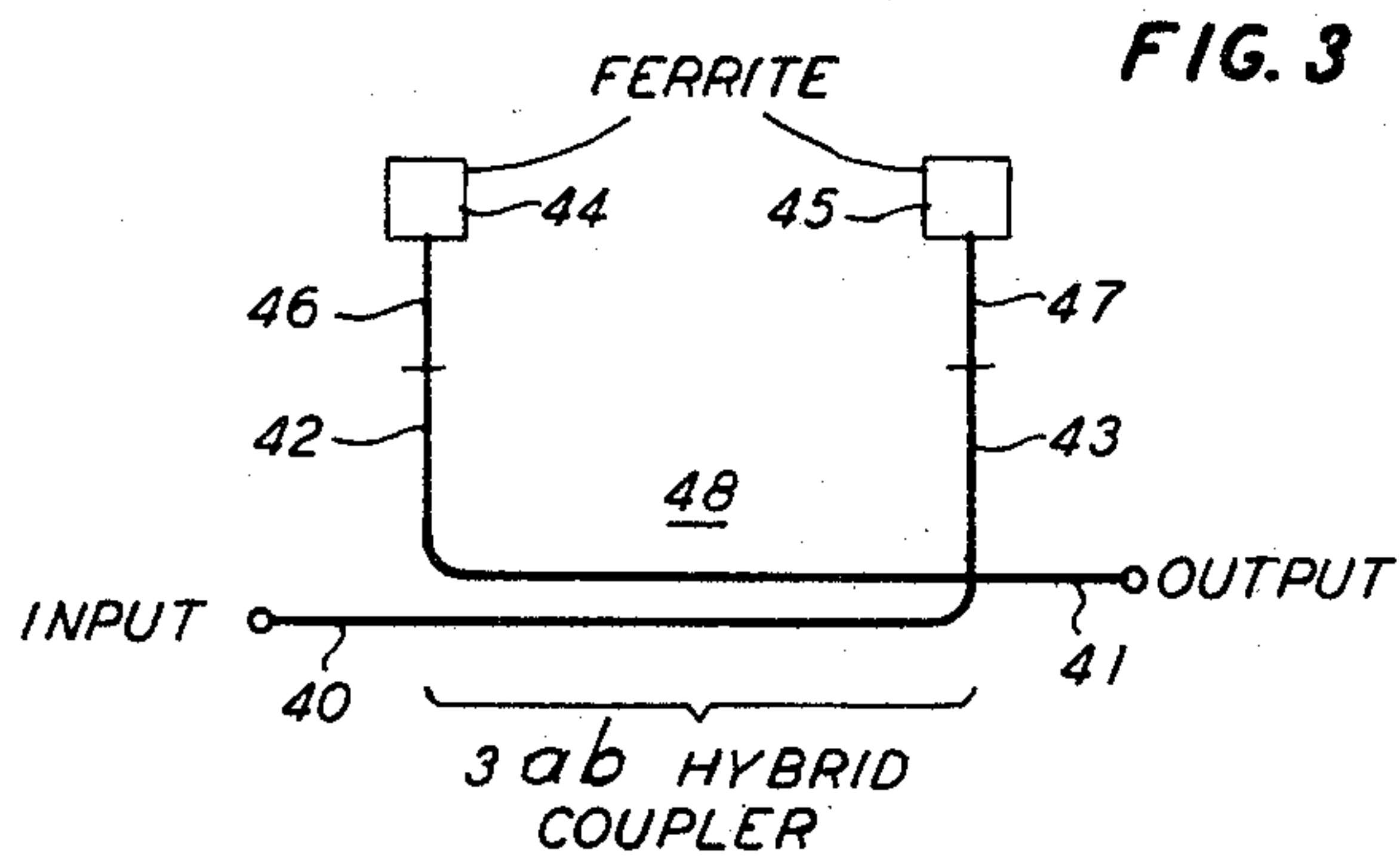
