

Dec. 30, 1941.

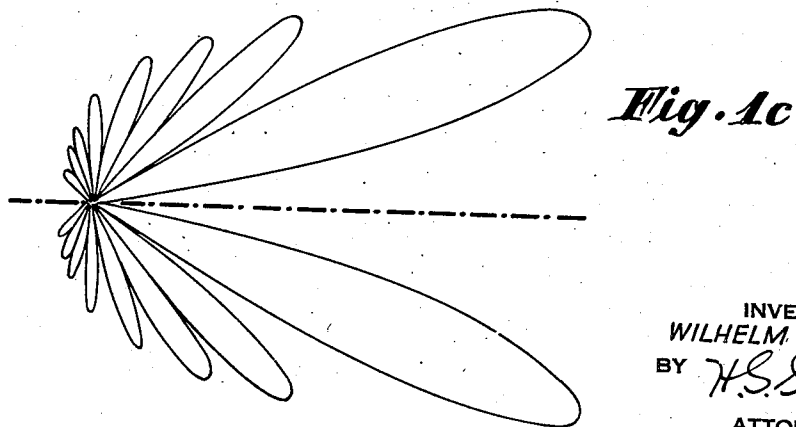
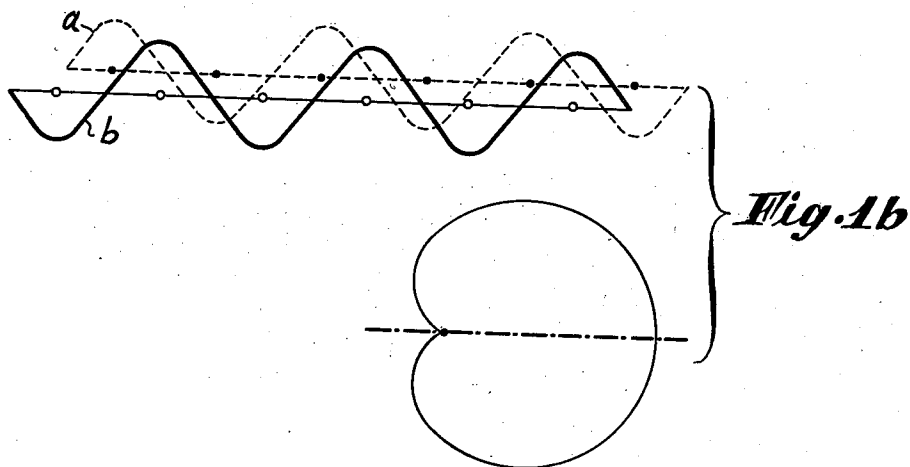
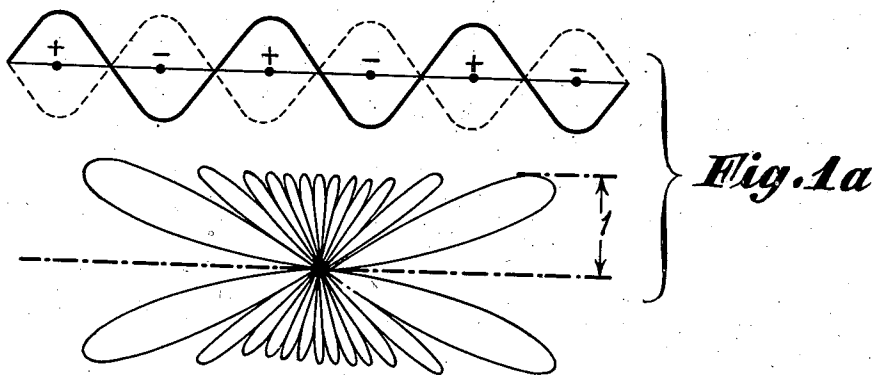
W. PETERS

