Spreading and Underground Antennas

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It was in the end of 1980s, during at my trip by bus from Gorkiy (now Nizniy Novgorod, Russia) to a small town at this region, while on route to my destination, I observed a huge field fenced with barbed wire. I asked my local fellow traveler what it might be and he replied that it was a military communications site. However, I noticed there weren't any antennas visible. My companion remarked that they were installed underground! So, for the first time I had seen an underground communications site.

The manner of constructing the underground antennas used on these sites especially interested me, but at the times I cannot found any information about underground antennas. Information of these antennas was considered highly confidential just before 90s. Recently with development of satellite and meteor radio communications systems such unusual antennas became almost obsolete. Classifications have been removed from underground and spreading antennas and information on the antennas may be found in the internet.

However, underground and spreading antennas are old type of antennas used by military of different countries. These antennas usually were exploited on classified signal radio communications sites.

Underground and spreading antennas are normally not used by the radio amateurs. Usually there are enough places where it is possible to install an antenna of choice. However, with cities getting larger and architectural demands to keep the exterior of houses and communities attractive, underground and spreading antennas may be one of the only solutions to be on the Air.

History of Underground and Spreading Antennas

During the First World War, an antenna mast of a field radio set had a significant altitude of 15-30 meters (50-100 feet) thereof it represented an easy target for enemy's artillery. But even when shells were downed the mast the spreading above the ground antenna allowed makes radio communication. It was found that the spreading antenna enabled fair communication in the same direction of the antenna wire leading from the transmitter. Knowing thus fact sometimes mast was not be installed for field radio set and military use the spreading antenna that represented just wire in thick insulation lying on the top of the ground which follows and blends with the irregularities of the earth surface and vegetation coverage.

Before the Second World War early researches into the operation of underground and spreading antennas were made for the purpose of espionage installation of invisible antennas. These antennas needed be easily installed and set up for operation on short-wave bands of 2-5 or 8-12 MHz, which was commonly used at the times by the spies for clandestine operation.

In practical way it was found that an effective spreading antenna may be formed from a wire of about 1 mm diameter enclosed by a dielectric with approximately 10-mm diameter to protect the wire from touching the ground surface. However as usual for clandestine spreading antenna it was used general electric wire in rubber isolation in length of about 30-45 meters. The wire may be placed on the ground, on the bushes or attached to a fence. It was easy installed and easy removed for radio operation and the wire may be easily found in a local electrical store.

Old direction-finding equipment had some irregular errors in finding location of transmitters using spreading and underground antennas.

Because of this the spreading and underground antennas were excellent for field espionage operation from suburbs of large cities, and for stationary operation from places located at remote distances from large cities and direction finding facilities.

After WWII in the World were developed underground and spreading antennas for stationary underground radio sites operating in a broad frequency range - from 9 kHz up to 50 MHz. Spreading antennas as well were used for field military communications as reserve antennas. The information on usage of underground and spreading antennas during World War II and modern times can be found in the internet, see for example, Reference **[1]**.

The theory for both underground vertical and underground horizontal antennas was developed in different countries. However publications on the thematic were classified. In the USSR only one book on the subject was open for public and only after 20 years when the book was published. The book is named Spreading and Underground Antennas, Reference **[2]**.

Design of Spreading and Underground Antennas

Figure 1 shows a typical an old spreading antenna with the Diagram of Directivity. The maximum direction of the spreading antenna is in line with the element of the antenna. Originally such antenna was invented by downed by shell vertical antenna of field radio set.

How the antenna does work? As is known from the theory of antennas, a horizontal wire antenna, installed close to the ground, during operation establishes in the ground a mirror image, see **Figure 1**. The currents flowing in an antenna and the mirror image are mutually cancelled at low altitudes foiling the antenna ability to radiate waves horizontally polarized. So a spreading antenna should poorly radiate horizontally polarized waves.

It is known that vertically polarized radio waves are not absorbed in soil to such a degree as horizontally polarized radio waves. Therefore, with the spreading antenna there is some radiation of vertically polarized radio waves present. If soil under antenna has good conductive, the antenna will be less effective compare to antenna placed above the soil with poor conductivity.

The spreading antenna as well may be considered as a kind of feedline being created by wire in the insulation and soil, as lossy second wire of the feedline. **Figure 2** shows a spreading antenna. Termination shown on the end of the antenna is the theoretical load that shows losses on radiation wire and losses of the electromagnetic energy in the soil.

Figure 3 shows an underground wire antenna. Underground antenna usually is wire covered with plastic or aerial isolation by thickness H and installed inside of the ground.

