Aug. 2, 1966 C. F. EDWARDS 3,264,584

ADJUSTABLE IMPEDANCE MATCHING TRANSFORMERS

Filed Nov. 15, 1961 4 Sheets-Sheet 1

FIG. 1A

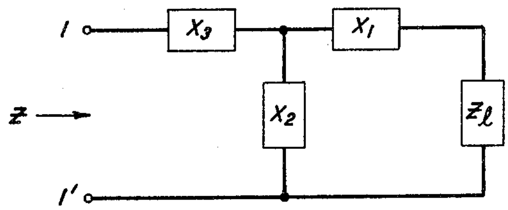

FIG. 1B

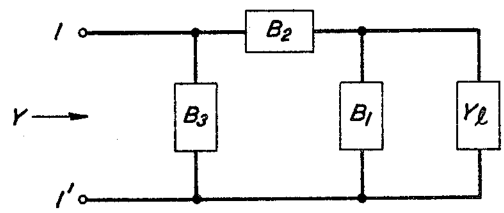

FIG. 2A

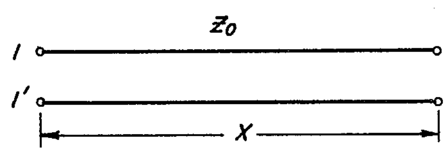

FIG. 2B

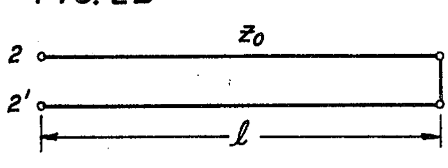

FIG. 4

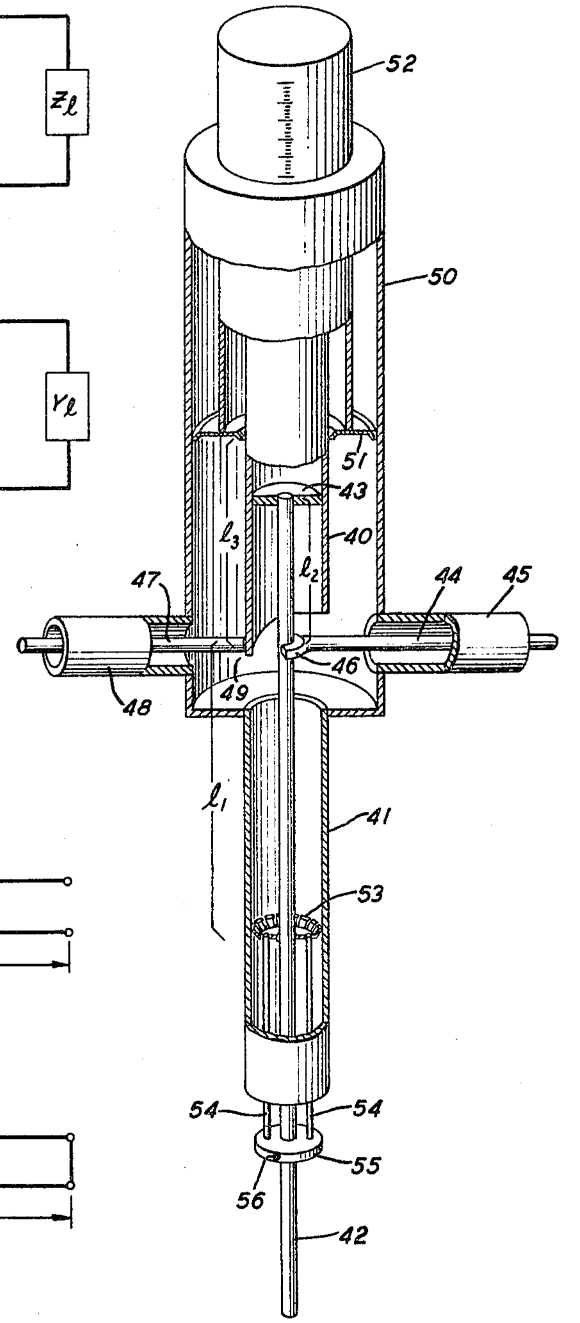

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FIG. 3B

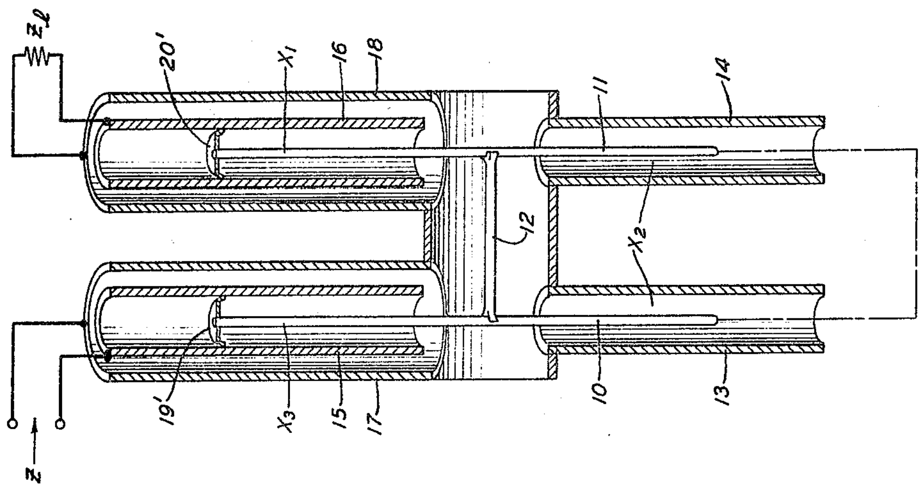
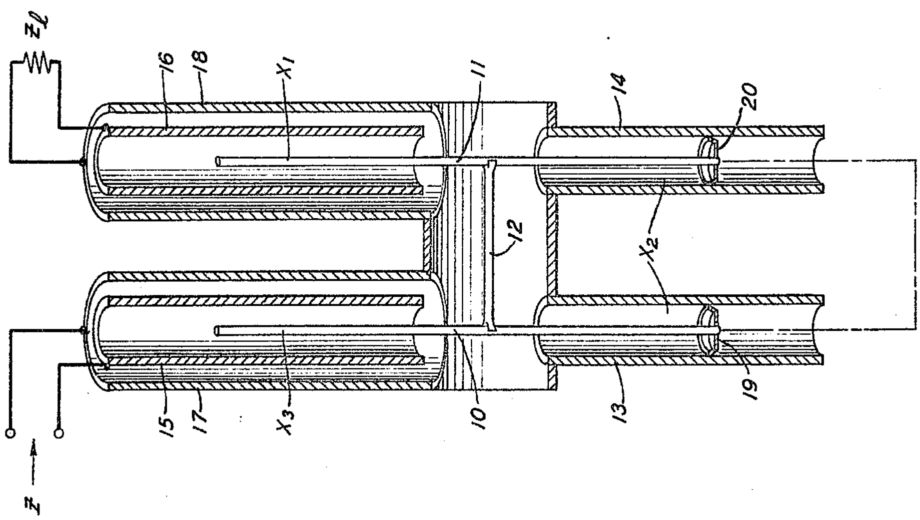


