

June 5, 1951

S. D. ROBERTSON

2,556,001

MICROWAVE IMPEDANCE MATCHING REACTOR

Filed Jan. 2, 1947

4 Sheets-Sheet 1

FIG. 1

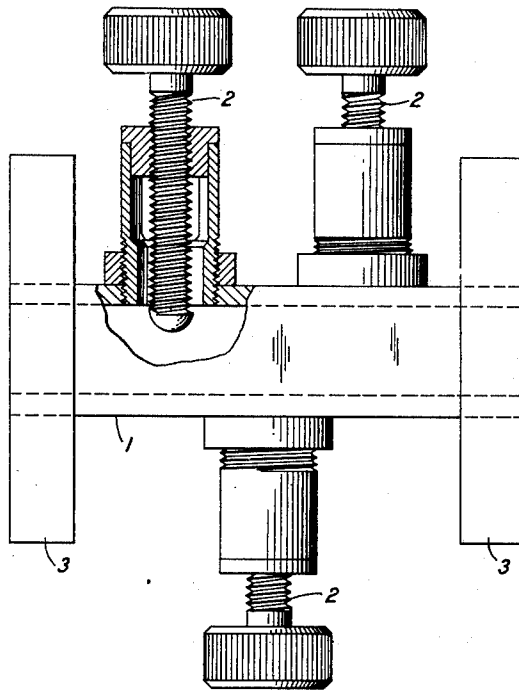
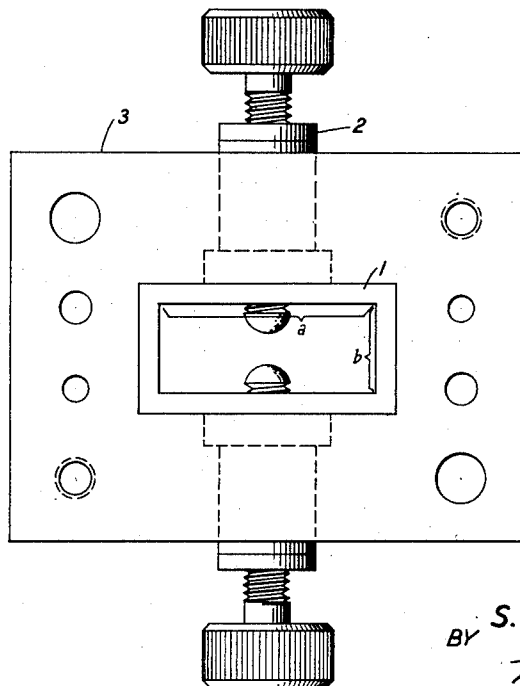


