

MEMORANDUM ON THE BEVERAGE WAVE ANTENNA
FOR RECEPTION OF FREQUENCIES IN THE
550 - 1500 KILOCYCLE BAND

BY

Benjamin Wolf
and
Adolph Andersen

The theory of the Beverage Wave Antenna is covered in a paper entitled "The Wave Antenna" by H. H. Beverage, O. W. Rice, and F. W. Kellogg, presented at the Midwinter Convention of the American Institute of Electrical Engineers at New York, February 14-17, 1923.

This memorandum is intended to outline some of the practical problems experienced in the erection and operation of this type of antenna for service in the Broadcast 550-1500 kilocycle band, at the Federal Communications Commission Central Monitoring Station at Grand Island, Nebraska.

Among the desirable properties of the Wave Antenna for monitoring purposes are:

- (a) Delivers a stronger signal over the entire band than a good simple antenna.
- (b) Unidirectional.
- (c) Atmospheric and industrial electrical interference considerably reduced especially when the source is in a direction other than that of the received signal.
- (d) Low cost, long life, and unlikely obsolescence.

LENGTH

The optimum length for a broadcast band wave antenna is approximately 1800 feet. This length delivers peak signal strength at closely 550 kilocycles and again at one-half its wave length in meters, or about 1100 kilocycles. The peaks are, however, rather broad and the signal delivered is considerably stronger than that from a good simple antenna throughout the entire band. Near the antenna peaks the increase in microvolts to receiver may reach more than 400 percent.

Where space is a consideration, the length can be reduced to 1400 or even 1000 feet, but the signal strength delivery and directivity will be proportionately reduced, and at less than 1000 feet the slight advantage of a wave antenna for the broadcast band over a good simple antenna does not warrant its erection.

CONDUCTOR HEIGHT

The surge impedance of the wave antenna is determined by its height above the ground, and by soil conditions with regard to moisture, etc. By erecting the conductors at a minimum of ten feet above the ground, the surge impedance remains more nearly constant during all seasons than when erected at a lower height. If erected at a height greater than fifteen feet the pickup of the vertical leads at the far and near terminals may considerably reduce directive properties. If a greater height is required at gates or other passages, the higher poles should be erected at the sides of the opening and the conductors brought down vertically, proceeding at the selected height after the high point has been bridged. Reasonably uniform height of the conductors throughout their length is, of course, preferable.

POLE ERECTION

The standard practice of telephone line construction is followed. The poles should be spaced approximately one hundred feet apart and for mechanical strength the conductors should be #12 B & S hard drawn copper. The line should generally follow the earth's contour, but small knolls are disregarded and the tops of the poles after planted may be trimmed for general or even grading of the conductors.

For single, uni-directional reception or single conductor antennas, the conductor can be mounted on ordinary pole brackets attached to the poles.

For uni-directional reception from front or rear, or both, the two-conductor type of construction is required. The conductors are mounted on short, standard cross arms without braces. With the locust insulator pins spaced 16" between centers. This with ordinary telephone line glass insulator gives the desired or adopted 18" spacing of conductors of the finished antenna.

GROUND

For maximum efficiency the resistance of the ground system at both the far and near ends of the antenna should approach zero, or at least be less than thirty ohms. The ground resistance is best determined by the voltmeter-ammeter, alternating current method, but reasonably satisfactory results can be obtained by the use of the battery and voltmeter voltage drop method.

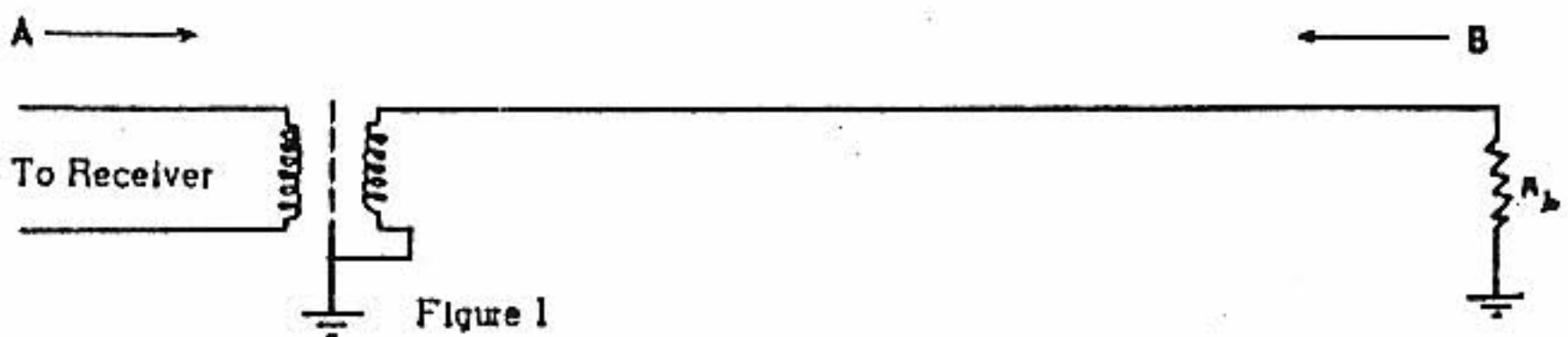
For measurement of a single ground the planted conductors are divided into equal halves and measured, and the result divided by two, or the far and near terminal resistances measured through the antenna conductors for the combined resistance of the two terminals or the series resistance of the entire system.

If the voltage drop method of measurement is used and should polarization or other direct current effects produce absurd readings such as negative resistance, a resistance of 100 ohms or more may be placed in series with the circuit and two measurements taken with changed polarity. The average of the two recorded values divided by two in the case of a divided system, less the added external resistance may then be considered a reasonable approach to the actual resistance. Due to polarization, readings of instruments should be taken at the moment of contact.