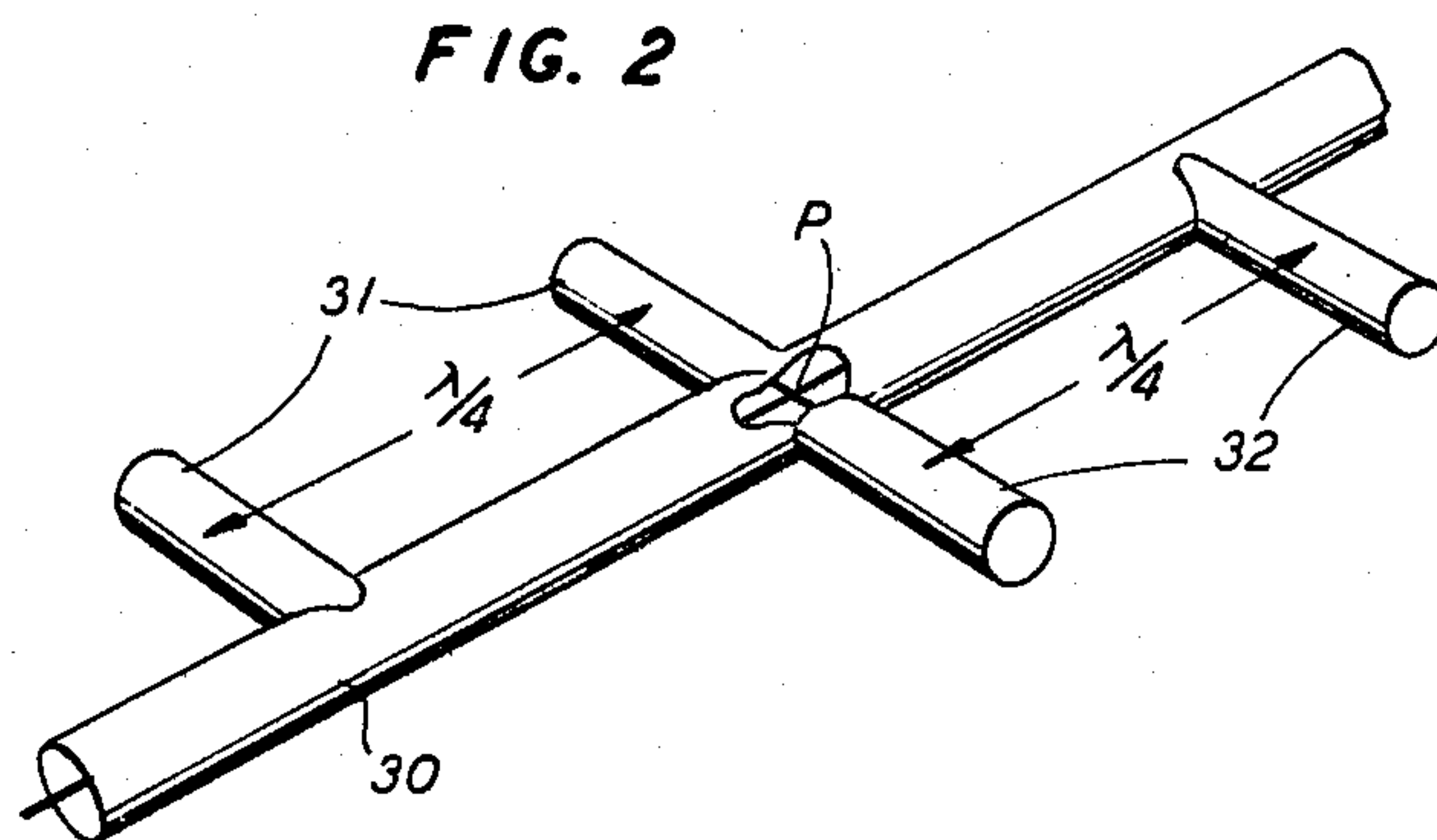