FIG. 3A



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ADJUSTABLE IMPEDANCE MATCHING TRANSFORMERS

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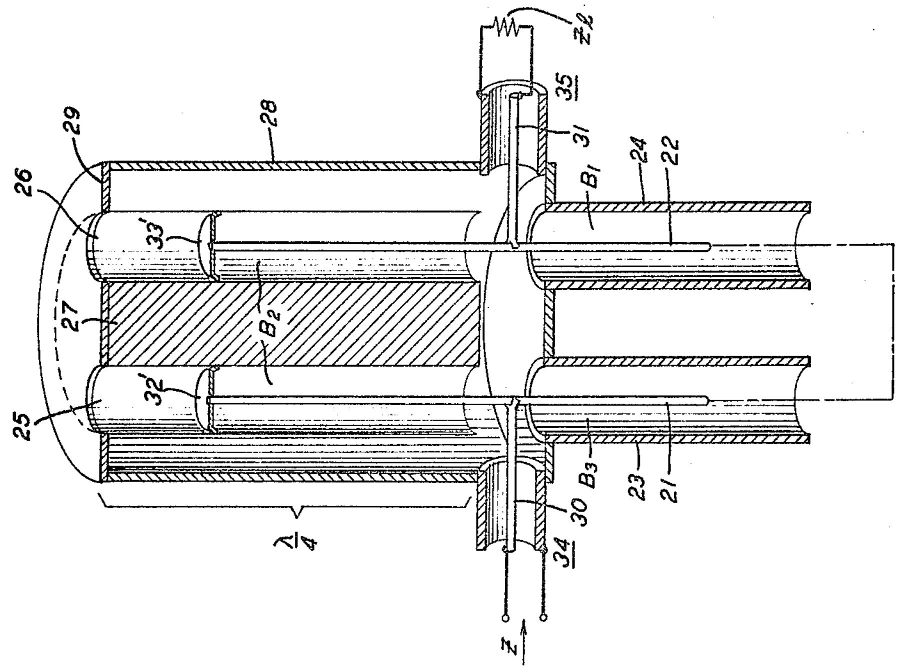

