Feb. 7, 1950 P. H. SMITH 2,496,643

IMPEDANCE MATCHING SYSTEM

Filed Oct. 14, 1944

FIG. 1

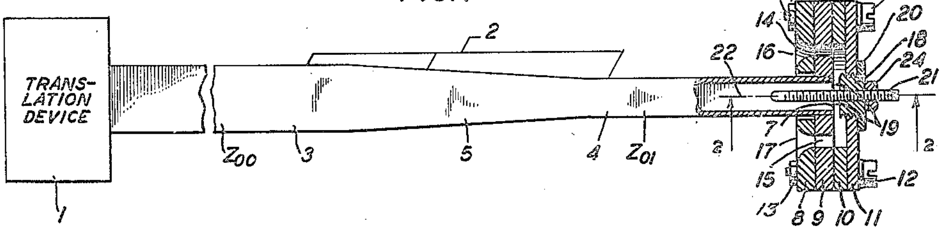


FIG. 2

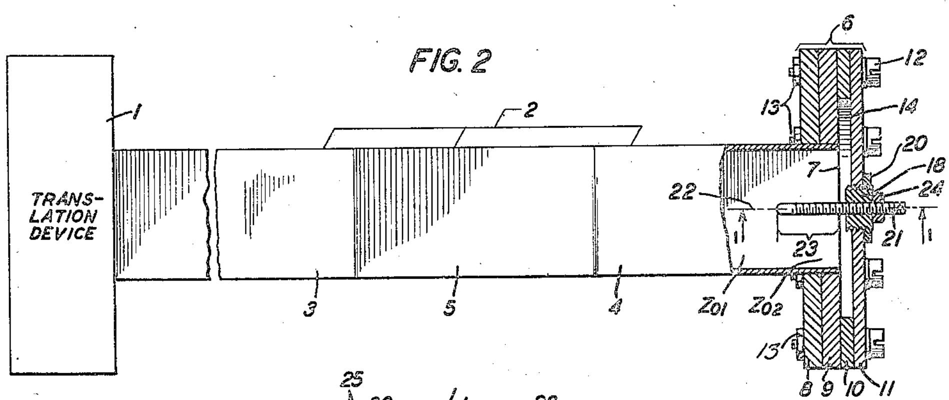


FIG. 3

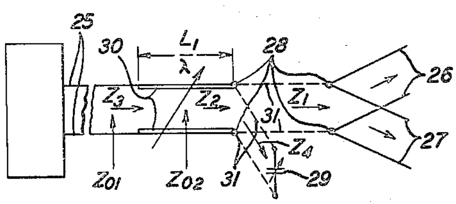
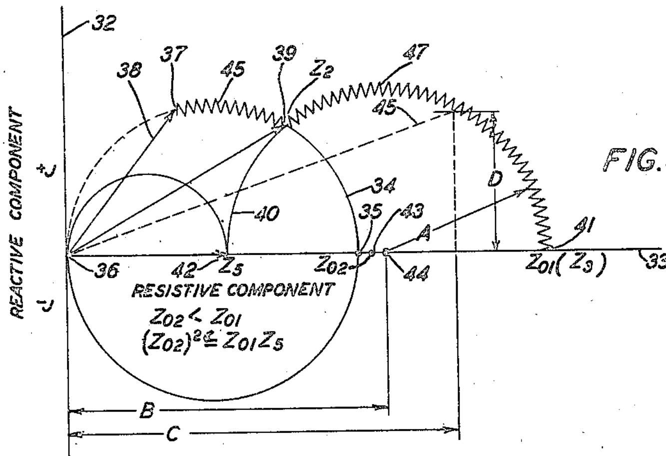


FIG. 4



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IMPEDANCE MATCHING SYSTEM

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5 Claims. (Cl. 250—33.63)

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This invention relates to impedance matching systems and particularly to wave guide impedance matching systems.