If difficulty is experienced in obtaining proper ground resistance values, the constructor is referred to U. S. Bureau of Standards' Technological Paper #108, issued June 20, 1918.

TERMINAL CONNECTIONS

Single Conductor for Forward Reception



A. Signals from A direction are dissipated either completely or partially in R_b .

B. Direction of reception.

Removal of R_b permits the antenna to be used bi-directionally or forward and rear.

Two Conductors for Forward Reception

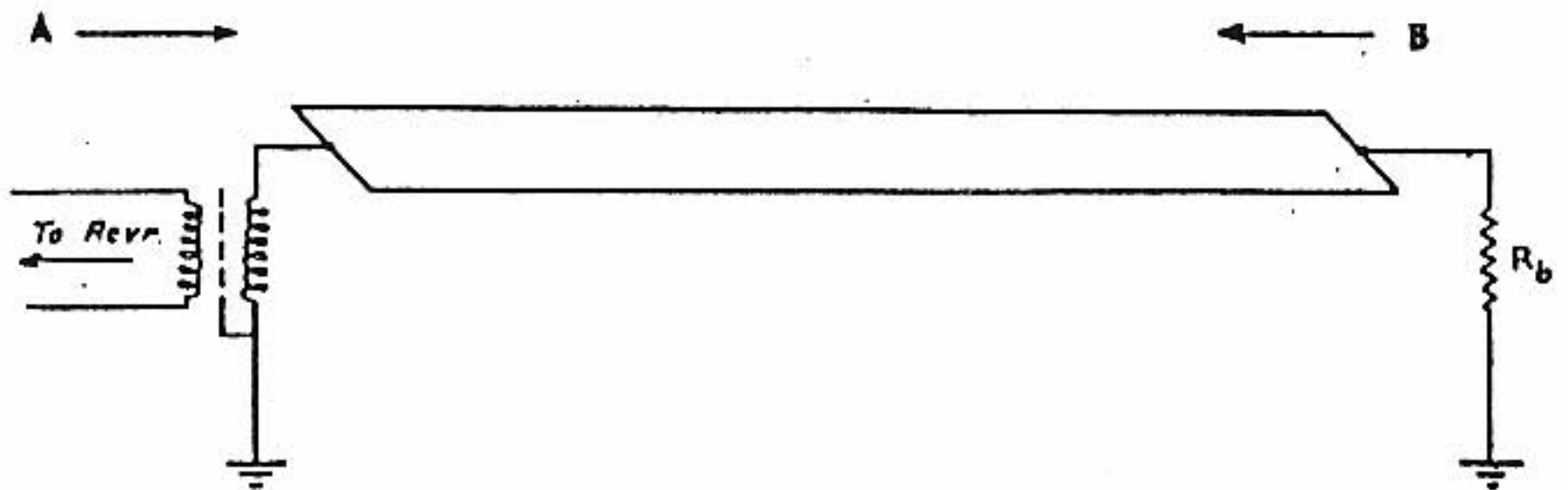


Figure 2

All factors are the same as the single conductor type except that the surge impedance will be lower as a result of the two conductors in parallel.

Two Conductors for Rear Reception

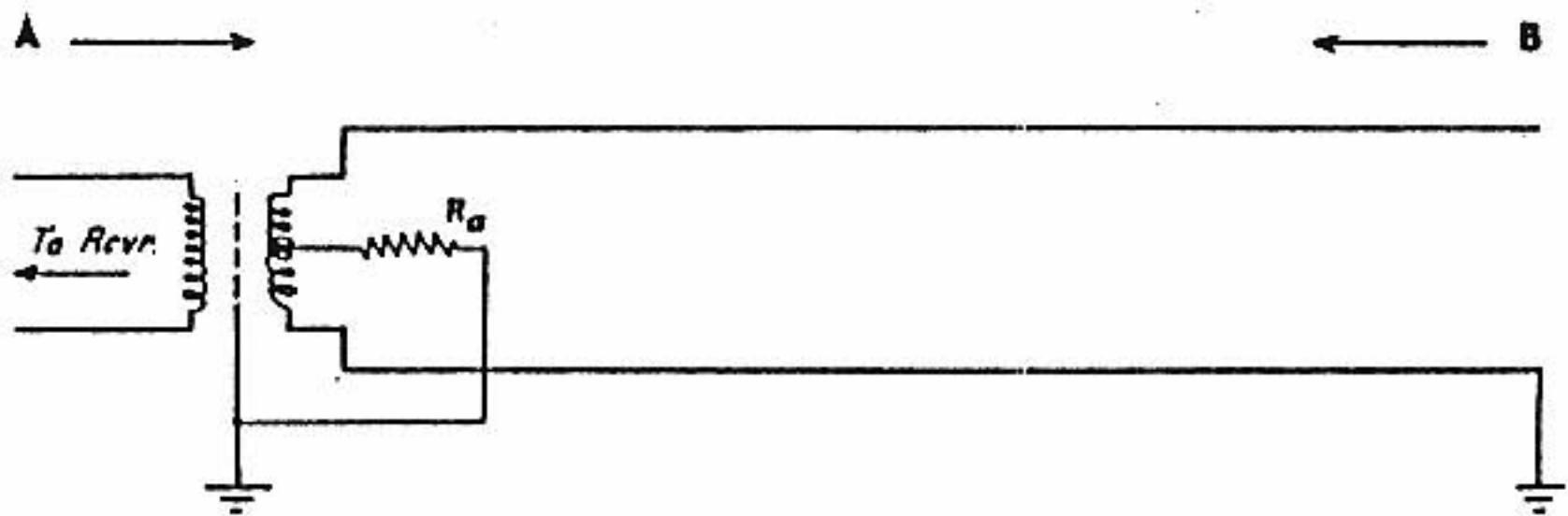


Figure 3

A. Direction reception.

The signal builds up until it reaches B where the phase is reversed by grounding one of the conductors and leaving the other free after which it is reflected back to T using the antenna conductors as an untransposed transmission line. The signals from B direction are dissipated either completely or partially in impedance R connected from the center tap of T to ground. It will be noted that Figures 2 and 3 are the same except with respect to far and near terminal connections. When it is changed as shown, the antenna can be made uni-directional for either forward or rear reception, but not for both forward and rear reception simultaneously.

