

[54] **INSERTION AND DIFFERENTIAL
PHASE-TRIM METHOD**

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[51] Int. Cl. **H01p 1/32**

[58] Field of Search **333/24 G, 24.1, 31 A**

[56] **References Cited**

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Primary Examiner—Paul L. Gensler

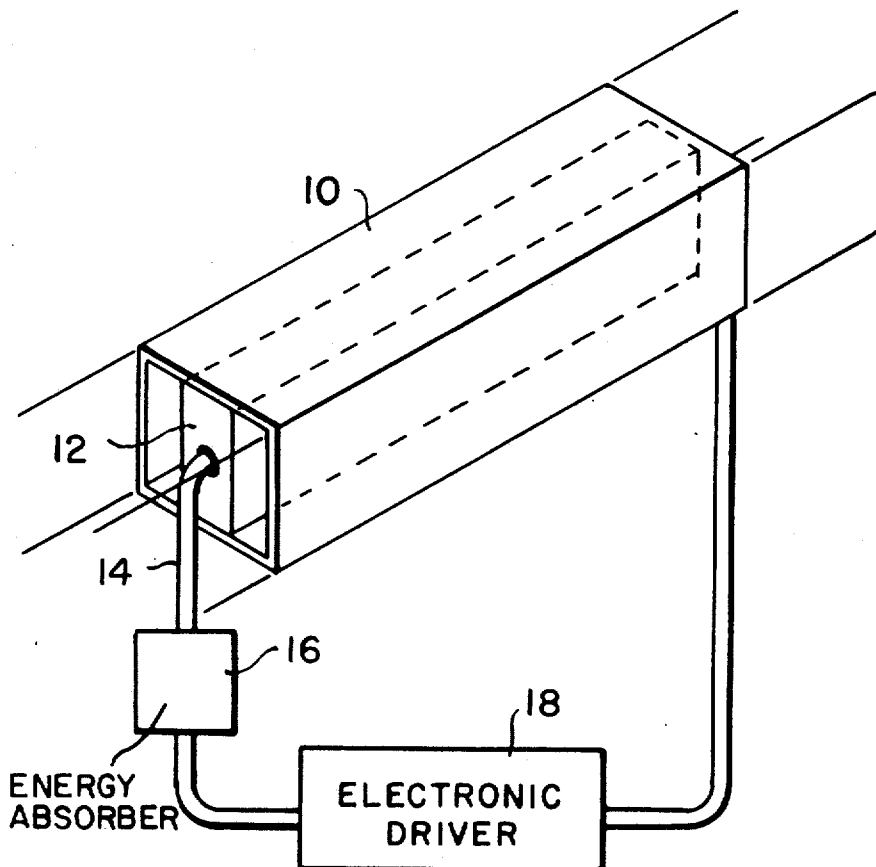
Attorney, Agent, or Firm—R. S. Sciascia; P. Schneider; W. T. Ellis

[57] **ABSTRACT**

A method and means for phase trimming of ferrimagnetic, latching phase-shifters in a waveguide without any electronic drive adjustments by running the drive-wire of the ferrimagnetic core through a second ferrimagnetic material external to the waveguide. If the insertion phase is too high, this second material is chosen, first, to have a square B/H loop with a low coercive field and second, to have flux excursion from a rest state to saturation which is long enough so that sufficient energy is absorbed initially from the drive-wire energy pulse so that the ferrimagnetic core is only driven to a predetermined reference value and no higher.

If the differential phase is too large, this second material is chosen to have approximately the same B/H loop shape and coercive field as the ferrimagnetic microwave core, but with only a fractional energy absorption over the pulse period. This second material is shaped so that the fraction of pulse energy absorbed over the entire pulse period is sufficient to prevent the differential phase from rising above a predetermined reference level.