2,267,945

LONG WIRE ANTENNA

Filed Dec. 30, 1939

4 Sheets-Sheet 1



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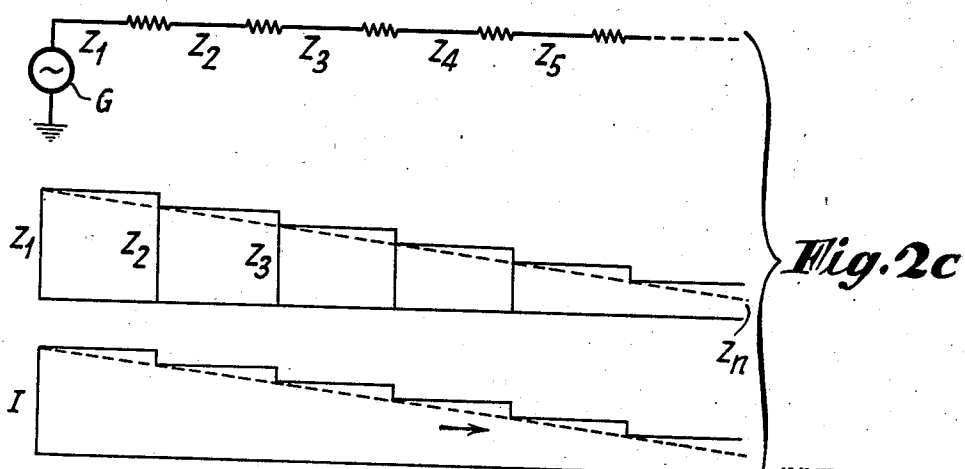
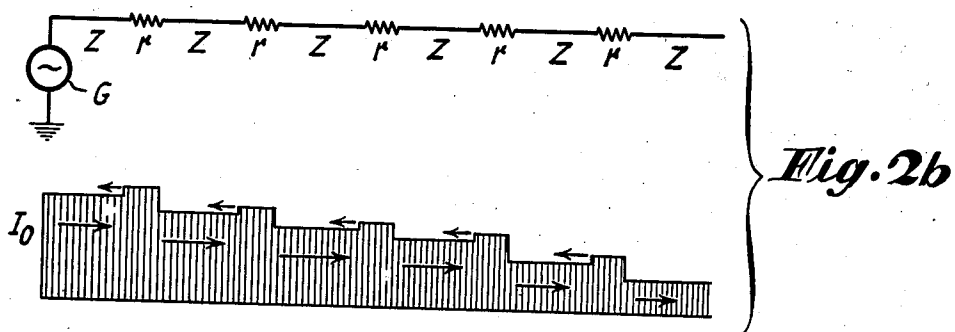
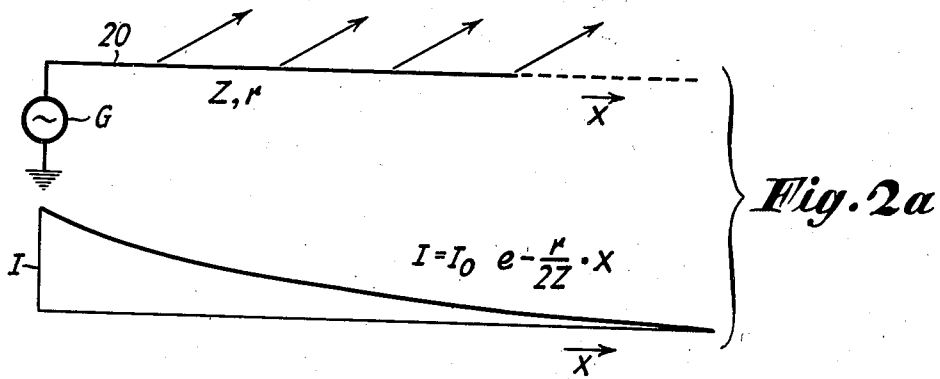
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4 Sheets-Sheet 2



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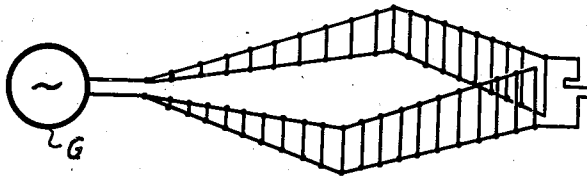