When the wave length of the signal to be rejected is a multiple of one-half wave of the length of the antenna, it is either completely or largely absorbed in resistances R_b or R_a . Odd multiple frequencies of one-quarter wave length of the antenna length deliver a greater residual or undesired signal to the receiver.

In order to balance out an undesired signal originating at an angle of more than ninety degree from the source of a desired signal originating in direction of maximum reception of the antenna, part of the undesired signal is reflected back to T in proper phase and magnitude to cancel it out. This is accomplished by the insertion of a tuned circuit in series with a variable resistor at the far terminal, as in Figure 4 for rear signal rejection, and as in Figure 5 for forward signal rejection.

Two Conductors for Forward Reception

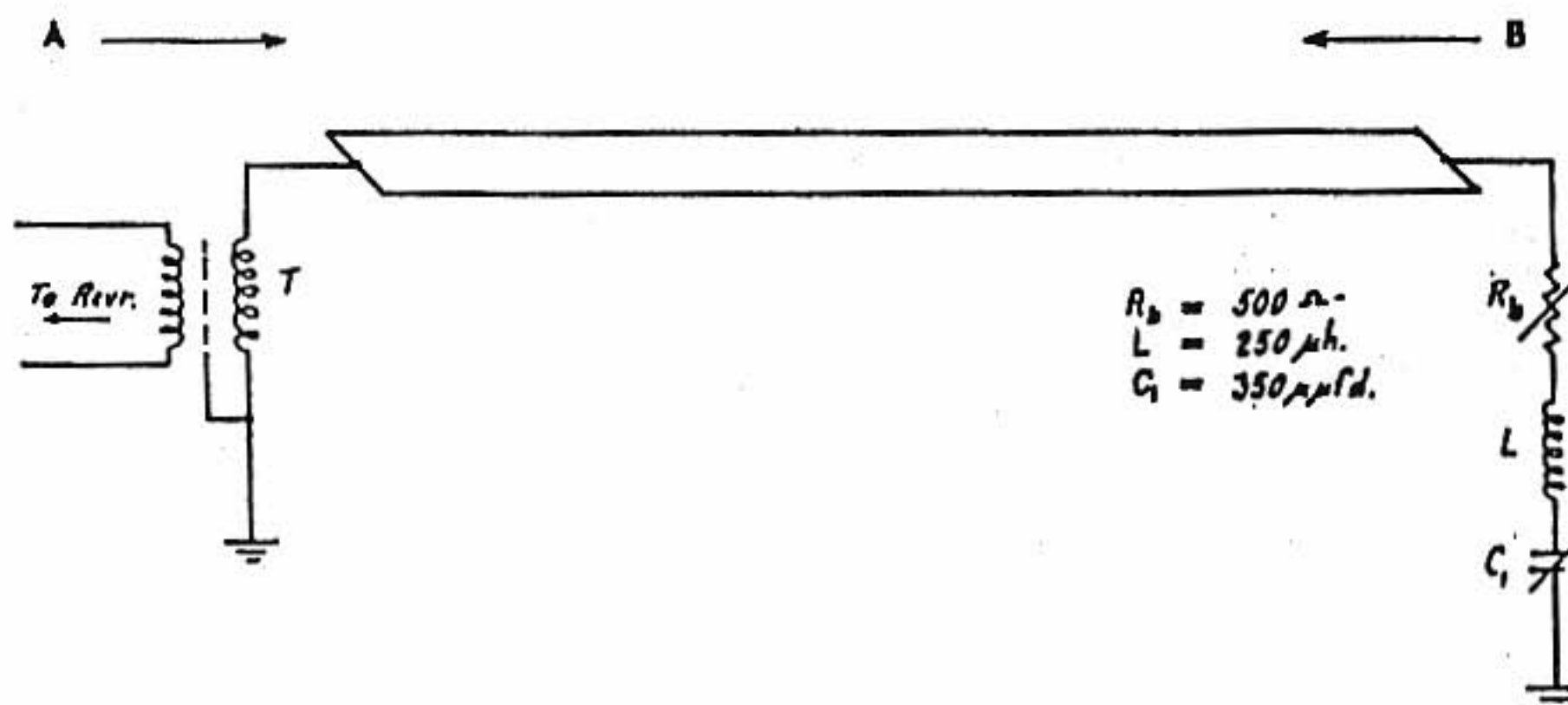


Figure 4

Two Conductors for Rear Reception with Rejector Circuit

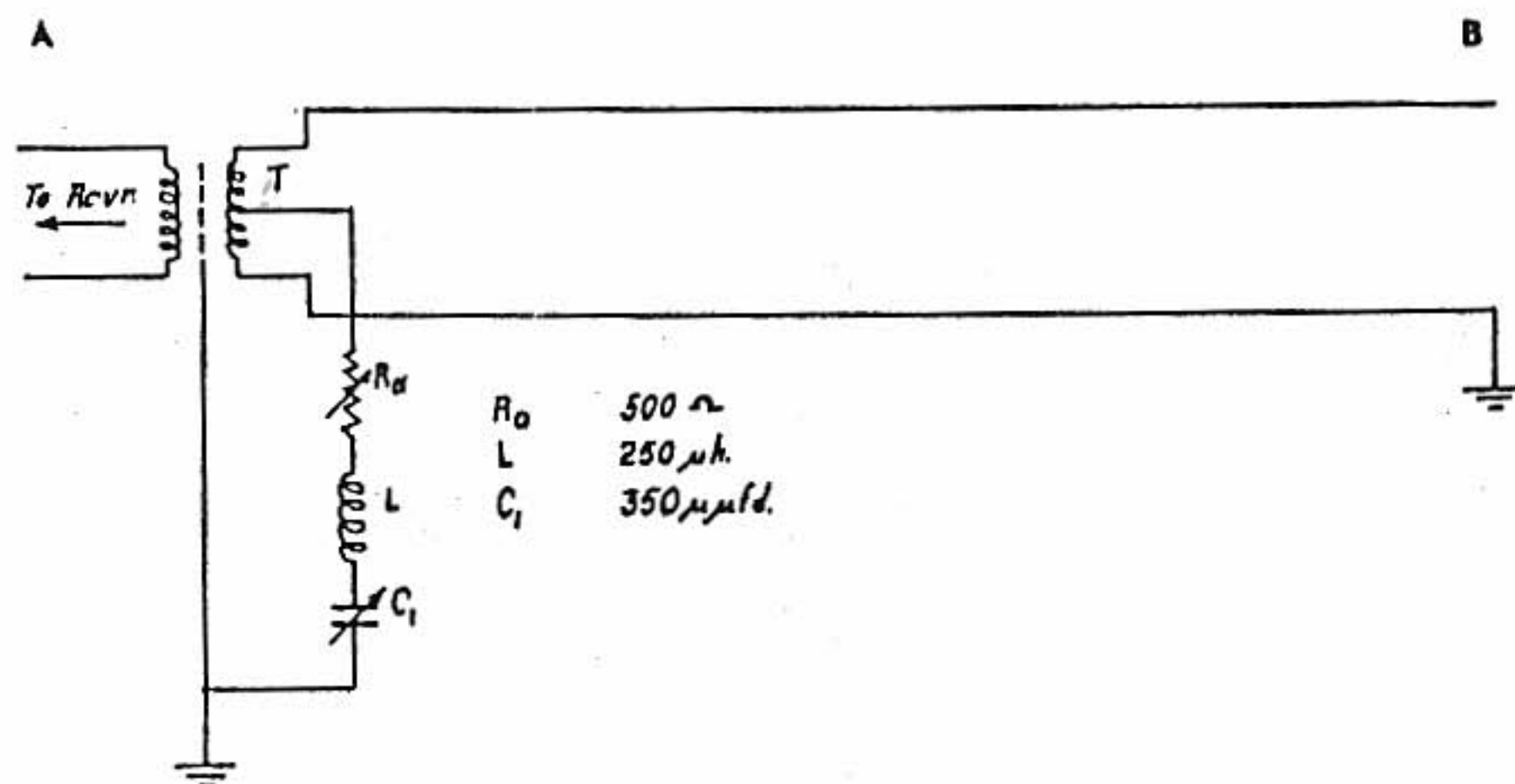
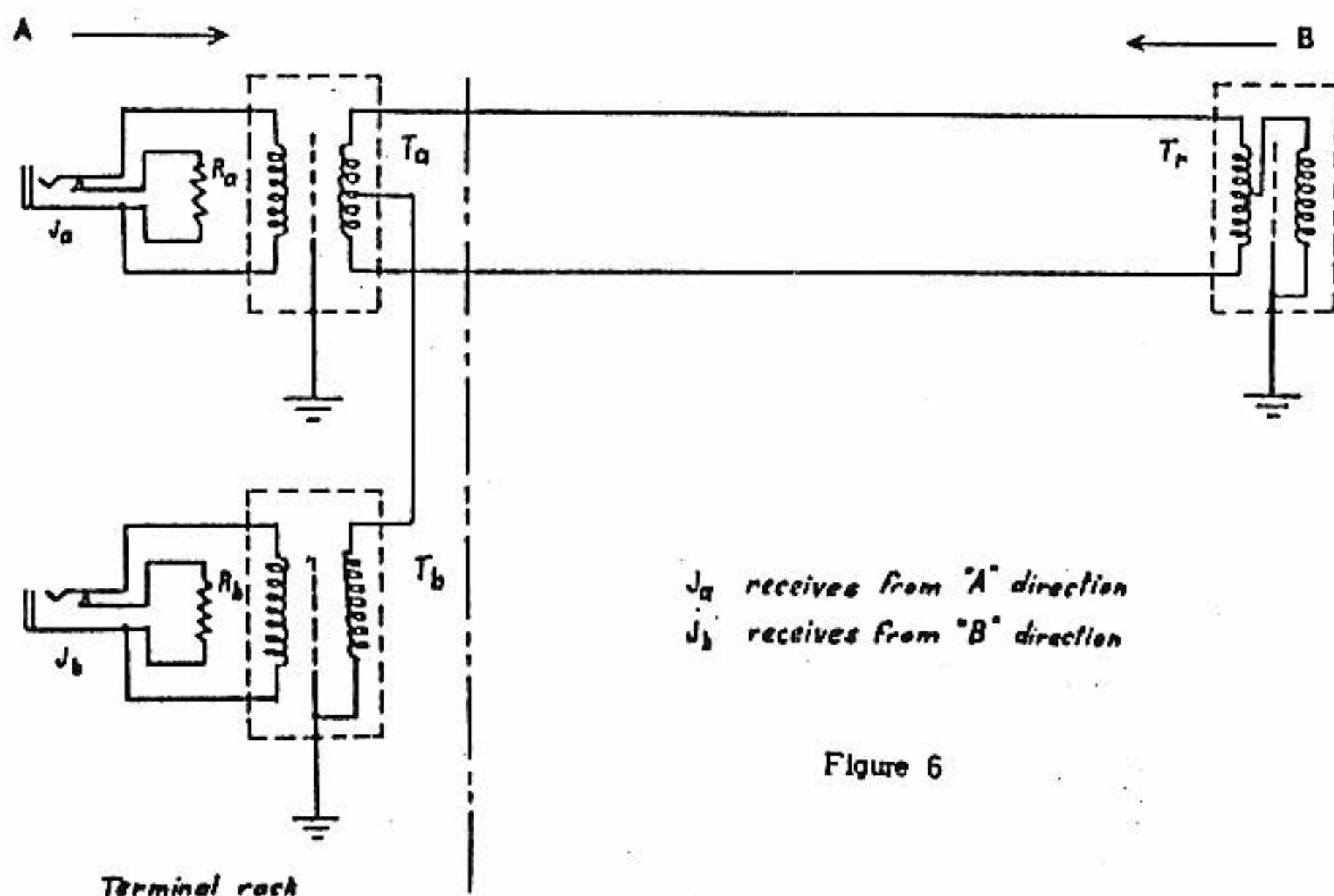