14 Claims, 12 Drawing Figures



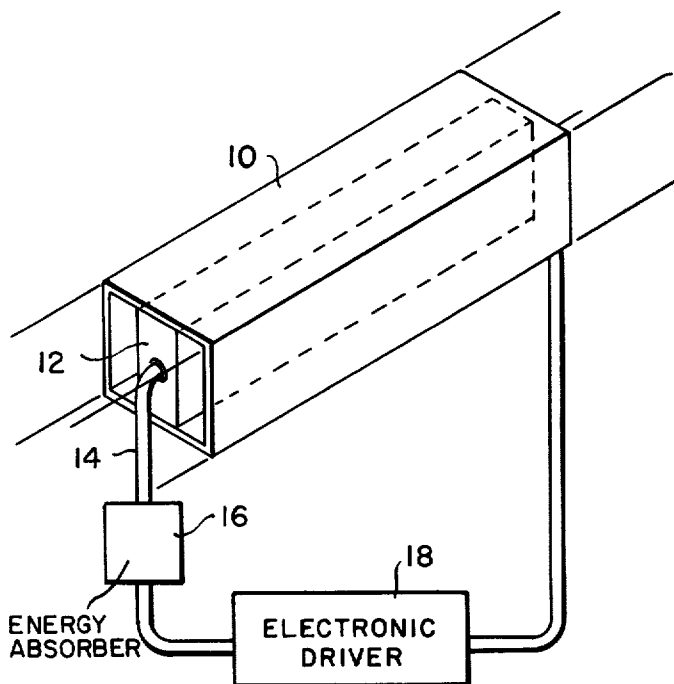


FIG. 1.

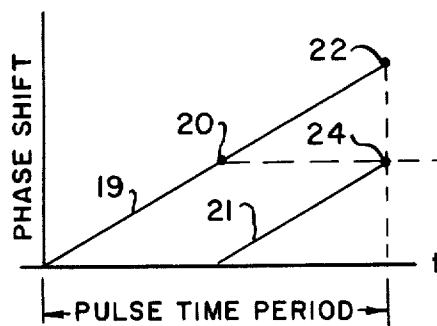


FIG. 2.

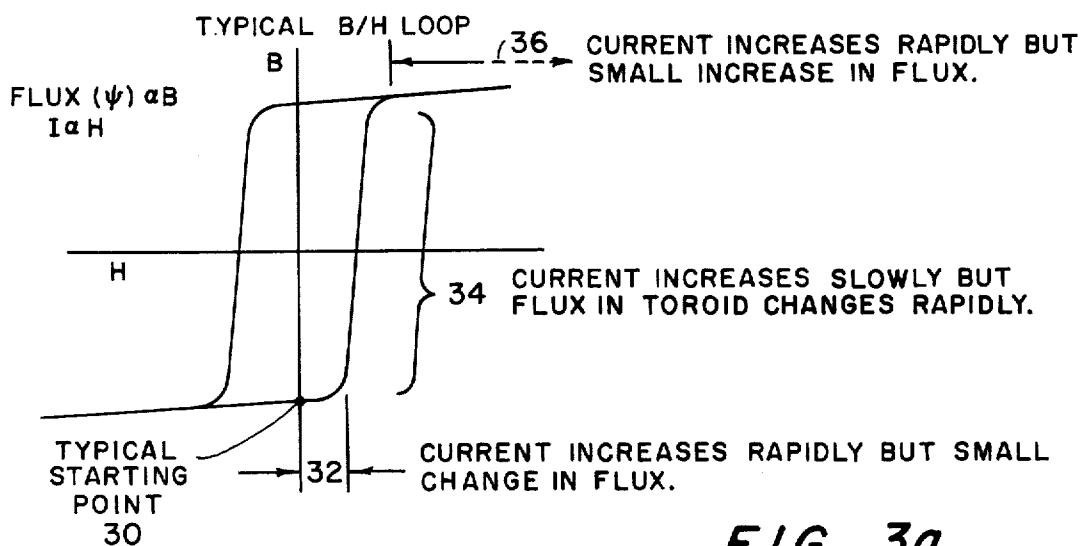


FIG. 3a.