FIG. 3D

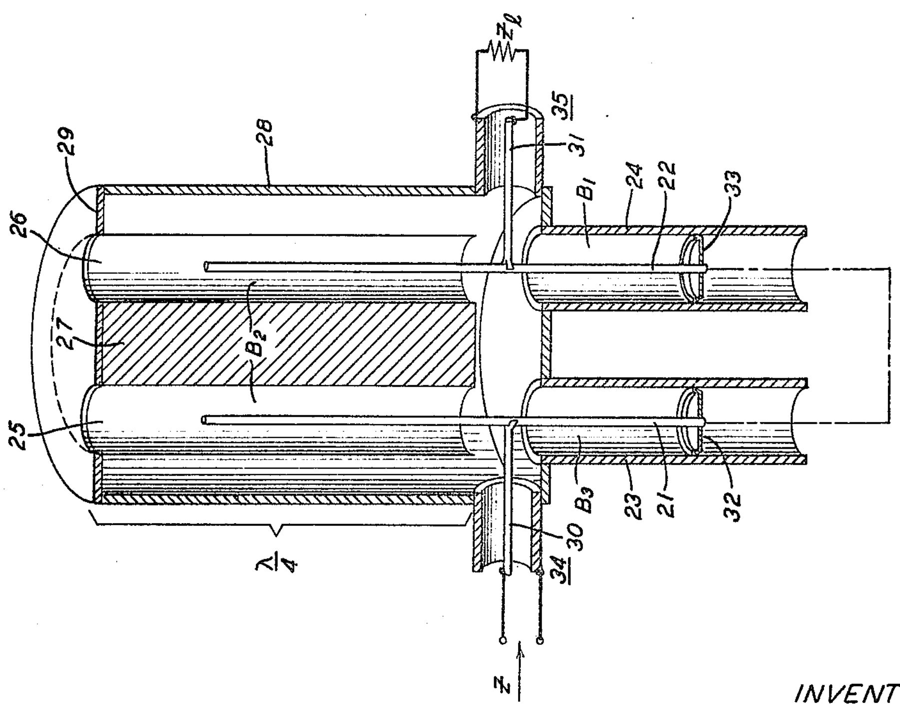

FIG. 3C

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ADJUSTABLE IMPEDANCE MATCHING TRANSFORMERS

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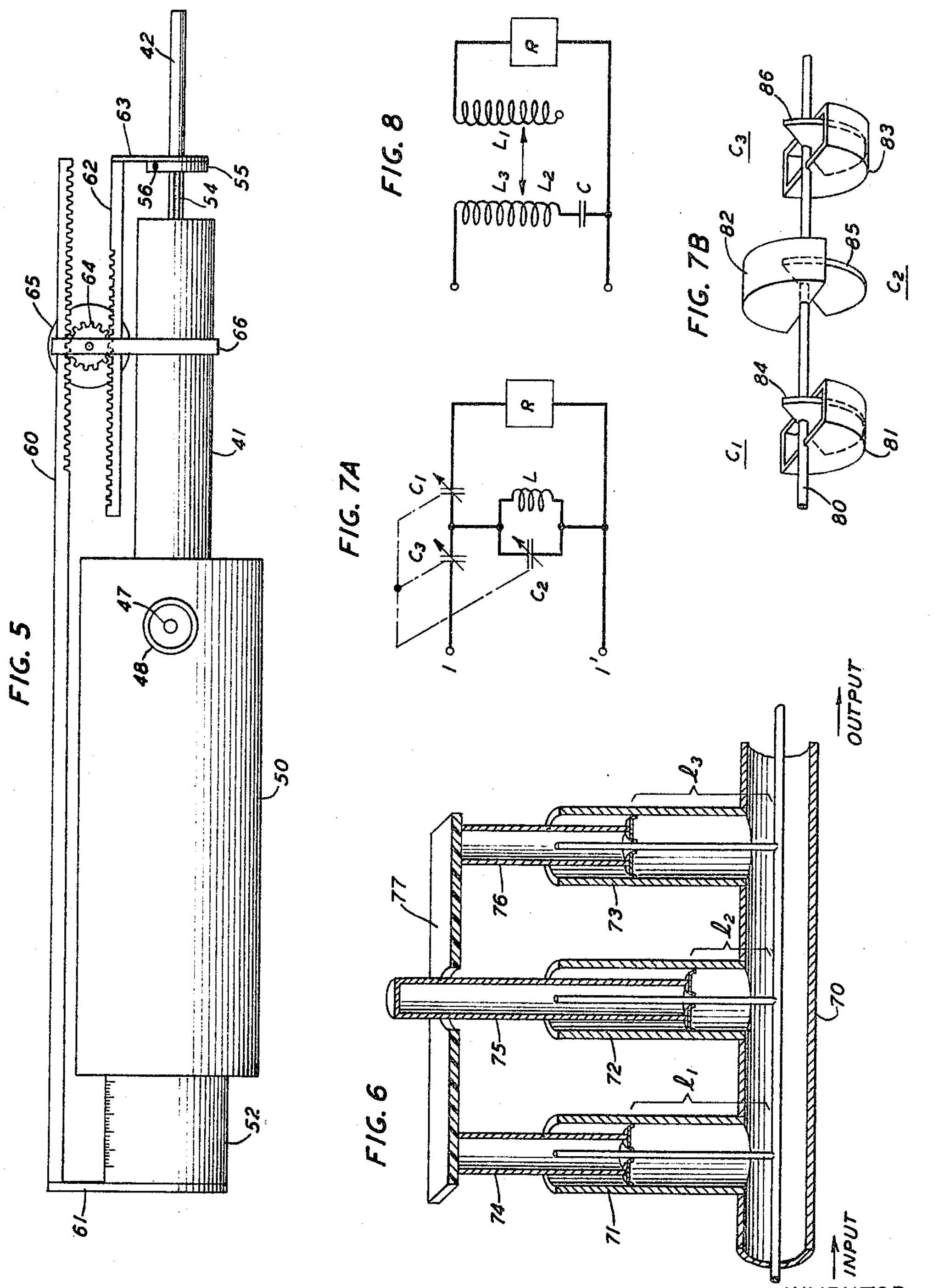

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ADJUSTABLE IMPEDANCE MATCHING TRANSFORMERS

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14 Claims. (Cl. 333—33)

This invention relates to electrical networks and more particularly to adjustable impedance matching transformers.

Generally, radio frequency transmission systems are composed of many separate component parts connected by a number of low-loss transmission lines. In such systems the impedance of each of the component parts is preferably made equal to the characteristic impedance of the transmission line connecting the parts. There are several reasons for matching impedances in arbitrary systems, the primary one being that maximum energy is transferred from one component to another when their impedances are matched; moreover, a matched condition eliminates reflected wave energy and minimizes the losses in the transmission line.

Typically, components of high frequency transmission systems intended to transmit or utilize wave energy are matched to the interconnecting transmission lines by means of reactive impedance matching networks. Such networks can be lengths of transmission line utilizing tuned stubs or dielectric elements. The behavior of such matching networks is substantially equivalent to the more conventional circuits used at lower frequencies. Typically the matching network is an integrated structure which is inserted between two components to be matched or between a component and a transmission line.

For laboratory and test use it is desirable that these "impedance transformers" be variable, so that a simple manual adjustment enables the operator to match any two impedances. Transformers of the "single," "double" and "triple-stub" variety have been used extensively for this purpose but they suffer from certain drawbacks, one of which is the fact that at least two manual adjustments must be made in order to match any two impedances.

In many instances, especially those encountered in laboratory practice, it is desirable to match impedances which are purely resistive. When using one of the prior art variable impedance transformers for this purpose, it is still necessary to make at least two manual adjustments in order to eliminate any reactance introduced by the transformer itself. By a novel arrangement of reactive elements, the present invention obviates this necessity.

It is, therefore, the general object of the present invention to provide a matched coupling between networks of diverse impedances.

It is a more specific object of the present invention to provide transformers for matching purely resistive impedances and capable of being adjusted by a single manual control.

It is yet another object of the present invention to provide impedance matching transformers wherein the reactive and resistive components can be adjusted separately.

In keeping with the principles of the present invention the foregoing objects are accomplished through the use of "T" and "π" networks comprising adjustable reactance elements. In the high frequency embodiments of the invention, open and shorted coaxial line stubs are utilized as the network elements, whereas in the low frequency embodiments inductors and capacitors are utilized as the network elements.

As mentioned above, a feature of the present invention is the mechanical coupling between the elements of

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the impedance matching transformer which allows the tuning to be done with one manual adjustment. In one specific embodiment of the invention the impedance matching ratio is adjusted by varying the reactances of a plurality of coupled open-circuited and short-circuited coaxial line sections. In accordance with the principles of the present invention the reactances are varied simultaneously and in such a manner that the reactances of two of the sections are always maintained equal to each other and the reactance of the third section is maintained equal to the negative of the other two.

In an illustrative embodiment of the invention, the mechanical means for performing this adjustment comprises a rack and pinion gear arrangement mounted on the transformer structure. In the low frequency embodiments of the invention the impedance matching ratio of the transformer is adjusted by varying either the capacitances or the inductances of the various network elements simultaneously. In these embodiments the mechanical means is easily integrated into the capacitor or inductor structure in the form of "ganged" capacitors and inductors.