Fig. 3

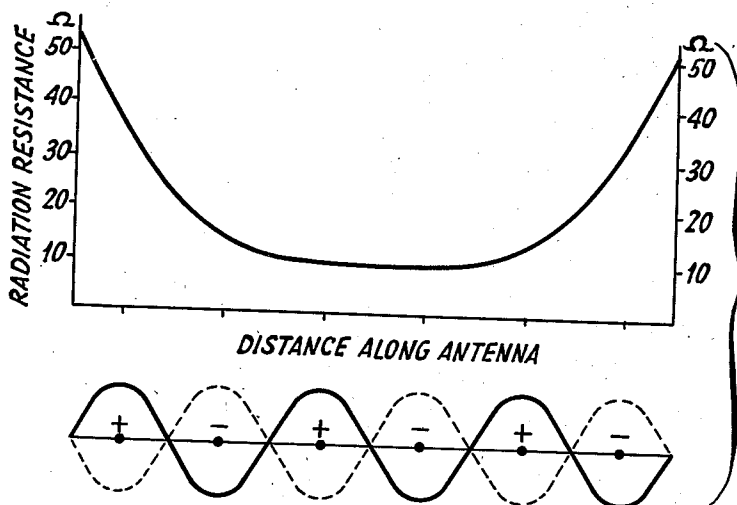


Fig. 4a

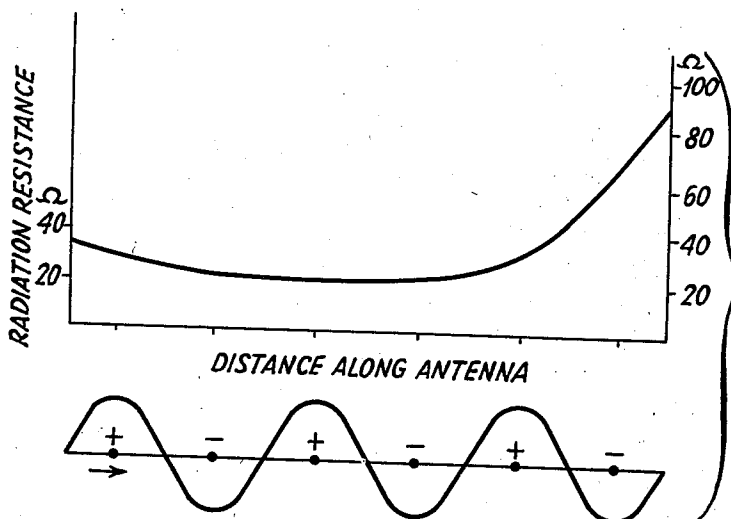


Fig. 4b

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Fig. 5a

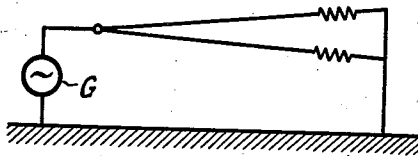


Fig. 5b

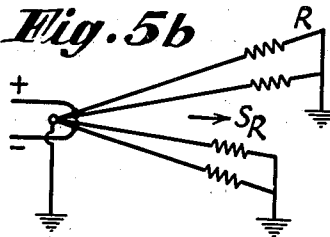


Fig. 5c

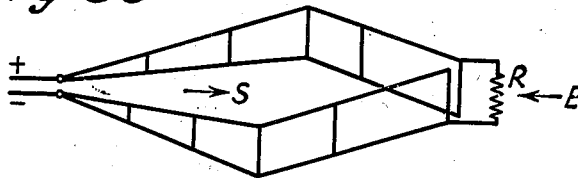


Fig. 5d

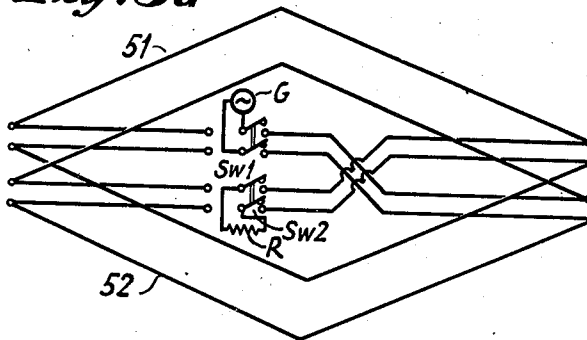
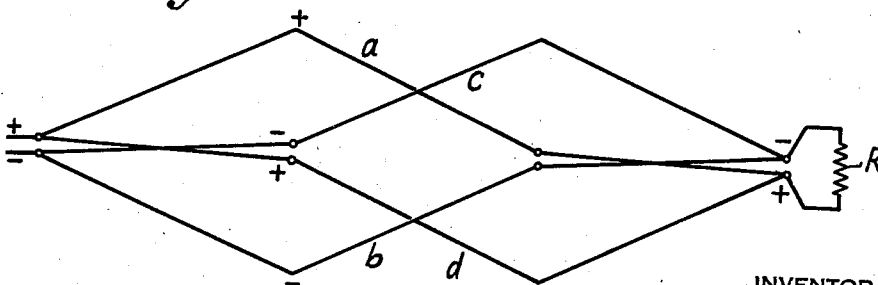


Fig. 6



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UNITED STATES PATENT OFFICE

2,267,945

LONG WIRE ANTENNA

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Application December 30, 1939, Serial No. 311,862
In Germany October 21, 1938

11 Claims. (Cl. 250—33)

In communication with short waves, trans-
mitter antennas and receiver antennas are re-
quired which, owing to the variation of the opti-
mum transmission wave from time to time, must
cover a rather wide short wave range, for in-
stance, a range from about 16 to 60 meters. Furthermore, such antennas are required to have
a favorable directional effect and favorable de-
gree of efficiency as regards this effect. There-
fore, antennas with tuned dipoles must be ex-
cluded for this type of service since for a varia-
tion of the operating wave the length of the di-
poles of such antennas as well as the relative
spacing and the length and phase of the re-
flectors thereof would have to be changed within
wide limits. But the above stated requirements
are favorably complied with by means of long
wire antennas whose length is several wave-
lengths and which are fed with travelling waves.
In fact, on these antennas the waves can appear
and propagate in accordance with the length
thereof. The greater the number of "travelling
dipoles" presented along the length of the wire
the more the direction of the main radiation ap-
proaches the direction of the axis of the wire.
Within a certain range the radiation angle
formed with the main axis remains unchanged
and hence, it is not sensitive as regards fre-
quency. Such an outstretched long wire whose
length is equal to several wave-lengths there-
fore produces a conical radiation diagram whose
