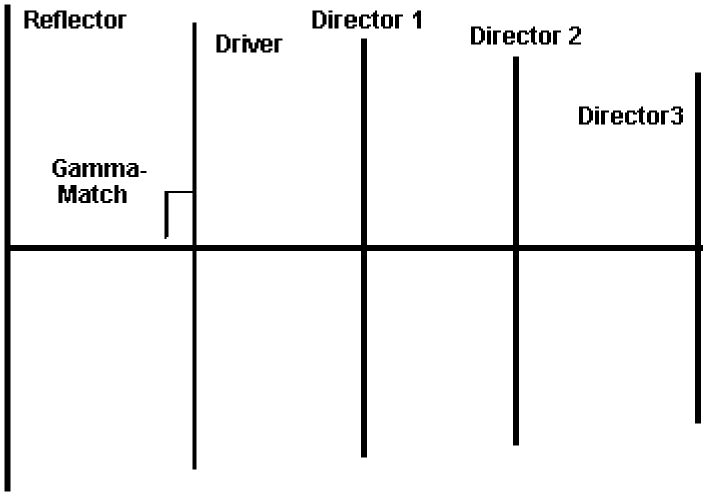
OD 25-mm	Reflector	Driver	Director 1	Director 2
Length, cm	722	684	658	614
Spacing to Reflector, cm	0	160	340	676

Another One 4-el YAGI for 21-MHz

F, MHz	21.0	21.175	21.35
G, dBd	7.74	8.0	8.26
F/B, dB	19.65	32.1	20.49
Z, Ohm	29-j58	24.2+j0.9	17.5+j10.6
SWR	1:1.53	1:1.15	1:1.54

OD 25-mm	Reflector	Driver	Director 1	Director 2
Length, cm	716	674	650	634
Spacing to Reflector, cm	0	210	516	880

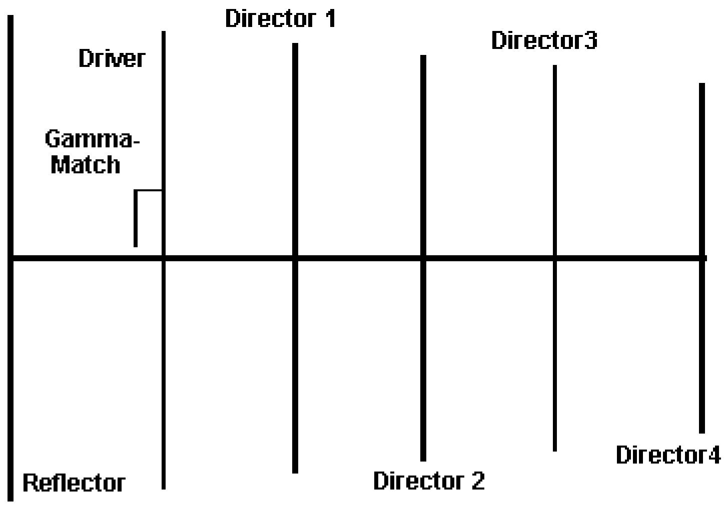
5-el YAGI for 21-MHz



F, MHz	21.0	21.175	21.35
G, dBd	8.19	8.39	8.54
F/B, dB	22.99	29.06	21.34
Z, Ohm	29.3-j8.8	29.3+j0.3	31.2+j11
SWR	1:1.39	1:1.02	1:1.4

OD 25-mm	Reflector	Driver	Director 1	Director 2	Director 3
Length, cm	700	675	645	643	622
Spacing to Reflector, cm	0	234	388	657	1022

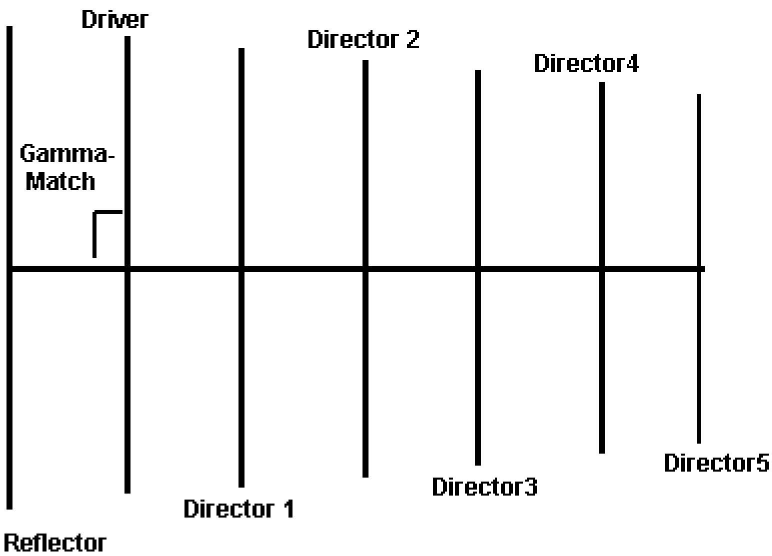
6-el YAGI for 21-MHz



F, MHz	21.0	21.175	21.35
G, dBd	9.46	9.63	9.62
F/B, dB	20.24	31.15	20.33
Z, Ohm	27.6-j8.3	23.8+j0.0	20.3+j13.7
SWR	1:1.65	1:1.16	1:1.64

OD 25-mm	Reflector	Driver	Director 1	Director 2	Director 3	Director 4
Length, cm	713	673	647	645	643	625
Spacing to Reflector, cm	0	218	413	658	1045	1450

7-el YAGI for 21-MHz

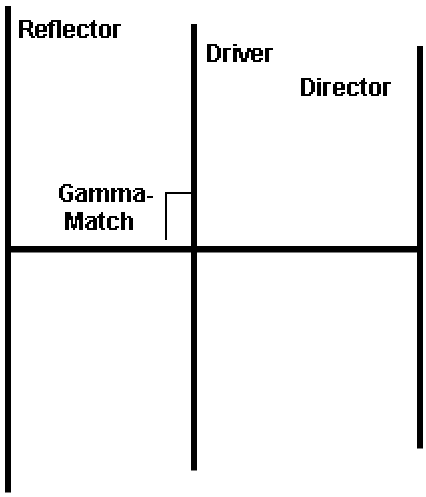


F, MHz	21.0	21.175	21.35
G, dBd	9.98	10.1	10.21
F/B, dB	23.61	24.14	20.00
Z, Ohm	29.5-j8.3	29.6+j0.1	30.7+j8.0
SWR	1:1.33	1:1	1:1.64

OD 25-mm	Reflector	Driver	Director 1	Director 2	Director 3	Director 4	Director 5
Length, cm	695	674	649	638	630	626	607
Spacing to Reflector, cm	0	275	466	725	1043	1417	1798

UR5LCV's YAGI FOR 14-MHz

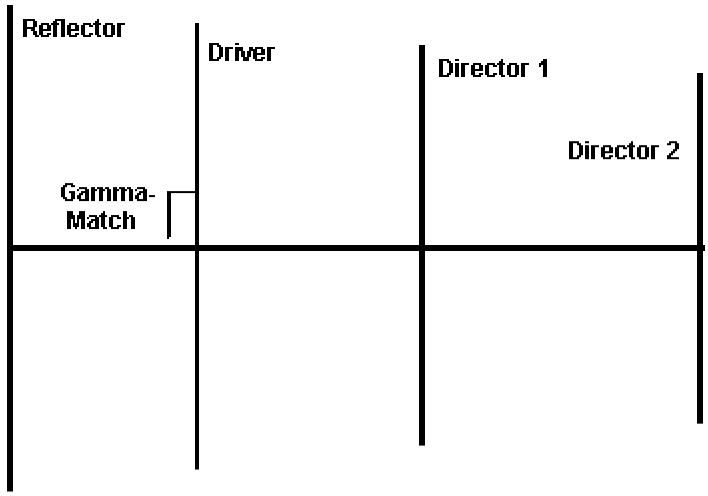
3-el YAGI for 14-MHz



F, MHz	14.0	14.15	14.3
G, dBd	5.96	6.11	6.29
F/B, dB	19.07	25.43	18.44
Z, Ohm	22.4-j10.5	22.5+j0.3	21.3+j11.6
SWR	1:1.64	1:1.02	1:1.64

OD 25-mm	Reflector	Driver	Director 1
Length, cm	1054	1010	947
Spacing to Reflector, cm	0	282	696

4-el YAGI for 14-MHz



F, MHz	14.0	14.15	14.3
G, dBd	6.86	7.0	7.12
F/B, dB	18.02	20.13	18.93
Z, Ohm	22.2-j8.9	22.6+j0.3	20.2+j8.6
SWR	1:1.5	1:1.02	1:1.5

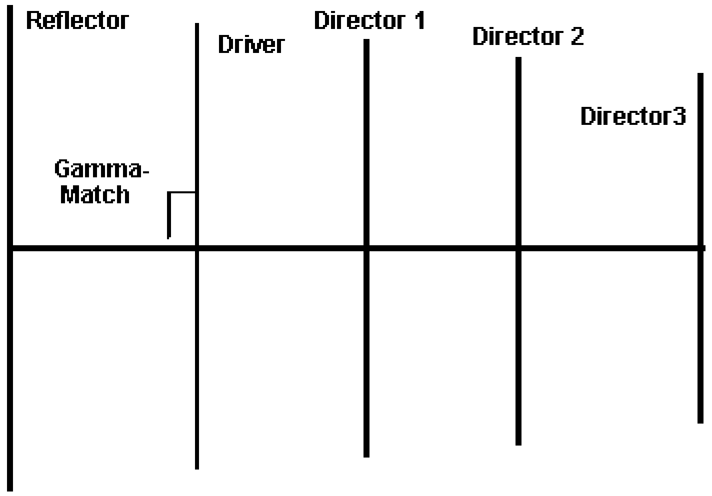
OD 25-mm	Reflector	Driver	Director 1	Director 2
Length, cm	1052	1018	982	920
Spacing to Reflector, cm	0	254	536	968

Another One 4-el YAGI for 14-MHz

F, MHz	14.0	14.15	14.3
G, dBd	7.5	7.84	8.24
F/B, dB	18.08	29.19	18.06
Z, Ohm	34.3-j5.9	28.3+j0.8	18.2+j14.3
SWR	1:1.68	1:1.26	1:1.67

OD 25-mm	Reflector	Driver	Director 1	Director 2
Length, cm	1079	1014	976	954
Spacing to Reflector, cm	0	326	771	1320

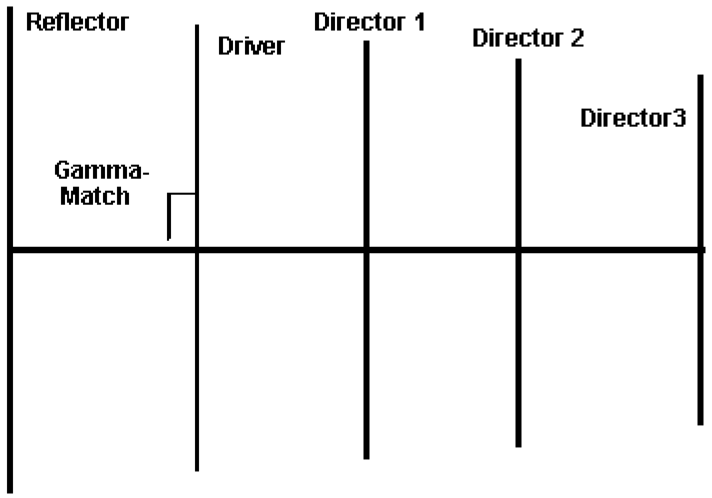
5-el YAGI for 14-MHz



F, MHz	14.0	14.15	14.3
G, dBd	8.23	8.53	8.77
F/B, dB	20.03	28.74	19.6
Z, Ohm	28.3-j9.4	25.7+j1.6	22.8+j14.4
SWR	1:1.61	1:1.07	1:1.67

OD 25-mm	Reflector	Driver	Director 1	Director 2	Director 3
Length, cm	1046	1013	972	961	929
Spacing to Reflector, cm	0	372	746	1237	1694

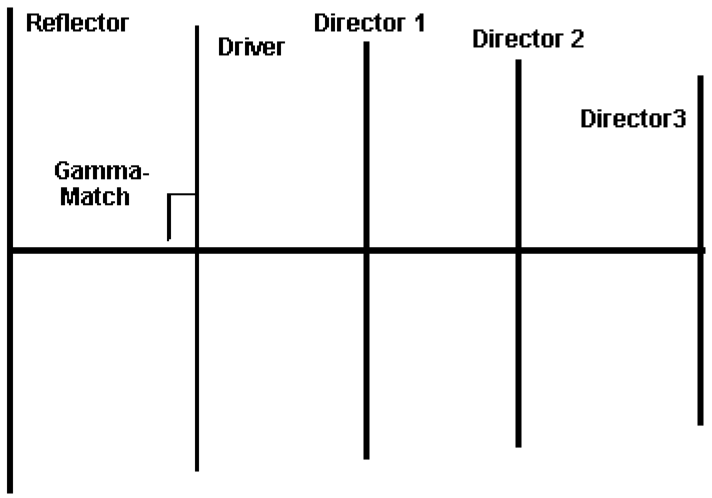
6el YAGI for 14-MHz



F, MHz	14.0	14.15	14.3
G, dBd	9.4	9.6	9.45
F/B, dB	17.46	26.31	18.1
Z, Ohm	32.9-j8.7	27.2+j0.3	23.3+j22
SWR	1:1.85	1:1.32	1:1.8

OD 25-mm	Reflector	Driver	Director 1	Director 2	Director 3	Director 4
Length, cm	1066	1016	979	973	971	952
Spacing to Reflector, cm	0	333	596	983	1574	2142

7el YAGI for 14-MHz



F, MHz	14.0	14.15	14.3
G, dBd	9.8	10.1	10.21
F/B, dB	22.07	24.03	19.01
Z, Ohm	31.2-j11.2	31.4+j0.1	33.3+j9.8
SWR	1:1.46	1:1	1:1.39

OD 25-mm	Reflector	Driver	Director 1	Director 2	Director 3	Director 4	Director 5
Length, cm	1044	1012	976	960	950	946	919
Spacing to Reflector, cm	0	413	697	1085	1561	2120	2690

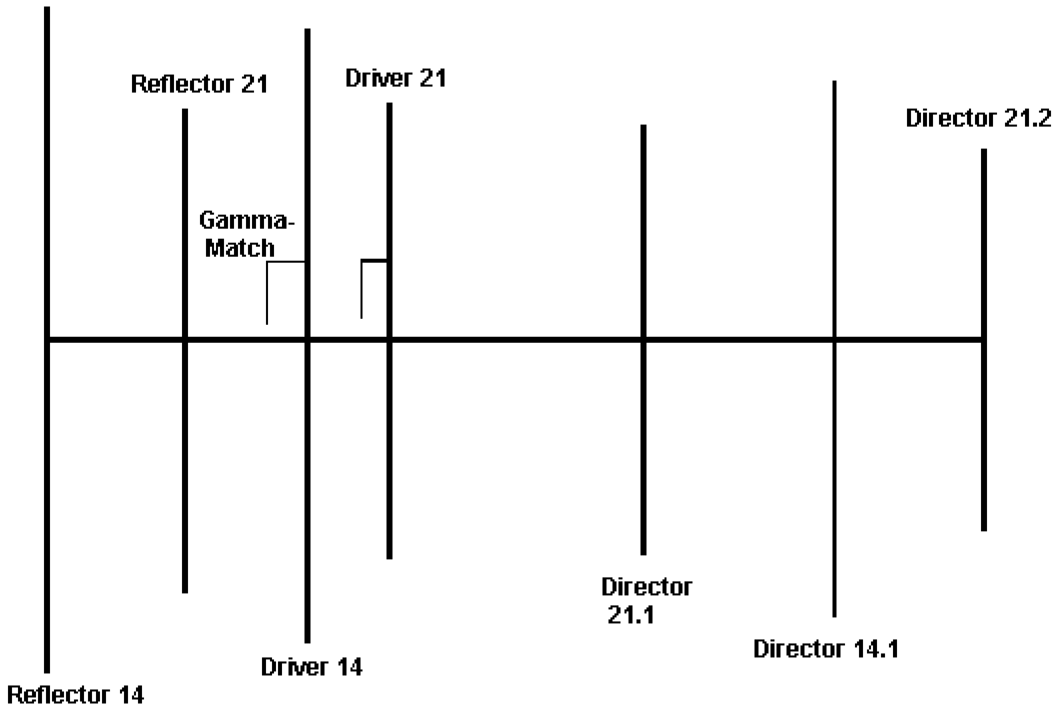
UR5LCV's YAGI FOR 7-MHz

3el YAGI for 14-MHz

F, MHz	7.0	7.05	7.1
G, dBd	6.12	6.3	6.5
F/B, dB	21.19	26.44	20.3
Z, Ohm	23.6-j7.7	22.2+j0.2	20.2+j8.8
SWR	1:1.46	1:1.03	1:1.46

OD 25-mm	Reflector	Driver	Director 1
Length, cm	2100	2037	1934
Spacing to Reflector, cm	0	675	1435

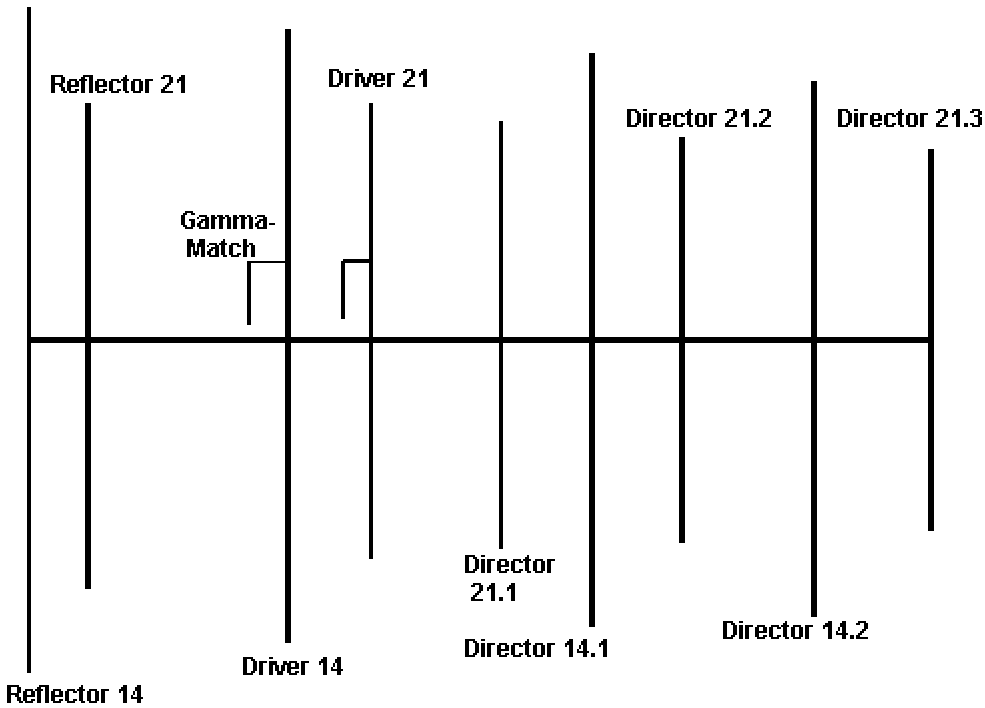
UR5LCV's One- Boom Two Bands YAGI: 3-el. 14-MHz & 4-el. 21-MHz



F, MHz	14.0	14.15	14.3	21.0	21.175	21.35
G, dBd	6.2	6.3	5.9	5.9	6.2	6.5
F/B, dB	16.7	20.4	16.8	18.6	19.5	19.8
Z, Ohm	19.5—j11.9	21.1+j0.8	22.0+j14.0	32.8+j6.0	28.8+j0.2	24.2+j7.5

OD 25- mm	Reflector 14	Reflector 21	Driver 14	Driver 21	Director 21.1	Director 14.1	Director 21.2
Length, cm	1054	708	1012	688	656	943	631
Spacing to Reflector 14, cm	0	200	282	380	575	725	830

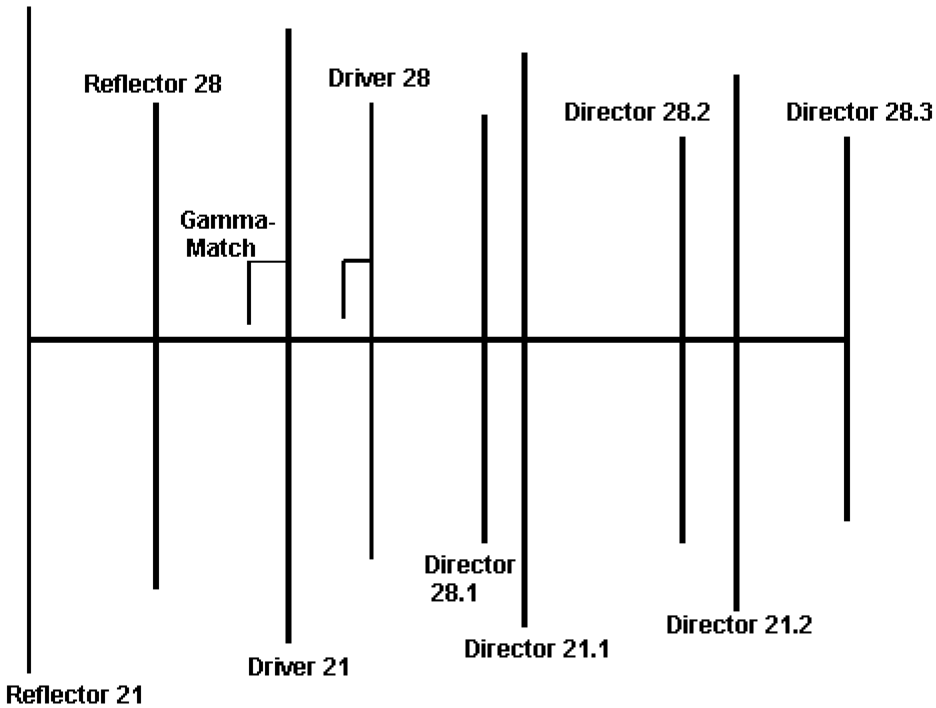
UR5LCV's One- Boom Two Bands YAGI: 4-el. 14-MHz & 5-el. 21-MHz