The above mentioned and other features and objects of this invention will become more apparent by reference to the following description taken in conjunction with the accompanying drawings in which:

FIGS. 1A and 1B are simplified circuit diagrams of "T" and "π" networks for facilitating the description of the invention;

FIGS. 2A and 2B are schematic representations of open and shorted transmission lines showing the impedances associated therewith;

FIGS. 3A, 3B, 3C, and 3D are cross-sectional views of four high frequency embodiments of the present invention;

FIG. 4 is a pictorial view, partially in cross section, of a preferred embodiment of the invention;

FIG. 5 is a pictorial view of the embodiment of FIG. 4 illustrating the mechanical ganging of the tuning controls;

FIG. 6 is a longitudinal cross-sectional view of a "triple stub" coaxial impedance transformer used as an aid in explaining the means by which principles of the present invention may be applied thereto;

FIG. 7A is a schematic representation of a low frequency embodiment in accordance with the principles of the present invention;

FIG. 7B is a pictorial view of a possible capacitor capable of being utilized in the embodiment of FIG. 7A; and

FIG. 8 is a schematic representation of yet another low frequency embodiment in keeping with the principles of the present invention.

Referring to the circuit of FIG. 1A, there is shown a T-network consisting of reactive elements X_1, X_2, and X_3 to which there is coupled a load impedance Z_l. The impedance Z of the circuit at terminals 1–1′ is given by the equation

$$Z=jX_3+\frac{1}{1/(Z_l+jX_1)+1/jX_2} \qquad (1)$$

By making $X_1=-X_2$, Equation 1 becomes

$$Z=\frac{X_1^2}{Z_l}+j(X_3-X_1) \qquad (2)$$

and if the T is made symmetrical by making $X_1=X_3$, then

$$Z=\frac{X_1^2}{Z_l} \qquad (3)$$

Similarly, in the π-network of FIG. 1B, if the reactive elements B_1, B_2, and B_3 are adjusted so that

$$B_1=B_3=-B_2$$

the equation for the admittance as seen across terminals **1–1'** is

$$Y=\frac{B_1^2}{Y_1} \qquad (4)$$

Equations 3 and 4 are similar in form to the input impedance and admittance of quarter-wave sections of transmission line terminated with loads Z_1 and Y_1, respectively. These equations are

$$Z=\frac{Z_0^2}{Z_1} \qquad Y=\frac{Y_0^2}{Y_1}$$

where Z_0 and Y_0 are the characteristic impedance and the characteristic admittance of the lines.

In other words, the networks of FIGS. 1A and 1B, when properly adjusted, behave electrically as quarter-wave transmission line sections and enjoy the same impedance transforming properties. The important distinction between an actual quarter-wave transmission line and a so-called "artificial transmission line" of FIG. 1A or 1B is that the characteristic impedance of the artificial transmission line can be easily varied whereas the characteristic impedance of a real line can not. And even if, with some difficulty, the impedance of a real line can be varied, the range of variation is quite limited.

If, however, sections of transmission line are connected together and their lengths proportioned in the manner to be explained in detail hereinbelow, the disadvantages peculiar to the individual transmission line when used as a quarter-wave matching section no longer exist. In accordance with the invention the several lengths of transmission line serve, not as impedance transformers, but as reactance elements in a "T" or "π" network.

FIG. 2A shows an open-circuited transmission line section of length x having a characteristic impedance Z_0. In practice, the resistive losses of a short line can be neglected and when this is done the impedance looking into terminals **1–1'** is a pure reactance given by:

$$X_{oc}=-Z_0 \cot \beta x$$

where the phase constant β equals $2\pi/\lambda$, and λ is the wavelength in the transmission line. If viewed from the admittance standpoint, the susceptance B_{oc} at terminals **1–1'** is given by:

$$B_{oc}=\frac{1}{Z_0} \tan \beta x$$

FIG. 2B shows a section of transmission line of length l and characteristic impedance Z_0 short-circuited at one of its ends. Again, if the resistive losses are neglected the impedance looking into terminals **2–2'** is a pure reactance

$$X_{sc}=Z_0 \tan \beta l \qquad (5)$$

and the admittance of the shorted line is a pure susceptance given by

$$B_{sc}=-\frac{1}{Z_0} \cot \beta l \qquad (6)$$

If the lengths of the two lines are made adjustable so that the sum of their lengths $x+l$ is equal to $\lambda/4$, the reactance of the open-circuited section can be written as

$$X_{oc}=-Z_0 \cot \beta x$$

Since $x=(\lambda/4-l)$,

$$X_{oc}=-Z_0 \cot \beta(\lambda/4-l)=-Z_0 \cot (\pi/2-\beta l)$$

However, since $\cot (\pi/2-A)=\tan A$, then

$$X_{oc}=-Z_0 \tan \beta l \qquad (7)$$

The susceptance of the open-circuited section is

$$B_{oc}=\frac{1}{Z_0} \tan \beta x$$

Substituting for x,

$$B_{oc}=1/Z_0 \tan \beta(\lambda/4-l)=1/Z_0 \tan (\pi/2-\beta l)$$

and since $\tan (\pi/2-A)=\cot A$, then

$$B_{oc}=\frac{1}{Z_0} \cot \beta l \qquad (8)$$

It is apparent from Equations 5 through 8 that $X_{sc}=-X_{oc}$ and $B_{sc}=-B_{oc}$. These, however, are the requirements that must be met by X_1 and X_2 and B_1 and B_2 in the networks of FIGS. 1A and 1B in order to obtain impedance transforming action. Thus, by combining an open and a shorted transmission line section, the sum of whose lengths is a quarter wavelength, and by adding another open or shorted transmission line section as the third reactive element, various circuits having the desired impedance transforming properties are obtained. Furthermore, if the reactance of the various sections is changed by varying their lengths, the circuits are capable of providing a wide range of impedance ratios.