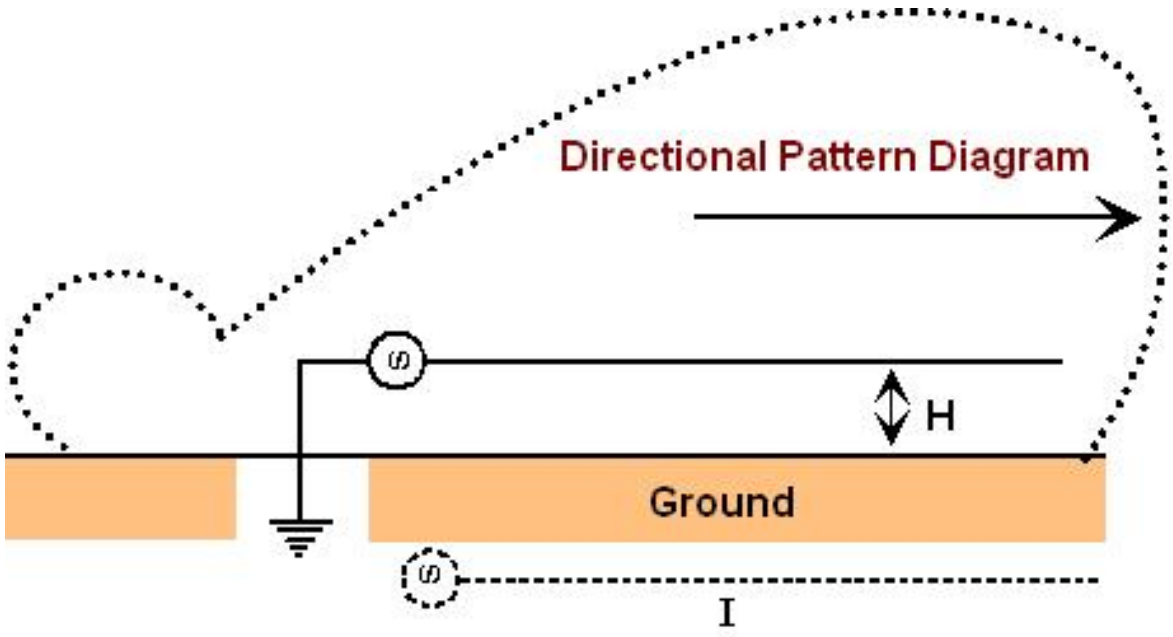

Figure 1
Old Spreading Antenna with DD

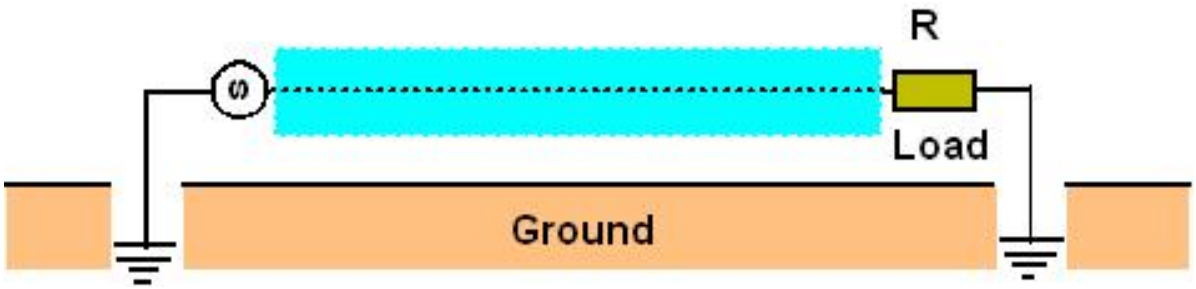

Figure 2
Spreading Antenna

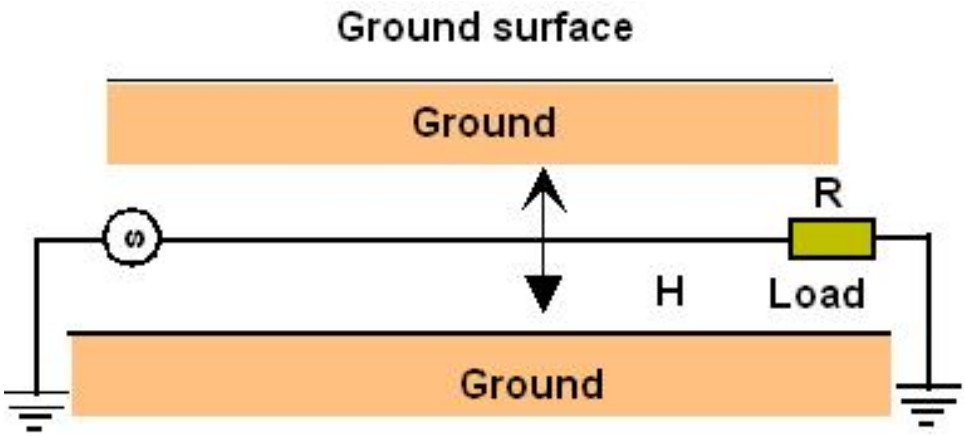

Figure 3
Underground Antenna

In the theory the underground antenna may be considered as a kind of coaxial feedline being created by antenna (center wire of the coaxial) and ambient soil, as lossy braid of the coaxial. Termination shown on the end of the coaxial line is the theoretical load that shows losses on radiation of the center wire and losses of the electromagnetic energy in the ground.

In the real life the termination load may be a real resistor that serves to eliminate high stand waves in the antenna wire and improve tuning of the antenna in wide or certain frequencies range. Determination of input impedance of spreading and underground antenna, both theoretically and practically, is very sophisticated task. Reference **[2]** gives information on the methods and ways how to do this.

Depending on the conductance and the dielectric property of the real soil and practical design of the underground or spreading antenna, the termination load may have resistance of 100-500 Ohms on frequencies from 2-30 MHz.

Sometimes for the underground and spreading antenna is used not loaded at the end wire, as shown on the **Figure 1**. It is so named ***Quasiresonance Antenna***. Distribution of current and voltage along the wire of the antenna is almost similar to current distribution that is normally present in resonant antenna. In contrast to an aperiodic antenna see **Figure 2, 3**) having a large bandwidth and stable parameters, the non-loaded antenna's parameters and resonance band are rather unstable.

It is happened because the electrical length and input impedance of the quasiresonance antenna depends on state of soil, on or in which the antenna is installed. As usual, conditions of the soil are vared over season of the year and dictate by the weather – cold or hot and rain or snow. But, sometimes, with stable soils (desert sands, frosted soil) it is possible to have quasiresonance antenna with stable parameters.

Length of Spreading and Underground Antenna

How does length affect the overall performance of spreading and underground antenna? It could be used very long wire to improve efficiency of the antenna?

Probably not, because in radiation from an antenna wire the basic role is played by the length of the antenna, during which the amplitude of a current in the antenna diminishes by a factor of 10 as contrasted to being at feed terminals of the antenna. In the Reference **[2]** is shown, that for the underground or spreading antenna installation (on basic types of soils), the length of the wire in 30 meters is enough for effective operation on HF bands. If the installation of the underground or spreading antenna is on dry, sandy soil, or on top of deep snow, the length may be greater than 60 meters. Then absorption RF energy from a long wire makes the long wire useless in antenna radiation.

Antenna Efficiency

As it shown in Reference **[2]**, with sufficient approximation it is possible to take that the efficiency of spreading antenna on HF ranges would be no more than 10 percent in comparison to an antenna of the same length and installed at a height of 2 meters above the same soil and operating on the same frequency. However ever with the efficiency it is possible to make QSOs on amateur bands at normal propagation conditions with power 100 watts going into the antenna.