F, MHz	14.0	14.15	14.3	21.0	21.175	21.35
G, dBd	6.9	7	7.1	7.6	8.0	8.3
F/B, dB	15.7	17.4	18.1	23.6	25.0	20.3
Z, Ohm	22.9—j8.9	23.5+j0.5	25.0+j7.0	24.2+j3.5	27.5+j0.7	32.5+j1.7

OD 25-mm	Ref. 14	Ref. 21	Driver 14	Driver 21	Director 21.1	Director 14.1	Director 21.2	Director 14.2	Director 21.3
Length, cm	1050	702	1020	686	664	982	648	920	640
Spacing to Reflector 14, cm	0	80	250	300	430	536	705	986	1075

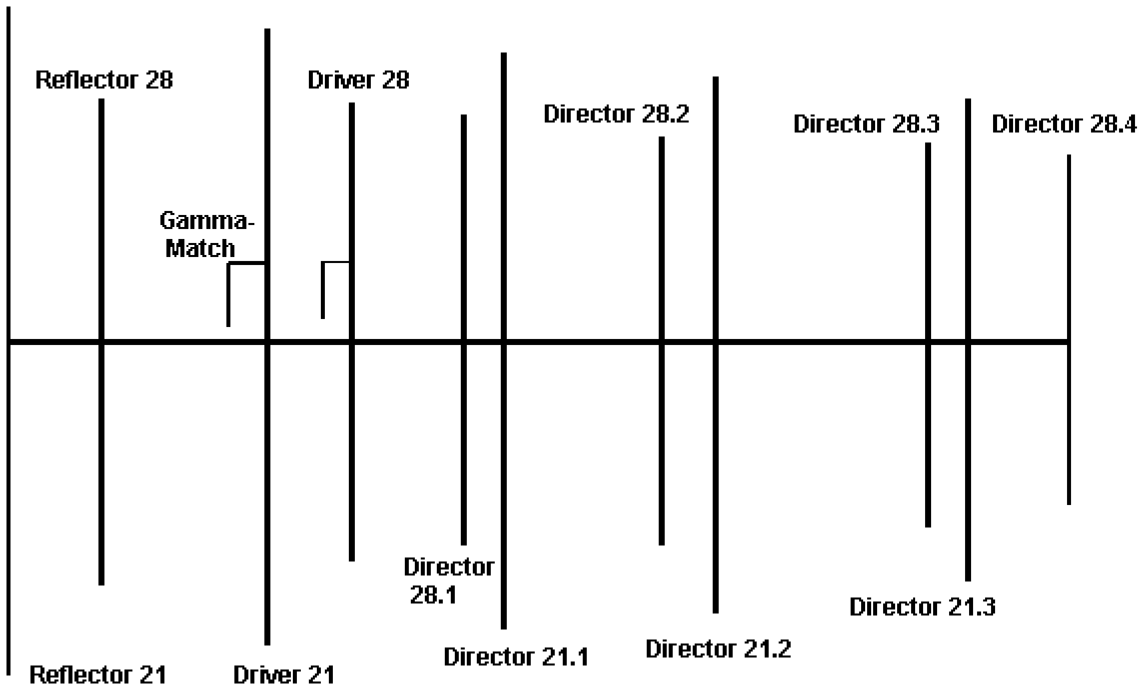
UR5LCV's
One - Boom Two Bands YAGI:
4 - el. 21 - MHz & 5 - el. 28 - MHz



F, MHz	21.0	21.175	21.35	28.0	28.35	28.7
G, dBd	7.9	8.1	8.2	6.5	7.3	8.1
F/B, dB	21.3	25.0	21.1	18.1	27.0	17.4
Z, Ohm	27.3—j11.0	24.1+j1.6	20.1+j17.0	31.9+j6.4	35.8+j0.2	41.0+j5.0

OD 25-mm	Ref. 21	Ref. 28	Driver 21	Driver 28	Director 28.1	Director 21.1	Director 28.2	Director 21.2	Director 21.3
Length, cm	716	520	626	508	490	682	475	628	472
Spacing to Reflector 14, cm	0	170	210	315	420	516	620	880	950

UR5LCV's One- Boom Two Bands YAGI: 5-el. 21-MHz & 6-el. 28-MHz



F, MHz	21.0	21.175	21.35	28.0	28.35	28.7
G, dBd	8.4	8.6	8.7	8.1	9.3	9.8
F/B, dB	24.8	25.1	18.6	13.4	20.4	14.3
Z, Ohm	25.9—j9.9	28.6+j0.9	34.9+j13.1	26.8-j4.8	23.5+j0.4	49.8+j51

OD 25-mm	Ref. 21	Ref. 28	Dr. 21	Dr. 28	Direct. 28.1	Direct. 21.1	Direct. 28.2	Direct. 21.2	Direct. 28.3	Direct. 21.3	Direct. 28.4
Length, cm	700	530	677	510	496	647	490	645	478	624	464
Spacing to Reflector 14, cm	0	70	234	270	340	388	560	657	900	1022	1200

A HELICAL LOPP ANTENNA FOR THE 20 METERS BAND

By Vladimir Kuz'min, UA9JKW,
KuzminVl@pn.yungjsc.com

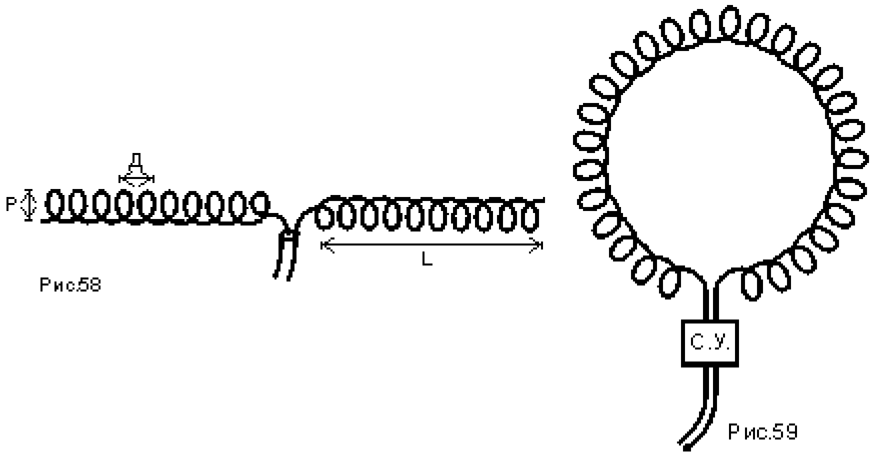
*Two years back I have moved to Nefteyugansk (Russia, Siberia) where I could not receive the sanction to installation for a full-sized HF- antenna on the roof of my house. , So I began to do experimenters with short indoors antennas. Most success design of my indoor antenna is a design similar to **Fig. 59**, given in **Reference 1**.*

I have used an inch OD plastic pipe to the form of the antennal. The pipe was bent in a hoop near1 meter diameter. Antenna has 580 turns (near 61 meters of length) of multicore isolated wire of 3 mm diameter with thickness of isolation of 1 mm. So, the spacing between turns is 2 mm. Antenna has SWR 1:1 to 50-Ohm coaxial cable to 14.100, bandwidth to SWR 1:1.5 is 300-kHz. I use a simple symmetrical device- 3 turns on a TV yoke ferrite core. Space from the antenna to the ceil is near 25 centimeters.

The antenna has quite good directed properties at rotation within 30-90 degrees the force of signals varied to 1-1,5 points on mine S-meter. I use a YAESU FT840 for my work in the ether. Change of polarization (at rotation of the antenna on the vertical side) appreciable changes has not given as well as change of feeding points has not given large change in the force of signals.

Helical Loop Antenna

Figure 58 & 59 from Reference 1



In the last summer I experimented and hung up of the antenna behind my balcony at 1.5 meters from a wall. I have received a significant improvement of the work of the antenna The antenna does very good operation in the ether, better than others indoors antennas. It gives low industrial noise and kills all TVI.

Reference:
I. Grigorov. Antennas for radio amateurs. - Majkop, 1998.

Get free the book from

http://www.cqham.ru/

UA9JKW at his shack

Top Load at Vertical Antennas

All amateurs know if at a vertical antenna a top load it is used, the self –resonance of the vertical antenna would be lower then a vertical without the top load. How a top load does influence to antenna resonance?

At **Reference 1** I found a very interesting table having the data. I have proved the table with **MMANA**, all okey, the table gives very reliable data, so it is possible to use it at many situations. Figure 1 shows different top loads. Data for loaded effect for the top load is shown in Table 1 given at **Reference 1**. K is coefficient: K = W/L, where W is a resonance wavelength for the vertical antenna, L is antenna length from the ground to the top load.

As it is seen, the “umbrella” top load (**Figure 1e**) gives the most effect on the resonance of a vertical antenna. For example, if to use an umbrella load for a vertical antenna in five meters height, the antenna quarter wave fundamental resonance wavelength would be changed from 20 to 50 meters!

Reference:

1. Polyakov V. Technique of radio: Simple AM receivers. – Moscow, DMK-Press, 2001.

73! I.G.

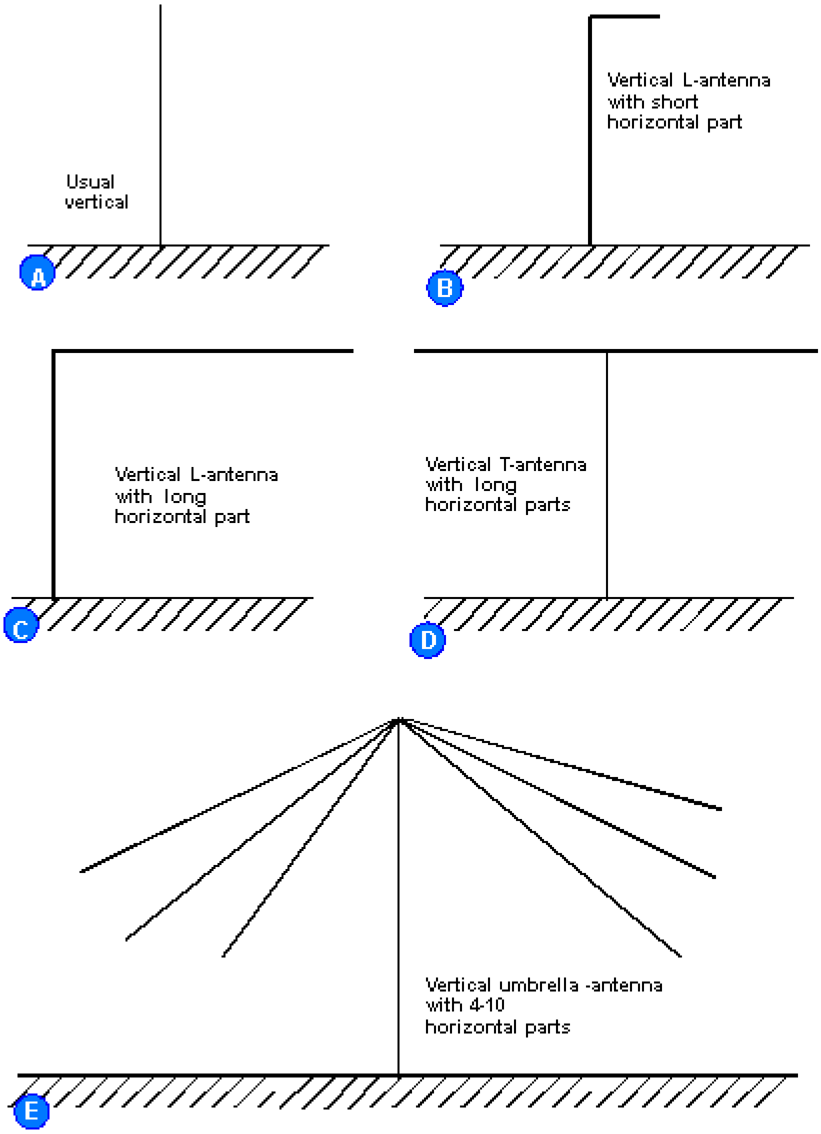


Figure 1

Kind of an antenna	K
Simple vertical **Figure 1a**	4
Inverted L with short horizontal part **Figure 1b**	4.5-5
Inverted L with long horizontal part **Figure 1c**	5-6
T- antenna with long horizontal part **Figure 1d**	6-8
Umbrella antenna with 4-8 wires **Figure 1e**	6-10

QRP- TALES

By Alexei Rusakov, UA4ARL/qrp (RU-QRP # 005) ua4arl@vistcom.ru

Continued from ANTENTOP- 03-2003

1'st March, 2003

The ARRL phone contest was today but propagation was bad into Volgograd. Even the CW portions were quiet. I checked all the CW portions of the bands this morning and figured that everyone was on SSB. In the evening I went back to check the condition of the bands but 21.060, 24.900 and 28.060 were already gone. While in 15 meters I slid down the band and heard some Europeans. LP's were 549 - 559 while HP's were no louder than 589 here in Volgograd. Around 21.006 there was someone that had a 559 signal with 3 or 4 stations calling him. However, he didn't give his call sign while I was listening.

I changed antennas from a North delta to an Africa oriented 2 element and the signal went to 579. That is a good sign, I thought. Suddenly DX starting sending CQ CQ C98RF UP. I tuned the signal in with anticipation. I went up 1.5 kHz and called, but without the /QRP. I must have been the only one that answered him because he came back to me on the first try! I then told him that I was running QRP.

After our QSO was over sounded the orchestra of calling stations on the same frequency. I sat and enjoyed listening to the pile-up of DXers. Easy propagation for about an hour and a half then the signals went down to 459.

72! UA4ARL/qrp Alexei Rusakov

Credit Line : http://ruqrp.narod.ru

A QRP-QSO WITHOUT AN ANTENNA

October 5, 2003. Robin, M5AEF, had an unique CW QSO with RX3BO from Moscow at 17 meters using only 1 watt output. You say 'it is nothing especial for 17 meters', but what do you say, if you know that Robin did not use any antenna?

Yes, Robin was doing a calibration for his FT- 757, and this one was connected to a dummy load. An antenna did not connected to the transceiver at this time, the antenna was connected to monitoring receiver, that does control for quality of the output signal from FT- 757. So, Robin heard Anatoly, RX3BO, from Moscow and they had QSO with each other. Robin had received 559 from Anatoly for his dummy- load antenna!

Some minutes later Robin connected his usual 1,5 lambda antenna to the FT – 757 and did QSO with RX3BO. Robin had received 579!

Don't say me that there are no miracles!

With the best regards!

Oleg ("Master-72") V.Borodin

72! de RV3GM (UE3QRP)

Credit Line:

http://groups.yahoo.com/group/ruqrp/

Dear Friends,

you can read about a QRP- QSO without antenna also at ANTENTOP – 01-2003.

72/73! I.G,

A Simple SSB Transceiver

Credit Line:

http://farhan.net.co.nr/

by Ashhar Farhan

computercorp@hotmail.com

A dual-band transceiver with a crisp receiver and a clean SSB signal is described. It started its life as an investigation of the excellent S7C receiver described in EMRFD. This transceiver was specifically designed to use components that are easily available in TV and Radio spares shops. The receiver sports an above average dynamic range, very clean signal and noiseless performance. Although the components are easily available, and every detail about making it is covered here, this is not a weekend project. The design is elaborate and invites improvisation.

We decided to pursue the following rules in designing this transceiver:

► Use what is easily available. Very often, we find designs that look good but they use exotic parts like TUF-1 mixers that are simply impossible to get hold of in India and other countries. Instead, we have tried using those spares that are universally available.

► Keep impedances and gain low: Often, we try coaxing maximum gain out of a stage making it difficult to duplicate and stabilize. We chose to take only modest gain out of each stage, using extensive feedback to make the circuit stable. Most of the interconnections between modules are for 50 ohms termination. In fact, the rig was a number of discrete board connected using RCA audio cables and sockets before we hooked it all up together to work.

► No PCB. We directly solder the components over a plain copper clad board (un-etched PCB). It is an excellent way to experiment, physically robust and has a quick and dirty appeal. You can usually solder up a whole circuit as you think it out in a few minutes. See the pictures.

► Broadband. We wanted to be able to use broadband design where applicable. We have found that the television balun cores are an excellent and very cheap (about Rs. 2 per balun, that is 5 cents) way of making broadband transformers.

► Modest cost. While we didn't want to use very expensive components. We didn't want to compromise the performance either. You will see that we have used 2N3866 exclusively. This was because we found that the BF195/BF194/2N2222 series transistors available in the market were consistently inferior in the HF range and performed below their stated specs. The 2N3866 is commonly used in cable TV equipment and has a good HF performance: both as a low noise small signal transistor as well as driver up to 1 watt level. 2N3866 is expensive (about Rs.20 each, but well worth the expense). It is used in a number of critical places.

► Measure what you have built. We used a 12 volt 1.5A power supply, a frequency counter, a test oscillator (to measure the crystals and coils) and a high impedance voltmeter with an RF probe to test and measure the design. All these test equipment were homemade. The transmitter design did require a PC-based oscilloscope. It helped us identify the spurs and harmonics using the in-built FFT functionality. But now that the design is complete, just an RF probe and a 14MHz receiver are enough to align the rig.

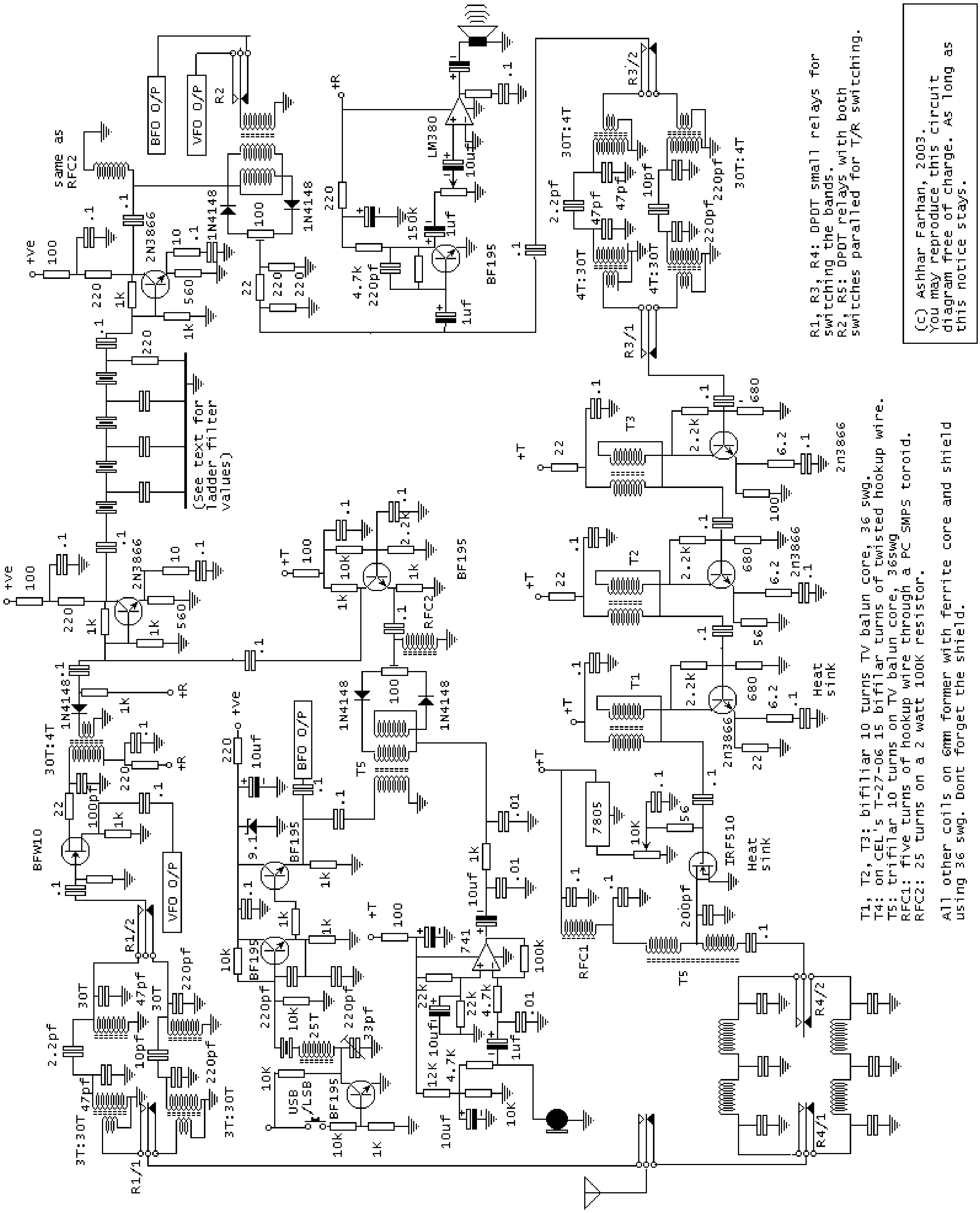
► Quality over quantity. A better signal is preferred to a bigger signal. This is a 6 watt design that will work off a simple 12V, 1.5A supply (using a single 7812).

The ladder crystal filter

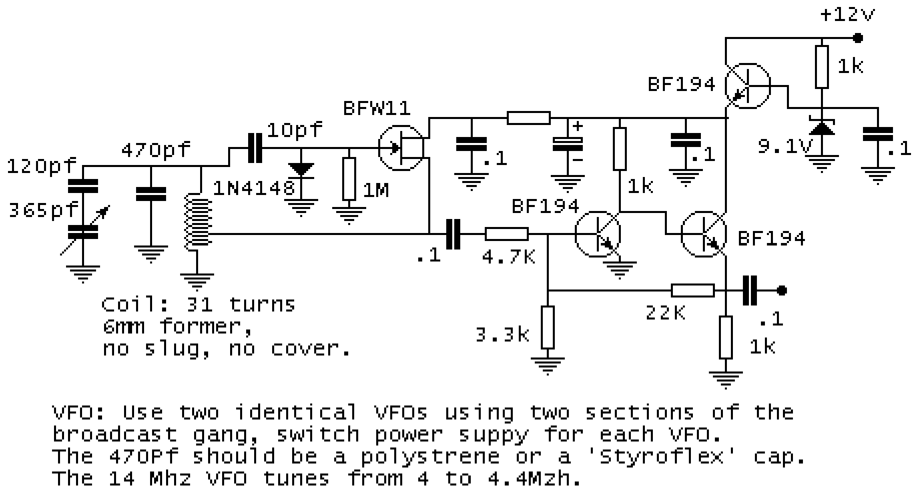
A good filter is central to the crispness of a receiver and the quality of the transmitter. There are two types of crystal filters possible, the lattice filter and the ladder filter. The lattice filter requires ordering crystals with 1.5 KHz frequency difference between them. This was ruled out, also procuring readymade filters from BEL India and other sources was ruled out as it is too expensive to do that. Instead, a ladder filter was chosen. The ladder filter offers results as good if not better than a lattice filter. However, the design is crucially dependent upon internal parameters of the crystals used. It is not possible to suggest any generic values for the capacitors to be used in the ladder filter. Rather, a method to measure each of the crystals and calculate the capacitor values has been worked out. We present this here. This design procedure will work only for 10 MHz crystals. 10Mhz is the chosen IF of our filter as the crystals are easily available and it sits comfortably between 7 and 14 MHz amateur bands. We have followed the Butterworth design methodology given in the new ARRL book 'Experimental Methods in RF Design'.