FIGS. 3A and 3B are cross-sectional views of two embodiments of the invention utilizing coaxial line construction arranged in the manner of a T-network. FIG. 3A shows a high-pass T-network consisting of substantially identical quarter-wavelength inner conducting rods **10** and **11** joined by conductor **12** which makes a slideable contact with each along their respective lengths. The regions of rods **10** and **11** below the slideable junction provided by conductor **12** are surrounded by cylindrical outer conductors **13** and **14**, respectively. The regions of rods **10** and **11** above these points are surrounded by cylindrical conducting sheaths **15** and **16** which, in turn, are surrounded by cylindrical outer conductors **17** and **18**, respectively. For the sake of clarity, the means whereby conductor **12** and sheaths **15** and **16** are held in position are not shown in FIG. 3A. Such means can, however, be any of the low-loss dielectric beads or spacers well known in the art.

Outer conductors **13**, **14**, **17**, and **18** are all conductively joined in a manner so as to provide a shield around rods **10** and **11**, conductor **12**, and sheaths **15** and **16**. Inner conducting rods **10** and **11** are shorted to outer conductors **13** and **14** by means of shorting disks **19** and **20**. This construction enables rods **10** and **11** to move in a direction parallel to their longitudinal axes while maintaining contact with outer conductors **13** and **14**. The dashed line connecting rods **10** and **11** indicates a mechanical connection for moving both rods simultaneously.

Input connections to the device are provided across the open ends of outer conductor **17** and sheath **15**. The load impedance Z_1 to be transformed is connected across outer conductor **18** and sheath **16**. The input and output connections can, of course, be interchanged as seen from the symmetry of the device.

Returning to the terminology of FIG. 1A, it is evident that the coaxial section formed by rod **11** and sheath **16** corresponds to the reactance X_1, and the coaxial section formed by rod **10** and sheath **15** corresponds to reactance X_3. The parallel combination of the two sections formed by rods **10** and **11** and outer conductors **13** and **14**, respectively, corresponds to the third reactance X_2.

In operation, the impedance transforming ratio is changed when rods **10** and **11** are moved simultaneously in a direction parallel to their axes. From the standpoint of symmetry, it is seen that X_1 and X_3 are always equal; and since the lengths of rods **10** and **11** are one-quarter wavelength at the operating frequency,

$$X_2=-X_1$$

In FIG. 3B, there is shown a low-pass T-network substantially identical to the high-pass network of FIG. 3A. In this figure like numerals have been utilized to indicate the correspondences between the elements of this embodiment and that of FIG. 3A. The only substantial difference between this embodiment and the previous one is that shorting disks **19'** and **20'** have replaced disks **19** and **20**, respectively. The functions of the various elements and combinations of elements are substantially the same as those of FIG. 3A except that rods **10** and **11** are now shorted to conducting sheaths **15** and **16**.

In keeping with the principles of the present invention, the coaxial line sections formed by rods **10** and **11** and sheaths **15** and **16**; and sheaths **15** and **16** and outer conductors **17** and **18** are designed so that their characteristic impedances are equal. Since the coaxial sections formed by rods **10** and **11** and outer conductors **13** and **14** are in parallel, they are designed to have a characteristic impedance equal to twice this value.

In FIG. 3C there is shown in cross section another embodiment of the present invention intended for operation at high radio frequencies. This embodiment is a coaxial π-network arranged in the manner of a high-pass filter. In this embodiment two substantially identical quarter-wavelength conducting rods **21** and **22** are slideably connected along their lengths to conductors **30** and **31**, respectively. Conductors **30** and **31**, in turn, serve as the inner conductors of the input and output coaxial line sections **34** and **35**, respectively. Rods **21** and **22** are surrounded by outer conductors **23** and **24** over that portion of their lengths below the points of connection with conductors **30** and **31**. The regions of rods **21** and **22** lying above these points extend into two cylindrical cavities **25** and **26**, respectively, which have been formed in a solid conducting element **27**.

Element **27**, which is proportioned so that its length is equal to one-quarter wavelength at the operating frequency, is, in turn, surrounded by an outer conductor **28** and conductively attached thereto by end-plate **29**. The coaxial input and output sections as well as outer conductors **23**, **24**, and **28** are conductively joined so as to provide a shield surrounding rods **21** and **22** and conductors **30** and **31**.

Shorting disks **32** and **33** are attached to the lower end points of rods **21** and **22**, respectively, so that each rod is slideably shorted to its corresponding outer conductor **23** and **24**. Again, for the sake of clarity, the means for positioning and holding conductors **30** and **31** have not been shown but can comprise any of the low-loss dielectric beads or spacers known in the art.

In the terminology set forth in connection with FIG. 1B, the coaxial section formed by rod **22** and outer conductor **24** corresponds to the susceptance B_1. The coaxial section formed by rod **21** and outer conductor **23** corresponds to susceptance B_3 and the series combination of the coaxial sections formed by rod **21** and cavity **25** and rod **22** and cavity **26** corresponds to the third susceptance B_2. Again, it is obvious from the symmetry of the structure that B_1 and B_3 are always equal; and since the lengths of rods **21** and **22** are one-quarter wavelength at the operating frequency, $B_2=-B_1$.

In FIG. 3D, there is shown another embodiment of the present invention substantially identical to that of FIG. 3C, wherein the numbering of the elements has been carried over from the corresponding elements of that embodiment. This embodiment is a low-pass π-network wherein the shorting disks **32'** and **33'** have replaced disks **32** and **33** so that rods **21** and **22** are slideably shorted to the inner conducting surface of cylindrical cavities **25** and **26**, respectively.

In operation, rods **21** and **22** in both embodiments **3C** and **3D** are moved simultaneously along their longitudinal axes. The mechanical means for operating this portion is not shown but merely indicated by the dashed line.

In the embodiments of FIGS. 3C and 3D the coaxial line sections formed by rods **21** and **22** inside outer conductors **23** and **24** are designed to have a given characteristic impedance, and since the coaxial sections formed by rods **21** and **22** inside cavities **25** and **26** are in series, these sections are designed to have a characteristic impedance of one-half this value. As mentioned above, the coaxial line section formed by element **27** and outer conductor **28** is one-quarter wavelength long; therefore, it has no effect on the other coaxial sections and its characteristic impedance is not critical.

In FIG. 4 there is shown, partially in cross section, a refinement of the present invention derived from the embodiment of FIG. 3C. This embodiment consists of hollow, cylindrical conductors **40** and **41** of substantially equal cross-sectional dimensions oriented so that their ends are in close proximity and their axes colinear. A conducting rod **42** extends along this common axis through conductor **41** and into conductor **40**.

