

Oct. 14, 1941.

W. H. C. HIGGINS

2,258,953

ANTENNA SYSTEM

Filed July 26, 1939

2 Sheets-Sheet 1

FIG. 1A

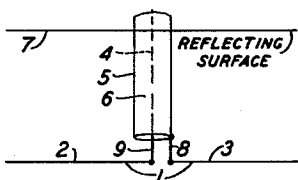


FIG. 1B

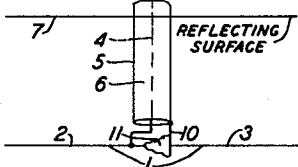


FIG. 1C

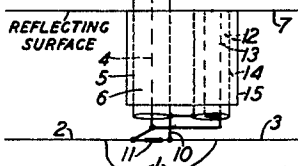


FIG. 3A

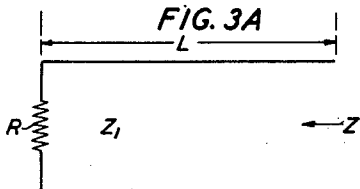


FIG. 3B

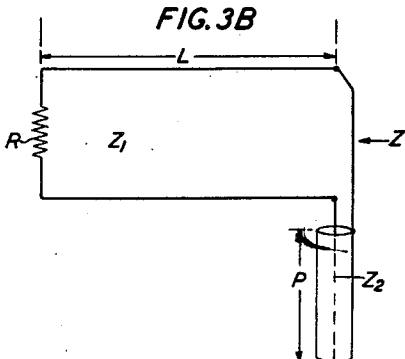


FIG. 2C

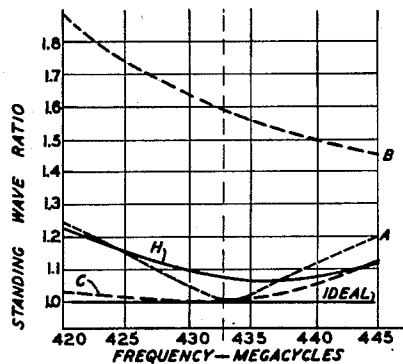


FIG. 2B

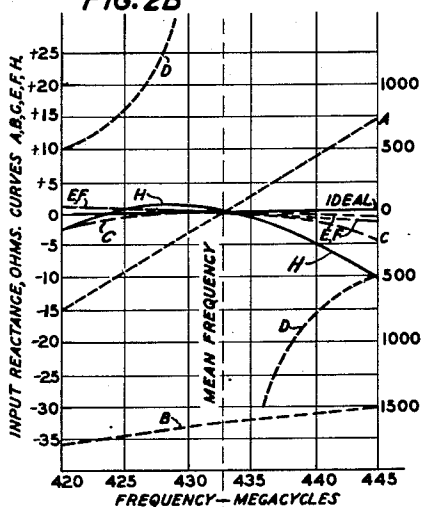
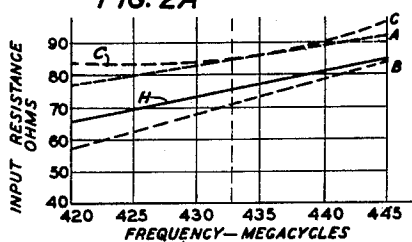


FIG. 2A



INVENTOR
W. H. C. HIGGINS

BY
A. J. Zerbarini

ATTORNEY

Oct. 14, 1941.

