Jan. 6, 1953 R. REDHEFFER 2,624,843

RADIO WAVE RADIATING SYSTEM

Filed June 7, 1945

FIG. 1

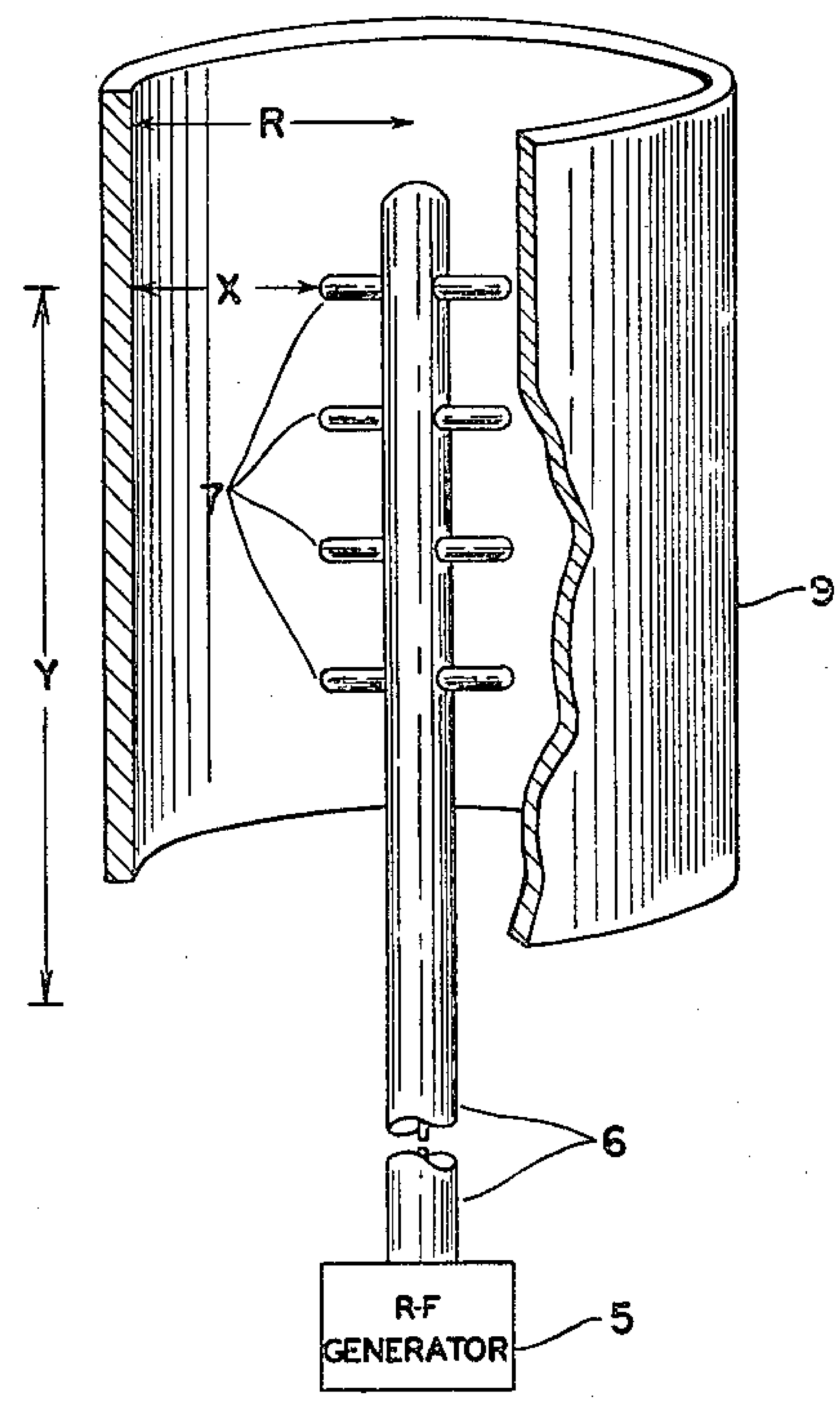
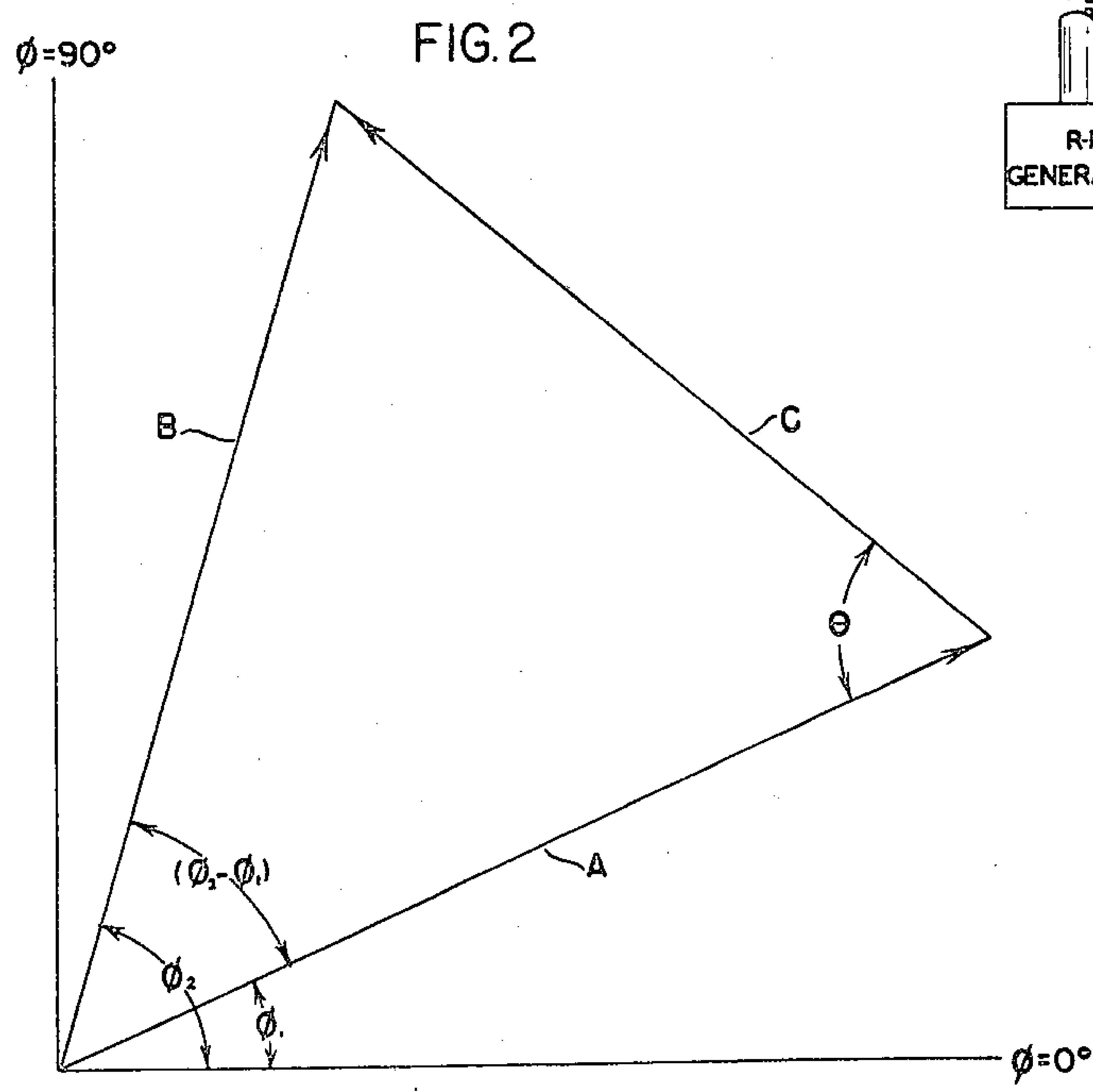