Rod **42** is conductively insulated from conductor **40** by dielectric disk **43** which allows longitudinal motion of rod **42** relative to conductor **40**. Rod **42** is joined to inner conductor **44** of coaxial transmission line section **45** by means of a spring contact **46**. Contact **46** is located in the region between conductors **40** and **41**. The nature of contact **46** is such that it allows rod **42** to move longitudinally while maintaining electrical contact with inner conductor **44**.

Cylindrical conductor **40** is conductively connected to inner conductor **47** of coaxial line transmission section **48** at its end nearest conductor **41**. Connection **49** is a rigid one and allows no relative motion between conductors **40** and **47**.

Conductor **40**, which surrounds a portion of rod **42**, is, in turn, surrounded by a cylindrical outer conductor **50**. Conductor **50** extends the entire length of conductor **40** and is joined to conductor **41** and the outer conductors of transmission line sections **45** and **48**. In this manner conductors **41** and **50** and the outer conductors of transmission line sections **45** and **48** form a continuous surface.

Conductors **40** and **50** are conductively shorted by annular shorting ring **51**. Ring **51** is attached to cylinder **52** which extends past the ends of conductors **40** and **50** and enables the position of the short provided by ring **51** to be adjusted.

Rod **42** is shorted to conductor **41** by means of annular shorting ring **53** which is attached by means of rods **54** to another ring **55** lying outside the end of conductor **41**. Set-screw **56** is provided in ring **55** in order to clamp the two rings **53** and **55** in position on rod **42**. Thus, ring **53** can be moved with respect to rod **42** and conductor **41** or with respect to conductor **41** only.

The lengths of the three coaxial sections which make up the impedance transformer in the present embodiment have been designated l_1, l_2, and l_3. Length l_1 is that of the shorted coaxial section formed by conductor **41** and rod **42** extending from spring contact **46** to shorting ring **53**. Length l_2 is that of the open-ended coaxial section formed by conductor **40** and rod **42** between contact **46** and the end of rod **42**. And length l_3 is that of the shorted coaxial section formed by outer conductor **50** and conductor **40** between junction **49** and shorting ring **51**. In keeping with the principles of the present invention, the three coaxial sections referred to are proportioned so that they all have the same characteristic impedance Z_0.

In operation, l_1 and l_3 are made equal by adjusting the position of shorting ring **51** or **53**. This adjustment is easily made if cylinder **52** and either of rods **54** has first been calibrated and the lengths marked thereon. After this preliminary adjustment rod **42** is adjusted so that the length l_1+l_2 is electrically equal to one-quarter wavelength at the operating frequency. This adjustment is facilitated by observing the impedance at input section **48** when the output section **45** is terminated with a purely resistive impedance. When the length l_1+l_2 is properly adjusted the impedance seen at the input of the device has no imaginary component.

In order to operate the device as an adjustable impedance matching transformer, it is necessary to vary the lengths so that l_1 and l_3 are always equal. The other requirement that l_1+l_2 equal one-quarter wavelength is met if the shorting ring **53** is clamped in place on rod **42** by means of set-screw **56** after its initial adjustment.

FIG. 5 illustrates the mechanical means utilized in adjusting the transformer of FIG. 4. Like numerals have been employed to designate like elements in the two figures. A dual rack and pinion arrangement comprising racks **60** and **62** and pinion gear **64** is mounted on the device as shown. Rack **60** is attached to cylinder **52** by means of end plate **61**. Similarly, rack **62** is attached to ring **55** by means of plate **63**. The two racks are engaged by pinion gear **64** which is manually adjusted by knob **65**. The whole assembly consisting of racks **60** and **62** and pinion gear **64** is mounted on outer conductor **41** by bracket **66**.

A rotational motion of knob **65** is transformed into a linear motion and varies the lengths l_1 and l_2 referred to above, while maintaining the relation $l_1=l_3$. Since l_1+l_2 has already been set equal to one-quarter wavelength by the preliminary adjustment of rod **42**, no further adjustment is necessary if the frequency remains unchanged.

If the output coaxial line **45** is terminated by a purely resistive impedance R then the transformed impedance looking into the input line **48** is given by:

$$Z=\frac{Z_0^2 \tan^2 \beta l_1}{R}$$

It is therefore seen that the range of impedance transformation can be quite large, depending on the range over which l_1, l_2 and l_3 can be varied.

It is understood that the mechanical means shown in FIG. 5 is for the purpose of illustration only and that many other mechanical ganging arrangements can be utilized in practicing the invention.

The principles of the present invention may also be applied to the prior art device known as the triple-stub tuner. FIG. 6 shows a simplified cross-sectional view of such a device. The triple-stub tuner of FIG. 6 comprises a main coaxial transmission line section **70** with three associated coaxial line stubs **71**, **72**, and **73**, arranged along the length thereof. In general, the longitudinal spacing between consecutive stubs is one-quarter wavelength at the operating frequency. The positions of the shorting rings within stubs **71**, **72**, and **73** are adjustable by means of cylinders **74**, **75**, and **76**, which may or may not be of conducting material.

The lengths of the input, intermediate, and output stubs have been designated l_1, l_2, and l_3, respectively, in order to explain the operation of the device of FIG. 6 modified by the principles of the present invention. In order to enable the triple-stub tuner to couple a network of one purely resistive impedance of a given value to that of another purely resistive impedance the following procedure should be followed. First, the lengths l_1 and l_3 are maintained substantially equal. For this purpose cylinders **74** and **76** are rigidly joined by member **77** which allows lengths l_1 and l_3 to be changed only simultaneously so that l_1 always equals l_3. Secondly, the lengths l_1+l_2 (and l_3+l_2) are made equal to one-quarter wavelength.

The second requirement is met by ganging cylinder **75** and cylinders **74** and **76** so that as l_1 and l_3 are increased l_2 is decreased by the same amount. This arrangement is easily accomplished, as it was with the embodiment of FIG. 4, by providing a rack and pinion arrangement similar to that of FIG. 5. Such a mechanism can be easily constructed by a skilled mechanic and is not illustrated in FIG. 6.