FIG. 2



INVENTOR
S. D. ROBERTSON
BY *N. D. Ewing*
ATTORNEY

June 5, 1951

S. D. ROBERTSON

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FIG. 3

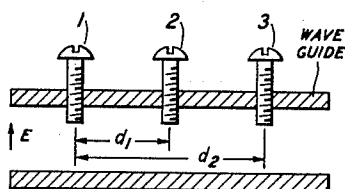


FIG. 4

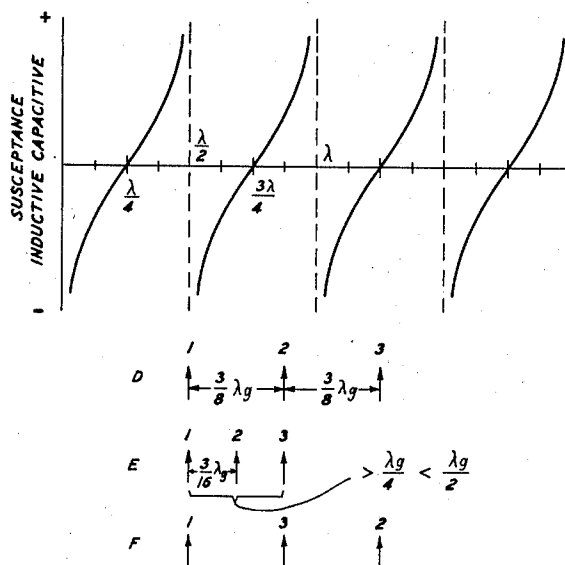


FIG. 5A

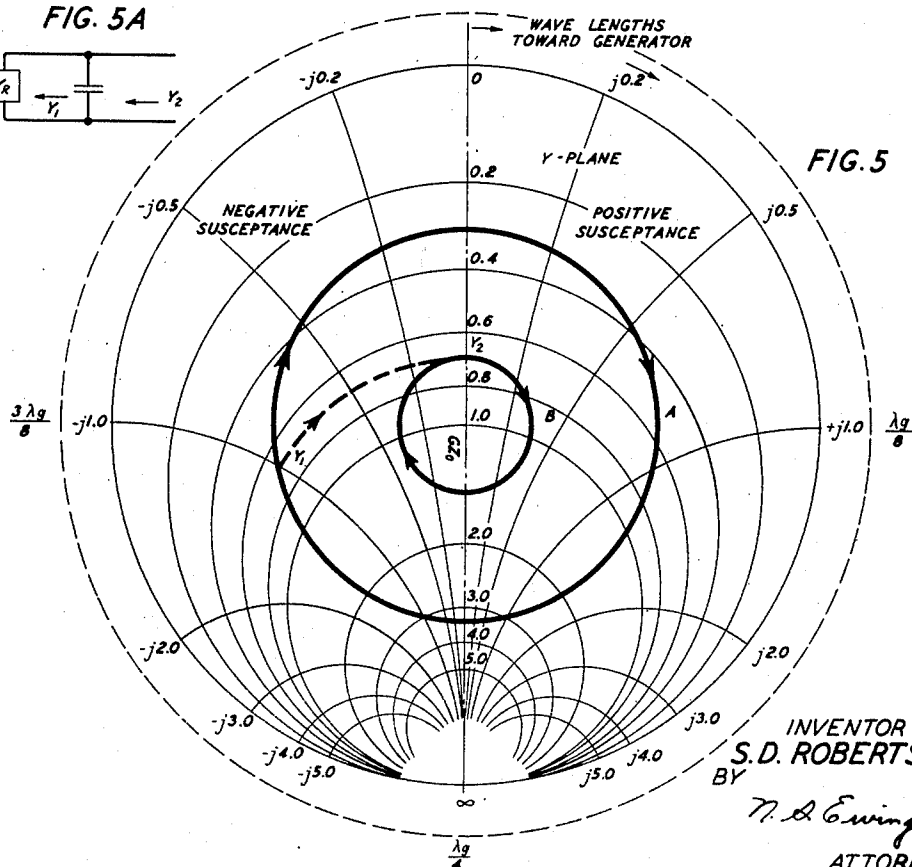
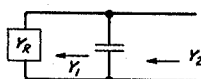