Spreading and Underground Antennas

The directivity of low height spreading antenna is almost similar to the above mentioned raised at the altitude of 2 meters above the ground antenna. However the vertical angle of radiation of a spreading antenna is going to be 10-20 percent higher, than for the raised antenna. It allows assume that a spreading antenna could be a choice for local QSO (up to 500 km) in the 160 and 80 meter Bands. On the bands higher than 40 meters, both local and long-distance QSO's are possible.

Files about Underground and Spreading Antennas

Let's take a look to practical design of the spreading and underground antennas used by the USSR military.

All these files were found by me in the internet and were declassified by 2000 year.

Practical Design of Spreading Antennas in the USSR

I have got some descriptions of Russian spreading antennas, which has now been declassified. **Figure 4** shows Russian spreading antenna named SA - 60/15 (CA – 60/15, in Russian letters it means Spreading Antenna 60 meter length, counterpoises 15 meter length).

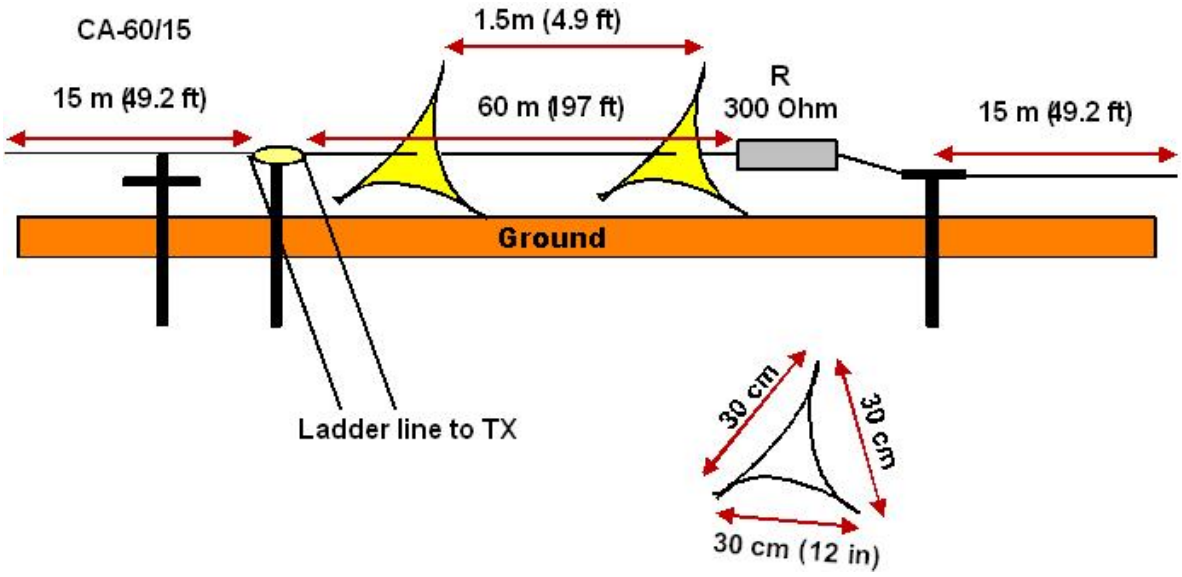

Figure 4
Spreading Antenna SA- 60/15

Antenna wire is a copper (at some references the wire made from a special brass) cord in thick strong plastic insulation. The length of this wire is 60 meter.The wire is strengthening with a steel core inside the copper cord. The antenna wire is going through plastic triangular insulators, which help keep it is isolated from the earth. The insulators placed at distance near 1.5 meter apart each other. The plastic triangles may be inserted into the ground by one end therefore they were made from a strong plastic.

The two-wire ladder line in strong plastic insulation is connected to the antenna wire and the counterpoise. The two wire line connected the antenna and counterpoise is going to transmitter. The length of this two wire line is 5 meter. The length of the counterpoise is 15 meter. Termination Load has 300 Ohm value. Load is protected from mechanical damage, water and atmospheric influences. The length of the counterpoise after termination load is 15 meter. Both counterpoises made from the same antenna wire. Counterpoises were connected to steel pins in 70 cm long, which were hammered into the ground. The antenna was operated in the frequency range from 1 to 50 MHz. The maximum power going into the antenna was depend on dissipative power of the termination load. There was antenna option for 5 kW RF power ever.

In the internet I found description one more very interesting Russian Spreading Antenna. The antenna is mentioned to be produced in 70s. Antenna is named SA- 60-2M-PK (СА – 60 -2М-ПК, in Russian letter). **Figure 5** shows design of the antenna.

The outer sheath of the antenna is made of from strong foam insulating material that could be floated on the surface of both fresh and salt water. The diameter of the plastic body is 16 cm. The surface of the plastic was special and it repelled water and dirt. The plastic insulation of this antenna was non-flammable. According to technical parameters, this antenna can withstand being run over by a tank weighting up to 100 tons. It does not fail even with close explosions of a nuclear bomb and direct hits by shells or mines.

Antenna wire in part B made from copper cord in diameter of 4 mm. The counterpoise of part A is made from a wire, similar to the antenna wire. Counterpoise of part C is made from a cord having a pure dc resistance of 100 ohms at its ends. This counterpoise is artificial termination load of the antenna. It allows the use to the antenna without grounding pins and on any type of the ground - sand, stone, permanent ice, etc. Special design of the artificial termination load allows match the antenna in the wide frequencies range.

A two-wire line by length of 5 meters is connected to the antenna. According to technical parameters the antenna works in frequencies range of 1-50 MHz and could stand up to 5 kW RF Power. This antenna is still workable if it is buried at a small depth in the ground.

Design of Underground Short Wave Radio Site

The underground radio sites were arranged for navigation and for emergency purposes, as a commander radio site. The commander underground communication sites were designed for operation on LW, MW and HF ranges. **Figure 6** shows design of a commander communication site for operation on HF bands.

The underground radio site consists of Equipment Room (1) located at depth of 15-30 meters underground. The room contained transmitting/ receiving equipment and place for personnel. The transmitting/ receiving equipment is connected by feeders (2) to the matching devices (3). Matching devices is placed at depth of 2-4 meters from the surface of the ground. The 4- 8 aperiodic loaded antennas (4) are connected to matching devices. The length of each of the antenna may be in range of 20 to 50 meter.