opening angle changes but slightly with the fre-
quency. Figure 1c shows such a diagram; it is
formed from the known diagram of a wire fed
with a standing wave as shown in Figure 1a,
wherein the radiation towards the front and rear
is symmetrical, in that the latter is converted into
a travelling wave by adding a wave of same
length which is displaced in space and as re-
gards time at 90°, whereby each current loop—
dipole of the latter acts as reflector of the former
wave, and thus the radiation diagram of Figure
1a is to be multiplied with the reflector group
characteristic of the cardioid of Figure 1b in
order to obtain the Figure 1c. This presentation
reveals that in the case of travelling waves the
effective reflector may be considered as always
moving along at the proper distance and phase
with variations of the wavelengths. In this way
there is always realized a favorable shielding to-
wards the rear. A further advantage of a travel-
ling wave antenna resides in the fact that the
transmitter always remains under effective load.
The effective resistance is equal to the wave re-
sistance for all frequencies. Since also the radia-

tion angle is almost constant, the result is that
the radiated field strength remains practically
constant within a wide frequency range. Now, in
order to obtain from the radiation cone a single
resultant pointed ray, two such long wire an-
tennas may be placed with respect to each other
in V-form and with opposite polarity and at such
an angle that the radiation will be doubled in the
direction of the bisector of the angle of the cone.
Since the radiation for other directions and
larger azimuth angles is extinguished by inter-
ference between the radiation from the two wires.
From the two ray cones of the individual wires
only the common mutually covered part in the
direction of the bisector of the angle remains and
is thereby doubled. Now, it is possible to com-
bine two or a greater number of such V-antennas
in the form of a rhombus which thus radiates
a field intensity which is four times that of a
single wire. The radiation power is thus con-
centrated into a much sharper cone.