FIG. 5

INVENTOR
S. D. ROBERTSON
BY
N. & Ewing
ATTORNEY

June 5, 1951

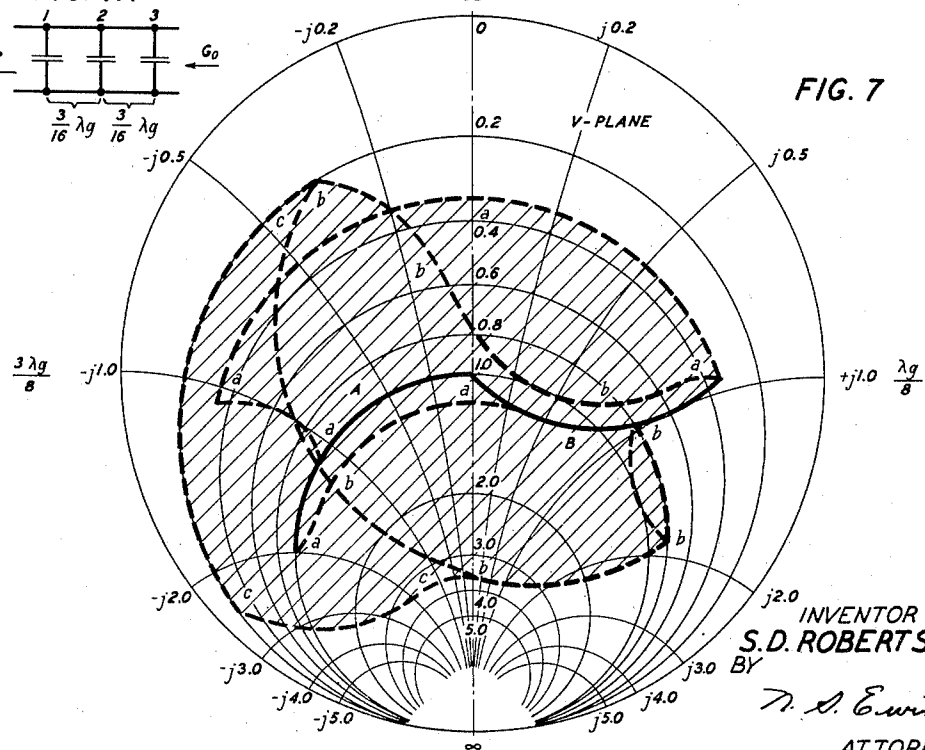
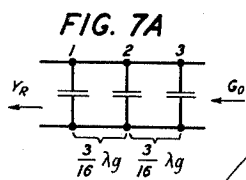
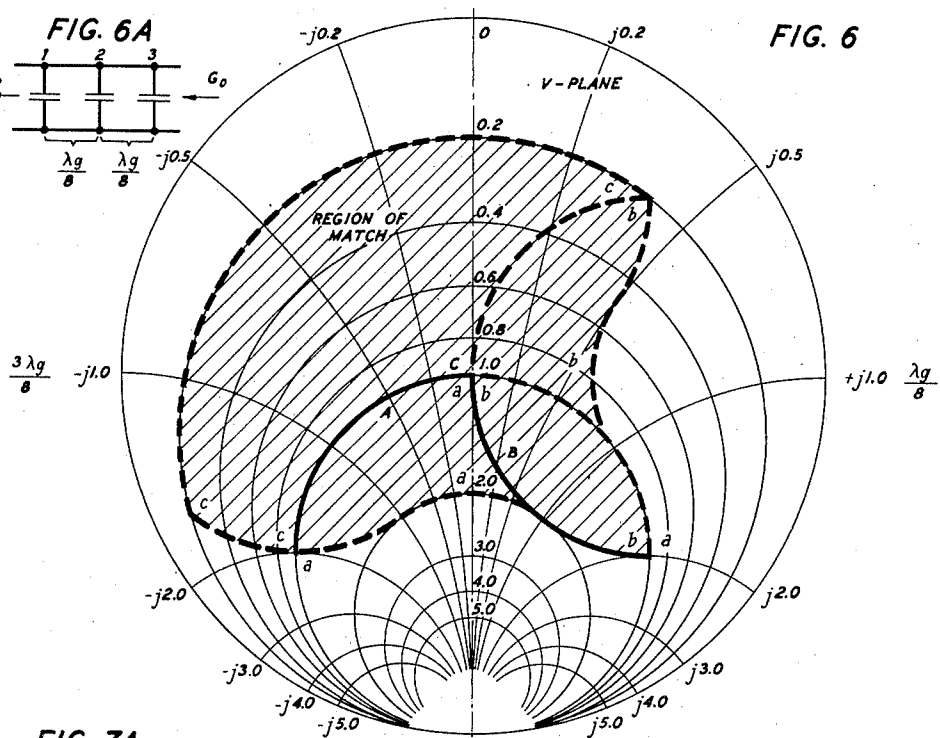
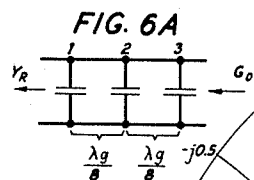
S. D. ROBERTSON

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INVENTOR
S. D. ROBERTSON
BY
N. D. Ewing
ATTORNEY