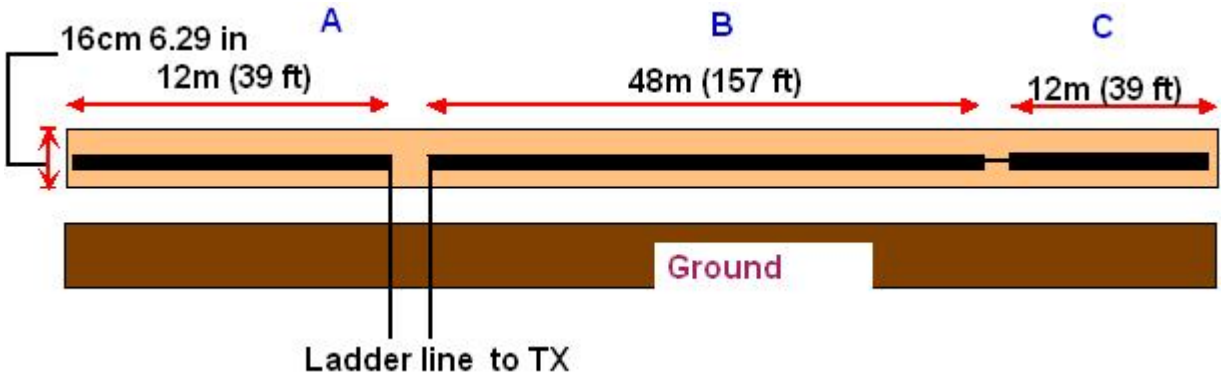

Figure 5
Spreading Antenna SA- 60/15 60-2M-PK

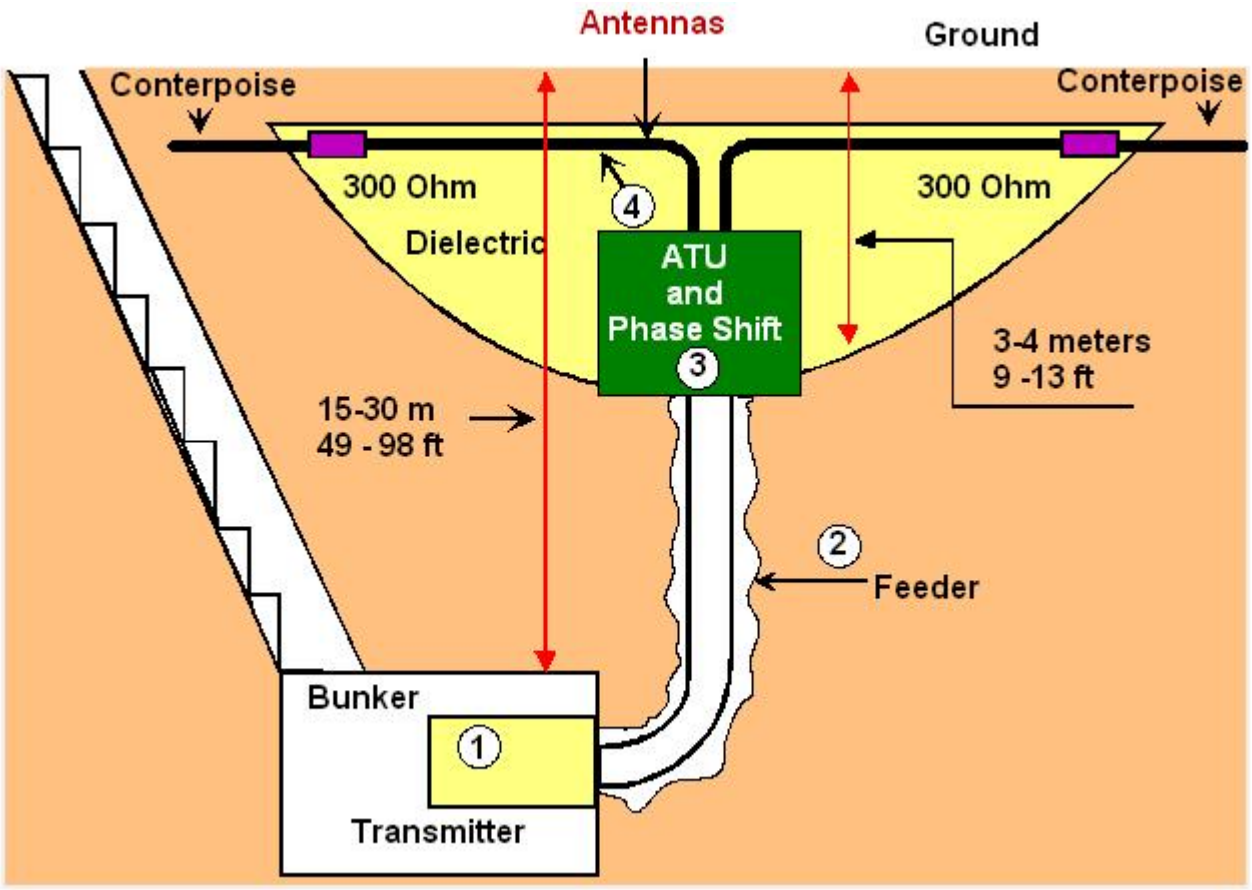

Figure 6
Underground Short Wave Radio Site

Counterpoises are buried close to the ground surface. Antennas and counterpoises may be made from bimetallic tubes (iron tube plated by copper) in diameter of 20 millimeters. With the matching devices connected to the phase shift circuits the antennas can be combined in groups for creation of a desirable Radiation Diagram. **Figure 7** shows top view on the antennas of the short wave underground radio site.

Antennas are installed in half-sphere trenches in depth of 2-3 meters underground. Then the trenches are filled up with dielectric stuff. Underground communication site is masked by ground covering with grass and sometimes with trees. Underground communication site may be fed by underground power cable from local electricity station or may have own underground nuclear or diesel electrical generator.

Vertical Underground Antennas

Through hours of searching in the internet the files about underground antennas I found data for vertical underground antennas. These antennas may be named as ***Mountain Antennas***, because these antennas are installed inside of mountain where rocks have low absorption of HF frequencies. **Figure 8** shows design of a vertical mountain underground antenna.