The circuit centers around a four crystal ladder filter. Each lot of crystals from each manufacturer differs from the others. We will describe a way to experimentally calculate the values of the capacitors for the filter. You should probably buy 10 crystals and select 5 of them.

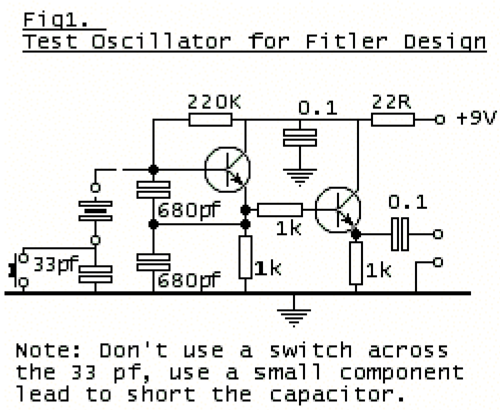
Circuit of the transceiver



VFO of the transceiver



For this purpose, construct the test circuit of **figure 1**. This is a simple Hartley-style crystal oscillator. You will require access to either a frequency counter or a general coverage receiver (ask a neighborhood ham to allow you to bring over your crystals to his shack and test them for few minutes). Mark each crystal with a number and solder it into the circuit (don't use a crystal socket). Connect the 9 volt battery and measure the frequency. If you are using a receiver, find out the frequency on which the crystal is absolutely zero. Note the frequencies with the 33 pf capacitor in series and shorted. You will have a pair of frequencies for each crystal. Select four crystals with pairs of frequencies that match within 50-40 Hz of each other. A fifth (for the carrier) oscillator crystal should be within 100 hz of the other four selected.



Calculate the value of the capacitors of **Fig.2** like this:

1. Calculate the average frequency shift of the four chosen crystals as F (in KHz).

2. C1 = 21 * F, C2 = 40 * F. Choose the nearest available fixed capacitor. If you can't find a fixed capacitor within 10% of this value, then parallel two capacitors to achieve the capacitance.

For instance, in the case of the first prototype, we measure an average of 5KHz of shift. Thus, the capacitors calculated were 107pf and 200pf. We used 100pf and two parallel 100pfs as a substitute for 200pf capacitors. These calculations are for 200 Ohms termination. For a complete discussion of this design method, you are referred to the excellent paper by Craver in the Communications Quarterly of 1993, Winter.

Broad-band design without Toroids

It was decided to use broad-band techniques where suitable and keep the circuit free of too many critically tuned circuits. We decided to investigate the TV baluns as cores for broadband transformers. The TV baluns as small ferrites as shown in the picture.

Almost all the broadband transformers are bifilar. Two (the modulator and the transmit mixer cum product detector) are trifilarly wound. They are simple to produce. Making a bifilar transformer:

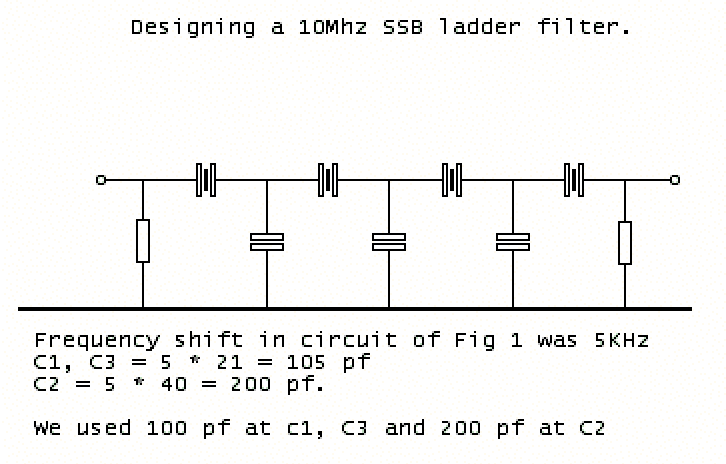
► Take two lengths of 36 swg copper enameled wire.

►Hold them together. Tie one end to a nail.

► Twist the wires together so that they cleanly have about 8-10 turns per inch.

► Check that the wires are evenly twisted (although there will be more twists towards the ends).

► If the balun core is mounted on a PCB, cut it out with a cutter and remove all the original windings.



► Pass the twisted pair through one hole to the other side, bend the wire back and pass it back through the other hole (like a U turn). This is one turn, like this, make similar 10 turns.

► Cut out the remaining ends of the windings leaving about half an inch of the twisted pair on each end.

► Scrap the enamel off to about quarter inch, and tin the leads.

► Using a VOM at low ohms setting, identify the two separate windings of the twisted pair. If we call the two wires X and Y, each will have two ends A and B. This you will have four ends AX, BX, AY and BY. Short AX and BY together and use this as the center point of the transformer in the circuits. Use AY and BX as the two opposite ends of the transformers.

Making a trifilar transformer is similar, except that you have to use three wires twisted together. Separate out the three wires as before, use the first two as described above, and the third winding as the secondary.

IF sub-system

The crystal filter and its associated IF circuitry is shared between the receiver and transmitter. Although the crystals are inexpensive enough to be able to afford separate filters for the transmitter and the receiver, we noted that each filter would have a different center frequency. This would make zero-tuning difficult for SSB operation. Therefore, it was decided to share the same crystal filter, carrier oscillator and the VFO between transmit and receive functions.

The crystal filter requires 200 ohms impedance matching at both ends to provide the correct bandwidth and low ripple. A regular practice among hams is to strap a resistor of approximately the same value as the terminating filter impedance across the input and output ends of the filter. This is incorrect. This looks like a resistor that is paralleled with a reactive impedance of the rest of the circuitry attached to the filter. When the crystal filter is not properly terminated and sees reactive termination, ripple and ringing are introduced. This will spoil the crispness of the receiver and spoil your on-the-air quality.

The crystal filter is terminated on both sides by 'strong' RC coupled amplifiers based on 2N3866. This is slightly unusual. The 2N3866 is used mostly as a VHF power amplifier. It has excellent low-noise characteristics, good gain and using it as a small signal device is now an established practice. The 2N3866 is an expensive transistor. It costs about Rs.20 in the open market. We think it is a good investment.

Using RC coupled broadband amplifiers makes the IF system a 'no-tune' affair. The output of the post-filter amplifier is coupled to a two diode mixer. The two-diode mixer uses a broadband bifilar wound transformer. It is next to impossible to get toroids in India. We have evaluated using TV baluns as substitutes for toroids. These baluns are available at most TV spare shops.

Most designs we have studied couple the RF input to the diode detector through the transformer and inject the BFO at the center of the transformer. This is a wrong practice. The diode mixer requires a minimum of 5mW of energy from the transformer input to operate properly. There should be enough energy to switch on both the diodes. This means about 1.2 v peak voltage. The received signals are rarely this level. As a result, the product detector operates like a regular envelope detector and the diodes act as distortion devices to mix the BFO with the signal. The correct configuration is to inject the BFO across the transformer

An unusual approach is taken here. The IF amplification gain is just enough to maintain good noise figure and recover the losses in the ladder filter. We measured almost 10 dB loss in the filter.

The Receiver

The receiver is minimal. By keeping the number of active devices low (3 devices between the antenna and the audio amplifier), very good fidelity is achieved. The circuit is kept at a low impedance and broadband everywhere except the front-end. This helps in stability.

The front-end uses a low-noise FET. We have used a BFW11 (because the local component shop ran out of BFW10). They have slightly different characteristics. Almost any FET can be used if it is biased properly. The FET should be biased for exactly half the pinch-off voltage. Wes Hayward (W7ZOI) has described the proper way to bias a FET Mixer for proper operation:

► Short gate and source and measure the current that flows through a 560 ohms resister connected to +12V through the drain. This gives the exact Idss.

► Place a 10K resistor between the source and the ground. Keeping the gate grounded and the drain still connected through the 560 ohms resister, measure the voltage between the source and the ground. This gives you the pinch-off voltage.

► The FET has to be biased such that the voltage on the source is exactly half the pinch-off voltage and there is half of Idss current flowing through the FET. Such a scheme assures you that the FET is driven between pinch-off and maximum drain by the VFO injected at the source. This gives the proper switching action for the mixer to operate as well as maximum gain. We measured the pinch-off voltage for BFW11s as 2.1 volts and Idss as 5mA. A standard 1K resistor at the source gives the proper bias.

It should be noted here that we first tried a double balanced diode ring mixer at the front-end. It has a number of spurious responses that literally made it impossible to use the receiver. We tried to properly terminate the diode ring mixer by inserting attenuators between the mixer and the Ladder filter's pre-amp. It didn't cure the problem. When we changed to the FET mixer, the noise figure improved, the receiver's dynamic range, while unmeasured, was never found lacking in the last one month of extensive usage at VU2PEP.

The output of the IF amplifier is detected in a balanced detector using just two diodes. Here gain, we break a common myth. You will see most of the HF receivers employing a two diode balanced detector with the BFO fed to the center tap and the incoming signal applied through the primary winding of the detector transformer. This is wrong. The signal applied through the primary winding should strong enough to switch the diodes on and off (requiring about 0.6 across each diode, that is, 1.2 volts across the winding). This roughly translates to about 5 mW power. The diodes switch the low level signal coupled at the center-tap of the coil to the detector output. Therefore, in our design we have applied the local oscillator through the primary of the transformer and the incoming signal from the IF stage to the center tap.

There is a 100 ohms preset used to null the local oscillator from appearing at the output. This is of importance during transmit where the balanced detector also doubles up as the transmitting mixer.
An audio pre-amplifier follows the detector. The capacitor of 220 pf between the base and the collector ensures that the 'hiss' is kept down. The audio amplifier used is an LM380. Almost any audio amplifier can be used. We have tried everything from the PC's ampli-speakers to a Sony amplifier to a TBA810 amplifier. We would recommend using a high fidelity, low cost amplifier like the TBA810 if you plan using a speaker. If most of your work is with headphones (to save your companion from the late night QRM), we recommend the LM386.

The Transmitter

The transmitter starts with the modulator using a 741. There is a three resistor network that biases the electret microphones. We use a Phillips 'walkman' style headphone with built-in microphone for our work. The electret microphone requires a bias that provides 5V as given by the circuit.

The balanced modulator also had two 22pf trimming capacitors for nulling the carrier. They were later found unnecessary (as long as both the diodes are purchased from the same roll) and removed. If you do find balance a bother, feel free to add a 22 pf trimmer to one side and a 10 pf fixed to the other side as indicated in the schematic.

The output of the balanced modulator is routed to the common IF amplifier through a buffer amplifier using a BF195. This serves to keep the carrier leak from the modulator out of the IF string during the reception mode.

The balanced detector of the receiver also doubles up as a mixer during transmit. It is important to balance out the VFO energy at the output by setting the 100 ohms trimmer properly. We noticed a 50mW residual out-of-band output from the transmitter when the VFO is unbalanced. The power chain is an interesting broad-band amplifier. You can use this in virtually any transmitter of up to 7 watts (and higher with more than 12 volts supply to the final stage). Three stages of broadband amplifiers feed an IRF510 PA. It is an interesting twist that the driver 2N3866 transistors cost more than the IRF510! The IRF510 should be biased for 80mA of standing current during transmit with the microphone disconnected (no modulation) and carrier nulled by the trimpot of the balanced modulator.

Construction

We heavily recommend constructing over pieces of un-etched PCBs. They are cheaply available everywhere. See the pictures as a guide to component layout. We recommend the following rules:

► Keep your leads short. Short connections are more important than components that are at right angles to each other. What might look neat to you might look unstable to the RF design.
► Keep the outputs and inputs isolated from each other. We have taken care to keep the high impedance points down to a minimum. But still, maintain design hygiene.
► Make one module at a time, test it completely, then move to the next one. Construct the transceiver in the following steps:
► Make the VFO. Check the RF output using an RF probe. Check the stability on a regular receiver or a frequency counter. With the tuning capacitor fully closed (the plates inside each other), set the trimmer so that the VF0 frequency is exactly 3.9995 MHz (keep 5 KHz margin at the band end)
► Make the BFO. Check the output on the RF probe.
► Calculate the ladder filter values and make the IF strip along with the audio preamplifier.
► Connect the BFO, VFO, IF strip and an external audio amplifier together. When you power on and attach a piece of 2-3 meter long wire to the input of the IF amplifier you should be able to hear the atmospheric noise. Tune the BFO coil by fully screwing the slug in and then slowly tuning it out until the IF noise sounds right (not too shrill and not too muffled).
► Wire up the receiver mixer, connect the VFO. Peak the mixer output and the RF input coils for maximum output. Then tune to a weak signal on the band and tune for the best signal. Be careful to tune for best quality of signal and not for maximum loudness. Take a break, spend a day or two listening to the band with your receiver. Nothing is more enjoyable than using a crisp receiver that you have homebrewed.
► Wire up the modulator. If you have an oscilloscope, you can check the modulation. The modulated output will be too low for you to be able to measure on the RF probe.
► Wire up the linear chain. DON'T solder the IRF510 yet.
► Put the transceiver in transmit mode. Whistle into the microphone and peak the transmit mixer output coils for about 6 volts peak RF voltage on the probe at the 56 ohms resistor where the gate of the IRF510 would be.
► Solder in the IRF510. ATTACH A DUMMY LOAD. We used four 220 ohms two watts resistors paralleled together.
► Keep the bias trimmer totally down towards zero. Attach VOM in series with point X in the power amplifier. Apply power in transmit mode and slow increase the bias until you have 80mA flowing through the IRF510.
► Connect the RF probe across the dummy load.
► As you whistle, You should get about 20-24volts of peak RF on the probe. When you pull out the microphone from the jack, the RF output should drop to complete zero. What if your transmitter is unstable?

- Don't curse your fate. All transmitters start out as unstable beasts. Relax.
- Start disconnecting power from the stages starting from final IRF510 and working backwards. When you have located the unstable stage, there are a number of things you can do to fix it.
- Try increasing the value of the 10 ohms resistor used in the emitter degeneration OR
- Strap a resistor of about 1K across the output transformer of the unstable stage to 'load' it.
- Move the linear amplifier away from the rest of the circuitry.
- Redo the board. This time spread the stages out. We guess that the linear chain should occupy about 6 inches of space, all laid out in one line.

Substitutions

The BF195 transistors can be substituted with any other HF transistor like 2N2222 etc. The 2N3866s are best not substituted. The circuit works with slight increase in the noise figure if BF195 or equivalents are used in place of 2N3866s in the IF stages. The output power on the transmitter absolutely needs the 2N3866s. Substituting them with other switching transistors didn't give good performance.

The IRF510 should not be substituted with any other transistor. The other IRFs, though rated higher, have higher input capacitance which makes them a bad choice for 14MHz operation.

The LM380/LM386 can be substituted with almost any other audio amplifier. Our first amplifier was Cambridge SoundWorks Sound System. If you turn down the bass, they are an excellent system for the shack. We have tried a TBA180, an LM386, an LM380 and even a glow-bug guitar amp. Feel free to experiment.

Final Notes

The first contact we made using this rig was DF6PW. He reported us 57. Within the first evening we had worked four continents. The rig is regularly used at VU2PEP. People are often surprised at how the transmitter quality is 'just like a commercial rig'. Many refused to believe that it is a seven watt rig.

72/73!

THE USA PATENTS OF NICOLA TESLA

#	Patent	Year	Month	Day	Title
1	334,823	1886	January	26	Commutator for Dynamo Electric Machines
2	335,786	1886	February	9	Electric Arc Lamp
3	335,787	1886	February	9	Electric Arc Lamp
4	336,961	1886	March	2	Regulator for Dynamo Electric Machines
5	336,962	1886	March	2	Regulator for Dynamo Electric Machines
6	350,954	1886	October	19	Regulator for Dynamo Elecric Machines
7	359,748	1887	March	22	Dynamo Electric Machine
8	381,968	1888	May	1	Electro Magnetic Motor
9	381,969	1888	May	1	Electro Magnetic Motor
10	381,970	1888	May	1	System of Electrical Distribution
11	382,279	1888	May	1	Electro Magnetic Motor
12	382,280	1888	May	1	Electrical Transmission of Power
13	382,281	1888	May	1	Electrical Transmission of Power
14	382,282	1888	May	1	Method of Converting and Distributing Electric Currents
15	382,845	1888	May	15	Commutator for Dynamo Electric Machines
16	390,413	1888	October	2	System of Electrical Distribution
17	390,414	1888	October	2	Dynamo Electric Machine
18	390,415	1888	October	2	Dynamo Electric Machine or Motor
19	390,721	1888	October	9	Dynamo Electric Machine
20	390,820	1888	October	9	Regulator for Alternate Current Motors
21	396,121	1889	January	15	Thermo Magnetic Motor
22	401,520	1889	April	16	Method of Operating Electro Magnetic Motors
23	405,858	1889	June	25	Electro Magnetic Motor
24	405,859	1889	June	25	Method of Electrical Power Transmission
25	406,968	1889	July	16	Dynamo Electric Machine
26	413,353	1889	October	22	Method of Obtaining Direct from Alternating Currents
27	416,191	1889	December	3	Electro Magnetic Motor
28	416,192	1889	December	3	Method of Operating Electro Magnetic Motors
29	416,193	1889	December	3	Electro Magnetic Motor
30	416,194	1889	December	3	Electric Motor
31	416,195	1889	December	3	Electro Magnetic Motor
32	417,794	1889	December	24	Armature for Electric Machines (A. Schmid & N. Tesla)
33	418,248	1889	December	31	Electro Magnetic Motor
34	424,036	1890	March	25	Electro Magnetic Motor
35	428,057	1890	May	13	Pyromagneto Electric Generator
36	433,700	1890	August	5	Alternating Current Electro Magnetic Motor
37	433,701	1890	August	5	Alternating Current Motor
38	433,702	1890	August	5	Electrical Transformer or Induction Device

#	Patent	Year	Month	Day	Title
39	433,703	1890	August	5	Electro Magnetic Motor
40	445,207	1891	January	27	Electro Magnetic Motor
41	447,920	1891	March	10	Method of Operating Arc Lamps
42	447,921	1891	March	10	Alternating Electric Current Generator
43	454,622	1891	June	23	System of Electric Lighting
44	455,067	1891	June	30	Electro Magnetic Motor
45	455,068	1891	June	30	Electrical Meter
46	455,069	1891	June	30	Electric Incandescent Lamp
47	459,772	1891	September	22	Electro Magnetic Motor
48	462,418	1891	November	3	Method of and Apparatus for Electrical Conversion and Distribution
49	464,666	1891	December	8	Electro Magnetic Motor
50	464,667	1891	December	8	Electrical Condenser
51	487,796	1892	December	13	System of Electrical Transmission of Power
52	511,559	1893	December	26	Electrical Transmission of Power
53	511,560	1893	December	26	System of Electrical Power Transmission
54	511,915	1894	January	2	Electrical Transmission of Power
55	511,916	1894	January	2	Electric Generator
56	512,340	1894	January	9	Coil for Electro Magnets
57	514,167	1894	February	6	Electrical Conductor
58	514,168	1894	February	6	Means for Generating Electric Currents
59	514,169	1894	February	6	Reciprocating Engine
60	514,170	1894	February	6	Incandescent Electric Light
61	514,972	1894	February	20	Electric Railway System
62	514,973	1894	February	20	Electrical Meter
63	517,900	1894	April	10	Steam Engine
64	524,426	1894	August	14	Electromagnetic Motor
65	555,190	1896	February	25	Alternating Motor
66	567,818	1896	September	15	Electrical Condenser
67	568,176	1896	September	22	Apparatus for Producing Electric Currents of High Frequency and Potential
68	568,177	1896	September	22	Apparatus for Producing Ozone
69	568,178	1896	September	22	Method of Regulating Apparatus for Producing Currents of High Frequency
70	568,179	1896	September	22	Method of and Apparatus for Producing Currents of High Frequency
71	568,180	1896	September	22	Apparatus for Producing Electrical Currents of High Frequency
72	577,670	1897	February	23	Apparatus for Producing Electric Currents of High Frequency
73	577,671	1897	February	23	Manufacture of Electrical Condensers, Coils, &c
74	583,953	1897	June	8	Apparatus for Producing Currents of High Frequency
75	593,138	1897	November	2	Electrical Transformer
76	609,245	1898	August	16	Electrical Circuit Controller
77	609,246	1898	August	16	Electric Circuit Controller
78	609,247	1898	August	16	Electric Circuit Controller
79	609,248	1898	August	16	Electric Circuit Controller

#	Patent	Year	Month	Day	Title
80	609,249	1898	August	16	Electric Circuit Controller
81	609,250	1898	August	16	Electrical Igniter for Gas Engines
82	609,251	1898	August	16	Electric Circuit Controller
83	611,719	1898	October	4	Electrical Circuit Controller
84	613,735	1898	November	8	Electric Circuit Controller
85	613,809	1898	November	8	Method of and Apparatus for Controlling Mechansim of Moving Vessels or Vehicles
86	645,576	1900	March	20	System of Transmission of Electrical Energy
87	649,621	1900	May	15	Apparatus for Transmission of Electrical Energy
88	655,838	1900	August	14	Method of Insulating Electric Conductors
89	11,865	1900	October	23	Method of Insulating Electric Conductors
90	685,012	1901	October	22	Means for Increasing the Intensity of Electrical Oscillations
91	685,953	1901	November	5	Method of Intensifying and Utilizing Effects Transmitted Through Natural Media
92	685,954	1901	November	5	Method of Utilizing Effects Transmitted Through Natural Media
93	685,955	1901	November	5	Apparatus for Utilizing Effects Transmitted From a Distance to a Receiving Device Through Natural Media
94	685,956	1901	November	5	Apparatus for Utilizing Effects Transmitted Through Natural Media
95	685,957	1901	November	5	Apparatus for the Utilization of Radiant Energy
96	685,958	1901	November	5	Method of Utilizing Radiant Energy
97	723,188	1903	March	17	Method of Signaling
98	725,605	1903	April	14	System of Signaling
99	787,412	1905	April	18	Art of Transmitting Electrical Energy Through the Natural Mediums
100	1,061,142	1913	April	29	Fluid Propulsion
101	1,061,206	1913	May	6	Turbine
102	1,113,716	1914	October	13	Fountain
103	1,119,732	1914	December	1	Apparatus for Transmitting Electrical Energy
104	1,209,359	1916	December	19	Speed Indicator
105	1,266,175	1918	May	14	Lightning Protector
106	1,274,816	1918	August	6	Speed Indicator
107	1,314,718	1919	September	2	Ship's Log
108	1,329,559	1920	February	3	Valvular Conduit
109	1,365,547	1921	January	11	Flow Meter
110	1,402,025	1922	January	3	Frequency Meter
111	1,655,113	1928	January	3	Method of Aerial Transportation
112	1,655,114	1928	January	3	Apparatus for Aerial Transportation

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THE STRANGE LIFE OF NICOLA TESLA

BY NICOLA TESLA

Nikola Tesla is the true unsung prophet of the electric age; without whom our radio, auto ignition, telephone, alternating current power generation and transmission, radio and television would all have been impossible. Yet his life and times have vanished largely from public access. This autobiography is released to remedy this situation, and to fill this *black hole* in information space.