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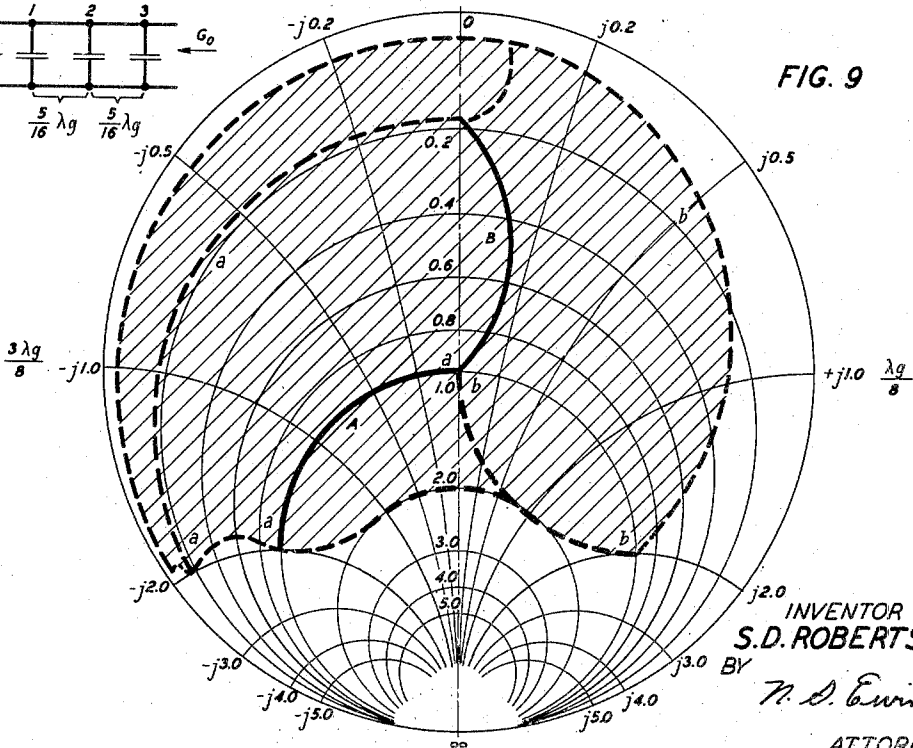
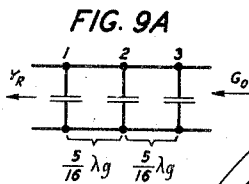
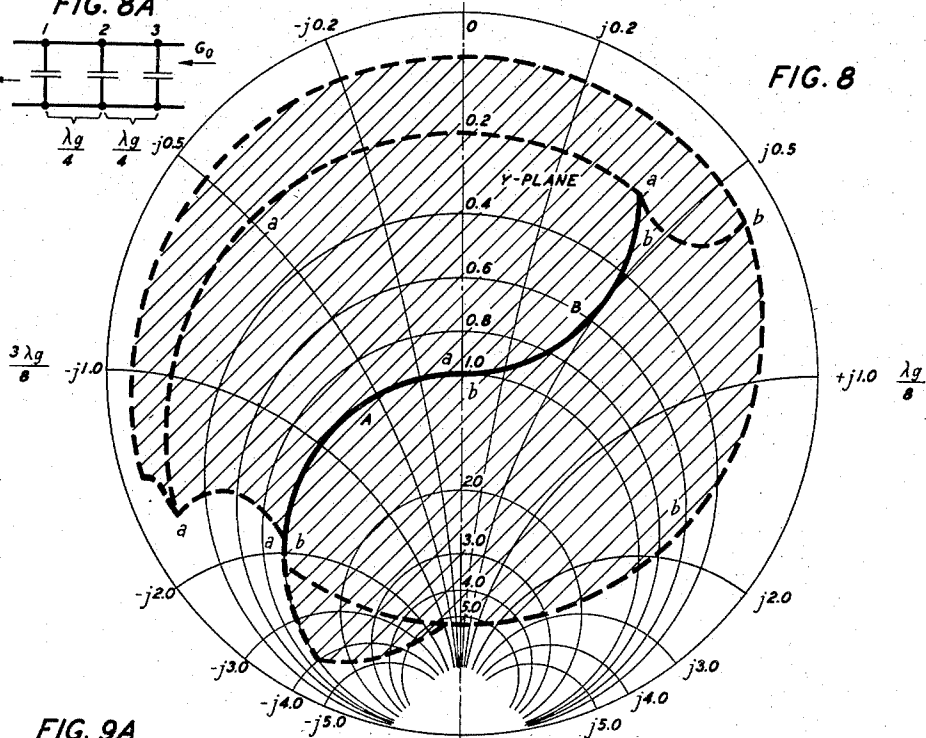
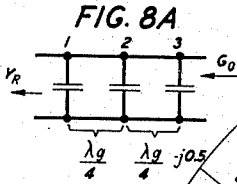
S. D. ROBERTSON