Figure 5

The system of changing directivity of the antennas and remote erasure adjustments as outlined is somewhat inconvenient because of required travel, terrain condition, time consumption and the fact that the antenna when made directive in one direction is not available for service in the opposite direction.

To overcome these undesirable features, a modified arrangement of the terminal coupling units and rejection system may be employed which permits the use of a two-conductor wave antenna for uni-directional reception both forward and rear simultaneously on the same or different frequencies within the band for which the antennas are designed, and with all variable factors under control at the receiver. The circuit is shown in Figure 6.

Two Conductors for Simultaneous Forward and Rear Unidirectional Reception



The signals are delivered from the near antenna terminal coupling transformers to a terminal rack through two 400-ohm transmission lines connected to a Graybar #223-A, three-point, switchboard jack. The receiver input lead connects to the terminating jack through a short length of good quality lamp cord and a Graybar 3-A phone cord plug. A fixed one-watt resistance unit of proper value is connected across points 1 and 2 of the Graybar jack which automatically connects across the transmission lines when the receiver plug is out.

INTER-ANTENNA COUPLING

In the event the erection of more than one wave antenna may be contemplated, the question of inter-coupling may arise. Tests covering this feature at Grand Island using a standard signal generator indicate that broadcast band wave antennas may be crossed within a few feet of one another at angles of sixty degrees or more without detrimental coupling effects or may be safely paralleled when spaced four hundred feet or more; in either case without noticeable or excess coupling.

When the antenna conductors run parallel over wire fences with non-conducting supports, the fence wires, to avoid interaction, should be broken with insulators at even lengths of about seventy-five feet.

Conductors such as fence wires and metal posts rubbing against one another within a hundred feet or so of the antennas, may be assumed to be a source of noise generation in the antennas.

LIGHTNING PROTECTION

During some weather conditions such as snow or dust storms, or summer electrical storms, voltages sufficiently high to break down unprotected coupling coil insulation are developed in the antenna system. To prevent transformer damage from all but direct lightning strikes, L. S. Braasch #270 neon-argon tube arresters or their equivalent with breakdown range of 200 to 300 volts may be connected to the two antenna terminals and ground at both far and near ends of the antenna; also to both terminals of the transmission line from antenna to receivers when the length exceeds two hundred feet. The ordinary 1-watt I.R.C. metallized resistance units as used at Grand Island for terminal impedances will almost always be found open circuited after each electrical storm occurring in the vicinity of the antennas whether or not protected by arresters.

TRANSMISSION LINES

Where it is not practical to erect the antenna with the near terminal direct to receiver location, it can be located at any distance up to a half-mile or more from receiver location and the signals brought to the receiver by transmission lines without noticeable loss. For long stretches the four parallel #14 B & S conductor type of transmission line is preferred. For distances of 100 feet or less requiring no intermediate supports the two conductor transposed line may be employed. Two or more transmission lines may be mounted on the same poles or other non-conducting supports when the separation equals or exceeds ten times the spacing of the transmission line conductors.

A coupling transformer with astatic shield is required at the receiver to keep the transmission line balanced and prevent possible pickup of the transmission line getting into the receiver.

When this resistance unit does not itself absorb or reject undesired interfering signals delivered to the receiver while the antenna is in service in the opposite direction, a shielded L.C.R. circuit, Figure 7, also terminated with a short length of lamp cord and Graybar 3-A plug is inserted in the opposite reception jack of the antenna and by manipulation of C and R the interfering signal can generally be largely or completely erased without reduction in strength of the desired signal, when the interfering signal is more than 90° from the direction of maximum reception of the antenna. It is not as effective for signals predominately sky wave because of their varying phase and intensity.