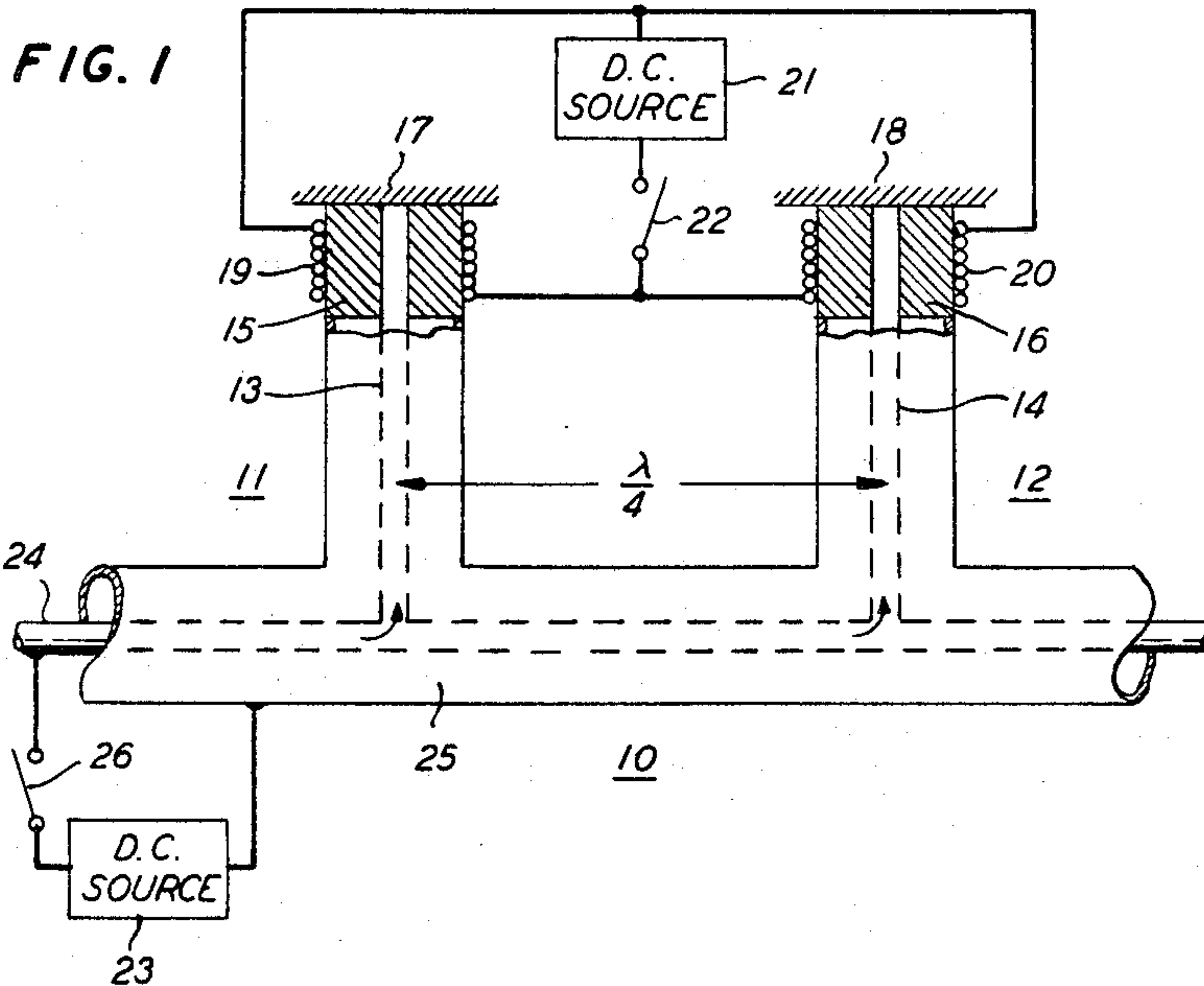