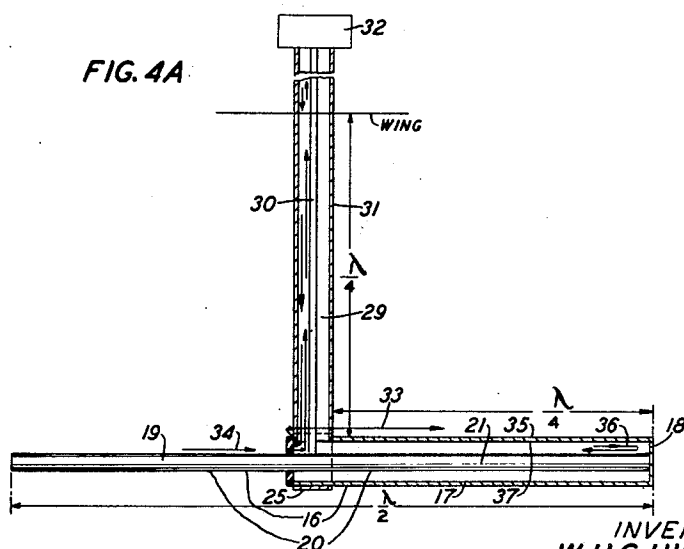
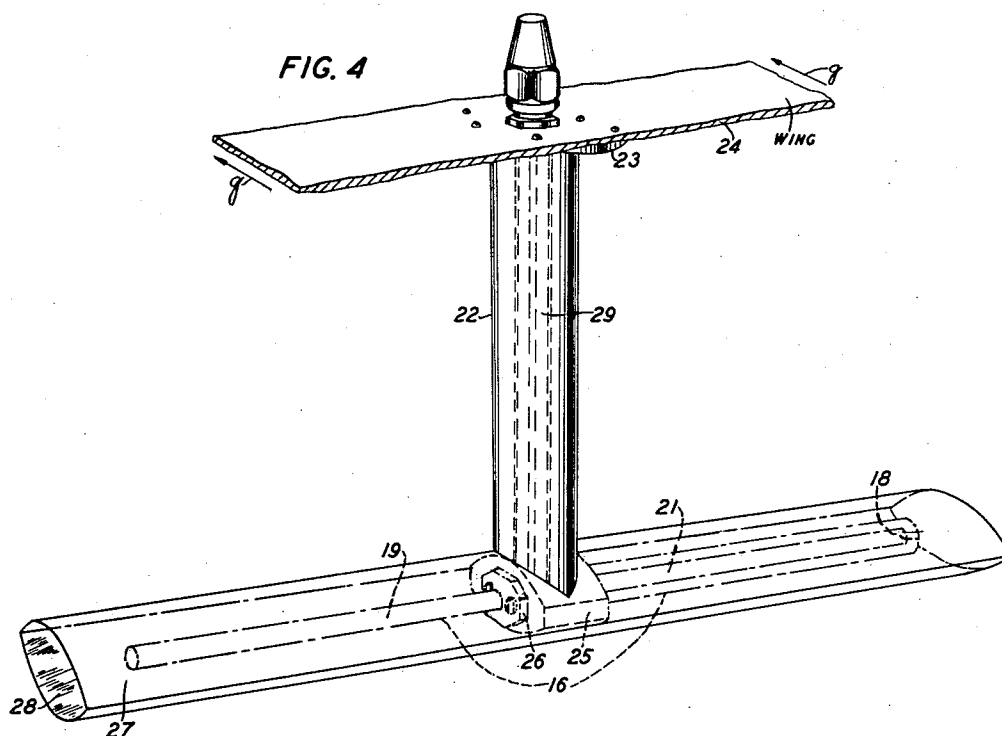
W. H. C. HIGGINS

2,258,953

ANTENNA SYSTEM

Filed July 26, 1939

2 Sheets-Sheet 2



INVENTOR
W. H. C. HIGGINS
BY
A. J. Zerbarini
ATTORNEY

UNITED STATES PATENT OFFICE

2,258,953

ANTENNA SYSTEM

William H. C. Higgins, West Orange, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application July 26, 1939, Serial No. 286,680

9 Claims. (Cl. 250—33)

This invention relates to antenna systems and particularly to means and methods for matching the input impedance of an antenna to the impedance of the associated line at a large number of operating frequencies.