FIG. 2



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RADIO WAVE RADIATING SYSTEM

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This invention relates in general to electromagnetic energy radiating devices and more particularly to a method for obtaining optimum performance of such devices.

The importance of matching an antenna for radiation of electromagnetic energy to the transmission means whereby energy is conducted to said antenna in order to obtain optimum performance of the system is well known in the art. In many cases it is most desirable to adjust the input impedance of the antenna so that standing waves of voltage and current on the radio frequency transmission line leading to the antenna are minimized.

Among the advantages gained by reduction of standing waves are: greater efficiency of the transmission line; there is less likelihood of altering the R.-F. oscillator output frequency by improper loading; the input impedance to the line, and hence the power input and output, is less sensitive to small changes of frequency or line length. The last of these is the most important.

A conventional method of obtaining the proper relation between the antenna impedance and the transmission line impedance is to place matching devices such as stub lines, quarter-wave line sections, or "line stretchers," at the proper points along the line. The theory and use of these matching devices is well known in the art and will not be included here.

Matching methods of this type, however, tend to be frequency sensitive and to reduce the power carrying capacity of the line.

Accordingly, it is one object of my invention to provide a method of matching an antenna assembly to a radio-frequency transmission line to achieve optimum electrical characteristics of the transmitting system.

Another object of my invention is to provide a simple method of matching an antenna to a transmission line.

Still another object is to provide a method for matching an antenna to a transmission line conveying energy thereto by which proper matching between the two may be obtained in the manufacturing process.

These and further objects of my invention will be apparent to those skilled in the art upon examination of the following specification, claims, and drawings, in which:

Fig. 1 is a perspective view of a representative antenna system to which my invention is applicable; and

Fig. 2 is a vector diagram which illustrates one of the steps in the method of matching which comprises my invention.

Briefly, the invention embodies a system for enclosing an antenna with a protective housing in such a fashion that the reflection coefficient introduced by the housing effectively cancels that

due to the antenna, thereby eliminating or minimizing standing waves in the transmission line leading to the antenna.

Referring now to Fig. 1, a radio-frequency generator represented by block **5** supplies oscillatory energy to a coaxial transmission line **6** which feeds an antenna array composed of a plurality of dipoles **7**. A cylindrical wave-transparent housing **9**, a portion of which is shown cut away to reveal the antenna structure, surrounds the radiating array. My invention is particularly adaptable to this type of antenna construction since the radial distance from each dipole **7** to housing **9** is the same.

In previous constructions of this nature, it has been necessary to insert in transmission line **6** one or more matching devices to permit adjustment for optimum electrical conditions in line **6**. My invention, however, makes it possible to dispense with such methods.

As has been stated hereinabove, the invention comprises a method of matching which can be broken down into five stages or steps.

First, radio-frequency power is fed through transmission line **6** to antenna array **7** before the latter is placed in a housing. In general, the input impedance to antenna array **7** will not be that value which is conducive to minimum standing waves in line **6**. Hence some of the energy propagated toward the antenna in the transmission line will be reflected back toward the radio-frequency generator. The reflected energy will be equal in amplitude to a constant, $|\Gamma|$, times the amplitude of the incident energy and will differ therefrom in phase by an angle ϕ. The symbol Γ represents a quantity, hereinafter referred to as the reflection coefficient, such that

$$\Gamma = |\Gamma| < \phi \qquad (1)$$

The magnitude of the reflection coefficient is obtained by measuring a maximum voltage point in the standing wave pattern on the line by any of the suitable methods known in the art, measuring a minimum voltage point, and taking the ratio of the maximum measured voltage to the minimum measured voltage. This ratio will hereinafter be designated as the standing wave ratio or ρ. $|\Gamma|$ can then be calculated from the relation

$$|\Gamma| = \frac{\rho - 1}{\rho + 1} \qquad (2)$$

The phase angle ϕ_1 is unimportant as will be shown.

The second step is to enclose the antenna array in a housing of the type which it is proposed to use in the complete transmitting installation. The addition of a housing will change the antenna input impedance as seen from the line by reason of the reflections from the housing wall. Therefore a new reflection coefficient, Γ_2, that of the antenna plus the housing, will exist. The standing wave pattern will in general be different from that measured heretofore and the value of $|\Gamma_2|$ can be found from Equation 2 using the new standing wave ratio obtained from measurements similar to those made in step 1.

It is to be expected also that ϕ_2 will differ from ϕ_1. This can be detected by a shift in the position of the voltage maxima and minima in the standing wave pattern on the transmission line. The amount of shift is measured and translated into the form of electrical degrees by knowledge of the wave-length of energy propagated on the line. Since the absolute magnitude of ϕ_1 and ϕ_2 is not important, but rather their relative values, both angles can be measured relative to any desired reference point. The location on the line of voltage maxima and minima is a measure of ϕ, hence if a minimum point when the line is feeding the antenna array without the housing is taken as a reference, the shift in the minimum point due to addition of the housing will be proportional to $\phi_2-\phi_1$. The equation which may be used for computation is

$$\Delta d=\frac{(\phi_2-\phi_1)\lambda}{4\pi} \qquad (3)$$

where Δd is the shift in the minimum point, λ is the wavelength of transmitted energy, and ϕ_2 and ϕ_1 are as defined hereinbefore.

Having determined $|\Gamma_1|$,$|\Gamma_2|$, and $(\phi_2-\phi_1)$, the third step of my invention is to construct a vector diagram proportional to these quantities. Such a diagram is shown in Fig. 2, wherein vector A represents the coefficient of reflection Γ_1 from the antenna array without a housing, vector B represents the coefficient of reflection Γ_2 resulting from the housing and antenna together, and vector C represents the coefficient of reflection Γ_3 of the housing alone. Vector C is determined by the vectors A and B since the coefficients of reflection of the antenna and housing must add vectorially to produce the coefficient of reflection of the antenna enclosed by the housing.