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FERRITE PHASE SHIFTER HAVING LONGITUDINAL AND CIRCULAR
MAGNETIC FIELDS APPLIED TO THE FERRITE
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FERRITE PHASE SHIFTER HAVING LONGITUDINAL AND CIRCULAR MAGNETIC FIELDS APPLIED TO THE FERRITE

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ABSTRACT OF THE DISCLOSURE

This application describes a coaxial line phase shifter utilizing ferrite elements to change the impedance of a pair of stubs spaced a quarter wavelength apart along the line. By placing the ferrite around the inner conductor of the coaxial line, the interaction between the signal field and the magnetic biasing fields are maximized, reducing the amplitude of the biasing field required.

This invention relates to electromagnetic wave phase shifters in which a change in phase shift is produced by altering the direction of magnetization within a magnetic element.

In accordance with the present invention, phase shift is produced by changing the input susceptance of a pair of substantially identical reactively terminated stubs coupled to a transmission line. In particular, the invention contemplates the use of TEM-mode transmission line, such as coaxial cable and strip transmission line, in which a ferrimagnetic material completely surrounds a portion of the inner conductor of each stub. In operation, the effective length of each stub and, hence, its input susceptance is changed by switching the direction of magnetization within the magnetic material between longitudinal and transverse circular. The result is to change the phase shift experienced by the signal wave propagating past the pair of stubs.

In a first illustrative embodiment of the invention, useful in narrow band applications, the two stubs are coupled directly to the principal transmission line and longitudinally spaced therealong a quarter of a wavelength at the operating frequency. It is an advantage of this first embodiment of the invention that the magnetic elements are not located in the principal signal path.

In a second embodiment of the invention, useful in broadband applications, the stubs are coupled to the signal path by means of a 3 db quadrature hybrid junction. In particular, the stubs are connected to one pair of conjugate branches of the hybrid junction and operate to change their effective lengths. The other pair of conjugate branches are connected in series with the signal path.

Thus, in both embodiments, the stubs are coupled to the principal signal path in a manner to be energized in time quadrature and, in both embodiments, phase shift is produced by altering the direction of magnetization of the magnetic element between longitudinal and transverse circular.

These and other objects and advantages, the nature of the present invention, and its various features, will appear more fully upon consideration of the various illustrative embodiments now to be described in detail in connection with the accompanying drawings, in which:

FIG. 1 shows a first embodiment of the invention illustrating the use of ferrite-loaded stubs coupled to a coaxial transmission line;

FIG. 2 shows the use of two pairs of stubs; and

FIG. 3 shows the use of ferrite-loaded stubs in hybrid-coupled phase shifters.

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Referring to the drawings, FIG. 1 shows a first illustrative embodiment of the invention comprising a section of coaxial transmission line 10 to which there are coupled two, substantially identical, longitudinally spaced coaxial stubs 11 and 12. In particular, the stubs are spaced apart a quarter of a wavelength at the operating frequency.

In general, the stubs can have any convenient length, and can be either open-circuited, short-circuited, or otherwise reactively terminated. In the embodiment of FIG. 1, the stubs are conductively short-circuited for convenience, as will be explained hereinbelow.

A portion of the inner conductors 13 and 14, of stubs 11 and 12, respectively, is completely surrounded by elements 15 and 16 of magnetic material. Advantageously, so-called "latching" ferrite is used as it has the convenient property that its magnetic polarization can be established by means of a current pulse. Consequently, no holding current is required and more efficient operation is realized. (For a discussion of latching ferrites see "Microwave 'Square Loop' Ferrimagnetic Materials for Application in Fast Switching Phased Array Components," by G. R. Harrison, L. R. Hodges, Jr., D. R. Taft and R. E. Greenwood, Technical Documentary Report No. RADDC-TDR-64-225, vol. 1, July 1964, pages 242-271.) In general, the ferrite can be located anywhere along the respective stubs. However, they are advantageously located in a region of high current, such as adjacent to the short circuits 17 and 18 at the ends of the respective stubs.

Each of the respective stubs is surrounded by a coil of wire 19 and 20 over a region substantially coextensive with the ferrite members. The coils are energized from a direct current source 21, through a switch 22. A second source of direct current 23 is connected between the inner conductor 24 and the outer conductor 25 of coaxial line 10 through a second switch 26.