Introduction & Editors Note

Chapter 1: My Early Life - *The progressive development of man is vitally dependent on invention. It is the most important product of his creative brain. Its ultimate purpose is the complete mastery of mind over the material world, the harnessing of the forces of nature to human needs.*

Chapter 2 - *I shall dwell briefly on these extraordinary experiences, on account of their possible interest to students of psychology and physiology and also because this period of agony was of the greatest consequence on my mental development and subsequent labors.*

Chapter 3: How Tesla Conceived The Rotary Magnetic Field - *At the age of ten I entered the Real Gymnasium which was a new and fairly well equipped institution. In the department of physics were various models of classical scientific apparatus, electrical and mechanical. The demonstrations and experiments performed from time to time by the instructors fascinated me and were undoubtedly a powerful incentive to invention.*

Chapter 4: The Discovery of the Tesla Coil and Transformer - *For a while I gave myself up entirely to the intense enjoyment of picturing machines and devising new forms. It was a mental state of happiness about as complete as I have ever known in life. Ideas came in an uninterrupted stream and the only difficulty I had was to hold them fast.*

Chapter 5 - *As I review the events of my past life I realize how subtle are the influences that shape our destinies. An incident of my youth may serve to illustrate.*

Chapter 6 - *No subject to which I have ever devoted myself has called for such concentration of mind, and strained to so dangerous a degree the finest fibers of my brain, as the systems of which the magnifying transmitter is the foundation.*

Introduction & Editors Note

Nikola Tesla was born in Croatia (then part of Austria-Hungary) on July 9, 1856, and died January 7, 1943. He was the electrical engineer who invented the AC (alternating current) induction motor, which made the universal transmission and distribution of electricity possible. Tesla began his studies in physics and mathematics at Gratz Polytechnic, and then took philosophy at the University of Prague. He worked as an electrical engineer in Budapest, Hungary, and subsequently in France and Germany. In 1888 his discovery that a magnetic field could be made to rotate if two coils at right angles are supplied with AC current 90 degrees out of phase made possible the invention of the AC induction motor. The major advantage of this motor being its brushless operation, which many at the time believed impossible.

Tesla moved to the United States in 1884, where he worked for Thomas Edison who quickly became a rival - Edison being an advocate of the inferior DC power transmission system. During this time, Tesla was commissioned with the design of the AC generators installed at Niagara Falls. George Westinghouse purchased the patents to his induction motor, and made it the basis of the Westinghouse power system which still underlies the modern electrical power industry today.

He also did notable research on high-voltage electricity and wireless communication; at one point creating an earthquake which shook the ground for several miles around his New York laboratory. He also devised a system which anticipated world-wide wireless communications, fax machines, radar, radio-guided missiles and aircraft.

Editors Note, September 21, 1994

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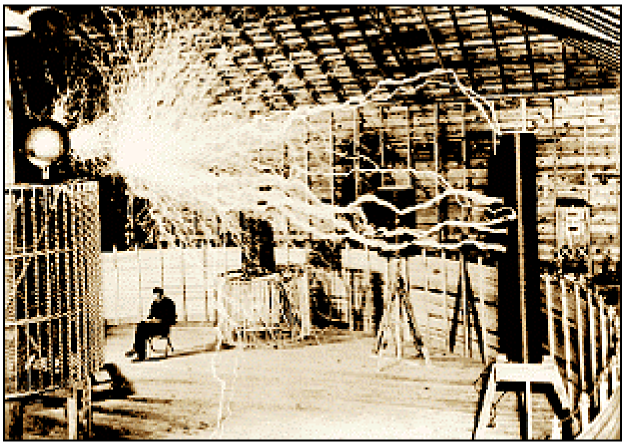
Chapter 1: My Early Life



The progressive development of man is vitally dependent on invention. It is the most important product of his creative brain. Its ultimate purpose is the complete mastery of mind over the material world, the harnessing of the forces of nature to human needs. This is the difficult task of the inventor who is often misunderstood and unrewarded. But he finds ample compensation in the pleasing exercises of his powers and in the knowledge of being one of that exceptionally privileged class without whom the race would have long ago perished in the bitter struggle against pitiless elements. Speaking for myself, I have already had more than my full measure of this exquisite enjoyment; so much, that for many years my life was little short of continuous rapture. I am credited with being one of the hardest workers and perhaps I am, if thought is the equivalent of labor, for I have devoted to it almost all of my waking hours. But if work is interpreted to be a definite performance in a specified time according to a rigid rule, then I may be the worst of idlers.

Every effort under compulsion demands a sacrifice of life-energy. I never paid such a price. On the contrary, I have thrived on my thoughts. In attempting to give a connected and faithful account of my activities in this story of my life, I must dwell, however reluctantly, on the impressions of my youth and the circumstances and events which have been instrumental in determining my career. Our first endeavors are purely instinctive promptings of an imagination vivid and undisciplined. As we grow older, reason asserts itself and we become more and more systematic and designing. But those early impulses, though not immediately productive, are of the greatest moment and may shape our very destinies. Indeed, I feel now that had I understood and cultivated instead of suppressing them, I would have added substantial value to my bequest to the world. But not until I had attained manhood did I realize that I was an inventor.

This was due to a number of causes. In the first place I had a brother who was gifted to an extraordinary degree; one of those rare phenomena of mentality which biological investigation has failed to explain. His premature death left my earth parents disconsolate. (I will explain my remark about my "earth parents" later.) We owned a horse which had been presented to us by a dear friend. It was a magnificent animal of Arabian breed, possessed of almost human intelligence, and was cared for and petted by the whole family, having on one occasion saved my dear father's life under remarkable circumstances.

My father had been called one winter night to perform an urgent duty and while crossing the mountains, infested by wolves, the horse became frightened and ran away, throwing him violently to the ground. It arrived home bleeding and exhausted, but after the alarm was sounded, immediately dashed off again, returning to the spot, and before the searching party were far on the way they were met by my father, who had recovered consciousness and remounted, not realizing that he had been lying in the snow for several hours. This horse was responsible for my brother's injuries from which he died. I witnessed the tragic scene and although so many years have elapsed since, my visual impression of it has lost none of its force. The recollection of his attainments made every effort of mine seem dull in comparison. Anything I did that was creditable merely caused my parents to feel their loss more keenly. So I grew up with little confidence in myself.

But I was far from being considered a stupid boy, if I am to judge from an incident of which I have still a strong remembrance. One day the Aldermen were passing through a street where I was playing with other boys. The oldest of these venerable gentlemen, a wealthy citizen, paused to give a silver piece to each of us. Coming to me, he suddenly stopped and commanded, "Look in my eyes." I met his gaze, my hand outstretched to receive the much valued coin, when to my dismay, he said, "No, not much; you can get nothing from me. You are too smart."

They used to tell a funny story about me. I had two old aunts with wrinkled faces, one of them having two teeth protruding like the tusks of an elephant, which she buried in my cheek every time she kissed me. Nothing would scare me more then the prospects of being kissed by these affectionate, unattractive relatives. It happened that while being carried in my mother's arms, they asked who was the prettier of the two. After examining their faces intently, I answered thoughtfully, pointing to one of them, "This here is not as ugly as the other."

Then again, I was intended from my very birth for the clerical profession and this thought constantly oppressed me. I longed to be an engineer, but my father was inflexible. He was the son of an officer who served in the army of the Great Napoleon and in common with his brother, professor of mathematics in a prominent institution, had received a military education; but, singularly enough, later embraced the clergy in which vocation he achieved eminence. He was a very erudite man, a veritable natural philosopher, poet and writer and his sermons were said to be as eloquent as those of Abraham a-Sancta-Clara. He had a prodigious memory and frequently recited at length from works in several languages. He often remarked playfully that if some of the classics were lost he could restore them. His style of writing was much admired. He penned sentences short and terse and full of wit and satire. The humorous remarks he made were always peculiar and characteristic. Just to illustrate, I may mention one or two instances.

Among the help, there was a cross-eyed man called Mane, employed to do work around the farm. He was chopping wood one day. As he swung the ax, my father, who stood nearby and felt very uncomfortable, cautioned him, "For God's sake, Mane, do not strike at what you are looking but at what you intend to hit."

On another occasion he was taking out for a drive a friend who carelessly permitted his costly fur coat to rub on the carriage wheel. My father reminded him of it saying, "Pull in your coat; you are ruining my tire."

He had the odd habit of talking to himself and would often carry on an animated conversation and indulge in heated argument, changing the tone of his voice. A casual listener might have sworn that several people were in the room.

Although I must trace to my mother's influence whatever inventiveness I possess, the training he gave me must have been helpful. It comprised all sorts of exercises - as, guessing one another's thoughts, discovering the defects of some form of expression, repeating long sentences or performing mental calculations. These daily lessons were intended to strengthen memory and reason, and especially to develop the critical sense, and were undoubtedly very beneficial.

My mother descended from one of the oldest families in the country and a line of inventors. Both her father and grandfather originated numerous implements for household, agricultural and other uses. She was a truly great woman, of rare skill, courage and fortitude, who had braved the storms of life and passed through many a trying experience. When she was sixteen, a virulent pestilence swept the country. Her father was called away to administer the last sacraments to the dying and during his absence she went alone to the assistance of a neighboring family who were stricken by the dread disease. She bathed, clothed and laid out the bodies, decorating them with flowers according to the custom of the country and when her father returned he found everything ready for a Christian burial.

My mother was an inventor of the first order and would, I believe, have achieved great things had she not been so remote from modern life and its multifold opportunities. She invented and constructed all kinds of tools and devices and wove the finest designs from thread which was spun by her. She even planted the seeds, raised the plants and separated the fibers herself. She worked indefatigably, from break of day till late at night, and most of the wearing apparel and furnishings of the home were the product of her hands. When she was past sixty, her fingers were still nimble enough to tie three knots in an eyelash.

There was another and still more important reason for my late awakening. In my boyhood I suffered from a peculiar affliction due to the appearance of images, often accompanied by strong flashes of light, which marred the sight of real objects and interfered with my thoughts and action. They were pictures of things and scenes which I had really seen, never of those imagined. When a word was spoken to me the image of the object it designated would present itself vividly to my vision and sometimes I was quite unable to distinguish whether what I saw was tangible or not. This caused me great discomfort and anxiety. None of the students of psychology or physiology whom I have consulted, could ever explain satisfactorily these phenomenon. They seem to have been unique although I was probably predisposed as I know that my brother experienced a similar trouble. The theory I have formulated is that the images were the result of a reflex action from the brain on the retina under great excitation. They certainly were not hallucinations such as are produced in diseased and anguished minds, for in other respects I was normal and composed. To give an idea of my distress, suppose that I had witnessed a funeral or some such nerve-wracking spectacle. Then, inevitably, in the stillness of night, a vivid picture of the scene would thrust itself before my eyes and persist despite all my efforts to banish it. If my explanation is correct, it should be possible to project on a screen the image of any object one conceives and make it visible. Such an advance would revolutionize all human relations. I am convinced that this wonder can and will be accomplished in time to come. I may add that I have devoted much thought to the solution of the problem.

I have managed to reflect such a picture, which I have seen in my mind, to the mind of another person, in another room. To free myself of these tormenting appearances, I tried to concentrate my mind on something else I had seen, and in this way I would often obtain temporary relief; but in order to get it I had to conjure continuously new images. It was not long before I found that I had exhausted all of those at my command; my 'reel' had run out as it were, because I had seen little of the world - only objects in my home and the immediate surroundings. As I performed these mental operations for the second or third time, in order to chase the appearances from my vision, the remedy gradually lost all its force. Then I instinctively commenced to make excursions beyond the limits of the small world of which I had knowledge, and I saw new scenes. These were at first very blurred and indistinct, and would flit away when I tried to concentrate my attention upon them. They gained in strength and distinctness and finally assumed the concreteness of real things. I soon discovered that my best comfort was attained if I simply went on in my vision further and further, getting new impressions all the time, and so I began to travel; of course, in my mind. Every night, (and sometimes during the day), when alone, I would start on my journeys - see new places, cities and countries; live there, meet people and make friendships and acquaintances and, however unbelievable, it is a fact that they were just as dear to me as those in actual life, and not a bit less intense in their manifestations.

This I did constantly until I was about seventeen, when my thoughts turned seriously to invention. Then I observed to my delight that I could visualize with the greatest facility. I needed no models, drawings or experiments. I could picture them all as real in my mind. Thus I have been led unconsciously to evolve what I consider a new method of materializing inventive concepts and ideas, which is radially opposite to the purely experimental and is in my opinion ever so much more expeditious and efficient. underlying principle. Results may be obtained, but always at the sacrifice of quality. My method is different. I do not rush into actual work. When I get an idea, I start at once building it up in my imagination. I change the construction, make improvements and operate the device in my mind. It is absolutely immaterial to me whether I run my turbine in thought or test it in my shop. I even note if it is out of balance. There is no difference whatever; the results are the same. In this way I am able to rapidly develop and perfect a conception without touching anything. When I have gone so far as to embody in the invention every possible improvement I can think of and see no fault anywhere, I put into concrete form this final product of my brain. Invariably my device works as I conceived that it should, and the experiment comes outexactly as I planned it. In twenty years there has not been a single exception. Why should it be otherwise? Engineering, electrical and mechanical, is positive in results. There is scarcely a subject that cannot be examined beforehand, from the available theoretical and practical data. The carrying out into practice of a crude idea as is being generally done, is, I hold, nothing but a waste of energy, money, and time.

My early affliction had however, another compensation. The incessant mental exertion developed my powers of developed my powers of observation and enabled me to discover a truth of great importance. I had noted that the appearance of images was always preceded by actual vision of scenes under peculiar and generally very exceptional conditions, and I was impelled on each occasion to locate the original impulse. After a while this effort grew to be almost automatic and I gained great facility in connecting cause and effect. Soon I became aware, to my surprise, that every thought I conceived was suggested by an external impression. Not only this but all my actions were prompted in a similar way. In the course of time it became perfectly evident to me that I was merely an automation endowed with power *of movement responding to the stimuli of the sense organs and thinking and acting accordingly*. The practical result of this was the art of teleautomatics which has been so far carried out only in an imperfect manner. Its latent possibilities will, however be eventually shown. I have been years planning self-controlled automata and believe that mechanisms can be produced which will act as if possessed of reason, to a limited degree, and will create a revolution in many commercial and industrial departments. I was about twelve years of age when I first succeeded in banishing an image from my vision by willful effort, but I never had any control over the flashes of light to which I have referred. They were, perhaps, my strangest and [most] inexplicable experience. They usually occurred when I found myself in a dangerous or distressing situations or when I was greatly exhilarated. In some instances I have seen all the air around me filled with tongues of living flame. Their intensity, instead of diminishing, increased with time and seemingly attained a maximum when I was about twenty-five years old.

While in Paris in 1883, a prominent French manufacturer sent me an invitation to a shooting expedition which I accepted. I had been long confined to the factory and the fresh air had a wonderfully invigorating effect on me. On my return to the city that night, I felt a positive sensation that my brain had caught fire. I was a light as though a small sun was located in it and I passed the whole night applying cold compressions to my tortured head. Finally the flashes diminished in frequency and force but it took more than three weeks before they wholly subsided. When a second invitation was extended to me, my answer was an emphatic NO!

These luminous phenomena still manifest themselves from time to time, as when a new idea opening up possibilities strikes me, but they are no longer exciting, being of relatively small intensity. When I close my eyes I invariably observe first, a background of very dark and uniform blue, not unlike the sky on a clear but starless night. In a few seconds this field becomes animated with innumerable scintillating flakes of green, arranged in several layers and advancing towards me. Then there appears, to the right, a beautiful pattern of two systems of parallel and closely spaced lines, at right angles to one another, in all sorts of colors with yellow, green, and gold predominating. Immediately thereafter, the lines grow brighter and the whole is thickly sprinkled with dots of twinkling light. This picture moves slowly across the field of vision and in about ten seconds vanishes on the left, leaving behind a ground of rather unpleasant and inert gray until the second phase is reached. Every time, before falling asleep, images of persons or objects flit before my view. When I see them I know I am about to lose consciousness. If they are absent and refuse to come, it means a sleepless night. To what an extent imagination played in my early life, I may illustrate by another odd experience.

Like most children, I was fond of jumping and developed an intense desire to support myself in the air. Occasionally a strong wind richly charged with oxygen blew from the mountains, rendering my body light as cork and then I would leap and float in space for a long time. It was a delightful sensation and my disappointment was keen when later I undeceived myself. During that period I contracted many strange likes, dislikes and habits, some of which I can trace to external impressions while others are unaccountable. I had a violent aversion against the earrings of women, but other ornaments, as bracelets, pleased me more or less according to design. The sight of a pearl would almost give me a fit, but I was fascinated with the glitter of crystals or objects with sharp edges and plane surfaces. I would not touch the hair of other people except, perhaps at the point of a revolver. I would get a fever by looking at a peach and if a piece of camphor was anywhere in the house it caused me the keenest discomfort. Even now I am not insensible to some of these upsetting impulses. When I drop little squares of paper in a dish filled with liquid, I always sense a peculiar and awful taste in my mouth. I counted the steps in my walks and calculated the cubical contents of soup plates, coffee cups and pieces of food, otherwise my meal was unenjoyable. All repeated acts or operations I performed had to be divisible by three and if I missed I felt impelled to do it all over again, even if it took hours. Up to the age of eight years, my character was weak and vacillating. I had neither courage or strength to form a firm resolve. My feelings came in waves and surges and variated unceasingly between extremes. My wishes were of consuming force and like the heads of the hydra, they multiplied. I was oppressed by thoughts of pain in life and death and religious fear. I was swayed by superstitious belief and lived in constant dread of the spirit of evil, of ghosts and ogres and other unholy monsters of the dark. Then all at once, there came a tremendous change which altered the course of my whole existence.

Of all things I liked books best. My father had a large library and whenever I could manage I tried to satisfy my passion for reading. He did not permit it and would fly in a rage when he caught me in the act. He hid the candles when he found that I was reading in secret. He did not want me to spoil my eyes. But I obtained tallow, made the wicking and cast the sticks into tin forms, and every night I would bush the keyhole and the cracks and read, often till dawn, when all others slept and my mother started on her arduous daily task.

On one occasion I came across a novel entitled *Aoafi*, (the son of Aba), a Serbian translation of a well known Hungarian writer, Josika. This work somehow awakened my dormant powers of will and I began to practice self-control. At first my resolutions faded like snow in April, but in a little while I conquered my weakness and felt a pleasure I never knew before - that of doing as I willed.

In the course of time this vigorous mental exercise became second to nature. At the outset my wishes had to be subdued but gradually desire and will grew to be identical. After years of such discipline I gained so complete a mastery over myself that I toyed with passions which have meant destruction to some of the strongest men. At a certain age I contracted a mania for gambling which greatly worried my parents. To sit down to a game of cards was for me the quintessence of pleasure. My father led an exemplary life and could not excuse the senseless waste of my time and money in which I indulged. I had a strong resolve, but my philosophy was bad. I would say to him, "I can stop whenever I please, but is it worth while to give up that which I would purchase with the joys of paradise?" On frequent occasions he gave vent to his anger and contempt, but my mother was different. She understood the character of men and knew that one's salvation could only be brought about through his own efforts. One afternoon, I remember, when I had lost all my money and was craving for a game, she came to me with a roll of bills and said, "Go and enjoy yourself. The sooner you lose all we possess, the better it will be. I know that you will get over it." She was right. I conquered my passion then and there and only regretted that it had not been a hundred times as strong. I not only vanquished but tore it from my heart so as not to leave even a trace of desire.

Ever since that time I have been as indifferent to any form of gambling as to picking teeth. During another period I smoked excessively, threatening to ruin my health. Then my will asserted itself and I not only stopped but destroyed all inclination. Long ago I suffered from heart trouble until I discovered that it was due to the innocent cup of coffee I consumed every morning. I discontinued at once, though I confess it was not an easy task. In this way I checked and bridled other habits and passions, and have not only preserved my life but derived an immense amount of satisfaction from what most men would consider privation and sacrifice.

After finishing the studies at the Polytechnic Institute and University, I had a complete nervous breakdown and, while the malady lasted, I observed many phenomena, strange and unbelievable...

Chapter 2

I shall dwell briefly on these extraordinary experiences, on account of their possible interest to students of psychology and physiology and also because this period of agony was of the greatest consequence on my mental development and subsequent labors. But it is indispensable to first relate the circumstances and conditions which preceded them and in which might be found their partial explanation.

From childhood I was compelled to concentrate attention upon myself. This caused me much suffering, but to my present view, it was a blessing in disguise for it has taught me to appreciate the inestimable value of introspection in the preservation of life, as well as a means of achievement. The pressure of occupation and the incessant stream of impressions pouring into our consciousness through all the gateways of knowledge make modern existence hazardous in many ways. Most persons are so absorbed in the contemplation of the outside world that they are wholly oblivious to what is passing on within themselves. The premature death of millions is primarily traceable to this cause. Even among those who exercise care, it is a common mistake to avoid imaginary, and ignore the real dangers. And what is true of an individual also applies, more or less, to a people as a whole.