Rejector Circuit

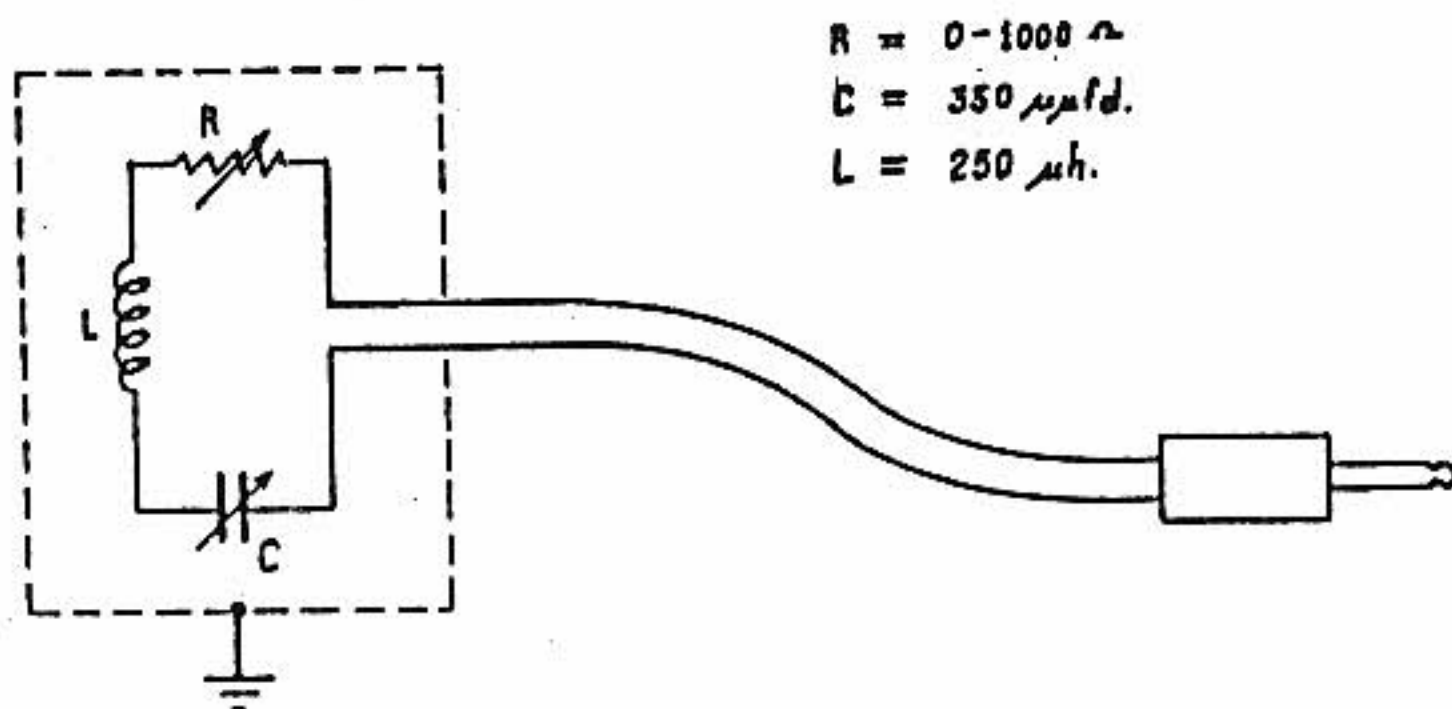


Figure 7

Some casual experiments and observations in service indicate that by disconnecting and grounding one or the other of the conductors of a two-conductor antenna at the station terminal, the forward reception pattern can be changed sufficiently to permit partial or complete erasure of interfering signals originating thirty or more degrees from either side of the antenna, depending upon which conductor is grounded and without noticeably affecting the strength of the desired signal originating more nearly directly forward or from an angle opposite the grounded conductor.

This seemingly unreasonable circuit connection is, apparently, more effective during afternoon hours or for several hours before local sunset. It is frequently not effective at all.

In some instances forward interfering strong signals can be more completely balanced out by connecting a simple or general purpose antenna to one of the terminals of the signal rejector for clear reception of weak signals on the same frequency originating in the rear.

In order to obtain a better balance at the far end, and to partially or completely eliminate pickup by the vertical ground lead at both far and near terminals, a beverage reflection transformer, T_r , Figure 6, is employed and a lead covered #12 B & S conductor used as a shielded vertical ground connection. The conductor with lead shield is made water tight at the bottom by soldering conductor and shield together and connecting the whole to the underground radials. The transformer housing is grounded to the upper end of the lead shielding and the coil terminal to the shielded conductor. This arrangement is an apparent improvement in directivity over the exposed, directly grounded, vertical section of the antenna conductor.

TEST FOR TRANSMISSION LINE BALANCE

The transmission line may be checked for signal pickup or unbalance by disconnecting the two antenna wires and connecting a resistance across the transformer in place of the antenna and equal to the surge impedance of the two antenna conductors. Very little pickup of signal or noise should register in the receiver from a well-balanced line.

TEST FOR TRANSFORMER BALANCE

The center-tapped coupling transformers may be tested for balance by the use of a signal generator and receiver connected as shown in Figure 8. When properly balanced the receiver will indicate nearly zero input or a very small transfer of energy to the secondary of the transformer.