As is well known, the input impedance of an antenna is usually matched in the case of a single frequency system by means of a coil type or distributed type transformer to the characteristic impedance of the associated transmission line, for the purpose of preventing reflection losses and the formation of standing waves on the line. In the case of a system designed for simultaneous utilization of a small number of frequencies, the antenna input impedance, which ordinarily varies greatly with frequency, may in effect be matched to the line by connecting a separate impedance transformer for each operating frequency across the line, as disclosed in the copending application of P. H. Smith, Serial No. 5,694, filed February 9, 1935, and in the case of antenna systems wherein the frequencies are used separately, by manually adjusting the physical length of the antenna for each frequency, so as to maintain the same electrical length and impedance, as disclosed in Patent 1,988,592, A. Gothe, January 22, 1935.

While the above impedance matching arrangements are useful in certain multifrequency systems, they are not entirely suitable for use in systems wherein an exceedingly large number of frequencies are supplied to or received from the antenna simultaneously, or in systems such as the altimeter system disclosed in the copending application of R. C. Newhouse, Serial No. 240,739, filed November 16, 1938, wherein the frequency supplied to or received from the doublet antenna varies periodically over a predetermined range. Moreover, these multifrequency impedance matching systems are not entirely practicable for use in systems as, for example, aircraft systems wherein the line is relatively short and the available space for mounting auxiliary line apparatus is limited.

It is one object of this invention to render the input impedance of an antenna substantially equal to the line impedance at each frequency in a large band of frequencies.

It is a second object of this invention to minimize in an antenna system the transmission line standing wave ratio at each frequency included in a given frequency band.

It is a further object of this invention to match the impedances of an antenna and associated line at a large plurality of frequencies utilizing a minimum amount of equipment and without affecting the directive characteristic of the antenna.

It is another object of this invention to provide a rigid support for an aircraft doublet an-

tenna and at the same time, to utilize a supporting insulator between the doublet elements having a relatively small size and capacity.

It is still another object of this invention to protect a doublet aircraft antenna from the weather and to prevent the formation of ice on the apparatus associated therewith.

According to one embodiment of this invention the system comprises a tubular conductor, a quarter wave-length long at the mean frequency in the operating band and closed at one end by means of a plug or cap, and a solid or tubular conductor approximately a half wave-length long having a smaller diameter than the tubular conductor and positioned coaxially therein. The smaller conductor is supported in part by the plug or cap and a supporting insulator of relatively small size and capacity is included between the open end of the tubular conductor and the approximate center portion of the half wave-length conductor. The tubular conductor and the half wave-length conductor are connected, respectively, to the inner and outer conductors of a coaxial line from the transmitter or receiver, the outer surface of the tubular conductor constituting what may be termed the counterpoise radiator of a doublet antenna system and the quarter wave-length exposed portion of the solid conductor forming the driven or exciter portion. The short-circuited coaxial line comprising the enclosed portion of the solid conductor and the inner surface of the tubular conductor is electrically less than a quarter wave-length long at the mean operating frequency and constitutes an inductive compensator connected in shunt with the antenna and the insulator.

The ratio of the inner diameter of the tubular conductor and the diameter of the enclosed conductor has a particular value, such that a spacing and therefore a characteristic impedance for the compensator are obtained which renders the input impedance of the entire doublet system substantially resistive and of the proper value to match satisfactorily the line impedance at each frequency. The compensator does not radiate energy and in no way affects the directive characteristic of the antenna. The support for the half wave-length conductor provided by the end cap permits the utilization of an insulator having a small size and, therefore, a small capacity whereby resonance may be easily obtained.

The invention will be more fully understood from the following description taken in conjunction with the drawings on which like reference characters designate elements of similar function and on which:

Figs. 1A and 1B illustrate prior art systems used for explaining the invention; and Fig. 1C

illustrates a simple embodiment of the invention;

Figs. 2A, 2B and 2C are curves and Figs. 3A and 3B are simplified schematics, also used in explaining the invention;

Fig. 4 illustrates a preferred embodiment of the invention; and

Fig. 4A is a simplified cross-sectional view of the embodiment of Fig. 4.