The copending application of C. C. Cutler, Serial No. 546,687, filed July 26, 1944, Patent No. 2,483,575, granted October 4, 1949, discloses an antenna system comprising a paraboloidal reflector, a main wave guide extending through the reflector vertex and connected to a primary antenna head positioned at the reflector focus. The head comprises a pair of antenna apertures facing the reflector and connected to the open end of the main wave guide through a wave guide cavity comprising a pair of short branch wave guides connected in parallel. An adjustable threaded short plug of relatively large diameter is inserted into the antenna head, at the junction of the branch guides and the main guide, for the purpose of matching the complex impedance of the open ended branch guides to the characteristic impedance of the main guide. As used herein, the term "complex impedance" denotes an impedance comprising resistance and capacitive (positive) or inductive (negative) reactance. In practice it has been found that optimum or complete matching is not always secured by means of the single plug adjustment. Moreover, it is often necessary, in addition to adjusting the plug, to change the dimensions of the cavity or branch guides, in order to secure a satisfactory impedance match. Accordingly, it now appears desirable to provide simple means for efficiently matching a complex impedance to the characteristic impedance of a guide. In particular it appears advantageous to match, in the antenna system described above, the complex input impedance of the branch guides to the main guide impedance without changing the dimensions of the antenna head.

It is one object of this invention to match, in a system comprising a load connected to a main wave guide and having a complex input impedance, the characteristic impedance of the main guide and the complex impedance of the load.

It is another object of this invention to match the complex impedance of an antenna structure comprising a pair of open ended branch wave guide sections to the characteristic impedance of a main guide connected to the branch main guides, without changing the dimensions of the branch guides.

In accordance with one embodiment of the invention, a long threaded probe or rod of small diameter extends coaxially through the short threaded plug in the antenna head described

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above and also extends an adjustable short distance along the axis of the main guide. Considered from one standpoint, the capacitance of the short plug is in effect connected in shunt with the junction impedance of the two branch wave guides. On the other hand the variable length section of wave guide enclosing the long rod is connected in series with the main wave guide. The characteristic impedance of the aforementioned variable section is, by reason of the presence of the long rod, lower than the characteristic impedance of the main wave guide. In other words, the plug is a capacitive shunt impedance transformer; and the portion of the main guide enclosing the long rod is a tandem or series impedance transformer having a smaller characteristic impedance than that of the main guide. The shunt impedance transformer functions to transform the complex input impedance of the two branch guides into another complex impedance which is transformed by the series impedance transformer into the characteristic impedance of the main guide. For a given complex load impedance and a given relatively large characteristic impedance of the main guide, the plug and the rod are each adjusted to effect the desired complete impedance transformation. The band-width characteristic of the wave guide system or head is not appreciably changed by the addition of the probe.

The invention will be more fully understood from a perusal of the following specification taken in conjunction with the drawing on which like reference characters denote elements of similar function and on which:

Figs. 1 and 2 are, respectively, top and side sectional views of one embodiment of the invention; and

Figs. 3 and 4 are, respectively, schematic and impedance diagrams used in explaining the invention.

Referring to Figs. 1 and 2, reference numeral **1** denotes a translation device such as a radar transceiver and numeral **2** designates a wave guide comprising the straight sections **3** and **4** and the intermediate tapered section **5**. The tapered section **5** functions to match the characteristic impedance Z_{00} of the wide section **3** to the characteristic impedance Z_{01} of the narrow section **4**. Numeral **6** denotes an antenna head connected to the open end **7** of main guide section **4** and comprising the metallic plate members **8**, **9**, **10** and **11**. The plate members are held together by means of the bolts **12** and nuts **13**. Plates **8**, **9** and **10** are apertured so as to form two open-ended short branch wave guides 14 and 15 which are connected to the open end 7 of the main guide 4. The branch guides 14, 15 are connected in parallel and the two open ends 16, 17 of these branch guides constitute transceiving apertures. Numeral 18 denotes a relatively short threaded plug having a large diameter and extending into the head at the junction 19, Fig. 1, of the main guide 4 and the branch guides 14 and 15. As previously indicated, the capacitive plug is in effect connected in shunt to the branch guides at the junction 19 and constitutes a shunt impedance transformer. Numeral 20 denotes a nut for locking the adjustable plug 18 in position. As described so far the structure is substantially the same as the dual aperture rear feed or head disclosed and claimed in the above-mentioned copending application of C. C. Cutler.

Reference numeral 21 denotes a relatively long threaded rod having a small diameter and extending, in accordance with the invention, coaxially through plug 18, and, for a short distance, coaxially along the axis 22 of the main guide 4. The coaxial wave guide section 23, Fig. 2, comprising the rod 21 and the portion of guide 4 enclosing the rod constitutes in effect a distributed series impedance transformer having a characteristic impedance Z_{02} which is lower than the characteristic impedance Z_{01} of the main guide 4. Numeral 24 denotes a nut for locking the adjustable rod 21 in position.