Antenna is installed or in the natural funnels or in the artificial adit. Equipment room is placed at the bottom of the adit or in the cave from which the natural funnels come through the mountain. The vertical part of the antenna depends on length of the opening and how close the opening is to an aquifer stratum, which usually (if it is present) is used as the grounding for the mountain vertical antenna. The grounding for underground vertical antenna consists of several non-resonant short ground rods and wire counterpoises, which are placed under the antenna base. The vertical radiator of the underground antenna is tuned to resonance with the help of Antenna Tuning Unit.

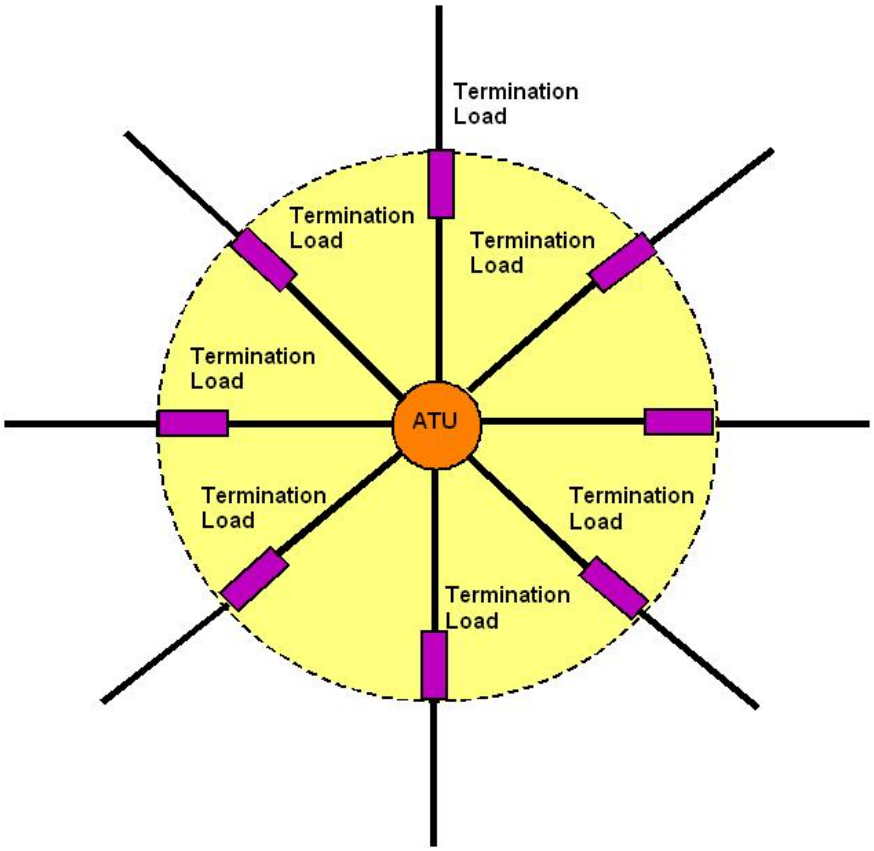

Figure 7
Top View on the Antennas of Short Wave Underground Radio Site

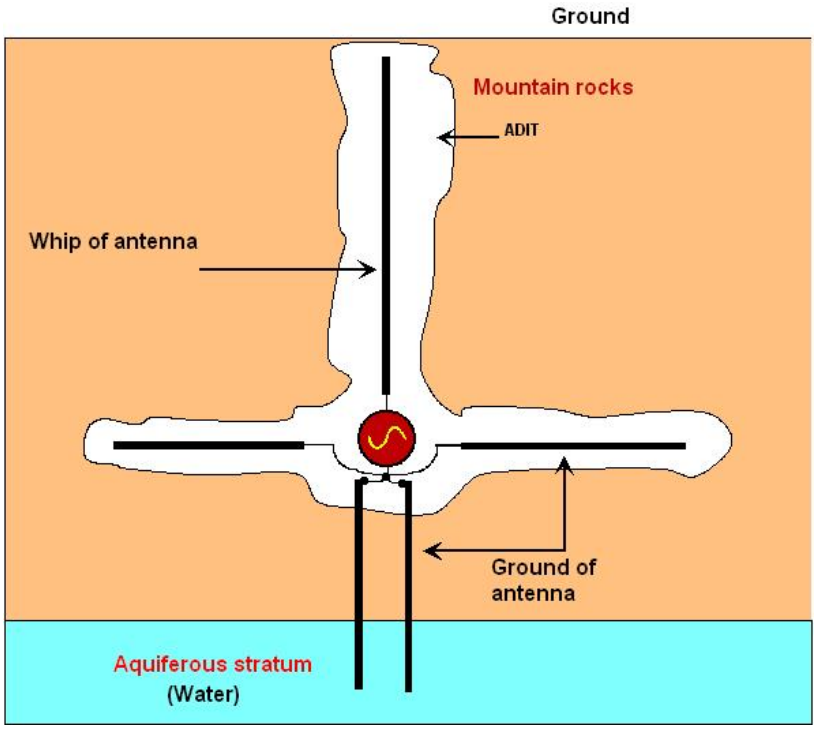

Figure 8
Vertical Mountain Underground Antenna

The underground vertical antenna shown in **Figure 8** was used at German Mountain Underground Radio Site during WWII. The site was operated in the Carpathians Mountains. Mountain Underground radio sites are very rare because it is difficult to find suitable place for the mountain antenna.

Cave Antennas

A kind of underground antennas is the Rhomb Underground Loaded Antenna. Before WWII, Rhomb Underground Loaded Antennas were tested in Russia in the Crimea and Georgian caves. Antenna wire may be placed underground as in vertical either in horizontal position depends on the cave.

Spreading and Underground Antennas

Figure 9 shows the Rhomb Vertical Underground Loaded Antenna.

The part of the antenna AB is placed immediately on the surface of the ground or at a small depth under the surface. The parts AC, BD, CD are placed in a hole either artificial or natural. The rhombic underground vertical antenna, as well as the above ground version has radiation directed toward the termination load. By switching the load from point B to point A, and accordingly switching feed point from point C to point D, the antenna directional radiation diagram could be changed to 180 degree.