2,556,001

MICROWAVE IMPEDANCE MATCHING REACTOR

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INVENTOR
S. D. ROBERTSON
BY
N. D. Ewing
ATTORNEY

UNITED STATES PATENT OFFICE

2,556,001

MICROWAVE IMPEDANCE MATCHING
REACTOR

Sloan D. Robertson, Red Bank, N. J., assignor to
Bell Telephone Laboratories, Incorporated,
New York, N. Y., a corporation of New York

Application January 2, 1947, Serial No. 719,741

2 Claims. (Cl. 178-44)

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This invention relates to variable impedance matching transformers for a wave guide.

An object of the invention is to match a wide range of loads to a wave guide.

A feature of the invention is a wave guide section capable of transforming one impedance value into another by three spaced, adjustable reactance tuning screws therein.

Another feature of the invention is a variable impedance matching transformer comprising a section of the wave guide, provided with three spaced reactance screws, the spacing between end screws being greater than

$$\frac{\lambda_g}{4}$$

and less than

$$\frac{\lambda_g}{2}$$

and the spacing of adjacent screws being less than

$$\frac{\lambda_g}{4}$$

than and greater than 0, where λ_g is the wave length in the wave guide.

Another feature of the invention is a variable, three screw impedance matching device for wave guides and the like, characterized by a

$$\frac{\lambda_g}{4}$$

spacing between adjacent screws for accommodating an optimum range of load impedances.

In systems operating with electromagnetic waves in the range of 1 to 10 centimeters wave length, the use of conventional methods for impedance transformation tends to become impractical.

To provide practical impedance transformation in this range and for a wider range of loads than heretofore, applicant has provided, in accordance with the invention, a wave guide section having three reactance screws spaced therealong in a predetermined manner with respect to the wave length in the guide. In one preferred embodiment the three screws project into a rectangular guide section parallel to the dominant electric field vector thereof, and are centrally located with respect to the long side of the rectangular section.

The reactance screws individually provide variable shunting capacitances in the wave guide section, their spacings and depths of penetration being arranged to provide either an improved impedance matching or perfect matching be-

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tween the characteristic impedance of the main wave guide and a wide range of loads.

Since the screws provide shunt reactances, it is convenient in what follows to deal with the admittance Y corresponding to an impedance Z. As is well known, the admittance Y is defined as the reciprocal of the impedance Z to wit:

$$Y = \frac{1}{Z} = \frac{1}{R + iX} = G + iB$$

wherein

R=resistance

G=conductance

X=reactance

B=susceptance

The law of composition for admittances in parallel involves a simple adding operation analogous to the law of composition for impedances in series.

Referring to the figures of the drawing:

Fig. 1 shows a three-screw reactance tuner adapted to match impedances in the wave guide.

Fig. 2 shows an end view thereof.

Fig. 3 shows a simplified longitudinal section of the three-screw tuner.

Fig. 4 is an explanatory diagram.

Figs. 5 to 9 are explanatory admittance circle diagrams.

Figs. 5A to 9A are equivalent circuits for the screw arrangements associated with the circle diagrams.