Abstinence was not always to my liking, but I find ample reward in the agreeable experiences I am now making. Just in the hope of converting some to my precepts and convictions I will recall one or two.

A short time ago I was returning to my hotel. It was a bitter cold night, the ground slippery, and no taxi to be had. Half a block behind me followed another man, evidently as anxious as myself to get under cover. Suddenly my legs went up in the air. At the same instant there was a flash in my brain. The nerves responded, the muscles contracted. I swung 180 degrees and landed on my hands. I resumed my walk as though nothing had happened when the stranger caught up with me. "How old are you?" he asked, surveying me critically.

"Oh, about fifty-nine," I replied, "What of it?"
"Well," said he, "I have seen a cat do this but never a man." About a month ago I wanted to order new eye glasses and went to an oculist who put me through the usual tests. He looked at me incredulously as I read off with ease the smallest print at considerable distance. But when I told him I was past sixty he gasped in astonishment. Friends of mine often remark that my suits fit me like gloves but they do not know that all my clothing is made to measurements which were taken nearly fifteen years ago and never changed. During this same period my weight has not varied one pound. In this connection I may tell a funny story.

One evening, in the winter of 1885, Mr. Edison, Edward H. Johnson, the President of the Edison Illuminating Company, Mr. Batchellor, Manager of the works, and myself, entered a little place opposite 65 Firth Avenue, where the offices of the company were located. Someone suggested guessing weights and I was induced to step on a scale. Edison felt me all over and said: "Tesla weighs 152 lbs. to an ounce," and he guessed it exactly. Stripped I weighed 142 pounds, and that is still my weight. I whispered to Mr. Johnson; "How is it possible that Edison could guess my weight so closely?"

"Well," he said, lowering his voice. "I will tell you confidentially, but you must not say anything. He was employed for a long time in a Chicago slaughter-house where he weighed thousands of hogs every day. That's why."

My friend, the Hon. Chauncey M. Dupew, tells of an Englishman on whom he sprung one of his original anecdotes and who listened with a puzzled expression, but a year later, laughed out loud. I will frankly confess it took me longer than that to appreciate Johnson's joke. Now, my well-being is simply the result of a careful and measured mode of living and perhaps the most astonishing thing is that three times in my youth I was rendered by illness a hopeless physical wreck and given up by physicians. *More* than this, through ignorance and lightheartedness, I got into all sorts of difficulties, dangers and scrapes from which I extricated myself as by enchantment. I was almost drowned, entombed, lost and frozen. I had hair-breadth escapes from mad dogs, hogs, and other wild animals. I passed through dreadful diseases and met with all kinds of odd mishaps and that I am whole and hearty today seems like a miracle. But as I recall these incidents to my mind I feel convinced that my preservation was not altogether accidental, but was indeed the work of divine power. An inventor's endeavor is essentially life saving. Whether he harnesses forces, improves devices, or provides new comforts and conveniences, he is adding to the safety of our existence. He is also better qualified than the average individual to protect himself in peril, for he is observant and resourceful. If I had no other evidence that I was, in a measure, possessed of such qualities, I would find it in these personal experiences. The reader will be able to judge for himself if I mention one or two instances.

On one occasion, when about fourteen years old, I wanted to scare some friends who were bathing with me. My plan was to dive under a long floating structure and slip out quietly at the other end. Swimming and diving came to me as naturally as to a duck and I was confident that I could perform the feat. Accordingly I plunged into the water and, when out of view, turned around and proceeded rapidly towards the opposite side. Thinking that I was safely beyond the structure, I rose to the surface but to my dismay struck a beam. Of course, I quickly dived and forged ahead with rapid strokes until my breath was beginning to give out. Rising for the second time, my head came again in contact with a beam. Now I was becoming desperate. However, summoning all my energy, I made a third frantic attempt but the result was the same. The torture of suppressed breathing was getting unendurable, my brain was reeling and I felt myself sinking. At that moment, when my situation seemed absolutely hopeless, I experienced one of those flashes of light and the structure above me appeared before my vision. I either discerned or guessed that there was a little space between the surface of the water and the boards resting on the beams and, with consciousness nearly gone, I floated up, pressed my mouth close to the planks and managed to inhale a little air, unfortunately mingled with a spray of water which nearly choked me. Several times I repeated this procedure as in a dream until my heart, which was racing at a terrible rate, quieted down, and I gained composure. After that I made a number of unsuccessful dives, having completely lost the sense of direction, but finally succeeded in getting out of the trap when my friends had already given me up and were fishing for my body. That bathing season was spoiled for me through recklessness but I soon forgot the lesson and only two years later I fell into a worse predicament.

There was a large flour mill with a dam across the river near the city where I was studying at the time. As a rule the height of the water was only two or three inches above the dam and to swim to it was a sport not very dangerous in which I often indulged. One day I went alone to the river to enjoy myself as usual. When I was a short distance from the masonry, however, I was horrified to observe that the water had risen and was carrying me along swiftly. I tried to get away but it was too late. Luckily, though, I saved myself from being swept over by taking hold of the wall with both hands. The pressure against my chest was great and I was barely able to keep my head above the surface. Not a soul was in sight and my voice was lost in the roar of the fall. Slowly and gradually I became exhausted and unable to withstand the strain longer. Just as I was about to let go, to be dashed against the rocks below, I saw in a flash of light a familiar diagram illustrating the hydraulic principle that the pressure of a fluid in motion is proportionate to the area exposed and automatically I turned on my left side. As if by magic, the pressure was reduced and I found it comparatively easy in that position to resist the force of the stream. But the danger still confronted me. I knew that sooner or later I would be carried down, as it was not possible for any help to reach me in time, even if I had attracted attention. I am ambidextrous now, but then I was left-handed and had comparatively little strength in my right arm. For this reason I did not dare to turn on the other side to rest and nothing remained but to slowly push my body along the dam. I had to get away from the mill towards which my face was turned, as the current there was much swifter and deeper. It was a long and painful ordeal and I came near to failing at its very end, for I was confronted with a depression in the masonry. I managed to get over with the last ounce of my strength and fell in a swoon when I reached the bank, where I was found. I had torn virtually all the skin from my left side and it took several weeks before the fever had subsided and I was well. These are only two of many instances, but they may be sufficient to show that had it not been for the inventor's instinct, I would not have lived to tell the tale.

Interested people have often asked me how and when I began to invent. This I can only answer from my present recollection in the light of which, the first attempt I recall was rather ambitious for it involved the invention of an apparatus and a method. In the former it was anticipated, but the later was original. It happened in this way. One of my playmates had come into the possession of a hook and fishing tackle which created quite an excitement in the village, and the next morning all started out to catch frogs. I was left alone and deserted owing to a quarrel with this boy. I had never seen a real hook and pictured it as something wonderful, endowed with peculiar qualities, and was despairing not to be one of the party. Urged by necessity, I somehow got hold of a piece of soft iron wire, hammered the end to a sharp point between two stones, bent it into shape, and fastened it to a strong string. I then cut a rod, gathered some bait, and went down to the brook where there were frogs in abundance. But I could not catch any and was almost discouraged when it occurred to me dangle the empty hook in front of a frog sitting on a stump. At first he collapsed but by and by his eyes bulged out and became bloodshot, he swelled to twice his normal size and made a vicious snap at the hook. Immediately I pulled him up. I tried the same thing again and again and the method proved infallible. When my comrades, who in spite of their fine outfit had caught nothing, came to me, they were green with envy. For a long time I kept my secret and enjoyed the monopoly but finally yielded to the spirit of Christmas. Every boy could then do the same and the following summer brought disaster to the frogs.

In my next attempt, I seem to have acted under the first instinctive impulse which later dominated me - to harness the energies of nature to the service of man. I did this through the medium of May bugs, or June bugs as they are called in America, which were a veritable pest in that country and sometimes broke the branches of trees by the sheer weight of their bodies. The bushes were black with them. I would attach as many as four of them to a cross-piece, rotably arranged on a thin spindle, and transmit the motion of the same to a large disc and so derive considerable "power." These creatures were remarkably efficient, for once they were started, they had no sense to stop and continued whirling for hours and hours and the hotter it was, the harder they worked. All went well until a strange boy came to the place. He was the son of a retired officer in the Austrian army. That urchin ate May bugs alive and enjoyed them as though they were the finest blue point oysters. That disgusting sight terminated my endeavors in this promising field and I have never since been able to touch a May bug or any other insect for that matter.
After that, I believe, I undertook to take apart and assemble the clocks of my grandfather. In the former operation I was always successful, but often failed in the latter. So it came that he brought my work to a sudden halt in a manner not too delicate and it took thirty years before I tackled another clockwork again.

Shortly thereafter, I went into the manufacture of a kind of pop-gun which comprised a hollow tube, a piston, and two plugs of hemp. When firing the gun, the piston was pressed against the stomach and the tube was pushed back quickly with both hands. the air between the plugs was compressed and raised to a high temperature and one of them was expelled with a loud report. The art consisted in selecting a tube of the proper taper from the hollow stalks which were found in our garden. I did very well with that gun, but my activities interfered with the window panes in our house and met with painful discouragement.

If I remember rightly, I then took to carving swords from pieces of furniture which I could conveniently obtain. At that time I was under the sway of the Serbian national poetry and full of admiration for the feats of the heroes. I used to spend hours in mowing down my enemies in the form of cornstalks which ruined the crops and netted me several spankings from my mother. Moreover, these were not of the formal kind but the genuine article.

I had all this and more behind me before I was six years old and had passed through one year of elementary school in the village of Smiljan where my family lived. At this juncture we moved to the little city of Gospic nearby. This change of residence was like a calamity to me. It almost broke my heart to part from our pigeons, chickens and sheep, and our magnificent flock of geese which used to rise to the clouds in the morning and return from the feeding grounds at sundown in battle formation, so perfect that it would have put a squadron of the best aviators of the present day to shame. In our new house I was but a prisoner, watching the strange people I saw through my window blinds. My bashfulness was such that I would rather have faced a roaring lion than one of the city dudes who strolled about. But my hardest trial came on Sunday when I had to dress up and attend the service. There I met with an accident, the mere thought of which made my blood curdle like sour milk for years afterwards. It was my second adventure in a church. Not long before, I was entombed for a night in an old chapel on an inaccessible mountain which was visited only once a year. It was an awful experience, but this one was worse.

There was a wealthy lady in town, a good but pompous woman, who used to come to the church gorgeously painted up and attired with an enormous train and attendants. One Sunday I had just finished ringing the bell in the belfry and rushed downstairs, when this grand dame was sweeping out and I jumped on her train. It tore off with a ripping noise which sounded like a salvo of musketry fired by raw recruits. My father was livid with rage. He gave me a gentle slap on the cheek, the only corporal punishment he ever administered to me, but I almost feel it now. The embarrassment and confusion that followed are indescribable. I was practically ostracized until something else happened which redeemed me in the estimation of the community.

An enterprising young merchant had organized a fire department. A new fire engine was purchased, uniforms provided and the men drilled for service and parade. The engine was beautifully painted red and black. One afternoon, the official trial was prepared for and the machine was transported to the river. The entire population turned out to witness the great spectacle. When all the speeches and ceremonies were concluded, the command was given to pump, but not a drop of water came from the nozzle. The professors and experts tried in vain to locate the trouble. The fizzle was complete when I arrived at the scene. My knowledge of the mechanism was nil and I knew next to nothing of air pressure, but instinctively I felt for the suction hose in the water and found that it had collapsed. When I waded in the river and opened it up, the water rushed forth and not a few Sunday clothes were spoiled. Archimedes running naked through the streets of Syracuse and shouting Eureka at the top of his voice did not make a greater impression than myself. I was carried on the shoulders and was hero of the day.

Upon settling in the city I began a four years course in the so-called Normal School preparatory to my studies at the College or Real-Gymnasium. During this period my boyish efforts and exploits as well as troubles, continued.

Among other things, I attained the unique distinction of champion crow catcher in the country. My method of procedure was extremely simple. I would go into the forest, hide in the bushes, and imitate the call of the birds. Usually I would get several answers and in a short while a crow would flutter down into the shrubbery near me. After that, all I needed to do was to throw a piece of cardboard to detract its attention, jump up and grab it before it could extricate itself from the undergrowth. In this way I would capture as many as I desired. But on one occasion something occurred which made me respect them. I had caught a fine pair of birds and was returning home with a friend. When we left the forest, thousands of crows had gathered making a frightful racket. In a few minutes they rose in pursuit and soon enveloped us. The fun lasted until all of a sudden I received a blow on the back of my head which knocked me down. Then they attacked me viciously. I was compelled to release the two birds and was glad to join my friend who had taken refuge in a cave.

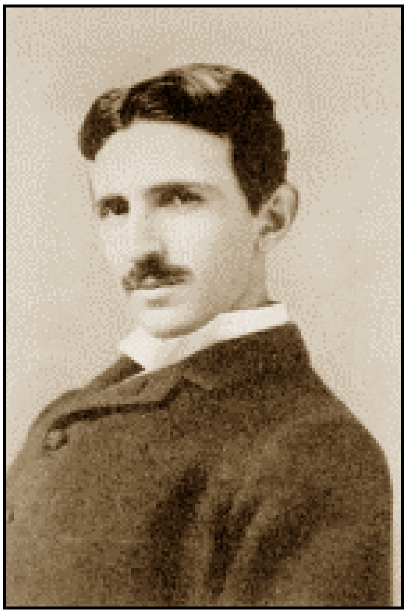
In the school room there were a few mechanical models which interested me and turned my attention to water turbines. I constructed many of these and found great pleasure in operating them. How extraordinary was my life an incident may illustrate. My uncle had no use for this kind of pastime and more than once rebuked me. I was fascinated by a description of Niagara Falls I had perused, and pictured in my imagination a big wheel run by the falls. I told my uncle that I would go to America and carry out this scheme. Thirty years later I was able to see my ideas carried out at Niagara and marveled at the unfathomable mystery of the mind.

I made all kinds of other contrivances and contraptions but among those, the arbalests I produced were the best. My arrows, when short, disappeared from sight and at close range traversed a plank of pine one inch thick. Through the continuous tightening of the bows I developed a skin on my stomach much like that of a crocodile and I am often wondering whether it is due to this exercise that I am able even now to digest cobble-stones! Nor can I pass in silence my performances with the sling which would have enabled me to give a stunning exhibit at the Hippodrome. And now I will tell of one of my feats with this unique implement of war which will strain to the utmost the credulity of the reader.

I was practicing while walking with my uncle along the river. The sun was setting, the trout were playful and from time to time one would shoot up into the air, its glistening body sharply defined against a projecting rock beyond. Of course any boy might have hit a fish under these propitious conditions but I undertook a much more difficult task and I foretold to my uncle, to the minutest detail, what I intended doing. I was to hurl a stone to meet the fish, press its body against the rock, and cut it in two. It was no sooner said than done. My uncle looked at me almost scared out of his wits and exclaimed "Vade retra Satanae!" and it was a few days before he spoke to me again. Other records, however great, will be eclipsed but I feel that I could peacefully rest on my laurels for a thousand years.

Chapter 3:
How Tesla Conceived The Rotary Magnetic Field

At the age of ten I entered the Real Gymnasium which was a new and fairly well equipped institution. In the department of physics were various models of classical scientific apparatus, electrical and mechanical. The demonstrations and experiments performed from time to time by the instructors fascinated me and were undoubtedly a powerful incentive to invention. I was also passionately fond of mathematical studies and often won the professor's praise for rapid calculation. This was due to my acquired facility of visualizing the figures and performing the operation, not in the usual intuitive manner, but as in actual life. Up to a certain degree of complexity it was absolutely the same to me whether I wrote the symbols on the board or conjured them before my mental vision. But freehand drawing, to which many hours of the course were devoted, was an annoyance I could not endure. This was rather remarkable as most of the members of the family



excelled in it. Perhaps my aversion was simply due to the predilection I found in undisturbed thought. Had it not been for a few exceptionally stupid boys, who could not do anything at all, my record would have been the worst.

It was a serious handicap, as under the then existing educational regime drawing being obligatory, this deficiency threatened to spoil my whole career and my father had considerable trouble in railroading me from one class to another.

In the second year at that institution I became obsessed with the idea of producing continuous motion through steady air pressure. The pump incident, of which I have been told, had set afire my youthful imagination and impressed me with the boundless possibilities of a vacuum. I grew frantic in my desire to harness this inexhaustible energy but for a long time I was groping in the dark. Finally, however, my endeavors crystallized in an invention which was to enable me to achieve what no other mortal ever attempted. Imagine a cylinder freely rotatable on two bearings and partly surrounded by a rectangular trough which fits it perfectly. The open side of the trough is enclosed by a partition so that the cylindrical segment within the enclosure divides the latter into two compartments entirely separated from each other by air-tight sliding joints. One of these compartments being sealed and once for all exhausted, the other remaining open, a perpetual rotation of the cylinder would result. At least, so I thought.

A wooden model was constructed and fitted with infinite care and when I applied the pump on one side and actually observed that there was a tendency to turning, I was delirious with joy. Mechanical flight was the one thing I wanted to accomplish although still under the discouraging recollection of a bad fall I sustained by jumping with an umbrella from the top of a building. Every day I used to transport myself through the air to distant regions but could not understand just how I managed to do it. Now I had something concrete, a flying machine with nothing more than a rotating shaft, flapping wings, and - a vacuum of unlimited power! From that time on I made my daily aerial excursions in a vehicle of comfort and luxury as might have befitted King Solomon. It took years before I understood that the atmospheric pressure acted at right angles to the surface of the cylinder and that the slight rotary effort I observed was due to a leak! Though this knowledge came gradually it gave me a painful shock.

I had hardly completed my course at the Real Gymnasium when I was prostrated with a dangerous illness or rather, a score of them, and my condition became so desperate that I was given up by physicians. During this period I was permitted to read constantly, obtaining books from the public library which had been neglected and entrusted to me for classification of the works and preparation of catalogues.

One day I was handed a few volumes of new literature unlike anything I had ever read before and so captivating as to make me utterly forget my hopeless state. They were the earlier works of Mark Twain and to them might have been due the miraculous recovery which followed. Twenty-five years later, when I met Mr. Clements and we formed a friendship between us, I told him of the experience and was amazed to see that great man of laughter burst into tears...

My studies were continued at the higher Real Gymnasium in Carlstadt, Croatia, where one of my aunts resided. She was a distinguished lady, the wife of a colonel who was an old war-horse having participated in many battles, I can never forget the three years I passed at their home. No fortress in time of war was under a more rigid discipline. I was fed like a canary bird. All the meals were of the highest quality and deliciously prepared, but short in quantity by a thousand percent. The slices of ham cut by my aunt were like tissue paper. When the colonel would put something substantial on my plate she would snatch it away and say excitedly to him; "Be careful. Niko is very delicate."

I had a voracious appetite and suffered like Tantalus.

But I lived in an atmosphere of refinement and artistic taste quite unusual for those times and conditions. The land was low and marshy and malaria fever never left me while there despite the enormous amounts of quinine I consumed. Occasionally the river would rise and drive an army of rats into the buildings, devouring everything, even to the bundles of fierce paprika. These pests were to me a welcome diversion. I thinned their ranks by all sorts of means, which won me the unenviable distinction of rat-catcher in the community. At last, however, my course was completed, the misery ended, and I obtained the certificate of maturity which brought me to the crossroads.

During all those years my parents never wavered in their resolve to make me embrace the clergy, the mere thought of which filled me with dread. I had become intensely interested in electricity under the stimulating influence of my professor of physics, who was an ingenious man and often demonstrated the principles by apparatus of his own invention. Among these I recall a device in the shape of a freely rotatable bulb, with tinfoil coating, which was made to spin rapidly when connected to a static machine. It is impossible for me to convey an adequate idea of the intensity of feeling I experienced in witnessing his exhibitions of these mysterious phenomena. Every impression produced a thousand echoes in my mind. I wanted to know more of this wonderful force; I longed for experiment and investigation and resigned myself to the inevitable with aching heart. Just as I was making ready for the long journey home I received word that my father wished me to go on a shooting expedition. It was a strange request as he had been always strenuously opposed to this kind of sport. But a few days later I learned that the cholera was raging in that district and, taking advantage of an opportunity, I returned to Gospic in disregard to my parent's wishes. It is incredible how absolutely ignorant people were as to the causes of this scourge which visited the country in intervals of fifteen to twenty years. They thought that the deadly agents were transmitted through the air and filled it with pungent odors and smoke. In the meantime they drank infested water and died in heaps. I contracted the dreadful disease on the very day of my arrival and although surviving the crisis, I was confined to bed for nine months with scarcely any ability to move. My energy was completely exhausted and for the second time I found myself at Death's door.

In one of the sinking spells which was thought to be the last, my father rushed into the room. I still see his pallid face as he tried to cheer me in tones belying his assurance. "Perhaps," I said, "I may get well if you will let me study engineering." "You will go to the best technical institution in the world," he solemnly replied, and I knew that he meant it. A heavy weight was lifted from my mind but the relief would have come too late had it not been for a marvelous cure brought through a bitter decoction of a peculiar bean. I came to life like Lazarus to the utter amazement of everybody.

My father insisted that I spend a year in healthful physical outdoor exercise to which I reluctantly consented. For most of this term I roamed in the mountains, loaded with a hunter's outfit and a bundle of books, and this contact with nature made me stronger in body as well as in mind. I thought and planned, and conceived many ideas almost as a rule delusive. The vision was clear enough but the knowledge of principles was very limited.

In one of my inventions, I proposed to convey letters and packages across the seas, through a submarine tube, in spherical containers of sufficient strength to resist the hydraulic pressure. The pumping plant, intended to force the water through the tube, was accurately figured and designed and all other particulars carefully worked out. Only one trifling detail, of no consequence, was lightly dismissed. I assumed an arbitrary velocity of the water and, what is more, took pleasure in making it high, thus arriving at a stupendous performance supported by faultless calculations. Subsequent reflections, however, on the resistance of pipes to fluid flow induced me to make this invention public property.