Such long-wire antennas or antenna systems
entail in their known mode of construction
serious disadvantages, among other things, a
poor effectiveness and incomplete shielding to-
wards the rear, the first mentioned disadvantage
reducing the effectiveness of such antennas as
transmitter antennas while the second disad-
vantage greatly decreases the effectiveness of said
antennas for receiving. For the production of
travelling waves the end of the antenna facing
away from the transmitter and receiver has
hitherto been terminated by an ohmic resistance
whose value is equal to the wave resistance of
the line since it was sought to realize the condi-
tion for travelling waves on the basis of the
theory of the telegraph line equation. The wave
resistance depends on the proportion between the
wire spacing s and diameter d and is calculated in
accordance with the following formula:

$$Z = 120 \log \frac{2s}{d}$$

The said wave resistance is about 400 to 600
ohms in general. For a radiation resistance of
about 300 ohms about one-half of the high fre-
quency energy would be lost in the terminal re-
sistance. A further disadvantage is the ap-
pearance of a back radiation which will be much
more appreciable than in the diagram shown in
Figure 1c.

It is the purpose of the following invention to
avoid these disadvantages of the travelling wave

antenna thereby improving the antenna. The degree of efficiency of the radiation is:

$$\eta = 1 - \left(\frac{I_e}{I_a} \right)^2 \cdot \frac{Z_e}{Z_a} \quad (1)$$

wherein I_a is the input current, Z_a is the input wave resistance, I_e is the current at the end and Z_e is the terminal resistance. From this follows that in accordance with the invention the degree of efficiency can be considerably improved by choosing as low as possible the proportion

$$\frac{I_e}{I_a}$$

i. e. by choosing the damping as high as possible. Since the damping coefficient is proportional to the quotient:

$$\frac{\text{radiation resistance}}{\text{wave resistance}}$$

it is necessary to choose the wave resistance as low as possible. In accordance with the invention this is accomplished by arranging the wires in the form of a cage and by providing connections between them or arranging them twisted about one another to obtain a uniform current distribution.

Figure 2a next shows an ideal long-wire radiator 20 which may have the wave resistance Z and the uniformly distributed radiation resistance r and which may be assumed as of infinite length and its associated graphical illustration of the current distribution along the wire. The beginning of the wire is connected to a high frequency voltage source G . Owing to the withdrawal of energy through lateral radiation which may be assumed as taking place ideally in a uniform manner across the length, the traveling current wave

$$I = I_0 e^{-\left(\frac{rx}{Z}\right)}$$

will be damped according to an exponential law. In connection with Figure 2b, which is similar to Figure 2a, except that the uniformly distributed resistance is assumed to be concentrated in certain equal distances, the above performance can be so conceived as if through the resistance diffractions would occur in the advancing wave

$$I_0/I_e = 1 - \frac{r}{2Z}$$

whereby owing to partial reflexions also rearward moving waves

$$I_r/I_0 = \frac{r}{2Z}$$

are produced which results from the complex resistance. This effect will repeat itself at each joint so that wave trains appear which move forwards and backwards. As shown in Figure 1, the latter produce, however, back radiation thus jeopardizing the shielding of the main wave. If the wave resistance is more and more reduced with constant radiation resistance for obtaining a high degree of efficiency of the radiation, it can be seen from the foregoing considerations that the portion of the standing wave also increases automatically thus jeopardizing the shielding towards the rear. In accordance with the invention backward moving waves are avoided by varying the wave resistance along the length of the conductor in accordance with the variation in radiation resistance. The required relation is such that for each element

of the radiator the resistances at each joint between Z_n must be the same in both directions. Since viewed from this place the resistance r lies in series with Z_{n+1} , it follows that