Circuit for Testing Transformer Balance

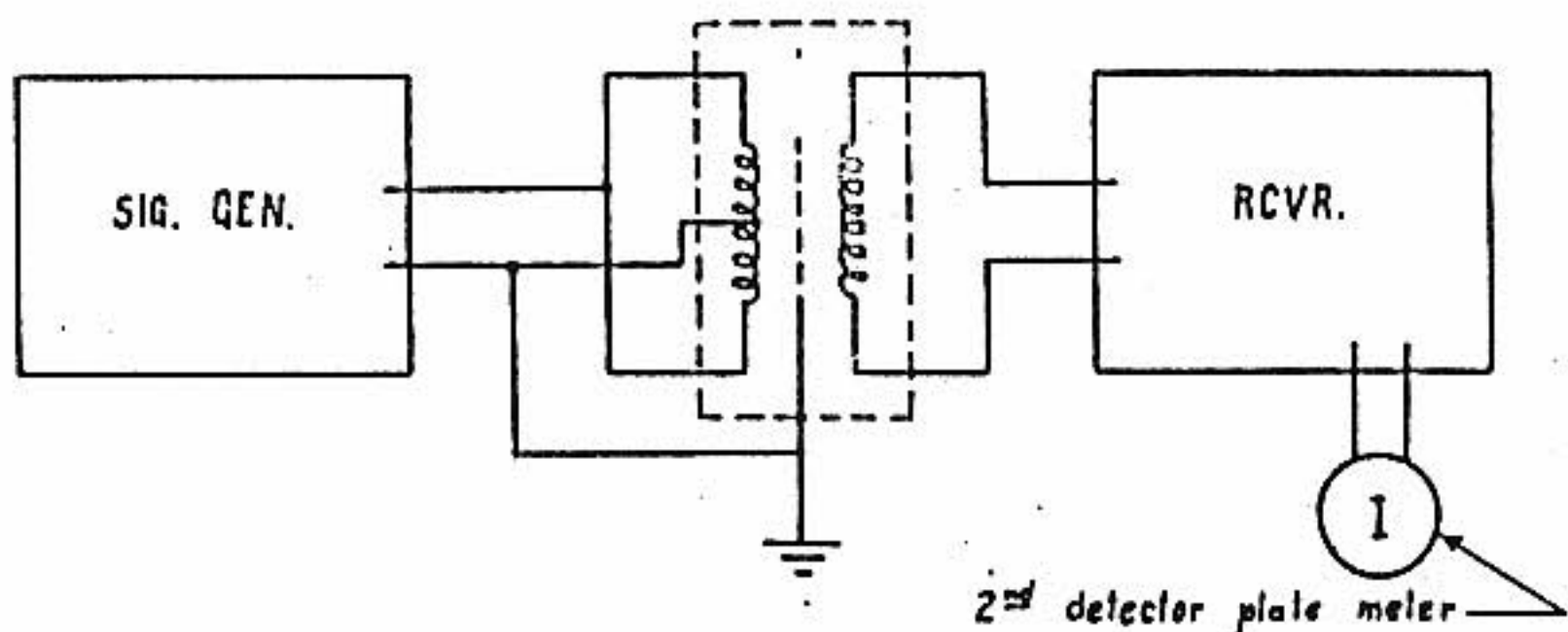


Figure 8

TERMINATIONS

Impedances R_a and R_b in Figure 6 should be equal to the surge impedance of the transmission line as calculated from:

$$Z_0 = 277 \log_{10} \frac{2s}{d} \text{ ohms}$$

(s equals spacing from center of wires)

(d equals diameter of wire [d and s in same units])

The transformer T_a couples the transmission line to the two-conductor antenna and the two wires are now acting only as transmission line to carry the reflected signal from A direction to the receiver. The impedance of the two-conductor antenna serving as a transmission line is calculated from the same formula. The Grand Island transmission lines are approximately 400 ohms and the antenna conductors 700 ohms.

The transformer T_b couples the transmission line to the antenna with the two wires acting as if they were in parallel, because the primary of T_a has practically no effect on signals arriving in phase at A from B direction. Therefore it is necessary to know the surge impedance of the two wires in parallel with respect to the ground.

The transformer T_c reverses the phase and sends the signal which arrives from A direction back over the two-wire line now acting only as a transmission line. The primary coil is designated to match the surge impedance of the two-conductor antenna line in parallel with respect to ground and the secondary to match the same two-conductor antenna as a transmission line back to the station.