Referring to Fig. 1, the three-screw tuner shown therein comprises a section of rectangular guide 1, provided with three spaced reactance screws penetrating therein to a variable distance. The reactance screws 2, which are of the type disclosed in the United States application of A. P. King, Serial No. 719,797, now abandoned, filed concurrently herewith, are located perpendicular to the long (a) side of the rectangle and in the median position thereof, so that effectively each screw is parallel to the dominant E vector of the rectangular guide 1.

The guide section 1 may be connected into a main wave guide by means of connecting flanges 3 or may constitute an integral part of such guide.

The three-screw tuner is adapted to match a wide range of loads to the main wave guide, the range depending on the spacing of the screws and their penetration into the guide section. By proper spacing of the screws and by suitable variation of the depth of penetration, one may obtain an improved match by the procedures described subsequently or even a perfect match.

These two cases, namely, of improved and perfect match are treated below in sections A and B.

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A. In the simplest case, the three-screw tuner may be regarded as a device whose purpose is merely to reduce an impedance mismatch present in a transmission line or wave guide. Thus for a wave guide, the problem is to locate three capacitive reactance screws so that at least one of the screws will always appear at a point where the susceptive component of the line admittance is inductive. The said capacitive screw can then be used to tune out the inductive component at this point. The admittance at this point then becomes more nearly a match and the standing waves along the line to the generator are reduced. This effect can be illustrated by the circle admittance diagram of Fig. 5. Such diagrams are commonly called Smith Charts, which are disclosed and explained in an article entitled "Transmission Line Calculator" by P. H. Smith in Electronics of January 1939.

Let it be assumed that a wave guide transmission line is terminated in a load admittance which is not equal to the characteristic admittance of the line. The admittance looking toward the load will then vary as one moves toward the generator or source. For a typical case the locus of this admittance might be represented by the circle A of Fig. 5. Each complete clockwise traverse of the circle A corresponds to a displacement along the axis of the guide in the direction of the generator equal to

$$\frac{\lambda_g}{2}$$

To the right of the $0-\infty$ axis of the diagram, the susceptance is positive or capacitive, to the left of the axis it is negative or inductive. If a variable shunt capacitance be connected across the line at a point in the inductive region such as point 1 of Figure 5, then the inductive susceptance at this point can be tuned out. This is illustrated by the dotted line of the figure. The line admittance (Figs. 5 and 5A) becomes Y_2 at point 1. The locus of the line admittance as we move toward the generator then follows the circle B. The impedance match has, therefore, been improved and the standing wave ratio has been reduced.

In order to arrive at the correct spacing of the three screws so that at least one of them will fall in an inductive region, consider the variation of susceptance along a short-circuited low loss transmission line. The variation of susceptance along the line is shown by the curves of Fig. 4. It will be observed that the sign of the susceptance changes every quarter wavelength. The latter statement is not only true for the short-circuited line but is also true for any low loss line terminated in an admittance which is not equal to the characteristic admittance.

Suppose the three tuning screws are spaced along the wave guide as shown in Fig. 3 and designated as (1), (2) and (3). The effect of a tuning screw whose axis is in the direction of the dominant electric vector E in a wave guide is that of a shunt capacitance. The spacing between screws 1 and 3 must be greater than

$$\frac{\lambda_g}{4}$$

If the spacing were less than

$$\frac{\lambda_g}{4}$$

all three screws might fall in a capacitive region

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which would violate the aforementioned requirement.

Assume that the three screws are spaced $\frac{3}{8}\lambda_g$. Then, looking at D of Fig. 4, it can be seen that a condition can prevail where none of the screws fall in an inductive region. Obviously, then the $\frac{3}{8}\lambda_g$ spacing is prohibited.

In case E of Fig. 4, a spacing is shown which will satisfy the condition of the problem. As shown here, screw number 2 falls in an inductive region. No situation can be found where the spacing of E fails. The spacing E does not represent a unique solution of the problem inasmuch as other spacings can be used which also satisfy the requirements. The requirements are in fact satisfied if the spacings conform to the following rule:

The distance from screw number 1 to screw number 3 shall be greater than

$$\frac{\lambda_g}{4}$$

and less than

$$\frac{\lambda_g}{2}$$

The distance between screw number 2 and either of the other two shall be less than

$$\frac{\lambda_g}{4}$$

and greater than zero.