In operation, assuming device 1 is a transmitter, waves generated in device 1 are supplied over guide sections 3, 5 and 4, series transformer 23, junction 19, and branch guides 14 and 15 to the antenna apertures 16 and 17. As explained below in connection with Figs. 3 and 4, the plug 18 and rod 21 function to match the complex load impedance Z_1, comprising the two parallel input impedances of branch guides 14 and 15, to the characteristic impedance Z_{01} of the main guide 4. The resistive impedance Z_{01} is relatively large as compared to the maximum value of the resistive component of the complex impedance Z_1.

Referring to the schematic diagram of Fig. 3, reference numerals 25, 26 and 27 denote, respectively, transmission lines corresponding to the guides 4, 14 and 15 of Figs. 1 and 2. Numerals 28, 29 and 30 denote, respectively, a junction, a shunt impedance transformer and a series impedance transformer corresponding to junction 19, the shunt impedance transformer or capacitive plug 18 and the series impedance transformer 23, of the system of Figs. 1 and 3. The line sections 31 shown in dotted lines are of negligible length and impedance, and are shown on the drawing merely for the sake of clarity. The reference characters Z_1, Z_2 and Z_3 denote, respectively, the input impedance of the load proper comprising lines 26 and 27, the input impedance looking into the junction of lines 26 and 27 and the shunt transformer 29, and the input impedance looking into the series transformer 30. Reference characters Z_{01} and Z_{02} represent the characteristic impedances of the main line 25 and the series transformer 30, respectively. The distributed series transformer 30 has an adjustable electrical length denoted by L_1/λ and the shunt transformer 29 has an adjustable capacitive reactance.

Referring to the impedance diagram of Fig. 4, the ordinate or vertical scale 32 represents the reactance component, $\pm j$, and the abscissa or horizontal scale 33 represents the resistance component, for any given complex impedance. Since it is desired to match the characteristic impedance Z_{01} of line 25 corresponding to the main guide 4, to the input impedance Z_3 of the series transformer 30, or 23 we have

$$Z_{01}=Z_3 \qquad (1)$$

As explained in the article "L-Type Impedance Transforming Circuits" by P. H. Smith published in "Electronics" March 1942, pages 48–52, 54 and 125, the range or variation in the impedance Z_2, obtainable by shunting Z_2 with a variable capacitive reactance Z_4 and varying Z_4 over its entire range, may be represented by the arc 34 of a circle intersecting the resistance scale 33 at point 35 and at the origin 36. Point 35 corresponds to the maximum value of the resistive component of the complex impedance Z_1. Reference numeral 37 on the arc 34 denotes the extremity of a vector 38 having its pole at the origin 36 and representing the load impedance Z_1. The arc 34 extends clockwise from point 37 through point 35 to the origin 36 and does not include the small arc 36, 37. To determine the particular value of Z_2, denoted by numeral 39, which may be transformed by the series transformer 30 into an input impedance $Z_3=Z_{01}$, a circle 40 is drawn which represents the impedance path followed by the input impedance vector Z_3 as the length of line L_1/λ is varied. As explained in the text book "Microwave Transmission" first edition, by J. C. Slater, Chapter 1, the circle is centered on the resistance scale 33 and intersects scale 33 at two points, namely, point 41 corresponding to the resistance Z_{01}, and at which $Z_3=Z_{01}$, and point 42 corresponding to a resistance value of Z_5. The two impedance paths, circles 34 and 40, intersect each other at point 39 coinciding with the extremity of the vector Z_2. Reference numeral 43 denotes the point on the resistance scale 33 corresponding to the characteristic impedance Z_{02} of the line section 30. The relation of points 41, 42 and 43 corresponding respectively to Z_{01}, Z_5, and Z_{02} is, as stated in the Slater text book,

$$Z_{02}^2=Z_{01}Z_5 \qquad (2)$$

The radius A of the circular path 40 and the distance B between the origin 36 and the center 44 of the circle 39 may be determined from the following equations

$$A=\frac{Z_{02}^2R}{K+\sqrt{K^2-4R^2Z_{02}^2}}+\frac{K+\sqrt{K^2-4R^2Z_{02}^2}}{4R} \qquad (3)$$

$$B=\frac{K+\sqrt{K^2-4R^2Z_{02}^2}}{4R}-\frac{Z_{02}^2R}{K+\sqrt{K^2-4R^2Z_{02}^2}} \qquad (4)$$