So far, the various embodiments of the present invention have only been described with regard to operation wherein one purely resistive impedance is transformed into another purely resistive impedance of a different value. For most laboratory purposes this is the only case that is encountered. If, however, it is desirable to adjust the reactive component of an impedance so as to eliminate it in the transformed impedance or to introduce a reactive component, a further step can be taken.

If it is desired to adjust the reactive component independently of the resistive component, a simple matching stub is shunted across either the input line or the output line of the device. The reactance of this stub is adjusted to any value desired without affecting the resistive component.

If, on the other hand, a small interaction between the resistive and reactive controls can be tolerated, this adjustment can be made without employing a separate stub. In this case, the real or resistive component can be adjusted using the invention as described hereinabove and then by disengaging the ganging mechanism and adjusting l_3 separately to the desired value of reactance.

The original T and π-networks of FIGS. 1A and 1B can be exploited to provide variable impedance transformers for lower frequencies. FIGS. 7A and 8 are schematic diagrams of two embodiments of the present invention employing lumped parameter circuit elements. FIG. 7A is a T-network useful in the low megacycle regions. It consists of ganged capacitors C_1, C_2, and C_3 and inductor L as the constituent reactive elements of the transformer. The input of the transformer is at terminals **1–1'** and the output is terminated by load impedance R.

Returning to the terminology developed in association with FIG. 1A, in FIG. 7A:

$$X_1=-\frac{1}{\omega C_1} \qquad (9)$$

$$X_3=-\frac{1}{\omega C_3} \qquad (10)$$

and

$$X_2=-\frac{1}{\left(\omega C_2-\frac{1}{\omega L}\right)} \qquad (11)$$

By setting $X_1=X_3$ and $X_1=-X_2$, we have:

$$-\frac{1}{\omega C_1}=\frac{1}{\left(\omega C_2-\frac{1}{\omega L}\right)}$$

or

$$\omega(C_1+C_2)=\frac{1}{\omega L}=\text{constant} \qquad (12)$$

By making the variable capacitances identical and by ganging them in such a way that C_1 and C_3 increase while C_2 decreases, then C_1+C_2 is maintained constant and Equation 12 is satisfied. The impedance of the transformer of FIG. 7A, looking into terminals **1–1'** is, from Equations 3 and 12:

$$Z=\frac{1}{(\omega C_1)^2 R}$$

FIG. 7B is a simplified pictorial illustration of a variable capacitor for use in the embodiment of FIG. 7A. The capacitor consists of shaft **80** on which there is mounted rotor plates **84**, **85**, and **86**. Stator plates **81**, **82**, and **83** are located on either side of each of the rotor plates **84**, **85**, and **86**, respectively. In this manner rotor plate **84** and stator plates **81** form a capacitor C_1, plates **82** and **85** form capacitor C_2; and plates **86** and **83** form capacitor C_3. The position of stator plates **82** are 180 physical degrees from the position of plates **81** and **83**. Therefore, the capacitance of C_2 decreases as that of C_1 and C_3 increases and if the physical dimensions and spacing of each set of plates are equal, C_1+C_2 is always constant and C_1 is always equal to C_3. The present invention should not be deemed limited by the capacitor shown in FIG. 7B, since it is included for purposes of illustration only.

FIG. 8 is a schematic representation of another low-frequency embodiment of the present invention. The low-pass T-network of FIG. 8 is similar to the high pass T of FIG. 7A except that inductances L_1, L_2, and L_3 have replaced C_1, C_2, and C_3 and capacitor C has replaced inductor L. The requirements in this transformer are that L_1 equal L_3 and L_1+L_2 or L_3+L_2 be constant. If identical tapped inductors are used it is readily seen that the above relationships can be satisfied.

In all cases it is understood that the abovedescribed arrangements are illustrative of a small number of the many specific embodiments which could represent an application of the principle of the invention. Other arrangements, including variable impedance transformers utilizing transmission lines other than the coaxial type can readily be devised in accordance with these principles by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. In combination, a plurality of variable reactances, means for connecting a first variable reactance X_1 between a first terminal and a first common junction, means for connecting a second variable reactance X_2 between said first common junction and a second common junction, means for connecting a third variable reactance X_3 between said first common junction and a second terminal where $X_1=X_3=-X_2$, input means connected between said first terminal and said second common junction, output means connected between said second terminal and said second common junction, and a single means for adjusting all of said reactances simultaneously while maintaining the relations $X_1=X_3=-X_2$.

2. The combination according to claim **1** wherein said first and third variable reactances are variable capacitors and said second variable reactance is a parallel combination of an inductor and a variable capacitor.

3. The combination according to claim **1** wherein said first and third variable reactances are variable inductors and said second variable reactance is a series combination of a capacitor and a variable inductor.

4. The combination according to claim **1** wherein said first and third variable reactances are open-circuited transmission line stubs and said second variable reactance is at least one short-circuited transmission line stub.

5. The combination according to claim **1** wherein said first and third variable reactances are short-circuited transmission line stubs and said second variable reactance is at least one open-circuited transmission line stub.

6. An adjustable impedance matching transformer comprising, in combination, a plurality of variable reactances, means for connecting a first variable reactance X_1 between a first terminal and a common junction, means for connecting a second variable reactance X_2 between said first terminal and a second terminal, means for connecting a third variable reactance X_3 between said second terminal and said common junction where $X_1=X_3=-X_2$, input means connected between said first terminal and said common junction, output means connected between said second terminal and said common junction, and a single means for adjusting all of said reactances simultaneously while maintaining the relations $X_1=X_3=-X_2$.

7. The combination according to claim **6** wherein said first and third variable reactances are open-circuited transmission line stubs and said second variable reactance is at least one open-circuited transmission line stub.

8. The combination according to claim **6** wherein said first and third variable reactances are short-circuited transmission line stubs and said second variable reactance is at least one open-circuited transmission line stub.