Referring to Figs. 1A, 1B and 1C, reference numeral 1 designates a half wave-length doublet antenna having an exciter or driven portion 2 and a counterpoise portion 3, each approximately a quarter wave-length long at the mean operating frequency, the exciter and counterpoise sections being connected respectively to the inner conductor 4 and the outer conductor 5 of a coaxial line 6. The line is connected to a multi-frequency transmitter or receiver, not illustrated, and the doublet is positioned parallel to, and approximately a quarter wave-length from, a reflecting surface 7. In the system of Fig. 1A the exciter and counterpoise are rigidly supported by means of the connections 8 and 9 whereas in the system of Figs. 1B and 1C the counterpoise 3 is supported by means of the rigid connection 10. Also in the system of Fig. 1B, the insulator 11 constitutes the sole support for the exciter 2, and is, therefore, of relatively large size and capacity. In the system of Fig. 1C the insulator 11 is of small size and capacity, it being assumed that the exciter 2 is supported partly by the insulator and partly by structure not shown. In a sense the system of Fig. 1A is a free space system since in all practical doublet systems, especially aircraft systems, a central supporting insulator is required.

In the system of Fig. 1C reference numeral 12 designates a distributed inductive impedance or short-circuited coaxial line, hereinafter termed a compensator, the compensator comprising an inner conductor 13 and an outer conductor 14, each slightly less than a quarter wave-length long at the mean frequency. As will be explained more fully, the characteristic impedance of the compensator 12 has, in accordance with the invention, a critical value such that it renders at each frequency in a large band of operating frequencies the impedance of the doublet system including the insulator substantially equal to the impedance of the line 6. Ordinarily, although not necessarily, the characteristic impedance of the compensator is substantially different from the main line characteristic impedance. A shield 15 is preferably provided for the coaxial lines 6 and 12 for the purpose of preventing distortion of the directive characteristic of the antenna-reflector system.

Figs. 2A, 2B and 2C illustrate, respectively, the calculated frequency-resistive characteristics, the frequency-reactance characteristics and the transmission line standing wave ratio characteristics for the systems of Figs. 1A, 1B and 1C, for an operating range of 420-445 megacycles. The curves A, B and C in Figs. 2A, 2B and 2C correspond, respectively, to the systems of Figs. 1A, 1B and 1C. In Fig. 2B, the vertical reactance scale at the left applies to curves A, B, C, E, F and H and the vertical reactance scale at the right applies to the curves D. These figures also illustrate the ideal reactance and standing wave characteristics for a multifrequency system. In the ideal system the input resistance has a constant value equal to the characteristic impedance of the line and, as shown in Figs. 2B and 2C, the ideal system has zero reactance and a standing

wave ratio, that is, a ratio of the minimum amplitude to the maximum amplitude of the standing wave on the line, equal to unity at each frequency. It will be seen from these figures that, for the simple prior art free space doublet with no insulator, illustrated by Fig. 1A, the doublet has zero reactance at the mean frequency and a unity standing wave ratio. Its input resistance may be made equal to that of the line. For the other frequencies, however, the input reactance varies from -15 ohms to +15 ohms over the assumed operating range and the input resistance varies from 77 to 92 ohms, the result being that the line is not matched at the various frequencies to the antenna, as is indicated by the standing wave ratio values of curve A, Fig. 2C, which values vary from one to 1.22.

For the more practical system utilizing an insulator, Fig. 1B, the reactance is exceedingly large, that is, greater than 30 ohms at every frequency in the band, as shown by curve B of Fig. 2B. Also, the input resistance varies from 58 to 82 ohms and at most frequencies is substantially different from the line characteristic impedance. The standing wave ratios at the various frequencies, resulting from the input reactance and resistance for this system, are also exceedingly large, that is, in the order of 1.4 to 1.87 as shown by curve B of Fig. 2C. Thus, in this practical system of the prior art, large reflection losses occur at all frequencies.