In practice a $\frac{1}{8}\lambda_g$ spacing between adjacent screws represents a good value to select. If this spacing is chosen, the guide wavelength can vary a substantial amount without violating the conditions imposed by the above rule. It should be understood, that the situation is not changed by moving any of the screws along the line a distance equal to an integral number of half wavelengths. This possibility is shown in F of Fig. 4 in which screw number 2 has been moved a half wavelength to the right. It will be observed that it still falls in an inductive region. The more general rule for locating the screws is given mathematically by the formulae applicable to Fig. 3.

$$d_1 = \frac{k\lambda_g}{4} - \Delta_1$$

$$d_2 = \frac{n\lambda_g}{2} - \Delta_2$$

where

$$k = \pm \text{odd integer}$$

where

$$n = \pm \text{integer (odd or even)}$$

and where

$$0 < \Delta_1 < \Delta_2 < \frac{\lambda_g}{4}$$

In the foregoing analysis it was required that at least one of the three screws occur at a point along the line when it could be used in improving the admittance match. Under certain conditions, even better performance may be obtained than this. Suppose screw number 1 falls in an inductive region. Then screw number 1 should be moved into the guide until the capacitive susceptance of the screw cancels the inductive susceptance of the line admittance. Then number 2 screw appears in a capacitive region and number 3 appears in an inductive region. By adding capacitive susceptance at number 3, it is possible to improve the admittance match further.

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It should be clear from the above discussion that one may use a number of three-screw susceptance tuners and approach arbitrarily close to an admittance match. The procedure for matching is straightforward. Starting at the tuner nearest the load one tests each screw in succession, introducing capacitance only when it results in a decrease in standing wave ratio.

In the above, it was only required that the three-screw reactor or tuner improve the admittance match. It was not required that the tuner give a perfect match. In the following section, the conditions under which the three-screw tuner can be used to effect a perfect match will be considered.

B. In the foregoing discussion, the three-screw reactor was operated in such a manner that each step of the adjustment or tuning-up process resulted in an improvement in the admittance match, but in general did not result in a perfect match. In the following, there will be considered a combination of values of the susceptances introduced by the three screws which will perfectly match a given load admittance to the line. It often happens that the first steps in the matching process lead to even greater admittance mismatches in order to shift the line admittance, so that at another tuning screw its conductive component will equal the characteristic conductance of the line and its susceptive component will be inductive. If these conditions can be made to prevail at one of the screws, it is then possible to add capacitive susceptance by means of that screw and cancel the inductive component.

In order to consider the reactance screw tuner with a view to determine the optimum screw spacing, it is necessary to limit the amount of capacitance which can be introduced. Let it be assumed that the capacitive susceptance which can be introduced by any one reactance screw is less than or equal to twice the characteristic conductance of the wave guide. There are various possible spacings, one of which will give the greatest range of load admittances which can be matched. The mathematical difficulties encountered in a problem of this type have made it imperative that a graphical approach be used. The details will be explained using the admittance diagram of Fig. 6.

The only requirement that must be met is that at one of the three screws the admittance looking toward the load must fall on Curve A. By adding shunt capacitance with this screw, a match can evidently be obtained. In order to illustrate the method of determining the range over which a given admittance can be matched, the case illustrated in Fig. 6a for $\frac{1}{6}\lambda_g$ spacing between adjacent screws will be considered. The procedure follows the steps listed below.

(1) If at any one of the three screws, the admittance in the direction of the load falls on Curve A, then as described above, it is necessary only to add capacitance with that one screw in order to obtain a match. This, of course, is a special case of infrequent occurrence.

(2) If the admittance at screw number 1 falls inside of area *aaaa*, then enough capacitance at 1 is added to shift the admittance to a point on Curve B which will then appear as a point on Curve A at screw number 2. The match can then be completed with screw number 2.