$$Z_n = r + Z_{n+1} \quad (2)$$

wherein Z_n is the wave resistance ahead of the radiation, r is the radiation resistance and Z_{n+1} is the wave resistance in back of the radiation. Then there is:

$$I_r/I_v = (Z_{n+1} - Z_n + r) : (Z_{n+1} + Z_n + r) = 0$$

This law which is not known in the customary antennas with standing waves, is a particularity of the antennas with travelling waves and denotes that the energy entering an antenna element will only in part be radiated, and the other part thereof will be transferred reflexion-free for radiation to the immediately following antenna elements. From this reasoning it is further seen that a radiation wire with a constant wave resistance also carries waves moving towards the rear when said wire radiates. The necessary condition for this radiation mechanism and transfer mechanism to operate without reflexion effects, is achieved in accordance with the present invention by decreasing the wave resistance along the line. With the assumption of the ideal condition that the radiation resistance along the line is constant, the wave resistance would then have to be reduced in a linear fashion such as is shown in Figure 2c. A comparison with the current curve of Figure 2b shows that now reflections no longer occur. Since the terminal resistance is always matched with the wave resistance at the end, the result is that for reflection-free operation the terminal resistance is lower according to the invention so that the efficiency of the radiation will be enhanced. In fact, if Z_1 is the resistance of the input waves, Z_2 the terminal resistance and R the total radiation resistance, then the efficiency of the radiation is

$$Z = \frac{4RZ_1}{(Z_1 + Z_2 + r)^2} \quad (3)$$

and for $Z_1 = Z_2 + R$ there is:

$$Z = \frac{R}{Z_1} \quad (4)$$

For $Z_1 = 500$ ohms, and $R = 400$ ohms the arrangement according to the invention has a terminal resistance $Z_2 = Z_1 - R = 100$ ohms and the efficiency of the radiation is 80% whereas in the hitherto customary arrangement the efficiency degree is only 40%. It is even possible in accordance with the present invention to reduce the terminal resistance practically to zero thus obtaining an efficiency of 100% if in accordance with Equation 3 the input resistance is chosen equal to the radiation resistance of the antenna, so that in accordance with Equation 1 there will be $Z_2 = 0$, which means that the antenna is simply short-circuited at the end. In this ideal case the transmitter feeds energy into the antenna in the form of traveling waves ($I^2 Z_1$) to the same extent that, owing to its electromagnetic fields, the antenna will actually radiate ($I^2 R$). In practice, a low terminal resistance will preferably be provided so as to assure certain possibilities of variation. Moreover, under these circumstances the termination in the arrangement according to the invention need not be carried out exactly with the wave resistance, but a lower resistance may be used to this end

since the wave moving towards the rear has hardly any radiation property owing to the wave resistance being dependent on direction of travel of the wave. The realized advantage in accordance with the invention resides in the fact that the matching of the terminal resistances can be chosen with lesser accuracy.

Actually, the distribution of the radiation along the line is not uniform. But the deliberations so far made remain substantially valid, it being only necessary that the variation of the wave resistance be matched with the distribution of the radiation resistance. Figure 4a shows next for a standing wave the distribution of the radiation resistance along the radiator. It is seen that in accordance with the lateral directional effect the radiation resistance becomes higher towards both sides while it is lowest in the center. In the case of a progressing wave with unilateral directional radiation according to Figure 1c, therefore, in accordance with Figure 4b, the radiation resistance greatly increases towards the end situated in the direction of the radiation. The decrease of the wave resistance must be chosen accordingly. The Figures 5a and 5b show examples for the single wire Beverage antenna and for the V-antenna which are dimensioned in accordance with these requirements. In the case of the rhombus various radiation wires are connected in parallel for each conductor and spread apart at the remote end to compensate for a higher radiation resistance for the sides facing away from the transmitter or receiver. This is shown in the example of Figure 3, as well as in Figure 5c. A variation of the wave resistance is herein obtained by the spreading apart of two parallel connected wires at each side. With constant wave resistance along the radiation line, in the case of an antenna situated in the open, the distance between said wires would have to increase symmetrically towards the center in accordance with a parabola. But due to the decrease of the wave resistance there results a form according to Figure 5c which will also be affected by the height above ground, since with the moving apart of the V-wires the wave resistance will be reduced by the counterinductance of the ground currents. Since, however, in order to obtain a favorable vertical diagram, the antenna is to be arranged at a rather considerable height above ground, the influence is not appreciable.