Circuit for Determining Surge Impedance Forward Reception

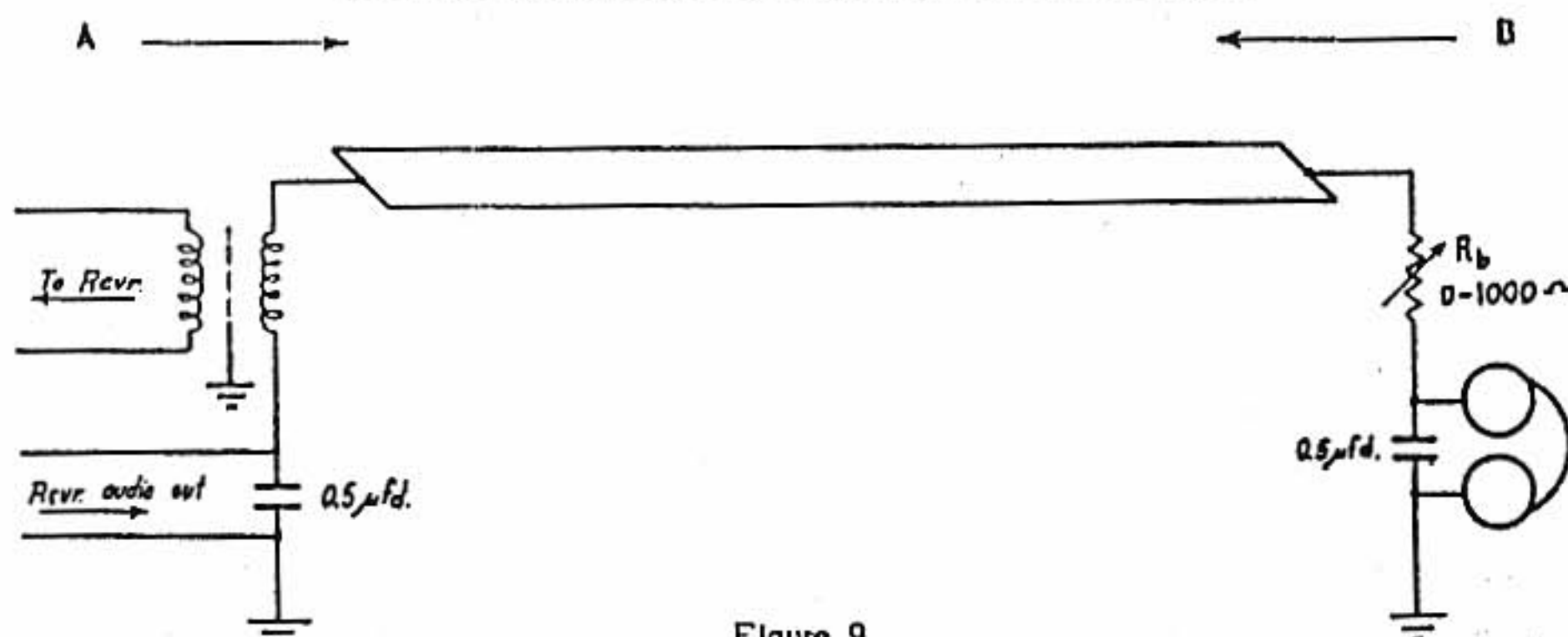


Figure 9

A signal is tuned in from A direction on the receiver. Frequencies of multiples of one-half wave length are preferred as they are more completely balanced out when the proper resistance value is used at R_b . The resistance R_b is adjusted for minimum signal in the phones and this value used as the antenna surge impedance. The surge impedance may also be determined by adjusting the resistance at the opposite end of the antenna.

Circuit for Determining Surge Impedance Rear Reception

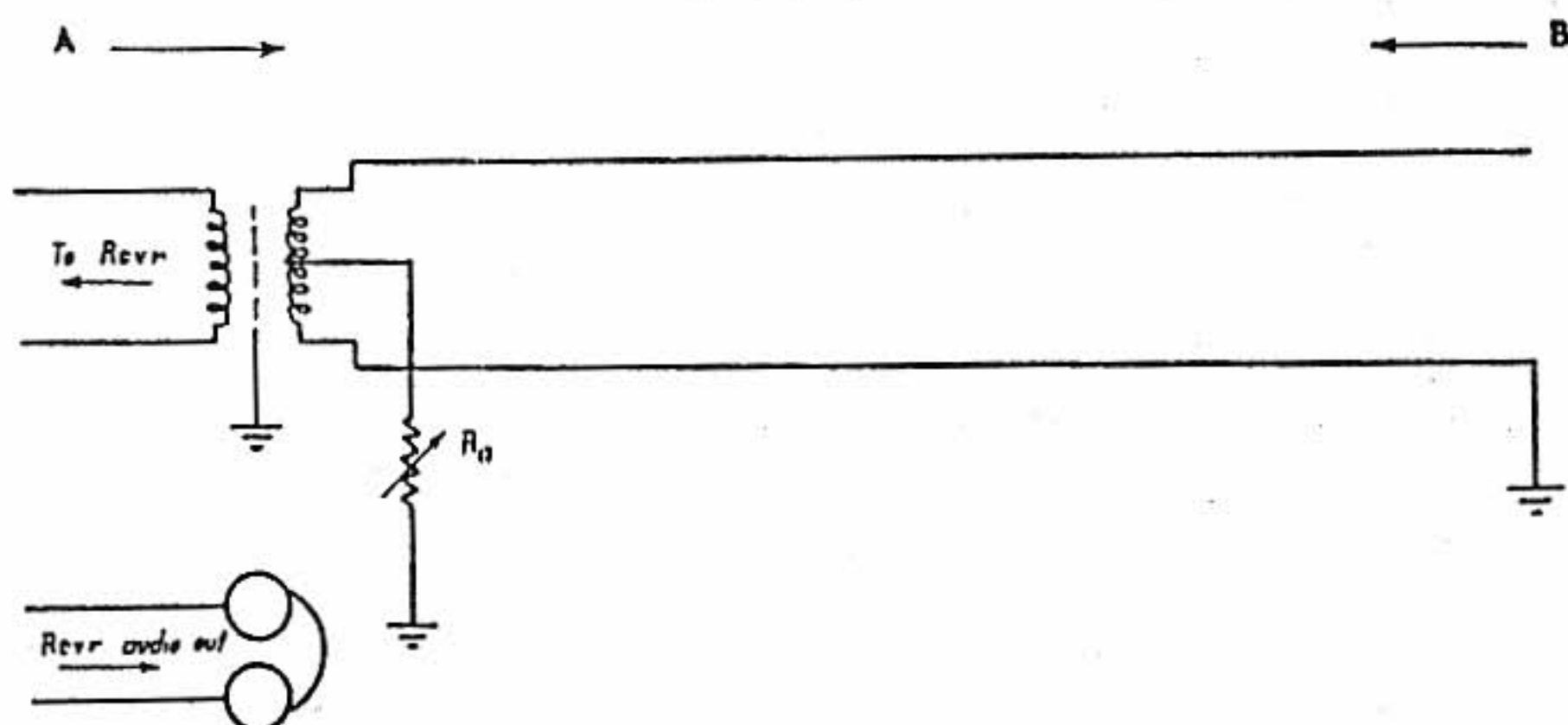


Figure 10

In this case signals from B direction are tuned in to the receiver and balanced out by varying R_a . This method will usually give a lower value of R_a than that recorded for R_b in the other case. The difference is due to the R.F. resistance of the primary of the transformer and some residual inductive reactance, as unity coupling between turns is not possible. If the recorded value of resistance is low it is an indication of high ground resistance. Values at Grand Island for two wires in parallel are approximately 300 ohms.

Another and more simple method which has been employed is to make the resistance R_a ; R_b variable in steps of 20 ohms from 230-440 ohms. With an observer at the receiver, the readings are recorded as changed at the antenna terminal and as indicated on a meter in the second detector plate circuit of the receiver for each changed step of the resistance. The observer at the receiver hears a click when the resistance is switched to the next step. Its value is known according to a shifting plan as prearranged with the antenna terminal collaborator and the proper impedance value thus determined.