where

$$K=Z_{02}^2+R^2+X^2 \qquad (5)$$

and

$$R\pm jX=Z_3 \qquad (6)$$

Assuming for the moment that Z_3 is not real, but complex, its impedance may be represented by the broken line vector 45, the resistive component being illustrated by the distance C and its positive reactance by the height D. The impedance Z_3 is, however, real in view of Equation 1 so we have

$$R=Z_3 \qquad (7)$$

$$\pm jX=0 \qquad (8)$$

$$K=Z_{02}^2+R^2 \qquad (9)$$

Assuming the complex impedance Z_1 has the value represented by vector 38, the shunt capacitive transformer 29, Fig. 3, functions to rotate the vector 38 so that its extremity moves along the portion 46, shown by a zig-zag line, of the arcuate path 34 from point 37 to the point coinciding with the intersection 39 of the circular impedance paths 34 and 40. The series transformer 30 functions to move the complex impedance Z_2 along the portion 47, shown by a zig-zag line, of the arcuate path 40 to the point 41 on the resistance scale 33. In other words, the shunt transformer 29 changes the complex impedance Z_1 into another complex impedance Z_2 and the series transformer 30 changes the complex impedance Z_2 into an impedance Z_3 equal to the characteristic impedance Z_{01} of the main line 25, whereby the two transformers function to match the load impedance Z_1 to the line characteristic impedance Z_{01}. In this connection it should be noted that, since the maximum value of the resistance component of Z_1 is smaller than Z_3 or Z_{01}, two adjustments are required to transform Z_1 into Z_3, that is, Z_1 must be moved along two intersecting circular impedance paths 34 and 40.

In an analogous manner, in the system of Figs. 1 and 2, the capacitive plug 18 transforms the complex input impedance of the open-ended branch guides 14 and 15 into another complex impedance which is transformed by the guide section 23 comprising rod 21 and the adjacent portion of guide 4 into a resistive impedance equal to the characteristic impedance of the main guide 4. While the schematic transmission line system of Fig. 3 may not be exactly comparable in all respects to the wave guide system of Figs. 1 and 2, the systems are believed to be sufficiently analogous for explaining one theory underlying the operation of the wave guide system of Figs. 1 and 2.

Although the invention has been explained in connection with a particular embodiment it is to be understood that it is not to be limited to the embodiment described inasmuch as other apparatus may be employed in successfully practicing the invention.

What is claimed is:

1. A method of matching a relatively large characteristic impedance of a main wave guide to a relatively small complex input impedance of a pair of open-ended wave guides connected to said main guide and in parallel with each other, utilizing at the junction of said parallel guides and said main guide a pair of independently adjustable cylindrical conductive members coaxially aligned with the axis of the main guide, the first of said members having a small axial dimension and a large diameter and the second of said members having a large axial dimension and a small diameter, which comprises inserting both members into said parallel guides at said junction and only said second member into said main wave guide, adjusting the projection of said first member into said parallel guides and thereby securing a different input complex impedance, and adjusting the projection of said second member into said main guide and thereby securing a resistive input impedance equal to said characteristic impedance.

2. In combination, a main wave guide, a pair of branch wave guides connected thereto and having a complex input impedance, and means for matching said input impedance and the characteristic impedance of said main guide comprising a conductive linear member extending through the junction of said branch guides and coaxially into said first main guide.

3. A combination in accordance with claim 2, the axial dimension of said member being greater than its largest cross-sectional dimension.

4. In combination, a source, a main wave guide connected thereto and having a relatively large characteristic impedance, a pair of branch wave guides connected to said main wave guide and each having at its other end an antenna aperture, a capacitive adjustable metallic plug projecting into said branch guides at their junction and a linear adjustable metallic rod extending coaxially through said plug and coaxially into said main guide, said rod and the enclosing portion of said main guide forming a section of wave guide, said section being included between said main guide and said junction and having a relatively low characteristic impedance.

5. In combination, a source, a first wave guide section connected thereto and having a relatively large characteristic impedance, a second wave guide section connected to said first section and having a relatively small characteristic impedance, a pair of parallel wave guides connected to said second section and having a complex input impedance, means projecting into the junction of said second section and said parallel guides for changing said complex input impedance into a different complex impedance, said second section comprising means for changing the length of said second section, whereby said different complex impedance may be changed to a resistive input impedance equal to the characteristic impedance of said first section.

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