As shown by curves C of Figs. 2A, 2B and 2C, which are calculated for the system of Fig. 1C, the use of a compensator having a particular value, in accordance with the invention, produces an input reactance for the entire system which is relatively low and, in fact, is theoretically zero for a large number of frequencies. Also, the input resistance curve is more horizontal and more nearly approaches the characteristic impedance of the line at each frequency. The line standing wave ratio is relatively small and is substantially equal to zero for a large number of frequencies. Thus, referring to curves C, the reactance value varies only from zero to -4.5 and the input resistance varies only from 82 to 96 ohms. Reflection losses are minimized at all frequencies and at a great number of frequencies, particularly those frequencies in the range of 420 to 440 megacycles, substantially eliminated.

Referring now to Figs. 3A and 3B, the method of determining the ratio of the diameter of the inner surface of the outer conductor 14 to the diameter of the inner conductor 13 and, therefore, of determining proper characteristic impedance for the compensator will now be explained. The free space antenna of Fig. 1A without an insulator may be schematically represented by the equivalent circuit of Fig. 3A where L represents the conductor length equal to a quarter wave-length at the mean operating frequency, Z is the input impedance, Z₁ the characteristic impedance, and R is a termination resistance value such that

$$\sqrt{RZ} = Z_1$$

The value of the input impedance as derived from Equation 5 given on page 91 of the textbook "Principles of Transmission in Telephony" by M. P. Weinbach is for a lossless or low loss line:

$$Z = Z_1 \frac{\frac{R}{Z_1} + j \tan \frac{2\pi L}{\lambda}}{1 + j \frac{R}{Z_1} \tan \frac{2\pi L}{\lambda}} \quad (1)$$

When, in the simplified circuit of Fig. 3A, the actual values are, $R=1610$ ohms and $Z_1=370$ ohms, the input reactance variation closely approximates, over the band of frequencies assumed, the input reactance, as given by curve A of Fig. 2B, of the antenna of Fig. 1A. The input resistance of the simplified circuit is substantially constant over the band of frequencies. The equivalent circuit of Fig. 3A may be considered to be one element of a band filter such as illustrated by Fig. 3B. The designed equations for this type of filter as given on page 4 of Patent 2,149,356, W. P. Mason, March 7, 1939, are as follows:

$$\Phi^2 = 1 + \frac{Z_1}{Z_2} = \frac{R}{Z} \quad (2)$$

$$Z_1 = \frac{R}{\Phi} \quad (3)$$

$$Z_2 = \frac{R}{\Phi(\Phi^2 - 1)} \quad (4)$$

$$P = \frac{C}{4F_M} \quad (5)$$

where:

Φ is the impedance ratio;

Z_1 and Z_2 are the characteristic impedances of the equivalent antenna and the compensator, respectively;

Z is the send end impedance, that is, the impedance looking into the filter input terminals; and R is the receiver impedance, that is, the impedance looking into the filter output terminals;

P is the length of the short-circuited line or compensator;

C is the velocity of propagation;

F_M is the mean operating frequency.

Substituting in these equations and assuming $Z=85$ ohms, by design, we have:

$$\Phi^2 = \frac{1610}{85} = 18.95 \quad (6)$$

$$\Phi = 4.35 \quad (7)$$

$$Z_1 = \frac{1610}{4.35} = 370 \text{ ohms} \quad (8)$$

$$Z_2 = \frac{1610}{4.35(18.95-1)} = 20.6 \text{ ohms} \quad (9)$$

The characteristic impedance of the short-circuited quarter wave-length line or compensator should, therefore, have a value of about 20.6 ohms. The ratio of conductor diameters for the compensator may be determined from the following equation:

$$Z_2 = 60 \log_e \frac{X}{Y} \quad (10)$$

where:

X is the inner diameter of the outer conductor and

Y is the diameter of the inner conductor;

thus

$$\frac{20.6}{60} = .343 = \log_e \frac{X}{Y} \quad (11)$$

and

$$\frac{X}{Y} = 1.408 \quad (12)$$

The reactance variation with frequency for the compensator taken alone is illustrated by curve D of Fig. 2B and the reactance for the parallel combination is illustrated by curve E. It will be

noted that the compensation is substantially ideal over the band.