Another one of my projects was to construct a ring around the equator which would, of course, float freely and could be arrested in its spinning motion by reactionary forces, thus enabling travel at a rate of about one thousand miles an hour, impracticable by rail. The reader will smile. The plan was difficult of execution, I will admit, but not nearly so bad as that of a well known New York professor, who wanted to pump the air from the torrid to temperate zones, entirely forgetful of the fact that the Lord had provided a gigantic machine for this purpose.

Still another scheme, far more important and attractive, was to derive power from the rotational energy of terrestrial bodies. I had discovered that objects on the earth's surface owing to the diurnal rotation of the globe, are carried by the same alternately in and against the direction of translatory movement. From this results a great change in momentum which could be utilized in the simplest imaginable manner to furnish motive effort in any habitable region of the world. I cannot find words to describe my disappointment when later I realized that I was in the predicament of Archimedes, who vainly sought for a fixed point in the universe.

At the termination of my vacation I was sent to the polytechnic school in Gratz, Styria (Austria), which my father had chosen as one of the oldest and best reputed institutions. That was the moment I had eagerly awaited and I began my studies under good auspices and firmly resolved to succeed. My previous training was above average, due to my father's teaching and opportunities afforded. I had acquired the knowledge of a number of languages and waded through the books of several libraries, picking up information more or less useful. Then again, for the first time, I could choose my subjects as I liked, and free-hand drawing was to bother me no more.
I had made up my mind to give my parents a surprise, and during the whole first year I regularly started my work at three o'clock in the morning and continued until eleven at night, no Sundays or holidays excepted. As most of my fellow-students took things easily, naturally I eclipsed all records. In the course of the year I passed through nine exams and the professors thought I deserved more than the highest qualifications. Armed with their flattering certificates, I went home for a short rest, expecting triumph, and was mortified when my father made light of these hard-won honors.

That almost killed my ambition; but later, after he had died, I was pained to find a package of letters which the professors had written to him to the effect that unless he took me away from the institution I would be killed through overwork. Thereafter I devoted myself chiefly to physics, mechanics and mathematical studies, spending the hours of leisure in the libraries.

I had a veritable mania for finishing whatever I began, which often got me into difficulties. On one occasion I started to read the works of Voltaire, when I learned, to my dismay that there were close to one hundred large volumes in small print which that monster had written while drinking seventy-two cups of black coffee per diem. It had to be done, but when I laid aside that last book I was very glad, and said, "Never more!"

My first year's showing had won me the appreciation and friendship of several professors. Among these, Professor Rogner, who was teaching arithmetical subjects and geometry; Professor Poeschl, who held the chair of theoretical and experimental physics, and Dr. Alle, who taught integral calculus and specialized in differential equations. This scientist was the most brilliant lecturer to whom I ever listened. He took a special interest in my progress and would frequently remain for an hour or two in the lecture room, giving me problems to solve, in which I delighted. To him I explained a flying machine I had conceived, not an illusory invention, but one based on sound, scientific principles, which has become realizable through my turbine and will soon be given to the world. Both Professors Rogner and Poeschl were curious men. The former had peculiar ways of expressing himself and whenever he did so, there was a riot, followed by a long embarrassing pause. Professor Poeschl was a methodical and thoroughly grounded German. He had enormous feet, and hands like the paws of a bear, but all of his experiments were skillfully performed with clock-like precision and without a miss. It was in the second year of my studies that we received a Gramoe Dyname from Paris, having the horseshoe form of a laminated field magnet, and a wire wound armature with a commutator. It was connected up and various effects of the currents were shown. While Professor Poeschl was making demonstrations, running the machine was a motor, the brushes gave trouble, sparking badly, and I observed that it might be possible to operate a motor without these appliances. But he declared that it could not be done and did me the honor of delivering a lecture on the subject, at the conclusion he remarked, "Mr. Tesla may accomplish great things, but he certainly will never do this. It would be equivalent to converting a steadily pulling force, like that of gravity into a rotary effort. It is a perpetual motion scheme, an impossible idea." But instinct is something which transcends knowledge. We have, undoubtedly, certain finer fibers that enable us to perceive truths when logical deduction, or any other willful effort of the brain, is futile.

For a time I wavered, impressed by the professor's authority, but soon became convinced I was right and undertook the task with all the fire and boundless confidence of my youth. I started by first picturing in my mind a direct-current machine, running it and following the changing flow of the currents in the armature. Then I would imagine an alternator and investigate the progresses taking place in a similar manner. Next I would visualize systems comprising motors and generators and operate them in various ways.

The images I saw were to me perfectly real and tangible. All my remaining term in Gratz was passed in intense but fruitless efforts of this kind, and I almost came to the conclusion that the problem was insolvable.

In 1880 I went to Prague, Bohemia, carrying out my father's wish to complete my education at the University there. It was in that city that I made a decided advance, which consisted in detaching the commutator from the machine and studying the phenomena in this new aspect, but still without result. In the year following there was a sudden change in my views of life.

I realized that my parents had been making too great sacrifices on my account and resolved to relieve them of the burden. The wave of the American telephone had just reached the European continent and the system was to be installed in Budapest, Hungary. It appeared an ideal opportunity, all the more as a friend of our family was at the head of the enterprise.

It was here that I suffered the complete breakdown of the nerves to which I have referred. What I experienced during the period of the illness surpasses all belief. My sight and hearing were always extraordinary. I could clearly discern objects in the distance when others saw no trace of them. Several times in my boyhood I saved the houses of our neighbors from fire by hearing the faint crackling sounds which did not disturb their sleep, and calling for help. In 1899, when I was past forty and carrying on my experiments in Colorado, I could hear very distinctly thunderclaps at a distance of 550 miles. My ear was thus over thirteen times more sensitive, yet at that time I was, so to speak, stone deaf in comparison with the acuteness of my hearing while under the nervous strain.

In Budapest I could hear the ticking of a watch with three rooms between me and the time-piece. A fly alighting on a table in the room would cause a dull thud in my ear. A carriage passing at a distance of a few miles fairly shook my whole body. The whistle of a locomotive twenty or thirty miles away made the bench or chair on which I sat, vibrate so strongly that the pain was unbearable. The ground under my feet trembled continuously. I had to support my bed on rubber cushions to get any rest at all. The roaring noises from near and far often produced the effect of spoken words which would have frightened me had I not been able to resolve them into their accumulated components. The sun rays, when periodically intercepted, would cause blows of such force on my brain that they would stun me. I had to summon all my will power to pass under a bridge or other structure, as I experienced the crushing pressure on the skull. In the dark I had the sense of a bat, and could detect the presence of an object at a distance of twelve feet by a peculiar creepy sensation on the forehead. My pulse varied from a few to two hundred and sixty beats and all the tissues of my body with twitchings and tremors, which was perhaps hardest to bear. A renowned physician who have me daily large doses of bromide of potassium, pronounced my malady unique and incurable.

It is my eternal regret that I was not under the observation of experts in physiology and psychology at that time. I clung desperately to life, but never expected to recover. Can anyone believe that so hopeless a physical wreck could ever be transformed into a man of astonishing strength and tenacity; able to work thirty-eight years almost without a day's interruption, and find himself still strong and fresh in body and mind? Such is my case. A powerful desire to live and to continue the work and the assistance of a devoted friend, an athlete, accomplished the wonder. My health returned and with it the vigor of mind.

In attacking the problem again, I almost regretted that the struggle was soon to end. I had so much energy to spare. When I understood the task, it was not with a resolve such as men often make. With me it was a sacred vow, a question of life and death. I knew that I would perish if I failed. Now I felt that the battle was won. Back in the deep recesses of the brain was the solution, but I could net yet give it outward expression.

One afternoon, which is ever present in my recollection, I was enjoying a walk with my friend in the City Park and reciting poetry. At that age, I knew entire books by heart, word for word. One of these was Goethe's *Faust*. The sun was just setting and reminded me of the glorious passage, "Sie ruckt und weicht, der Tag ist uberlebt, Dort eilt sie hin und fordert neues Leben. Oh, das kein Flugel mich vom Boden hebt Ihr nach und immer nach zu streben! Ein schöner Traum indessen sie entweicht, Ach, au des Geistes Flügein wird so leicht Kein korperlicher Flugel sich gesellen!" As I uttered these inspiring words the idea came like a flash of lightening and in an instant the truth was revealed. I drew with a stick on the sand, the diagram shown six years later in my address before the American Institute of Electrical Engineers, and my companion understood them perfectly. The images I saw were wonderfully sharp and clear and had the solidity of metal and stone, so much so that I told him, "See my motor here; watch me reverse it." I cannot begin to describe my emotions. Pygmalion seeing his statue come to life could not have been more deeply moved. A thousand secrets of nature which I might have stumbled upon accidentally, I would have given for that one which I had wrested from her against all odds and at the peril of my existence...

Chapter 4: The Discovery of the Tesla Coil and Transformer (The Basic Part of Every Radio and T.V.)

For a while I gave myself up entirely to the intense enjoyment of picturing machines and devising new forms. It was a mental state of happiness about as complete as I have ever known in life. Ideas came in an uninterrupted stream and the only difficulty I had was to hold them fast. The pieces of apparatus I conceived were to me absolutely real and tangible in every detail, even to the minutest marks and signs of wear. I delighted in imagining the motors constantly running, for in this way they presented to the mind's eye a fascinating sight. When natural inclination develops into a passionate desire, one advances towards his goal in seven-league boots. In less than two months I evolved virtually all the types of motors and modifications of the system which are now identified with my name, and which are used under many other names all over the world. It was, perhaps, providential that the necessities of existence commanded a temporary halt to this consuming activity of the mind.

I came to Budapest prompted by a premature report concerning the telephone enterprise and, as irony of fate willed it, I had to accept a position as draughtsman in the Central Telegraph Office of the Hungarian government at a salary which I deem it my privilege not to disclose. Fortunately, I soon won the interest of the inspector-in-chief and was thereafter employed on calculations, designs and estimates in connection with new installations, until the telephone exchange started, when I took charge of the same. The knowledge and practical experience I gained in the course of this work, was most valuable and the employment gave me ample opportunities for the exercise of my inventive faculties. I made several improvements in the central station apparatus and perfected a telephone repeater or amplifier which was never patented or publicly described but would be creditable to me even today. In recognition of my efficient assistance the organizer of the undertaking, Mr. Puskas, upon disposing of his business in Budapest, offered me a position in Paris which I gladly accepted.

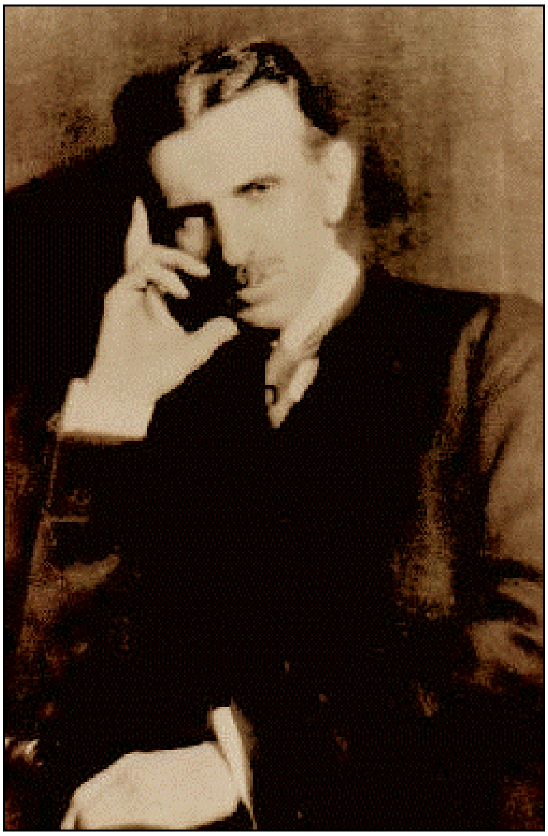
I never can forget the deep impression that magic city produced on my mind. For several days after my arrival, I roamed through the streets in utter bewilderment of the new spectacle. The attractions were many and irresistible, but, alas, the income was spent as soon as received. When Mr. Puskas asked me how I was getting along in the new sphere, I described the situation accurately in the statement that"The last twenty-nine days of the month are the toughest." I led a rather strenuous life in what would now be termed "Rooseveltian fashion." Every morning, regardless of the weather, I would go from the boulevard St-Marcel, where I resided, to a bathing house on the Seine; plunge into the water, loop the circuit twenty-seven times and then walk an hour to reach Ivry, where the company's factory was located.

There I would have a wood-chopper's breakfast at half-past seven o'clock and then eagerly await the lunch hour, in the meanwhile cracking hard nuts for the manager-of-the-works, Mr. Charles Batchellor, who was an intimate friend and assistant of Edison. Here I was thrown in contact with a few Americans who fairly fell in love with my because of my proficiency in Billiards! To these men I explained my invention and one of them, Mr. D. Cunningham, foreman of the mechanical department, offered to form a stock company. The proposal seemed to me comical in the extreme. I did not have the faintest conception of what he meant, except that it was an American way of doing things. Nothing came of it, however, and during the next few months I had to travel from one place to another in France and Germany to cure the ills of the power plants.

On my return to Paris, I submitted to one of the administrators of the company, Mr. Rau, a plan for improving their dynamos and was given an opportunity. My success was complete and the delighted directors accorded me the privilege of developing automatic regulators which were much desired. Shortly after, there was some trouble with the lighting plant which had been installed at the new railroad station in Strasbourg, Alsace. The wiring was defective and on the occasion of the opening ceremonies, a large part of a wall was blown out through a short-circuit, right in the presence of old Emperor William I. The German government refused to take the plant and the French company was facing a serious loss. On account of my knowledge of the German language and past experience, I was entrusted with the difficult task of straightening out matters and early in 1883, I went to Strasbourg on that mission.

Some of the incidents in that city have left an indelible record on my memory. By a curious coincidence, a number of the men who subsequently achieved fame, lived there about that time. In later life I used to say, "There were bacteria of greatness in that old town." Others caught the disease, but I escaped!" The practical work, correspondence, and conferences with officials kept me preoccupied day and night, but as soon as I was able to manage, I undertook the construction of a simple motor in a mechanical shop opposite the railroad station, having brought with me from Paris some material for that purpose. The consummation of the experiment was, however, delayed until the summer of that year, when I finally had the satisfaction of seeing the rotation effected by alternating currents of different phase, and without sliding contacts or commutator, as I had conceived a year before. It was an exquisite pleasure but not to compare with the delirium of joy following the first revelation.

Among my new friends was the former mayor of the city, Mr. Sauzin, whom I had already, in a measure, acquainted with this and other inventions of mine and whose support I endeavored to enlist. He was



sincerely devoted to me and put my project before several wealthy persons, but to my mortification, found no response. He wanted to help me in every possible way and the approach of the first of July, 1917, happens to remind me of a form of "assistance" I received from that charming man, which was not financial, but none the less appreciated. In 1870, when the Germans invaded the country, Mr. Sauzin had buried a good sized allotment of St. Estephe of 1801 and he came to the conclusion that he knew no worthier person than myself to consume that precious beverage. This, I may say, is one of the unforgettable incidents to which I have referred. My friend urged me to return to Paris as soon as possible and seek support there. This I was anxious to do, but my work and negotiations were protracted, owing to all sorts of petty obstacles I encountered, so that at times the situation seemed hopeless. Just to give an idea of German thoroughness and "efficiency," I may mention here a rather funny experience.

An incandescent lamp of 16 c.p. was to be placed in a hallway, and upon selecting the proper location, I ordered the "monteur" to run the wires. After working for a while, he concluded that the engineer had to be consulted and this was done. The latter made several objections but ultimately agreed that the lamp should be placed two inches from the spot I had assigned, whereupon the work proceeded. Then the engineer became worried and told me that Inspector Averdeck should be notified. That important person was called, he investigated, debated, and decided that the lamp should be shifted back two inches, which was the place I had marked! It was not long, however, before

Averdeck got cold feet himself and advised me that he had informed Ober-Inspector Hieronimus of the matter and that I should await his decision. It was several days before the ober-inspector was able to free himself of other pressing duties, but at last he arrived and a two hour debate followed, when he decided to move the lamp two inches further. My hopes that this was the final act, were shattered when the ober-inspector returned and said to me, "Regierungsrath Funke is particular that I would not dare to give an order for placing this lamp without his explicit approval." Accordingly, arrangements for a visit from that great man were made. We started cleaning up and polishing early in the morning, and when Funke came with his retinue he was ceremoniously received. After two hours of deliberation, he suddenly exclaimed, "I must be going!," and pointing to a place on the ceiling, he ordered me to put the lamp there. It was the exact spot which I had originally chosen! So it went day after day with variations, but I was determined to achieve, at whatever cost, and in the end my efforts were rewarded.

By the spring of 1884, all the differences were adjusted, the plant formally accepted, and I returned to Paris with pleasing anticipation. One of the administrators had promised me a liberal compensation in case I succeeded, as well as a fair consideration of the improvements I had made to their dynamos and I hoped to realize a substantial sum. There were three administrators, whom I shall designate as A, B, and C for convenience. When I called on A, he told me what B had the say. This gentleman thought that only C could decide, and the latter was quite sure that A alone had the power to act. After several laps of this *circulus viciousus*, it dawned upon me that my reward was a castle in Spain.

The utter failure of my attempts to raise capital for development was another disappointment, and when Mr. Bachelor pressed me to go to America with a view of redesigning the Edison machines, I determined to try my fortunes in the Land of Golden Promise. But the chance was nearly missed. I liquefied my modest assets, secured accommodations and found myself at the railroad station as the train was pulling out. At that moment, I discovered that my money and tickets were gone. What to do was the question. Hercules had plenty of time to deliberate, but I had to decide while running alongside the train with opposite feeling surging in my brain like condenser oscillations. Resolve, helped by dexterity, won out in the nick of time and upon passing through the usual experience, as trivial and unpleasant, I managed to embark for New York with the remnants of my belongings, some poems and articles I had written, and a package of calculations relating to solutions of an unsolvable integral and my flying machine. During the voyage I sat most of the time at the stern of the ship watching for an opportunity to save somebody from a watery grave, without the slightest thought of danger. Later, when I had absorbed some of the practical American sense, I shivered at the recollection and marveled at my former folly. The meeting with Edison was a memorable event in my life. I was amazed at this wonderful man who, without early advantages and scientific training, had accomplished so much. I had studied a dozen languages, delved in literature and art, and had spent my best years in libraries reading all sorts of stuff that fell into my hands, from Newton's *Principia* to the novels of Paul de Kock, and felt that most of my life had been squandered. But it did not take long before I recognized that it was the best thing I could have done. Within a few weeks I had won Edison's confidence, and it came about in this way.

The S.S. Oregon, the fastest passenger steamer at that time, had both of its lighting machines disabled and its sailing was delayed. As the superstructure had been built after their installation, it was impossible to remove them from the hold. The predicament was a serious one and Edison was much annoyed. In the evening I took the necessary instruments with me and went aboard the vessel where I stayed for the night. The dynamos were in bad condition, having several short-circuits and breaks, but with the assistance of the crew, I succeeded in putting them in good shape. At five o'clock in the morning, when passing along Fifth Avenue on my way to the shop, I met Edison with Bachelor and a few others, as they were returning home to retire. "Here is our Parisian running around at night," he said. When I told him that I was coming from the Oregon and had repaired both machines, he looked at me in silence and walked away without another word. But when he had gone some distance I heard him remark, "Bachelor, this is a good man." And from that time on I had full freedom in directing the work. For nearly a year my regular hours were from 10:30 A.M. until 5 o'clock the next morning without a day's exception. Edison said to me, "I have had many hard working assistants, but you take the cake." During this period I designed twenty-four different types of standard machines with short cores and uniform pattern, which replaced the old ones. The manager had promised me fifty thousand dollars on the completion of this task, but it turned out to be a practical joke. This gave me a painful shock and I resigned my position.

Immediately thereafter, some people approached me with the proposal of forming an arc light company under my name, to which I agreed. Here finally, was an opportunity to develop the motor, but when I broached the subject to my new associates they said, "No, we want the arc lamp. We don't care for this alternating current of yours." In 1886, my system of arc lighting was perfected and adopted for factory and municipal lighting, and I was free, but with no other possession than a beautifully engraved certificate of stock of hypothetical value. Then followed a period of struggle in the new medium for which I was not fitted, but the reward came in the end, and in April, 1887, the Tesla Electric Co. was organized, providing a laboratory and facilities. The motors I built there were exactly as I had imagined them. I made no attempt to improve the design, but merely reproduced the pictures as they appeared to my vision and the operation was always as I expected.

In the early part of 1888, an arrangement was made with the Westinghouse Company for the manufacture of the motors on a large scale. But great difficulties had still to be overcome. My system was based on the use of low frequency currents and the Westinghouse experts had adopted 133 cycles with the objects of securing advantages in transformation. They did not want to depart with their standard forms of apparatus and my efforts had to be concentrated upon adapting the motor to these conditions. Another necessity was to produce a motor capable of running efficiently at this frequency on two wires, which was not an easy accomplishment.

At the close of 1889, however, my services in Pittsburgh being no longer essential, I returned to New York and resumed experimental work in a Laboratory on Grand Street, where I began immediately the design of high-frequency machines. The problems of construction in this unexplored field were novel and quite peculiar, and I encountered many difficulties. I rejected the inductor type, fearing that it might not yield perfect sine waves, which were so important to resonant action. Had it not been for this, I could have saved myself a great deal of labor. Another discouraging feature of the high-frequency alternator seemed to be the inconstancy of speed which threatened to impose serious limitations to its use. I had already noted in my demonstrations before the American Institution of Electrical Engineers, that several times the tune was lost, necessitating readjustment, and did not yet foresee what I discovered long afterwards, a means of operating a machine of this kind at a speed constant to such a degree as not to vary more than a small fraction of one revolution between the extremes of load. From many other considerations, it appeared desirable to invent a simpler device for the production of electric oscillations. In 1856, Lord Kelvin had exposed the theory of the condenser discharge, but no practical application of that important knowledge was made. I saw the possibilities and undertook the development of induction apparatus on this principle. My progress was so rapid as to enable me to exhibit at my lecture in 1891 a coil giving sparks of five inches. On that occasion I frankly told the engineers of a defect involved in the transformation by the new method, namely, the loss in the spark gap. Subsequent investigation showed that no matter what medium is employed, be it air, hydrogen, mercury vapor, oil, or a stream of electrons, the efficiency is the same. It is a law very much like the governing of the conversion of mechanical energy. We may drop a weight from a certain height vertically down, or carry it to the lower level along any devious path; it is immaterial insofar as the amount of work is concerned. Fortunately however, this drawback is not fatal, as by proper proportioning of the resonant, circuits of an efficiency of 85 percent is attainable. Since my early announcement of the invention, it has come into universal use and wrought a revolution in many departments, but a still greater future awaits it.