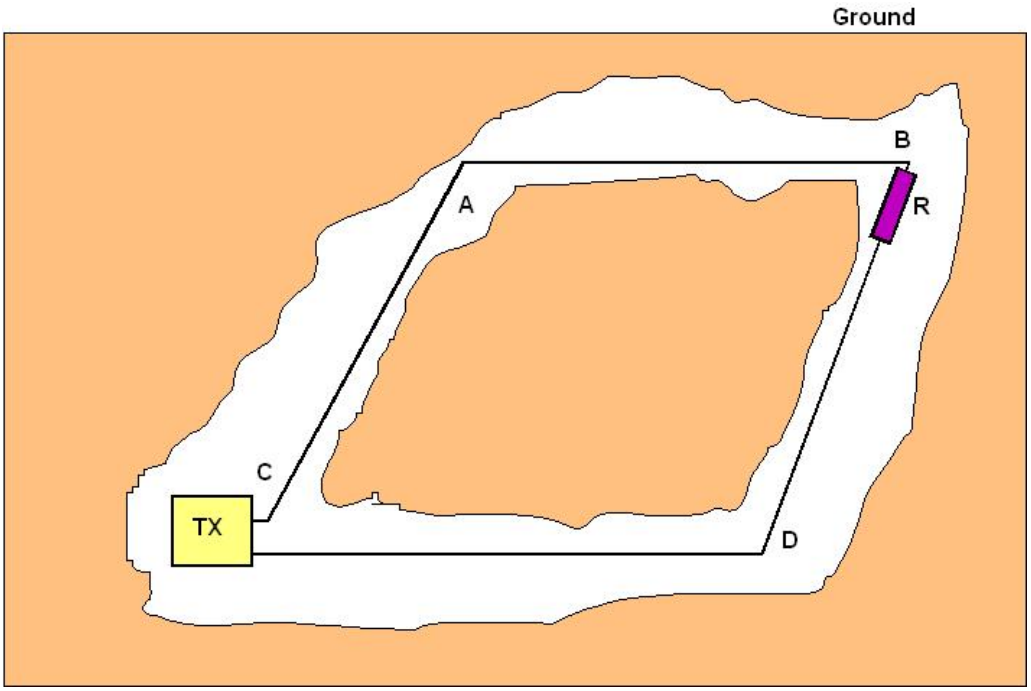

Figure 9
Rhomb Vertical Underground Loaded Antenna

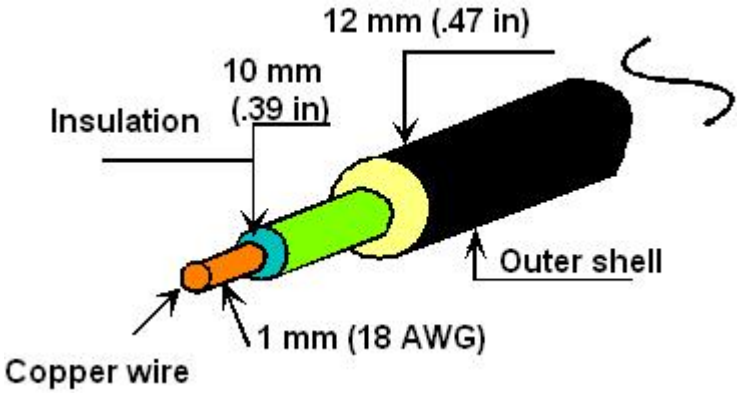

Figure 10
Antenna Wire for Underground Antenna

Underground radio sites that used the Vertical Rhombic Terminated Antenna are restricted to area in which the terrain has high resistance and a small dielectric constant. Therefore it has a low absorption of Radio Waves.

For antenna wire of these antennas, a wire with a diameter of 1 mm in plastic insulation with a diameter of 10 mm was used. It is like a thick coaxial cable with the outer conductive braid removed. However the cable has strong plastic outer covering. **Figure 10** shows the antenna wire.

Underground Radio Sites for Long Wave

Underground radio sites for Long Wave and Super Long-Wave are more common the Short Wave Underground Radio Site. The sites are used for navigation and for emergency radio communications. Sometimes at a short distance from a Long Wave Radio Site it is placed a Short Wave Radio Site. The antennas at the Long Wave Radio Site usually are not used for short wave communications however in rare occasions there have been double applications.

The length of effective spreading (or underground) antenna on Super Long band as usual is in limits 150 - 250 meters. Because due losses in the ground it is hard to improve efficiency of antenna just by length. To improve the antenna efficiency on the Underground Radio Communication Site of Super Long Wave there are used to a quasiresonance antennas. **Figure 11** shows design of the spreading antenna for Super Long range.

The antenna consists of two bent elements 1 and 4 which with the help of the matching devices 2 and 3 are tuned to resonance. The antenna at top view has shape of a boomerang. Therefore such antennas in the USSR have the nick name ***Boomerang***.

Spreading and Underground Antennas

There are underground Long Wave sites where there are used several antennas, as usual 4 or 6. These antennas feed through phasing devices that may create desired directional radiation pattern. **Figure 12** shows the top view of such spreading antenna system. This antenna system has nick name ***Spider,*** because it looks like a spider from the top view.