Thus far the effect of the central supporting insulator has not been considered. In order to overcome the capacity effect of the insulator the impedance of the coaxial line of the compensator is made inductive by shortening the compensator or line a particular amount so as to achieve resonance at the mean operating frequency. As is well known, the impedance looking into a short-circuited quarter wave-length line is purely resistive, a short-circuited line slightly less than a quarter wave-length long inductive, and a short-circuited line slightly greater than a quarter wave-length capacitive. Thus, assuming the insulator capacity is small, as for example, .8 micromicrofarad, as would be the case when the additional support for the exciter is provided, the capacity reactance of the insulator is 460 ohms at the mean operating frequency of 432.5 megacycles. The reactance of the compensator or short-circuited line is given by the following equation:

$$X = Z_2 \tan \frac{2\pi P}{\lambda} \quad (13)$$

Substituting

$$460 = 20.6 \frac{\tan 2\pi P}{\lambda} \quad (14)$$

$$\frac{460}{20.6} = \frac{\tan 2\pi P}{\lambda} = 22.4 \quad (15)$$

The angle

$$\frac{2\pi P}{\lambda} = 87.45^\circ = \frac{(87.45)(\pi)}{180} \text{ radians} \quad (16)$$

$$P = .243 \text{ wave-lengths at the mean frequency} \quad (17)$$

The compensation obtained under the condition of resonance at the mean operating frequency, is illustrated by curve F of Fig. 2B. Since the line or compensator is shortened only a small amount, the compensation is not appreciably affected.

The discussion and mathematical treatment above are based on a circuit which is equivalent to the free space antenna with respect to reactance only. As stated before, the input resistance of the system of Fig. 1A taken alone varies over the band as shown by curve A of Fig. 2A. The input reactance and input resistance of the parallel combination of the antenna, insulator and compensator may now be computed for different frequencies in a manner well known in the art. The curves C of Figs. 2A, 2B and 2C already discussed above were obtained in this manner. The calculated standing wave ratio curves A, B and C of Fig. 2C were obtained by computing the input reactance and the input resistance of the aforementioned parallel combination at a number of different frequencies and applying the teaching of the article entitled "Transmission Line Calculator" by P. H. Smith published in Electronics, page 29, January 1939, the characteristic impedance of the main line being known.

Referring to Figs. 4 and 4A which illustrate a preferred embodiment of the invention, particularly suitable for use on metallic aircraft, reference numeral 16 designates a doublet comprising a tubular conductor 17 slightly less than a quarter wave-length long and closed at one end by a metallic cap or plug 18, and the exposed quarter wave-length portion 19 of a substantially half wave-length rigid conductor 20 which has a

smaller diameter than the tubular conductor 17, the conductors 17 and 20 being coaxially positioned and one-half of conductor 20 designated by numeral 21 being enclosed by tubular conductor 17.

The doublet is supported by means of the metallic transmission line housing 22 attached to plate 23 and metallic airplane wing 24 and is spaced a quarter wave-length from the wing which functions as a reflector. When used as the receiving antenna or the transmitting antenna in the altimeter system described in the above-mentioned application of R. C. Newhouse, the doublet is preferably, although not necessarily, positioned perpendicular to the longitudinal axis of the aircraft. In Fig. 4, the arrows 6 are parallel to the longitudinal axis. More specifically, the tubular conductor 17 is supported by the housing 22 and metallic block 25. The member 20 is supported at one end by the end plug 18 and at its approximate center point by means of the insulator 26 which is attached to the block 25. The use of the end support for the conductor 20 permits the utilization of an insulator 26 having a size and, therefore, a capacity smaller than otherwise would be required.