It should be emphasized that the coefficient of reflection of the housing as computed from data on a plain sheet of dielectric material in free space will differ from the apparent coefficient of reflection introduced into the transmission line by placing the housing around the antenna although it will be substantially proportional thereto. The free space coefficient is customarily used in designing a housing, hence it is necessary to convert the apparent coefficient of reflection into the free space coefficient. This will be done in a later step.

Construction of the diagram of Fig. 2 shows an angle θ between vectors A and C. Clearly, to minimize vector B θ must first be reduced to zero, putting vector C 180° out of phase with vector A. C then subtracts from A to give B. When this is accomplished the magnitude of C can be adjusted to approximate that of A, substantially eliminating B. Rotation of C is accomplished by the fact that a change in housing radius of one wavelength shifts the phase of C relative to A 720°, the direction of rotation depending on the nature of the change in radius. Therefore, the housing radius may be either increased or decreased, as may be preferable, to cause vector C to coincide with vector A. The equation representing this relation is

$$\Delta R=\frac{\theta\lambda}{720^\circ} \qquad (4)$$

wherein ΔR is the change in housing radius and θ and λ are as defined before. Thus the optimum housing radius is determined.

The fourth step is to compute the desired free space reflection coefficient. Vector C is proportional to the free space reflection coefficient of the housing used in making measurements and A is proportional to the free space coefficient of the ideal housing since C will approximately equal A in the final design. The proportionality factor is the same in both instances, hence the desired free space reflection coefficient is found by multiplying the free space coefficient of the test housing by the ratio A/C.

The fifth step is to calculate the thickness dimension of the ideal housing taking into consideration the dielectric constant of the material of which it is to be composed and using standard data on the free space reflection coefficient of a plain sheet of such material.

If the standing wave ratio existing on the transmission line with the new housing in place is still higher than is desirable, the process may be repeated.

To summarize the foregoing, my invention comprises a method of matching an antenna enclosed in a housing to a transmission line, the method being as follows:

(1) Determine the reflection coefficient of the radiating array alone by measurement and Equation 2;

(2) Place a housing of a desired type around the radiating array and determine the new reflection coefficient by Equation 2 and the phase difference between the old and new reflection coefficients by Equation 3;

(3) Construct a vector diagram similar to Fig. 2, from the values found in steps 1 and 2, and use Equation 4 to find the optimum housing radius;

(4) Compute the desired housing free space reflection coefficient from the free space coefficient of the housing used for measurements;

(5) Design a housing having the desired free space reflection coefficient.

Since the housing itself forms the matching device, a radiating system constructed according to the principles of my invention tends to be insensitive to changes in frequency. This is true because the distance of the matching device from the radiating elements is an important factor in deviations from optimum operating conditions. The distance Y which represents the distance from a point in the transmission line where a conventional matching device would customarily be inserted to one of dipoles 7 in Fig. 1 may be several times as great as the distance X which is the distance between radiating elements 7 and housing 9. Hence a change in oscillator frequency will affect the standing wave ratio on line 6 and the power output of the antenna less when my invention is used to provide matching.

Also it will be apparent to those skilled in the art that my invention obviates the need for matching devices in the transmission line itself and affords the many advantages derived from proper matching of an antenna to a transmission line together with the benefits of protecting the antenna by a housing.

It is to be emphasized that certain minor deviations may be made from the invention and its application as disclosed hereinabove without substantial loss of its advantages. Hence I claim all such modifications and adaptations as may fall fairly within the spirit and scope of the hereinafter appended claims.

What I claim is:

1. A wave radiating system comprising a radio wave generator; an antenna; a transmission line connecting the two; said antenna being mismatched with respect to said generator, whereby a first resultant reflected wave is obtained along said transmission line; and means, including a substantially wave-transparent dielectric housing at least partially enclosing said antenna, for providing a second resultant reflected wave along said transmission line which is substantially equal in amplitude to said first resultant wave and is substantially 180° phase displaced therefrom, whereby said second resultant wave substantially cancels said first resultant wave.

2. A wave guide radiating system according to claim 1, wherein said housing alone has a reflection coefficient substantially equal to the reflection coefficient of said antenna alone, and wherein said housing is spaced a distance from said antenna which provides a substantially 180° phase displacement between said first and second resultant waves.

3. A wave radiating system according to claim 2, wherein said housing consists of a single cylinder, and wherein said antenna is symmetrically disposed with respect to the longitudinal axis of said cylinder.

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