Now, owing to the particularly pronounced variation of the wave resistance the antenna is not readily reversible. It possesses a pronounced direction of radiation in the direction of the terminal transmitter and which is at the same time the most favorable direction of reception for the waves arriving in the opposite direction. In the opposite directions the antenna radiates and receives only at a reduced effectiveness. Now this difficulty can be overcome in accordance with the invention by arranging two such antenna systems having opposite directions and of which at least one or both together can be operated with the same or with different programs. This is shown in Figure 5d wherein a pair of superposed rhombic antennas 51 and 52 are connected through double pole double throw switches SW₁ and SW₂ to a transmitter G and a terminating resistance R. Thus, either 51 may be connected at the proper ends to the transmitter and resistance for transmission in one direction, or 52 may be similarly connected for transmission in the other direction. The rhombics are shown as

single wires for simplicity but should be constructed as shown in Figures 3 and 5c.

Figure 6 shows how a plurality of rhombics may be placed in tandem to increase the directivity without occupying too much space by arranging them to substantially overlap.

I claim:

1. A radiating conductor having a length at least equal to several times the operating wavelength, a transducer means connected thereto at one end, said conductor having a wave resistance and a radiation resistance each varying along the length of said conductor, said wave resistance decreasing in proportion to the distance from said one end, while said radiation resistance increases in proportion to the distance from said one end.

2. A radiating conductor having a length at least equal to several times the operating wavelength, and having a wave resistance and a radiation resistance each varying along the length of said conductor, a transducer means connected thereto at one end, said wave resistance decreasing with increasing distance along the length of said conductor from said one end, said radiation resistance increasing in proportion to the decrease in wave resistance along said conductor.

3. A radiating conductor having a length at least equal to several times the operating wavelength, said conductor having a wave resistance and a radiation resistance each varying along its length, a transducer means connected thereto at one end, said wave resistance constantly decreasing with increasing distance from said one end, said radiation resistance varying inversely with respect to said wave resistance.

4. A V antenna comprising a pair of conductors as set forth in claim 2.

5. An antenna comprising a pair of conductors as set forth in claim 3, said conductors being arranged in a generally diamond-shaped plan.

6. A bi-directional antenna comprising two pairs of conductors as set forth in claim 3, each pair of said conductors being arranged in a generally diamond-shaped plan, the conductors of one pair being oppositely arranged to the other pair.

7. A bi-directional antenna comprising two pairs of conductors as set forth in claim 3, each pair of said conductors being arranged in a generally diamond-shaped plan, the conductors of one pair being oppositely arranged to the other pair, said pairs of conductors being arranged one immediately above the other.

8. A radiating conductor having a length at least equal to several times the operating wavelength, said conductor having a wave resistance and a radiation resistance each varying along its length, a transducer means connected thereto at one end, said wave resistance constantly decreasing with increasing distance from said one end, said radiation resistance varying inversely with respect to said wave resistance, the other end of said conductor being directly connected to ground at its other end.

9. A V-antenna comprising a pair of conductors as set forth in claim 2, said conductors being connected to ground at their other ends through a low resistance connection.

10. A bi-directional antenna comprising two pairs of conductors as set forth in claim 3, each pair of said conductors being arranged in a generally diamond-shaped plan, the conductors of one pair being oppositely arranged to the other

pair and means for selectively or simultaneously connecting said pairs of conductors to said transducer means.

11. An antenna system comprising a conductor having a length at least equal to several times the operating wavelength, a transducer means connected thereto at one end, the impedance of

said transducer means being equal to the radiation resistance of said conductor at said one end, said conductor having a constantly decreasing wave resistance toward its other end where it is connected to ground.

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