When in 1900 I obtained powerful discharges of 1,000 feet and flashed a current around the globe, I was reminded of the first tiny spark I observed in my Grand Street laboratory and was thrilled by sensations akin to those I felt when I discovered the rotating magnetic field.

Chapter 5

As I review the events of my past life I realize how subtle are the influences that shape our destinies. An incident of my youth may serve to illustrate. One winter's day I managed to climb a steep mountain, in company with other boys. The snow was quite deep and a warm southerly wind made it just suitable for our purpose. We amused ourselves by throwing balls which would roll down a certain distance, gathering more or less snow, and we tried to out-do one another in this sport. Suddenly a ball was seen to go beyond the limit, swelling to enormous proportions until it became as big as a house and plunged thundering into the valley below with a force that made the ground tremble. I looked on spellbound incapable of understanding what had happened. For weeks afterward the picture of the avalanche was before my eyes and I wondered how anything so small could grow to such an immense size.

Ever since that time the magnification of feeble actions fascinated me, and when, years later, I took up the experimental study of mechanical and electrical resonance, I was keenly interested from the very start. Possibly, had it not been for that early powerful impression I might not have followed up the little spark I obtained with my coil and never developed my best invention, the true history of which I will tell.

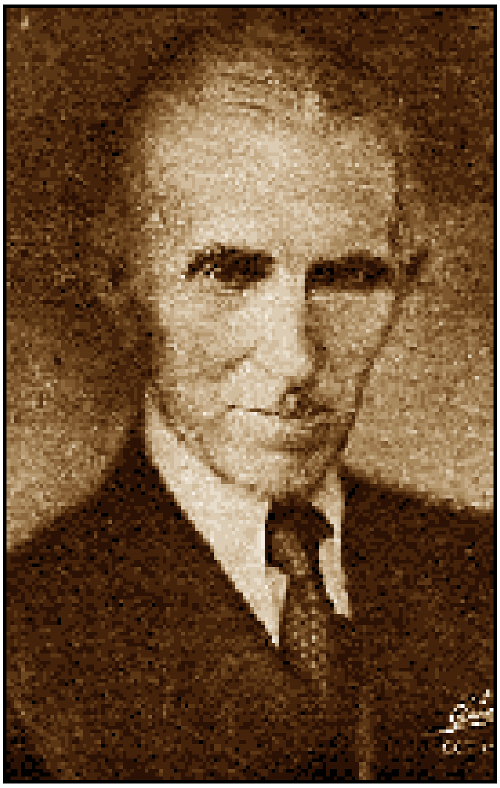
Many technical men, very able in their special departments, but dominated by a pedantic spirit and nearsighted, have asserted that excepting the induction motor, I have given the world little of practical use. This is a grievous mistake. A new idea must not be judged by its immediate results. My alternating system of power transmission came at a psychological moment, as a long sought answer to pressing industrial questions, and although considerable resistance had to be overcome and opposing interests reconciled, as usual, the commercial introduction could not be long delayed.

Now, compare this situation with that confronting my turbines, for example. One should think that so simple and beautiful an invention, possessing many features of an ideal think that confronting my turbines, for example. One should that so simple and beautiful an invention, possessing many features of an ideal motor, should be adopted at once and, undoubtedly, it would under similar conditions. But the prospective effect of the rotating field was not to render worthless existing machinery; on the contrary, it was to give it additional value. The system lent itself to new enterprise as well as to improvement of the old. My turbine is an advance of a character entirely different. It is a radical departure in the sense that its success would mean the abandonment of the antiquated types of prime movers on which billions of dollars have been spent. Under such circumstances, the progress must need be slow and perhaps the greatest impediment is encountered in the prejudicial opinions created in the minds of experts by organized opposition.

Only the other day, I had a disheartening experience when I met my friend and former assistant, Charles F. Scott, now professor of Electric Engineering at Yale. I had not seen him for a long time and was glad to have an opportunity for a little chat at my office. Our conversation, naturally enough, drifted onto my turbine and I became heated to a high degree. "Scott," I exclaimed, carried away by the vision of a glorious future, "My turbine will scrap all the heat engines in the world." Scott stroked his chin and looked away thoughtfully, as though making a mental calculation. "That will make quite a pile of scrap," he said, and left without another word!

These and other inventions of mine, however, were nothing more than steps forward in a certain directions. In evolving them, I simply followed the inborn instinct to improve the present devices without any special thought of our far more imperative necessities. The "Magnifying Transmitter" was the product of labors extending through years, having for their chief object, the solution of problems which are infinitely more important to mankind than mere industrial development.

If my memory serves me right, it was in November, 1890, that I performed a laboratory experiment which was one of the most extraordinary and spectacular ever recorded in the annal of Science. In investigating the behavior of high frequency currents, I had satisfied myself that an electric field of sufficient intensity could be produced in a room to light up electrodeless vacuum tubes. Accordingly, a transformer was built to test the theory and the first trial proved a marvelous success. It is difficult to appreciate what those strange phenomena meant at the time. We crave for new sensations, but soon become indifferent to them. The wonders of yesterday are today common occurrences. When my tubes were first publicly exhibited, they were



viewed with amazement impossible to describe. From all parts of the world, I received urgent invitations and numerous honors and other flattering inducements were offered to me, which I declined. But in 1892 the demand became irresistible and I went to London where I delivered a lecture before the Institution of Electrical Engineers.

It has been my intention to leave immediately for Paris in compliance with a similar obligation, but Sir James Dewar insisted on my appearing before the Royal Institution. I was a man of firm resolve, but succumbed easily to the forceful arguments of the great Scotchman. He pushed me into a chair and poured out half a glass of a wonderful brown fluid which sparkled in all sorts of iridescent colors and tasted like nectar. "Now," said he, "you are sitting in Faraday's chair and you are enjoying whiskey he used to drink." (Which did not interest me very much, as I had altered my opinion concerning strong drink). The next evening I have a demonstration before the Royal Institution, at the termination of which, Lord Rayleigh addressed the audience and his generous words gave me the first start in these endeavors. I fled from London and later from Paris, to escape favors showered upon me, and journeyed to my home, where I passed through a most painful ordeal and illness.

Upon regaining my health, I began to formulate plans for the resumption of work in America. Up to that time I never realized that I possessed any particular gift of discovery, but Lord Rayleigh, whom I always considered as an ideal man of science, had said so and if that was the case, I felt that I should concentrate on some big idea.

At this time, as at many other times in the past, my thoughts turned towards my Mother's teaching. The gift of mental power comes from God, Divine Being, and if we concentrate our minds on that truth, we become in tune with this great power. My Mother had taught me to seek all truth in the Bible; therefore I devoted the next few months to the study of this work.

One day, as I was roaming the mountains, I sought shelter from an approaching storm. The sky became overhung with heavy clouds, but somehow the rain was delayed until, all of a sudden, there was a lightening flash and a few moments after, a deluge. This observation set me thinking. It was manifest that the two phenomena were closely related, as cause and effect, and a little reflection led me to the conclusion that the electrical energy involved in the precipitation of the water was inconsiderable, the function of the lightening being much like that of a sensitive trigger. Here was a stupendous possibility of achievement. If we could produce electric effects of the required quality, this whole planet and the conditions of existence on it could be transformed. The sun raises the water of the oceans and winds drive it to distant regions where it remains in a state of most delicate balance. If it were in our power to upset it when and wherever desired, this mighty life sustaining stream could be at will controlled. We could irrigate arid deserts, create lakes and rivers, and provide motive power in unlimited amounts. This would be the most efficient way of harnessing the sun to the uses of man. The consummation depended on our ability to develop electric forces of the order of those in nature.

It seemed a hopeless undertaking, but I made up my mind to try it and immediately on my return to the United States in the summer of 1892, after a short visit to my friends in Watford, England; work was begun which was to me all the more attractive, because a means of the same kind was necessary for the successful transmission of energy without wires.

At this time I made a further careful study of the Bible, and discovered the key in Revelation. The first gratifying result was obtained in the spring of the succeeding year, when I reaching a tension of about 100,000,000 volts - one hundred million volts - with my conical coil, which I figured was the voltage of a flash of lightening. Steady progress was made until the destruction of my laboratory by fire, in 1895, as may be judged from an article by T.C. Martin which appeared in the April number of the *Century Magazine*. This calamity set me back in many ways and most of that year had to be devoted to planning and reconstruction. However, as soon as circumstances permitted, I returned to the task.

Although I knew that higher electric-motive forces were attainable with apparatus of larger dimensions, I had an instinctive perception that the object could be accomplished by the proper design of a comparatively small and compact transformer. In carrying on tests with a secondary in the form of flat spiral, as illustrated in my patents, the absence of streamers surprised me, and it was not long before I discovered that this was due to the position of the turns and their mutual action. Profiting from this observation, I resorted to the use of a high tension conductor with turns of considerable diameter, sufficiently separated to keep down the distributed capacity, while at the same time preventing undue accumulation of the charge at any point. The application of this principle enabled me to produce pressures of over 100,000,000 volts, which was about the limit obtainable without risk of accident. A photograph of my transmitter built in my laboratory at Houston Street, was published in the *Electrical Review* of November, 1898.

In order to advance further along this line, I had to go into the open, and in the spring of 1899, having completed preparations for the erection of a wireless plant, I went to Colorado where I remained for more than one year. Here I introduced other improvements and refinements which made it possible to generate currents of any tension that may be desired. Those who are interested will find some information in regard to the experiments I conducted there in my article, "The Problem of Increasing Human Energy," in the *Century Magazine* of June 1900, to which I have referred on a previous occasion.

I will be quite explicit on the subject of my magnifying transformer so that it will be clearly understood. In the first place, it is a resonant transformer, with a secondary in which the parts, charged to a high potential, are of considerable area and arranged in space along ideal enveloping surfaces of very large radii of curvature, and at proper distances from one another, thereby insuring a small electric surface density everywhere, so that no leak can occur even if the conductor is bare. It is suitable for any frequency, from a few to many thousands of cycles per second, and can be used in the production of currents of tremendous volume and moderate pressure, or of smaller amperage and immense electromotive force. The maximum electric tension is merely dependent on the curvature of the surfaces on which the charged elements are situated and the area of the latter. Judging from my past experience there is no limit to the possible voltage developed; any amount is practicable. On the other hand, currents of many thousands of amperes may be obtained in the antenna. A plant of but very moderate dimensions is required for such performances. Theoretically, a terminal of less than 90 feet in diameter is sufficient to develop an electromotive force of that magnitude, while for antenna currents of from 2,000-4,000 amperes at the usual frequencies, it need not be larger than 30 feet in diameter. In a more restricted meaning, this wireless transmitter is one in which the Hertzwave radiation is an entirely negligible quantity as compared with the whole energy, under which condition the damping factor is extremely small and an enormous charge is stored in the elevated capacity. Such a circuit may then be excited with impulses of any kind, even of low frequency and it will yield sinusoidal and continuous oscillations like those of an alternator. Taken in the narrowest significance of the term, however, it is a resonant transformer which, besides possessing these qualities, is accurately proportioned to fit the globe and its electrical constants and properties, by virtue of which design it becomes highly efficient and effective in the wireless transmission of energy. Distance is then *absolutely eliminated, there being no diminuation in the intensity* of the transmitted impulses. It is even possible to make the actions increase with the distance from the plane, according to an exact mathematical law. This invention was one of a number comprised in my "World System" of wireless transmission which I undertook to commercialize on my return to New York in 1900.

As to the immediate purposes of my enterprise, they were clearly outlined in a technical statement of that period from which I quote, "The world system has resulted from a combination of several original discoveries made by the inventor in the course of long continued research and experimentation. It makes possible not only the instantaneous and precise wireless transmission of any kind of signals, messages or characters, to all parts of the world, but also the inter-connection of the existing telegraph, telephone, and other signal stations without any change in their present equipment. By its means, for instance, a telephone subscriber here may call up and talk to any other subscriber on the Earth. An inexpensive receiver, not bigger than a watch, will enable him to listen anywhere, on land or sea, to a speech delivered or music played in some other place, however distant." These examples are cited merely to give an idea of the possibilities of this great scientific advance, which annihilates distance and makes that perfect natural conductor, the Earth, available for all the innumerable purposes which human ingenuity has found for a line-wire. One far-reaching result of this is that any device capable of being operated through one or more wires(at a distance obviously restricted) can likewise be actuated, without artificial conductors and with the same facility and accuracy, at distances to which there are no limits other than those imposed by the physical dimensions of the earth. Thus, not only will entirely new fields for commercial exploitation be opened up by this ideal method of transmission, but the old ones vastly extended. The World System is based on the application of the following import and inventions and discoveries:

1. The Tesla Transformer: This apparatus is in the production of electrical vibrations as revolutionary as gunpowder was in warfare. Currents many times stronger than any ever generated in the usual ways and sparks over one hundred feet long, have been produced by the inventor with an instrument of this kind.

2. The Magnifying Transmitter: This is Tesla's best invention, a peculiar transformer specially adapted to excite the earth, which is in the transmission of electrical energy when the telescope is in astronomical observation. By the use of this marvelous device, he has already set up electrical movements of greater intensity than those of lightening and passed a current, sufficient to light more than two hundred incandescent lamps, around the Earth.

3. The Tesla Wireless System: This system comprises a number of improvements and is the only means known for transmitting economically electrical energy to a distance without wires. Careful tests and measurements in connection with an experimental station of great activity, erected by the inventor in Colorado, have demonstrated that power in any desired amount can be conveyed, clear across the globe if necessary, with a loss not exceeding a few per cent.

4. The Art of Individualization: This invention of Tesla is to primitive tuning, what refined language is to unarticulated expression. It makes possible the transmission of signals or messages absolutely secret and exclusive both in the active and passive aspect, that is, non-interfering as well as non-interferable. Each signal is like an individual of unmistakable identity and there is virtually no limit to the number of stations or instruments which can be simultaneously operated without the slightest mutual disturbance.

5. The Terrestrial Stationary Waves: This wonderful discovery, popularly explained, means that the Earth is responsive to electrical vibrations of definite pitch, just as a tuning fork to certain waves of sound. These particular electrical vibrations, capable of powerfully exciting the globe, lend themselves to innumerable uses of great importance commercially and in many other respects. The first "World System" power plant can be put in operation in nine months. With this power plant, it will be practicable to attain electrical activities up to ten million horse-power and it is designed to serve for as many technical achievements as are possible without due expense. Among these are the following:

1. The inter-connection of existing telegraph exchanges or offices all over the world;
2. The establishment of a secret and non-interferable government telegraph service;
3. The inter-connection of all present telephone exchanges or offices around the globe;
4. The universal distribution of general news by telegraph or telephone, in conjunction with the press;
5. The establishment of such a "World System" of intelligence transmission for exclusive private use;
6. The inter-connection and operation of all stock tickers of the world;
7. The establishment of a "World System" - of musical distribution, etc.;
8. The universal registration of time by cheap clocks indicating the hour with astronomical precision and requiring no attention whatever;
9. The world transmission of typed or handwritten characters, letters, checks, etc.;
10. The establishment of a universal marine service enabling the navigators of all ships to steer perfectly without compass, to determine the exact location, hour and speak; to prevent collisions and disasters, etc.;
11. The inauguration of a system of world printing on land and sea;
12. The world reproduction of photographic pictures and all kinds of drawings or records..."

I also proposed to make demonstration in the wireless transmission of power on a small scale, but sufficient to carry conviction. Besides these, I referred to other and incomparably more important applications of my discoveries which will be disclosed at some future date. A plant was built on Long Island with a tower 187 feet high, having a spherical terminal about 68 feet in diameter. These dimensions were adequate for the transmission of virtually any amount of energy. Originally, only from 200 to 300 K.W. were provided, but I intended to employ later several thousand horsepower. The transmitter was to emit a wave-complex of special characteristics and I had devised a unique method of telephonic control of any amount of energy. The tower was destroyed two years ago (1917) but my projects are being developed and another one, improved in some features, will be constructed.

On this occasion I would contradict the widely circulated report that the structure was demolished by the government, which owing to war conditions, might have created prejudice in the minds of those who may not know that the papers, which thirty years ago conferred upon me the honor of American citizenship, are always kept in a safe, while my orders, diplomas, degrees, gold medals and other distinctions are packed away in old trunks. If this report had a foundation, I would have been refunded a large sum of money which I expended in the construction of the tower. On the contrary, it was in the interest of the government to preserve it, particularly as it would have made possible, to mention just one valuable result, the location of a submarine in any part of the world. My plant, services, and all my improvements have always been at the disposal of the officials and ever since the outbreak of the European conflict, I have been working at a sacrifice on several inventions of mine relating to aerial navigation, ship propulsion and wireless transmission, which are of the greatest importance to the country. Those who are well informed know that my ideas have revolutionized the industries of the United States and I am not aware that there lives an inventor who has been, in this respect, as fortunate as myself - especially as regards the use of his improvements in the war.

I have refrained from publicly expressing myself on this subject before, as it seemed improper to dwell on personal matters while all the world was in dire trouble. I would add further, in view of various rumors which have reached me, that Mr. J. Pierpont Morgan did not interest himself with me in a business way, but in the same large spirit in which he has assisted many other pioneers. He carried out his generous promise to the letter and it would have been most unreasonable to expect from him anything more. He had the highest regard for my attainments and gave me every evidence of his complete faith in my ability to ultimately achieve what I had set out to do. I am unwilling to accord to some small-minded and jealous individuals the satisfaction of having thwarted my efforts. These men are to me nothing more than microbes of a nasty disease. My project was retarded by laws of nature. The world was not prepared for it. It was too far ahead of time, but the same laws will prevail in the end and make it a triumphal success.

Chapter 6

No subject to which I have ever devoted myself has called for such concentration of mind, and strained to so dangerous a degree the finest fibers of my brain, as the systems of which the "Magnifying Transmitter" is the foundation. I put all the intensity and vigor of youth in the development of the rotating field discoveries, but those early labors were of a different character. Although strenuous in the extreme, they did not involve that keen and exhausting discernment which had to be exercised in attacking the many problems of the wireless.

Despite my rare physical endurance at that period, the abused nerves finally rebelled and I suffered a complete collapse, just as the consummation of the long and difficult task was almost in sight. Without doubt I would have paid a greater penalty later, and very likely my career would have been prematurely terminated, had not providence equipped me with a safety device, which seemed to improve with advancing years and unfailingly comes to play when my forces are at an end. So long as it operates I am safe from danger, due to overwork, which threatens other inventors, and incidentally, I need no vacations which are indispensable to most people. When I am all but used up, I simply do as the darkies who "naturally fall asleep while white folks worry."

To venture a theory out of my sphere, the body probably accumulates little by little a definite quantity of some toxic agent and I sink into a nearly lethargic state which lasts half an hour to the minute. Upon awakening I have the sensation as though the events immediately preceding had occurred very long ago, and if I attempt to continue the interrupted train of thought I feel veritable nausea. Involuntarily, I then turn to other tasks and am surprised at the freshness of the mind and ease with which I overcome obstacles that had baffled me before. After weeks or months, my passion for the temporarily abandoned invention returns and I invariably find answers to all the vexing questions, with scarcely any effort. In this connection, I will tell of an extraordinary experience which may be of interest to students of psychology.

I had produced a striking phenomenon with my grounded transmitter and was endeavoring to ascertain its true significance in relation to the currents propagated through the earth. It seemed a hopeless undertaking, and for more than a year I worked unremittingly, but in vain. This profound study so entirely absorbed me, that I became forgetful of everything else, even of my undermined health. At last, as I was at the point of breaking down, nature applied the preservative inducing lethal sleep. Regaining my senses, I realized with consternation that I was unable to visualize scenes from my life except those of infancy, the very first ones that had entered my consciousness. Curiously enough, these appeared before my vision with startling distinctness and afforded me welcome relief. Night after night, when retiring, I would think of them, and more and more of my previous existence was revealed. The image of my mother was always the principal figure in the spectacle that slowly unfolded, and a consuming desire to see her again gradually took possession of me. This feeling grew so strong that I resolved to drop all work and satisfy my longing, but I found it too hard to break away from the laboratory, and several months elapsed during which I had succeeded in reviving all the impressions of my past life, up to the spring of 1892. In the next picture that came out of the mist of oblivion, I saw myself at the Hotel de la Paix in Paris, just coming to from one of my peculiar sleeping spells, which had been caused by prolonged exertion of the brain. Imagine the pain and distress I felt, when it flashed upon my mind that a dispatch was handed to me at that very moment, bearing the sad news that my mother was dying. I remembered how I made the long journey home without an hour of rest and how she passed away after weeks of agony.

It was especially remarkable that during all this period of partially obliterated memory, I was fully alive to everything touching on the subject of my research. I could recall the smallest detail and the least insignificant observations in my experiments and even recite pages of text and complex mathematical formulae.

My belief is firm in a law of compensation. The true rewards are ever in proportion to the labor and sacrifices made. This is one of the reasons why I feel certain that of all my inventions, the magnifying transmitter will prove most important and valuable to future generations. I am prompted to this prediction, not so much by thoughts of the commercial and industrial revolution which it will surely bring about, but of the humanitarian consequences of the many achievements it makes possible. Considerations of mere utility weigh little in the balance against the higher benefits of civilization. We are confronted with portentous problems which can not be solved just by providing for our material existence, however abundantly. On the contrary, progress in this direction is fraught with hazards and perils not less menacing than those born from want and suffering. If we were to release the energy of atoms or discover some other way of developing cheap and unlimited power at any point on the globe, this accomplishment, instead of being a blessing, might bring disaster to mankind in giving rise to dissension and anarchy, which would ultimately result in the enthronement of the hated regime of force. The greatest good will come from technical improvements tending to unification and harmony, and my wireless transmitter is preeminently such. By its means, the human voice and likeness will be reproduced everywhere, and factories driven from thousands of miles away by waterfalls furnishing power. Aerial machines will be propelled around the earth without a stop and the sun's energy controlled to create lakes and rivers for motive purposes and transformation of arid deserts into fertile land. Its introduction for telegraphic, telephonic and similar uses will automatically cut out the static and all other interferences which at present, impose narrow limits to the application of the wireless. This is a timely topic on which a few words might not be amiss.