Reference numeral 27 designates a plexiglass doublet housing supported by metallic plug 25. The housing prevents the accumulation of moisture and the formation of ice on the antenna elements and associated insulator. The antenna housing 27 and also the transmission housing 22 each have a streamlined shape modified as shown by the end section 28 of the antenna housing to have at the front an exceedingly sharp straight line edge whereby the formation of ice thereon is substantially prevented. The transmission line 29 comprising inner conductor 30 and outer conductor 31, and enclosed by the housing 22, is connected to a multifrequency transmission device 32. As previously stated, the device may be designed to supply or receive a large number of frequencies simultaneously or as in the altimeter system mentioned above, a frequency which varies repeatedly over a given range.

In operation, referring more particularly to Fig. 4A, current to or from the device 32 flows along the inner surface of conductor 31, the inside surface of block 25, the outside surface of block 25 and the outside surface 35 of tubular conductor 17, as illustrated by the arrow 33 and current of opposite wire phase flows along the inner conductor 30 of line 29 and thence along conductor 19, as indicated by arrow 34, whereby conductor 19 and the outside surface 35 of tubular conductor 17 constitute, respectively, the exciter and counterpoise elements of the doublet. The current represented by arrow 36, and flowing along the inner surface 37 of tubular conductor 17 and the enclosed portion 21 of member 20, and the current 33 are as is well known entirely independent. The short-circuited line comprising the inner surface 37 and the member 21 form the compensator of the invention and functions as explained in connection with Fig. 1C to minimize the standing wave ratio at the various frequencies in the operating range.

In effect the coaxial line constituting the compensator has an electrical length slightly less than a quarter wave-length at the mean frequency since the dielectric utilized is air and the velocity of the waves in the compensator is substantially equal to the velocity of a space wave. On the other hand, the counterpoise element or

surface 35 of this same conductor 17 has an electrical length substantially equal to a quarter wave-length since at the mean frequency the velocity on a radiating element is less than that of a wave in space. See "Electric Oscillations and Electric Waves" by G. W. Pierce, 1st edition pages 332-334 and the article, "Impedance of Antennas," equation 30, by E. Siegel and J. Labus published in "Hochfrequenztechnik und Elektroakustik," vol. 43, No. 5, May 1934, pages 166-172. In one system, which is in actual use, the ratio of the inner diameter of outer conductor of the compensator to the outer diameter of the inner conductor is approximately 2. It may be desired to utilize a single rod or member for the elements 19 and 21 and if necessitated by mechanical considerations, the ratio may be slightly different from the theoretical value without materially affecting the compensation.

The curves H of Figs. 2A, 2B and 2C are measured characteristics for a system utilizing the invention and constructed in accordance with Figs. 4 and 4A. It will be observed that as compared to the characteristics of the prior art systems of Figs. 1A and 1B illustrated by curves A and B the measured input resistance for the system of Figs. 4 and 4A is more uniform, the measured input reactance more nearly approaches the ideal zero reactance and at substantially all frequencies the measured standing wave ratio more nearly approaches the ideal unity value.

The embodiment illustrated by Figs. 4 and 4A have several distinct advantages. In the first place, compensation for matching an exceedingly large number of frequencies is accomplished with a minimum amount of apparatus. Also, distortion of the directive characteristic of the antenna by the compensator or impedance transformation apparatus is entirely prevented by including the compensator entirely within one element of the radiating system. Considered from a mechanical standpoint a highly satisfactory end support is obtained for the member 20 and exciter 19 whereby a relatively small central supporting insulator may be utilized. In turn, the capacity of the small insulator is such that resonance may be easily obtained without unfavorably changing the length of the counterpoise surface.