In order to produce maximum phase shift with minimum magnetic material, it is necessary that a maximum change in interaction is produced between the magnetic material and the signal wave when the direction of magnetization within the magnetic material is switched. As is known, the interaction between a ferrite element and a signal is maximum when the magnetic field associated with the signal and the direction of magnetization within the ferrite material are perpendicular to each other. On the other hand, this interaction is minimal when the signal field and the magnetization are parallel to each other. Since the signal magnetic field configuration in a coaxial line is transverse circular, one of selected magnetization states utilized, in accordance with the teachings of the present invention, is the transverse circular state. This is produced in the ferrite by momentarily closing switch 26, which completes a conductive path from one side of source 23, through the inner conductor 24 of line 10 to each of the inner conductors 13 and 14 of the respective stubs, through the terminating shorts 17 and 18, and back to the other side of source 23 through the outer conductor 25 of line 10. The resulting current pulse produces precisely the same magnetic field configuration in the ferrite member as does the signal. Thus, the signal field and the magnetic bias field are parallel at all points and the resulting interaction between the signal and the ferrite material is minimal.

A longitudinal magnetization is produced in the ferrite by momentarily closing switch 22 and energizing coils 19 and 20. This produces a state of magnetization in the ferrite which is perpendicular to the signal magnetic field at all points. In this latter state of magnetization the resulting interaction between the signal and the ferrite material is a maximum.

If the input susceptance of each stub for the two different magnetization states are designated β_1 and β_2 , respectively, the net change in phase shift $\Delta\psi$ between the

two stubs for the two magnetization states is given approximately by

$$\Delta\psi \approx \frac{|\beta_1 - \beta_2|}{Z_0}$$

where Z_0 is the characteristic impedance of the line. In one phase shifter, constructed in the manner described and operated at 3 kmc., 30 degrees of phase shift was obtained using $\frac{1}{4}$ inch ferrite elements. Where greater phase shift is required, additional pairs of stubs are used, as illustrated in FIG. 2, wherein two pairs of quarter-wave spaced stubs 31 and 32 are shown distributed along a transmission line 30. The pairs of stubs can be spaced any arbitrary distance apart. In FIG. 2 this distance is zero as one of the stubs of each pair of stubs is shown coupled to line 30 at a common point P.

FIG. 3 illustrates diagrammatically the use of lengths of ferrite-loaded coaxial transmission line in a hybrid-coupled phase shifter. In this application ferrite-loaded stubs 46 and 47, similar to those described in connection with FIG. 1, are connected to a pair of conjugate branches 42 and 43 of a 3 db quadrature hybrid coupler 48. By changing the direction of magnetization in the ferrite elements 44 and 45 between longitudinal and transverse circular, (by means similar to those shown in FIG. 1) the electrical length of each of the stubs 46 and 47 is changed, thereby changing the net phase shift between the input branch 40 and the conjugate output branch 41.

In all cases it is understood that the above-described arrangements are simply illustrative of but a small number of the many possible specific embodiments which can represent applications of the principles of the invention. Thus, numerous and varied other uses and arrangements for producing the longitudinal and transverse circular magnetic bias can readily be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A phase shifter comprising:

a pair of substantially identical sections of transmission line having an inner conductor and an outer conductor;

said sections of line being coupled to a signal transmission path 90 degrees out of time phase with each other at the frequency of interest;

ferrite material surrounding corresponding portions of the inner conductors of said sections of line;

means for producing a magnetic field in said material parallel to said conductors;

and means for producing a circular magnetic field in said material transverse to said conductors;

said producing means being activated in time sequence.

2. The phase shifter according to claim 1 wherein said sections of line constitute a pair of stubs coupled a quarter wavelength apart along said signal transmission path.

3. The phase shifter according to claim 1 including a 3 db quadrature hybrid junction having two pair of conjugate branches wherein

said sections of line are connected respectively to the branches of one pair of conjugate branches of said hybrid junction;

and wherein said other pair of conjugate branches are connected to said signal path.

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