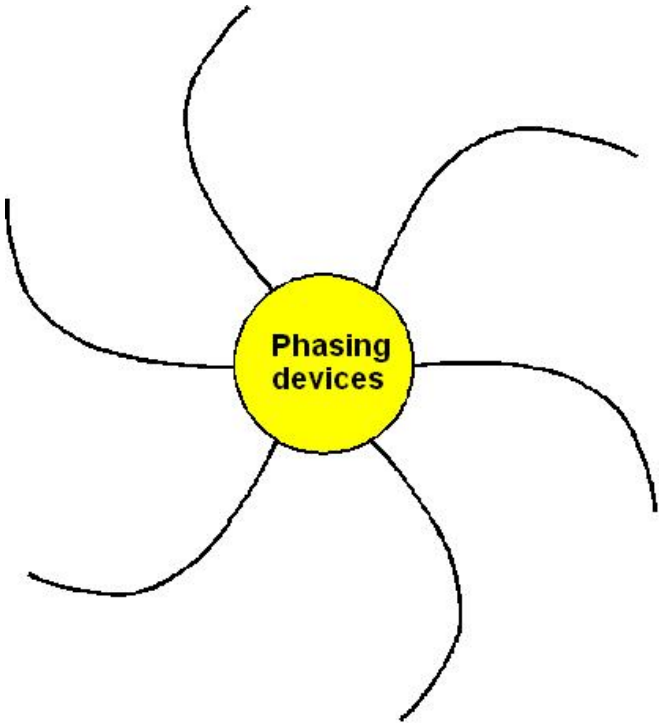

Figure 12
Top View of ***Spider*** Spreading Antenna System

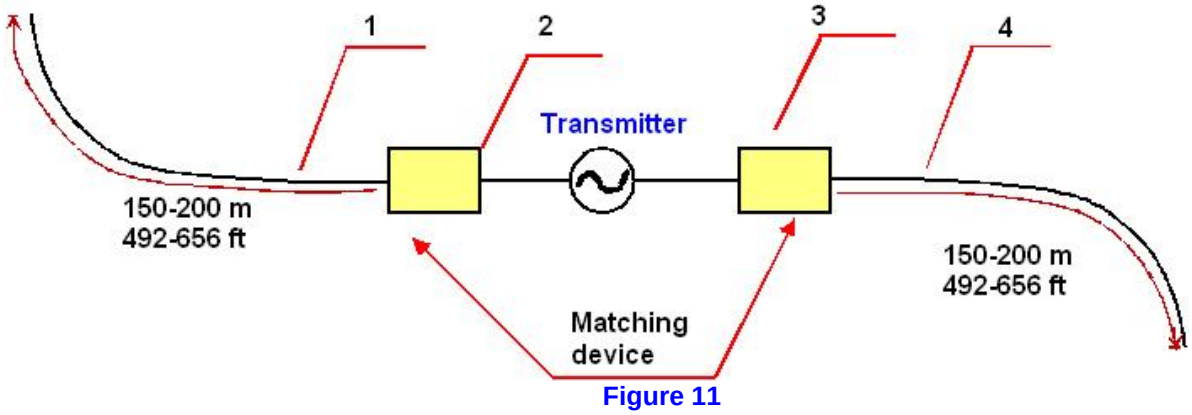

Figure 11
Design of Spreading Antenna for Super Long Range

Figure 13 shows underground Long Wave Transmitting Site. Antennas of the radio site are installed in the depth of 0.5-1 meter. Antennas may just lay in special kind of the ground or installed in center of plastic tubes in diameter near 1 foot. Feed lines from the antennas go through cable tunnel to Phasing and Matching Room. In the room there are installed matching devices for matching the antennas with transmitters and Phasing devices for creating desired radiation diagram.

Room with transmitters is located just below the room with phasing and matching devices. The operations control room and life-support systems are installed below or at the same level with the room where transmitters are installed. The Underground Long Wave Transmitting Site may get electricity through underground power electric cable or feed from diesel or nuclear power electric generator.

Some Experiments with Spreading Antenna

I tested a spreading antenna having 80 meter length that was lying on the ground.

Spreading and Underground Antennas

Spreading antenna was made from old 75- Ohm coaxial cable with removed outer metal braid. Antenna had three counterpoises in 40, 20 and 10 meter length. Antenna fed through transformer 1 to 4 (75/300 Ohm). Monitoring Beverage antenna was installed at 20 meters apart of the spreading antenna. I used home- made transceiver with separate attenuator. Attenuator was savaged from an old RF Generator. Antennas were reconnected to the attenuator with help of RF Connectors. **Figure 14** shows design of the two antennas and schematic of the test.

A-B test showed that on the 40, 20 and 10- meter Bands there was difference in receiving mode in 2- 6 dB, spreading antenna loose. In transmitting mode correspondents gave me 1- 2 balls on scale S for the Beverage antenna over the spreading antenna. On the 80 and 160 meter Bands the difference between spreading and Beverage antenna in receiving mode was near 6- 12 dB in favour of the Beverage antenna. In transmitting mode correspondents gave me 2- 3 balls on scale S in favour of the Beverage antenna.