Although the invention has been described in connection with certain specific embodiments and apparatus, it should be understood that it is not to be limited to these embodiments inasmuch as other structures may be successfully employed without exceeding the scope of the invention. Thus compensation may be applied to other types of antennas and the compensator may comprise a two-wire line or a lump reactance.

What is claimed is:

1. A method of matching a load comprising an antenna input impedance to the impedance of a transmission line over a band of frequencies which comprises determining the termination resistance value of a circuit having an input reactance substantially equal at each frequency in the band to the input reactance of said antenna, and connecting to the antenna input terminals an auxiliary line having a length of approximately a quarter wave-length at one of said frequencies and a characteristic impedance depending upon the value of said resistance and the value of the input impedance of the entire load including the input impedances of said antenna and said auxiliary line.

2. A method of matching the impedance of a load comprising an antenna, an auxiliary line and an insulator, all connected in parallel, to the impedance of the line connected to the load over a band of frequencies, which comprises matching the combined input impedance of the antenna and auxiliary line to the line impedance in accordance with claim 1 and shortening said line a particular amount dependent upon the reactance of said insulator.

3. In combination, an antenna comprising only a radiator or collector, a line connected thereto and means for matching the antenna and line impedances over a band of frequencies, said means comprising a line connected to the input terminals of the antenna and having a characteristic impedance dependent upon the termination resistance value of a properly terminated smooth line having a frequency-input reactance characteristic similar to the frequency-input characteristic of the antenna.

4. In combination, a line, a doublet radiator or collector comprising a tubular conductor and a second conductor of smaller diameter, said conductors having a common axis, and means for matching the line impedance and the impedance of the radiator or collector over a band of operating frequencies comprising a conductor enclosed by said tubular conductor and connected to the second conductor.

5. In combination, a system comprising an antenna and a supporting insulator, a line connected to said antenna, and means for matching the impedance of said system and the impedance of said line over a frequency band having any width from one cycle to at least twenty-five megacycles, substantially, said means comprising a line connected to the antenna input terminals and having an input inductive reactance equal and opposite to the capacity reactance of said insulator and a characteristic impedance related to the input impedance of the antenna.

6. In combination, an antenna system comprising an antenna and a supporting insulator, a multifrequency translation device, a line connecting said antenna and device, and an auxiliary line for minimizing the line standing wave ratio at the operating frequencies, said line having a characteristic impedance related to the in-

put impedance of said antenna and a length depending upon the capacitive reactance of said insulator.

7. In combination, an antenna comprising two sections, an insulator included between said sections, a line connecting said sections to a multifrequency translation device, a means connected to the input terminals of said antenna for minimizing at each frequency the standing wave ratio on said line, said means comprising a distributed reactance having a characteristic impedance depending upon the input impedance of said antenna and a length depending upon the capacitive reactance of said insulator.

8. In combination, a multifrequency translation device, a tubular conductor approximately a quarter wave-length long and having one end closed, a second conductor approximately a half wave-length long and positioned coaxially within the tubular conductor and having one extremity connected to the closed end of the tubular conductor, an insulator connected between the open end of said tubular conductor and the approximate center point of the second conductor, whereby the outside surface of the tubular conductor and the exposed half of the second conductor constitute a doublet antenna and the enclosed half of the second conductor and the inner surface of the tubular conductor constitute an auxiliary line approximately a quarter wave-length long and connected in shunt to said insulator and doublet.

9. In combination, a doublet antenna system comprising a tubular counterpoise conductor approximately a quarter wave-length long and a second conductor approximately a half wave-length long and having a smaller diameter than that of the tubular conductor and means for supporting the second conductor coaxially with respect to the tubular conductor so that a quarter wave-length portion of the second conductor is exposed and forms the exciter element of the doublet, said means comprising an insulator included between one end of the tubular conductor and the center portion of the second conductor and a metallic member included between the other end of said tubular conductor and one end of said second conductor.

WILLIAM H. C. HIGGINS.