9. A variable impedance transformer including, in combination, a plurality of sections of coaxial transmission line all having the same characteristic impedance, and connected as follows: a first section of coaxial transmission line comprising a hollow inner conductive cylinder and a surrounding outer conductive cylinder; second and third sections of coaxial transmission line, each having an inner conductor and a surrounding outer conductor, and each having one end thereof abutting upon one end of said first line; adjustable means for conductively terminating the other end of said first line located at a distance l_3 from said one end; the outer conductors of said second and third lines making conductive contact with the outer cylinder of said first line; means for connecting the inner conductor of said second line to the inner cylinder of said first line at said one end; a fourth section of coaxial transmission line having an inner conductor and a surrounding outer conductor colinearly aligned with said first line with the outer conductors thereof in conductive contact; the inner conductor of said fourth line extending past the inner conductor of said third line and making slidable contact therewith and further extending into said hollow inner cylinder a distance l_2 past said slidable contact and forming therewith a fifth section of coaxial transmission line; adjustable means for conductively terminating said fourth line at a distance l_1 from said slidable contact; means for simultaneously varying said distances l_1, l_2 and l_3 while maintaining the relationships $l_1=l_3$ and l_1+l_2 equal to a constant; and input and output means connected to the other ends of said second and third lines respectively.

10. An adjustable impedance matching transformer arranged in the manner of a high-pass T-network comprising a pair of parallel conducting rods, means for conductively connecting said rods at corresponding points intermediate the ends thereof, a first pair of hollow cylindrical conductors coaxial to and surrounding a portion of each of said rods and extending from said points past one pair of corresponding ends of said rods, a second pair of hollow cylindrical conductors coaxial to and surrounding a portion of each of said rods and extending from said points past the other corresponding ends of said rods, said first and second pairs of cylindrical conductors being conductively insulated from each other, a third pair of hollow cylindrical conductors coaxial to and surrounding said second pair of cylindrical conductors over the entire lengths thereof, said first and third pairs of cylindrical conductors being conductively connected, a single mechanical means for simultaneously varying the position of said points along the lengths of said rods, input means connected between one of said second pair of cylindrical conductors and the corresponding conductor of said third pair of cylindrical conductors, output means connected between the other of said second pair of cylindrical conductors and the corresponding conductor of said third pair of cylindrical conductors, and means for conductively connecting corresponding ends of said rods to adjacent points on the respective conductors of said first pair of cylindrical conductors.

11. An adjustable impedance matching transformer arranged in the manner of a low-pass T-network comprising a pair of parallel conducting rods, means for conductively connecting said rods at corresponding points intermediate the ends thereof, a first pair of hollow cylindrical conductors coaxial to and surrounding a portion of each of said rods and extending from said points past one pair of corresponding ends of said rods, a second pair of hollow cylindrical conductors coaxial to and surrounding a portion of each of said rods and extending from said points past the other corresponding ends of said rods, said first and second pairs of cylindrical conductors being conductively insulated from each other, a third pair of hollow cylindrical conductors coaxial to and surrounding said second pair of cylindrical conductors over the entire lengths thereof, said first and third pairs of cylindrical conductors being conductively connected, a single mechanical means for simultaneously varying the position of said points along the lengths of said rods, input means connected between one of said second pair of cylindrical conductors and the corresponding conductor of said third pair of cylindrical conductors, output means connected between the other of said second pair of cylindrical conductors and the corresponding conductor of said third pair of cylindrical conductors, and means for conductively connecting corresponding ends of said rods to adjacent points on the respective conductors of said second pair of cylindrical conductors.

12. An adjustable impedance matching transformer arranged in the manner of a high-pass π-network comprising a pair of parallel conducting rods, means for conductively connecting the inner conductors of a pair of coaxial transmission line sections to said rods at corresponding points intermediate the ends thereof, a first pair of hollow cylindrical conductors coaxial to and surrounding a portion of each of said rods and extending from said points past one pair of corresponding ends of said rods, the other corresponding ends of said rods extending into a pair of cylindrical cavities formed in a solid cylindrical conductor, a third hollow cylindrical conductor coaxial to and surrounding said solid cylindrical conductor over the entire length thereof, said third hollow cylindrical conductor being conductively connected to said solid cylindrical conductor, to said first pair of hollow cylindrical conductors, and to the outer conductors of said pair of coaxial transmission line sections, input means connected to one of said coaxial transmission line sections and output means connected to the other of said coaxial transmission line sections, a single mechanical means for simultaneously varying the position of said points along the lengths of said rods, and means for conductively connecting corresponding ends of said rods to adjacent points on said first pair of cylindrical conductors.

13. An adjustable impedance matching transformer arranged in the manner of a low-pass π-network comprising a pair of parallel conducting rods, means for conductively connecting the inner conductors of a pair of coaxial transmission line sections to said rods at corresponding points intermediate the ends thereof, a first pair of hollow cylindrical conductors coaxial to and surrounding a portion of each of said rods and extending from said points past one pair of corresponding ends of said rods, the other corresponding ends of said rods extending into a pair of cylindrical cavities formed in a solid cylindrical conductor, a third hollow cylindrical conductor coaxial to and surrounding said solid cylindrical conductor over the entire length thereof, said third hollow cylindrical conductor being conductively connected to said solid cylindrical conductor, to said first pair of hollow cylindrical conductors, and to the outer conductors of said pair of coaxial transmission line sections, input means connected to one of said coaxial transmission line sections and output means connected to the other of said coaxial transmission line sections, a single mechanical means for simultaneously varying the position of said points along the lengths of said rods, and means for conductively connecting corresponding ends of said rods to adjacent points on the inner surface of said cylindrical cavities.

14. A triple-stub coaxial line tuner comprising, in combination, a main coaxial line section, first, second, and third short-circuited stubs connected in shunt with said main section along the length thereof and spaced one-quater wavelength apart, said stubs having effective electrical lengths equal to l_1, l_2, and l_3, respectively, a single mechanical means for adjusting all of said lengths simultaneously while maintaining the relations $l_1=l_3$ and l_1+l_2=constant.

References Cited by the Examiner

UNITED STATES PATENTS

2,284,529	5/1942	Mason	333—33
2,373,233	4/1945	Dow	333—33
2,390,839	12/1945	Klingaman	333—33
2,404,279	7/1946	Dow	333—33
2,419,985	5/1947	Brown	333—33
2,422,160	6/1947	Woodward	333—33
2,428,272	9/1947	Evans	333—73
2,428,485	10/1947	Carter	333—33
2,438,912	4/1948	Hansen	333—33

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