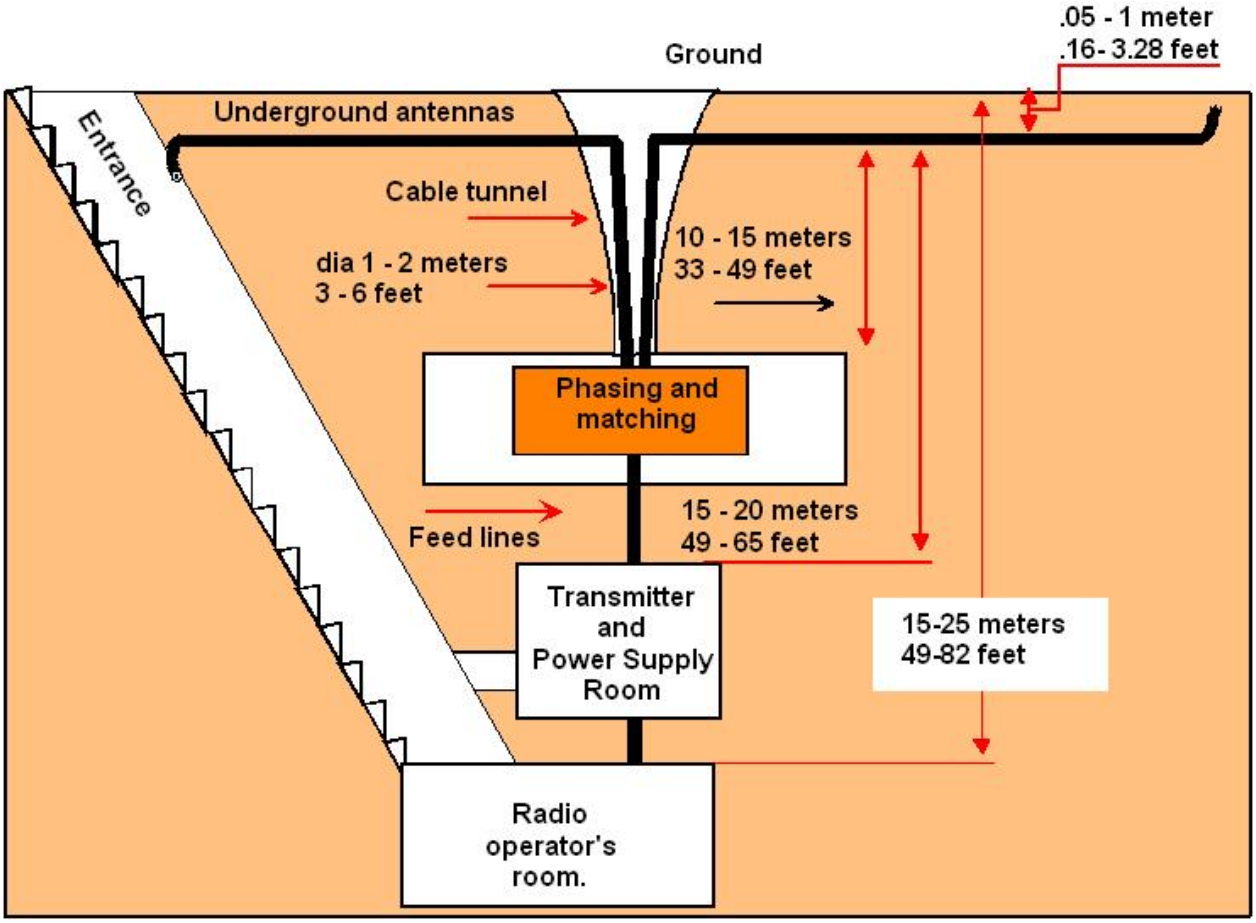

Figure 13
Underground Long Wave Transmitting Site

The test was made in summer time 1999, when propagation was not too bad. Spreading and Beverage antennas were installed in a wild field near forest and were directed to the West. Spreading and Beverage Antennas had SWR no more the 2.0:1.0 on the tested bands 10-160- m.

Conclusion

Spreading and Underground antennas still are waiting for amateurs with experiments. The antennas maybe installed at lots places where usual antennas cannot be installed.

Spreading and Underground Antennas

The Spreading and Underground antennas may be almost invisible for bystander but the antennas allow operate in the Air.

References:

1. http://www.antentop.org/book/c_underground.htm

2. G.A.Lavrov, A.S. Knyazev. Spreading and Underground Antennas. Moscow: Soviet Radio, 1965, 472 pages.
The book may be downloaded at:
http://www.antentop.org/library/shelf_underground_antennas.htm

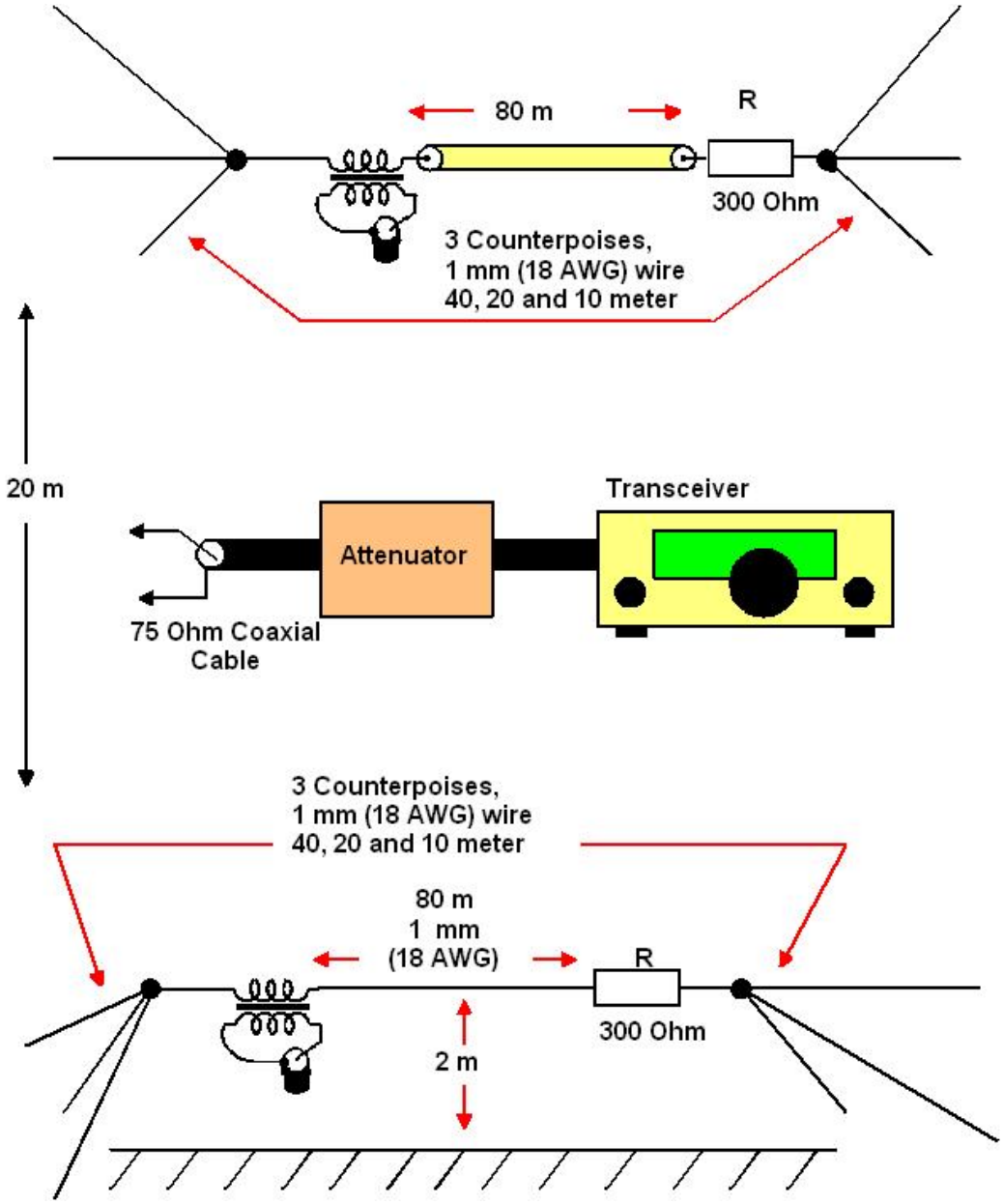

Figure 14
Test with the Field Spreading and Beverage Antenna