During the past decade a number of people have arrogantly claimed that they had succeeded in doing away with this impediment. I have carefully examined all of the arrangements described and tested most of them long before they were publicly disclosed, but the finding was uniformly negative. Recent official statement from the U.S. Navy may, perhaps, have taught some beguilable news editors how to appraise these announcements at their real worth. As a rule, the attempts are based on theories so fallacious, that whenever they come to my notice, I can not help thinking in a light vein. Quite recently a new discovery was heralded, with a deafening flourish of trumpets, but it proved another case of a mountain bringing forth a mouse. This reminds me of an exciting incident which took place a year ago, when I was conducting my experiments with currents of high frequency.

Steve Brodie had just jumped off the Brooklyn Bridge. The feat has been vulgarized since by imitators, but the first report electrified New York. I was very impressionable then and frequently spoke of the daring printer. On a hot afternoon I felt the necessity of refreshing myself and stepped into one of the popular thirty thousand institutions of this great city, where a delicious twelve per cent beverage was served, which can now be had only by making a trip to the poor and devastated countries of Europe. The attendance was large and not over-distinguished and a matter was discussed which gave me an admirable opening for the careless remark, "This is what I said when I jumped off the bridge." No sooner had I uttered these words, than I felt like the companion of Timothens in the poem of Schiller. In an instant there was pandemonium and a dozen voices cried, "It is Brodie!" I threw a quarter on the counter and bolted for the door, but the crowd was at my heels with yells, "Stop, Steeve!", which must have been misunderstood, for many persons tried to hold me up as I ran frantically for my haven of refuge. By darting around corners, I fortunately managed, through the medium of a fire escape, to reach the laboratory, where I threw off my coat, camouflaged myself as a hard-working blacksmith and started the forge. But these precautions proved unnecessary, as I had eluded my pursuers. For many years afterward, at night, when imagination turns into specters the trifling troubles of the day, I often thought, as I tossed on the bed, what my fate would have been, had the mob caught me and found out that I was not Steve Brodie!

Now the engineer who lately gave an account before a technical body of a novel remedy against static based on a "heretofore unknown law of nature," seems to have been as reckless as myself when he contended that these disturbances propagate up and down, while those of a transmitter proceed along the earth. It would mean that a condenser as this globe, with its gaseous envelope, could be charged and discharged in a manner quite contrary to the fundamental teachings propounded in every elemental text book of physics. Such a supposition would have been condemned as erroneous, even in Franklin's time, for the facts bearing on this were then well known and the identity between atmospheric electricity and that developed by machines was fully established. Obviously, natural and artificial disturbances propagate through the earth and the air in exactly the same way, and both set up electromotive forces in the horizontal as well as vertical sense. Interference can not be overcome by any such methods as were proposed. The truth is this: In the air, the potential increases at the rate of about fifty volts per foot of elevation, owing to which there may be a difference of pressure amounting to twenty, or even forty thousand volts between the upper and lower ends of the antenna. The masses of the charged atmosphere are constantly in motion and give up electricity to the conductor, not continuously, but rather disruptively, this producing a grinding noise in a sensitive telephonic receiver. The higher the terminal and the greater the space encompassed by the wires, the more pronounced is the effect, but it must be understood that it is purely local and has little to do with the real trouble.

In 1900, while perfecting my wireless system, one form of apparatus compressed four antennae. These were carefully calibrated in the same frequency and connected in multiple with the object of magnifying the action in receiving from any direction. When I desired to ascertain the origin of the transmitted impulse, each diagonally situated pair was put in series with a primary coil energizing the detector circuit. In the former case, the sound was loud in the telephone; in the latter it ceased, as expected, the two antennae neutralizing each other, but the true statics manifested themselves in both instances and I had to devise special preventives embodying different principles. By employing receivers connected to two points of the ground, as suggested by me long ago, this trouble caused by the charged air, which is very serious in the structures as now built, is nullified and besides, the liability of all kinds of interference is reduced to about one-half because of the directional character of the circuit. This was perfectly self-evident, but came as a revelation to some simple-minded wireless folks whose experience was confined to forms of apparatus that could have been improved with an ax, and they have been disposing of the bear's skin before killing him. If it were true that strays performed such antics, it would be easy to get rid of them by receiving without aerials. But, as a matter of fact, a wire buried in the ground which, conforming to this view, should be absolutely immune, is more susceptible to certain extraneous impulses than one placed vertically in the air. To state it fairly, a slight progress has been made, but not by virtue of any particular method or device. It was achieved simply by discerning the enormous structures, which are bad enough for transmission but wholly unsuitable for reception and adopting a more appropriate type of receiver. As I have said before, to dispose of this difficulty for good, a radical change must be made in the system and the sooner this is done the better.

It would be calamitous, indeed, if at this time when the art is in its infancy and the vast majority, not excepting even experts, have no conception of its ultimate possibilities, a measure would be rushed through the legislature making it a government monopoly. This was proposed a few weeks ago by Secretary Daniels and no doubt that distinguished official has made his appeal to the Senate and House of Representatives with sincere conviction. But universal evidence unmistakably shows that the best results are always obtained in healthful commercial competition. There are, however, exceptional reasons why wireless should be given the fullest freedom of development. In the first place, it offers prospects immeasurably greater and more vital to betterment of human life than any other invention or discovery in the history of man. Then again, it must be understood that this wonderful art has been, in its entirety, evolved here and can be called "American" with more right and propriety than the telephone, the incandescent lamp or the aeroplane.

Enterprising press agents and stock jobbers have been so successful in spreading misinformation, that even so excellent a periodical as the *Scientific American*, accords the chief credit to a foreign country. The Germans, of course, gave us the Hertz waves and the Russian, English, French and Italian experts were quick in using them for signaling purposes. It was an obvious application of the new agent and accomplished with the old classical and unimproved induction coil, scarcely anything more than another kind of heliography. The radius of transmission was very limited, the result attained of little value, and the Hertz oscillations, as a means for conveying intelligence, could have been advantageously replaced by sound waves, which I advocated in 1891. Moreover, all of these attempts were made three years after the basic principles of the wireless system, which is universally employed today, and its potent instrumentalities had been clearly described and developed in America.

No trace of those Hertzian appliances and methods remains today. We have proceeded in the very opposite direction and what has been done is the product of the brains and efforts of citizens of this country. The fundamental patents have expired and the opportunities are open to all. The chief argument of the secretary is based on interference. According to his statement, reported in the *New York Herald* of July 29th, signals from a powerful station can be intercepted in every village in the world. In view of this fact, which was demonstrated in my experiments in 1900, it would be of little use to impose restrictions in the United States.

As throwing light on this point, I may mention that only recently an odd looking gentleman called on me with the object of enlisting my services in the construction of world transmitters in some distant land. "We have no money," he said, "but carloads of solid gold, and we will give you a liberal amount." I told him that I wanted to see first what will be done with my inventions in America, and this ended the interview. But I am satisfied that some dark forces are at work, and as time goes on the maintenance of continuous communication will be rendered more difficult. The only remedy is a system immune against interruption. It has been perfected, it exists, and all that is necessary is to put it in operation.

The terrible conflict is still uppermost in the minds and perhaps the greatest importance will be attached to the magnifying transmitter as a machine for attack and defense, more particularly in connection with *telautamatics*. This invention is a logical outcome of observations begun in my boyhood and continued throughout my life. When the first results were published, the *Electrical Review* stated editorially that it would become one of the "most potent factors in the advance of civilization of mankind." The time is not distant when this prediction will be fulfilled. In 1898 and 1900, it was offered by me to the government and might have been adopted, were I one of those who would go to Alexander's shepherd when they want a favor from Alexander!

At that time I really thought that it would abolish war, because of its unlimited destructiveness and exclusion of the personal element of combat. But while I have not lost faith in its potentialities, my views have changed since. War can not be avoided until the physical cause for its recurrence is removed and this, in the last analysis, is the vast extent of the planet on which we live. Only though annihilation of distance in every respect, as the conveyance of intelligence, transport of passengers and supplies and transmission of energy will conditions be brought about some day, insuring permanency of friendly relations. What we now want most is closer contact and better understanding between individuals and communities all over the earth and the elimination of that fanatic devotion to exalted ideals of national egoism and pride, which is always prone to plunge the world into primeval barbarism and strife. No league or parliamentary act of any kind will ever prevent such a calamity. These are only new devices for putting the weak at the mercy of the strong.

I have expressed myself in this regard fourteen years ago, when a combination of a few leading governments, a sort of Holy alliance, was advocated by the late Andrew Carnegie, who may be fairly considered as the father of this idea, having given to it more publicity and impetus than anybody else prior to the efforts of the President. While it can not be denied that such aspects might be of material advantage to some less fortunate peoples, it can not attain the chief objective sought. Peace can only come as a natural consequence of universal enlightenment and merging of races, and we are still far from this blissful realization, because few indeed, will admit the reality < that God made man in His image < in which case all earth men are alike. There is in fact but one race, of many colors. Christ is but one person, yet he is of all people, so why do some people think themselves better than some other people?

As I view the world of today, in the light of the gigantic struggle we have witnessed, I am filled with conviction that the interests of humanity would be best served if the United States remained true to its traditions, true to God whom it pretends to believe, and kept out of "entangling alliances." Situated as it is, geographically remote from the theaters of impending conflicts, without incentive to territorial aggrandizement, with inexhaustible resources and immense population thoroughly imbued with the spirit of liberty and right, this country is placed in a unique and privileged position. It is thus able to exert, independently, its colossal strength and moral force to the benefit of all, more judiciously and effectively, than as a member of a league.

I have dwelt on the circumstances of my early life and told of an affliction which compelled me to unremitting exercise of imagination and self-observation. This mental activity, at first involuntary under the pressure of illness and suffering, gradually became second nature and led me finally to recognize that I was but an automaton devoid of free will in thought and action and merely responsible to the forces of the environment. Our bodies are of such complexity of structure, the motions we perform are so numerous and involved and the external impressions on our sense organs to such a degree delicate and elusive, that it is hard for the average person to grasp this fact. Yet nothing is more convincing to the trained investigator than the mechanistic theory of life which had been, in a measure, understood and propounded by Descartes three hundred years ago. In his time many important functions of our organisms were unknown and especially with respect to the nature of light and the construction and operation of the eye, philosophers were in the dark.

In recent years the progress of scientific research in these fields has been such as to leave no room for a doubt in regard to this view on which many works have been published. One of its ablest and most eloquent exponents is, perhaps, Felix le Dantec, formerly assistant of Pasteur. Professor Jacques Loeb has performed remarkable experiments in heliotropism, clearly establishing the controlling power of light in lower forms of organisms and his latest book, *Forced Movements*, is revelatory. But while men of science accept this theory simply as any other that is recognized, to me it is a truth which I hourly demonstrate by every act and thought of mine. The consciousness of the external impression prompting me to any kind of exertion, < physical or mental, is ever present in my mind. Only on very rare occasions, when I was in a state of exceptional concentration, have I found difficulty in locating the original impulse. The by far greater number of human beings are never aware of what is passing around and within them and millions fall victims of disease and die prematurely just on this account. The commonest, every-day occurrences appear to them mysterious and inexplicable. One may feel a sudden wave of sadness and rack his brain for an explanation, when he might have noticed that it was caused by a cloud cutting off the rays of the sun. He may see the image of a friend dear to him under conditions which he construes as very peculiar, when only shortly before he has passed him in the street or seen his photograph somewhere. When he loses a collar button, he fusses and swears for an hour, being unable to visualize his previous actions and locate the object directly. Deficient observation is merely a form of ignorance and responsible for the many morbid notions and foolish ideas prevailing. There is not more than one out of every ten persons who does not believe in telepathy and other psychic manifestations, spiritualism and communion with the dead, and who would refuse to listen to willing or unwilling deceivers?

Just to illustrate how deeply rooted this tendency has become even among the clear-headed American population, I may mention a comical incident. Shortly before the war, when the exhibition of my turbines in this city elicited widespread comment in the technical papers, I anticipated that there would be a scramble among manufacturers to get hold of the invention and I had particular designs on that man from Detroit who has an uncanny faculty for accumulating millions. So confident was I, that he would turn up some day, that I declared this as certain to my secretary and assistants. Sure enough, one fine morning a body of engineers from the Ford Motor Company presented themselves with the request of discussing with me an important project. "Didn't I tell you?," I remarked triumphantly to my employees, and one of them said, "You are amazing, Mr. Tesla. Everything comes out exactly as you predict."

As soon as these hard-headed men were seated, I of course, immediately began to extol the wonderful features of my turbine, when the spokesman interrupted me and said, "We know all about this, but we are on a special errand. We have formed a psychological society for the investigation of psychic phenomena and we want you to join us in this undertaking." I suppose these engineers never knew how near they came to being fired out of my office.

Ever since I was told by some of the greatest men of the time, leaders in science whose names are immortal, that I am possessed of an unusual mind, I bent all my thinking faculties on the solution of great problems regardless of sacrifice. For many years I endeavored to solve the enigma of death, and watched eagerly for every kind of spiritual indication. But only once in the course of my existence have I had an experience which momentarily impressed me as supernatural. It was at the time of my mother's death.

I had become completely exhausted by pain and long vigilance, and one night was carried to a building about two blocks from our home. As I lay helpless there, I thought that if my mother died while I was away from her bedside, she would surely give me a sign. Two or three months before, I was in London in company with my late friend, Sir William Crookes, when spiritualism was discussed and I was under the full sway of these thoughts. I might not have paid attention to other men, but was susceptible to his arguments as it was his epochal work on radiant matter, which I had read as a student, that made me embrace the electrical career. I reflected that the conditions for a look into the beyond were most favorable, for my mother was a woman of genius and particularly excelling in the powers of intuition. During the whole night every fiber in my brain was strained in expectancy, but nothing happened until early in the morning, when I fell in a sleep, or perhaps a swoon, and saw a cloud carrying angelic figures of marvelous beauty, one of whom gazed upon me lovingly and gradually assumed the features of my mother. The appearance slowly floated across the room and vanished, and I was awakened by an indescribably sweet song of many voices. In that instant a certitude, which no words can express, came upon me that my mother had just died. And that was true. I was unable to understand the tremendous weight of the painful knowledge I received in advance, and wrote a letter to Sir William Crookes while still under the domination of these impressions and in poor bodily health. When I recovered, I sought for a long time the external cause of this strange manifestation and, to my great relief, I succeeded after many months of fruitless effort.

I had seen the painting of a celebrated artist, representing allegorically one of the seasons in the form of a cloud with a group of angels which seemed to actually float in the air, and this had struck me forcefully. It was exactly the same that appeared in my dream, with the exception of my mother's likeness. The music came from the choir in the church nearby at the early mass of Easter morning, explaining everything satisfactorily in conformity with scientific facts.

This occurred long ago, and I have never had the faintest reason since to change my views on psychical and spiritual phenomena, for which there is no foundation. The belief in these is the natural outgrowth of intellectual development. Religious dogmas are no longer accepted in their orthodox meaning, but every individual clings to faith in a supreme power of some kind.

We all must have an ideal to govern our conduct and insure contentment, but it is immaterial whether it be one of creed, art, science, or anything else, so long as it fulfills the function of a dematerializing force. It is essential to the peaceful existence of humanity as a whole that one common conception should prevail. While I have failed to obtain any evidence in support of the contentions of psychologists and spiritualists, I have proved to my complete satisfaction the automatism of life, not only through continuous observations of individual actions, but even more conclusively through certain generalizations. these amount to a discovery which I consider of the greatest moment to human society, and on which I shall briefly dwell.

I got the first inkling of this astonishing truth when I was still a very young man, but for many years I interpreted what I noted simply as coincidences. Namely, whenever either myself or a person to whom I was attached, or a cause to which I was devoted, was hurt by others in a particular way, which might be best popularly characterized as the most unfair imaginable, I experienced a singular and undefinable pain which, for the want of a better term, I have qualified as"cosmic" and shortly thereafter, and invariably, those who had inflicted it came to grief. After many such cases I confided this to a number of friends, who had the opportunity to convince themselves of the theory of which I have gradually formulated and which may be stated in the following few words: Our bodies are of similar construction and exposed to the same external forces. This results in likeness of response and concordance of the general activities on which all our social and other rules and laws are based. We are automata entirely controlled by the forces of the medium, being tossed about like corks on the surface of the water, but mistaking the resultant of the impulses from the outside for the free will. The movements and other actions we perform are always life preservative and though seemingly quite independent from one another, we are connected by invisible links. So long as the organism is in perfect order, it responds accurately to the agents that prompt it, but the moment that there is some derangement in any individual, his self-preservative power is impaired.

Everybody understands, of course, that if one becomes deaf, has his eyes weakened, or his limbs injured, the chances for his continued existence are lessened. But this is also true, and perhaps more so, of certain defects in the brain which drive the automaton, more or less, of that vital quality and cause it to rush into destruction. A very sensitive and observant being, with his highly developed mechanism all intact, and acting with precision in obedience to the changing conditions of the environment, is endowed with a transcending mechanical sense, enabling him to evade perils too subtle to be directly perceived. When he comes in contact with others whose controlling organs are radically faulty, that sense asserts itself and he feels the "cosmic" pain.

The truth of this has been borne out in hundreds of instances and I am inviting other students of nature to devote attention to this subject, believing that through combined systematic effort, results of incalculable value to the world will be attained. The idea of constructing an automaton, to bear out my theory, presented itself to me early, but I did not begin active work until 1895, when I started my wireless investigations. During the succeeding two or three years, a number of automatic mechanisms, to be actuated from a distance, were constructed by me and exhibited to visitors in my laboratory.

In 1896, however, I designed a complete machine capable of a multitude of operations, but the consummation of my labors was delayed until late in 1897.

This machine was illustrated and described in my article in the *Century Magazine* of June, 1900; and other periodicals of that time and when first shown in the beginning of 1898, it created a sensation such as no other invention of mine has ever produced. In November, 1898, a basic patent on the novel art was granted to me, but only after the examiner-in-chief had come to New York and witnessed the performance, for what I claimed seemed unbelievable. I remember that when later I called on an official in Washington, with a view of offering the invention to the Government, he burst out in laughter upon my telling him what I had accomplished. Nobody thought then that there was the faintest prospect of perfecting such a device. It is unfortunate that in this patent, following the advice of my attorneys, I indicated the control as being affected through the medium of a single circuit and a well-known form of detector, for the reason that I had not yet secured protection on my methods and apparatus for individualization. As a matter of fact, my boats were controlled through the joint action of several circuits and interference of every kind was excluded.

Most generally, I employed receiving circuits in the form of loops, including condensers, because the discharges of my high-tension transmitter ionized the air in the (laboratory) so that even a very small aerial would draw electricity from the surrounding atmosphere for hours.

Just to give an idea, I found, for instance, that a bulb twelve inches in diameter, highly exhausted, and with one single terminal to which a short wire was attached, would deliver well on to one thousand successive flashes before all charge of the air in the laboratory was neutralized. The loop form of receiver was not sensitive to such a disturbance and it is curious to note that it is becoming popular at this late date. In reality, it collects much less energy than the aerials or a long grounded wire, but it so happens that it does away with a number of defects inherent to the present wireless devices.

In demonstrating my invention before audiences, the visitors were requested to ask questions, however involved, and the automaton would answer them by signs. This was considered magic at the time, but was extremely simple, for it was myself who gave the replies by means of the device.

At the same period, another larger telautomatic boat was constructed, a photograph of which was shown in the October 1919 number of the *Electrical Experimenter*. It was controlled by loops, having several turns placed in the hull, which was made entirely water-tight and capable of submergence. The apparatus was similar to that used in the first with the exception of certain special features I introduced as, for example, incandescent lamps which afforded a visible evidence of the proper functioning of the machine. These automata, controlled within the range of vision of the operator, were, however, the first and rather crude steps in the evolution of the art of Telautomatics as I had conceived it.

The next logical improvement was its application to automatic mechanisms beyond the limits of vision and at great distances from the center of control, and I have ever since advocated their employment as instruments of warfare in preference to guns. The importance of this now seems to be recognized, if I am to judge from casual announcements through the press, of achievements which are said to be extraordinary but contain no merit of novelty, whatever. In an imperfect manner it is practicable, with the existing wireless plants, to launch an aeroplane, have it follow a certain approximate course, and perform some operation at a distance of many hundreds of miles. A machine of this kind can also be mechanically controlled in several ways and I have no doubt that it may prove of some usefulness in war. But there are to my best knowledge, no instrumentalities in existence today with which such an object could be accomplished in a precise manner. I have devoted years of study to this matter and have evolved means, making such and greater wonders easily realizable.

As stated on a previous occasion, when I was a student at college I conceived a flying machine quite unlike the present ones. The underlying principle was sound, but could not be carried into practice for want of a prime-mover of sufficiently great activity. In recent years, I have successfully solved this problem and am now planning aerial machines *devoid of sustaining planes, ailerons, propellers, and other external* attachments, which will be capable of immense speeds and are very likely to furnish powerful arguments for peace in the near future. Such a machine, sustained and propelled *entirely by reaction*, is shown on one of the pages of my lectures, and is supposed to be controlled either mechanically, or by wireless energy. By installing proper plants, it will be practicable to *project a missile of this kind into the air and drop it* almost on the very spot designated, which may be thousands of miles away.

But we are not going to stop at this. Telautomats will be ultimately produced, capable of acting as if possessed of their own intelligence, and their advent will create a revolution. As early as 1898, I proposed to representatives of a large manufacturing concern the construction and public exhibition of an automobile carriage which, left to itself, would perform a great variety of operations involving something akin to judgment. But my proposal was deemed chimerical at the time and nothing came of it.

At present, many of the ablest minds are trying to devise expedients for preventing a repetition of the awful conflict which is only theoretically ended and the duration and main issues of which I have correctly predicted in an article printed in the *Sun* of December 20, 1914. The proposed League is not a remedy but, on the contrary, in the opinion of a number of competent men, may bring about results just the opposite.

It is particularly regrettable that a punitive policy was adopted in framing the terms of peace, because a few years hence, it will be possible for nations to fight without armies, ships or guns, by weapons far more terrible, to the destructive action and range of which there is virtually no limit. Any city, at a distance, whatsoever, from the enemy, can be destroyed by him and no power on earth can stop him from doing so. If we want to avert an impending calamity and a state of things which may transform the globe into an inferno, we should push the development of flying machines and wireless transmission of energy without an instant's delay and with all the power and resources of the nation.

THE END

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ANTENTOP

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