(3) If the admittance seen at screw number 1 falls inside of or can, by the addition of capacitance at screw 1 be made to fall inside of the crescent shaped area *bbbb*, then at screw number

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2 the admittance will fall inside of *aaaa*. Then add enough capacitance at number 2 to shift the admittance to a point on Curve B. At screw number 3 this will appear as a point on Curve A. By adding capacitance at number 3 the match can be completed.

Points falling inside of *cccc* can be brought inside of *bbbb* by the addition of capacitance with screw number 1.

Therefore all admittances which fall inside of the total shaded area of Fig. 6 can be matched with three reactance screws spaced

$$\frac{\lambda_g}{8}$$

In no case has it been required to add a shunt susceptance greater than twice the characteristic conductance of the wave guide. The latter assumption is merely illustrative, and one which tests have shown can readily be achieved in practice.

In Figs. 7, 8 and 9, similar graphical solutions are disclosed for screw spacings of $\frac{1}{6}\lambda_g$,

$$\frac{\lambda_g}{4}$$

and $\frac{1}{3}\lambda_g$, which spacings are illustrated in the equivalent circuit representations of Figs. 7A, 8A and 9A. Evidently, the range of admittances which can be matched with the

$$\frac{\lambda_g}{4}$$

spacing is somewhat greater than with either the $\frac{1}{6}\lambda_g$ or the $\frac{1}{3}\lambda_g$ space. All indications are that the maximum range is obtained with a

$$\frac{\lambda_g}{4}$$

spacing or at least in the immediate vicinity thereof.

In the graph for the $\frac{3}{8}\lambda_g$ which has also been worked out, the range of admittances which can be matched therewith is much less than for the case of the $\frac{1}{6}\lambda_g$ spacing.

Although in the previous disclosure, rectangular guide sections have been described, it should be apparent and understood by those skilled in the art that other types of cross sections for wave guide may be used, for example, circular sections and alike. The three screw impedance matching arrangement may likewise be provided in coaxial conductor systems.

Although the reactance screws have heretofore been disclosed as capacitance, it should be understood that an arrangement of three screws, each providing an inductive reactance may similarly be used for impedance matching of a wide range of loads. The screws provide inductive reactance when inserted perpendicular to the small side (*b*) of the rectangular section at the medium position thereof.

What is claimed is:

1. In combination, a source of microwave oscillations, a load, a rectangular wave guide forming an enclosed conductive device connected to said source for propagating microwaves therethrough, said wave guide extending between said source and said load, and an impedance matching transformer in said wave guide adjacent said load comprising three capacitance reactance screws paralleling each other and spaced along said wave guide, each screw being adjustable transversely of the longitudinal axis of said guide and projecting through the wall of said guide

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into the interior thereof, each screw extending along the electric vector of the dominant mode oscillations, the end screws being mounted on one longitudinal face of said wave guide and the intermediate screw being mounted on the opposite face, the spacing between adjacent screws being equal to

$$\frac{3\lambda_g}{16}$$

where λ_g is the wavelength propagated in said wave guide, one of said screws being thereby at a point where the susceptive component of the wave-guide admittance is inductive, whereby said screws may be adjusted to cancel said inductive component.

2. In combination, a source of microwave oscillations, a load, a rectangular wave guide forming an enclosed conductive device connected to said source for propagating microwaves there-through, said wave guide having a characteristic impedance and extending between said source and load, and an impedance matching transformer in said wave guide comprising three capacitance reactance screws paralleling each other and spaced along said wave guide, each screw being adjustable transversely of the longitudinal axis of said guide and projecting through the wall of said guide into the interior thereof, each screw extending along the electric vector of the dominant mode oscillations, the end screws being mounted on one longitudinal face of said wave guide and the intermediate screw being mounted on the opposite face, the spacing between adjacent screws being equal to

$$\frac{3\lambda_g}{16}$$

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where λ_g is the wavelength propagated in said wave guide, one of said screws being thereby at a point where the susceptive component of the wave-guide admittance is inductive, whereby said screws may be adjusted to cancel said inductive component, the maximum penetration of each of said screws into the interior of the wave guide being limited to a length corresponding to a capacitance susceptance not greater than twice the characteristic conductance of said guide.

SLOAN D. ROBERTSON.

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