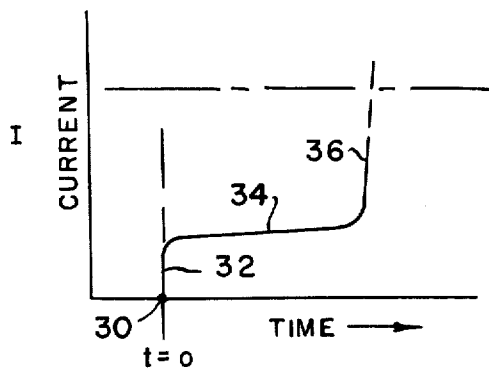


FIG. 3b.

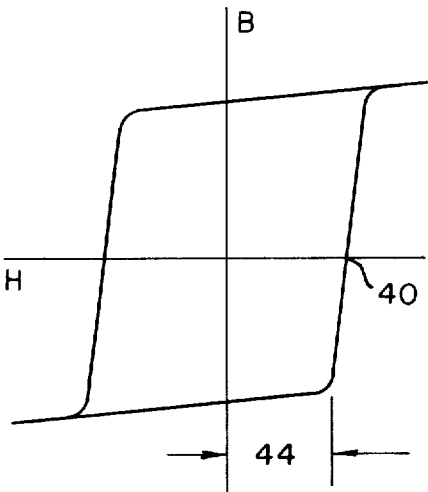


FIG. 4a.

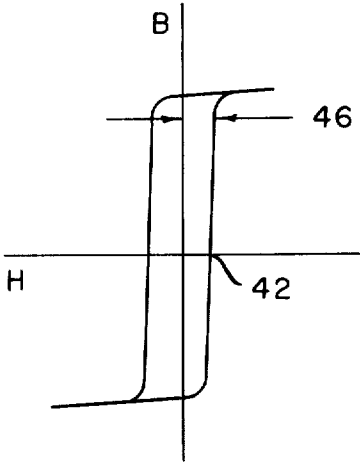


FIG. 4b.

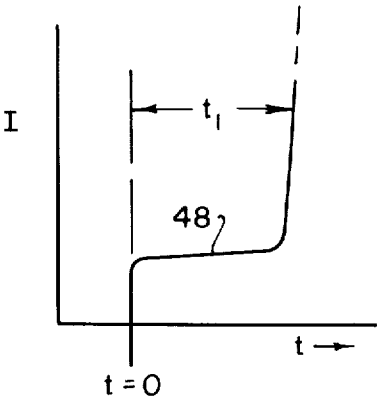


FIG. 4c.

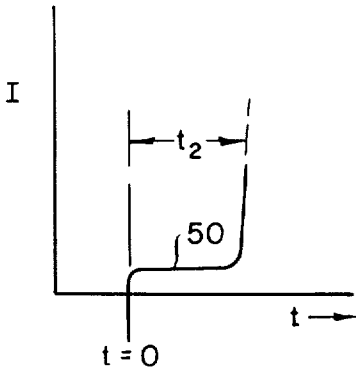


FIG. 4d.

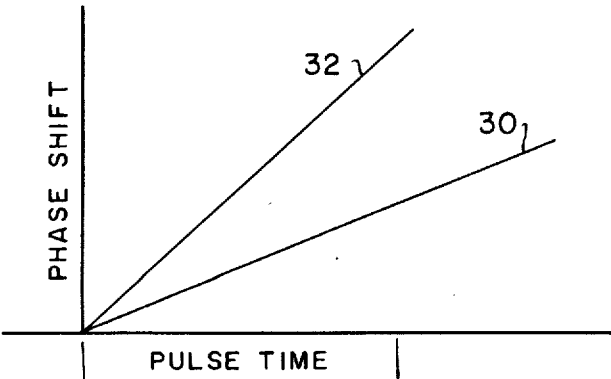
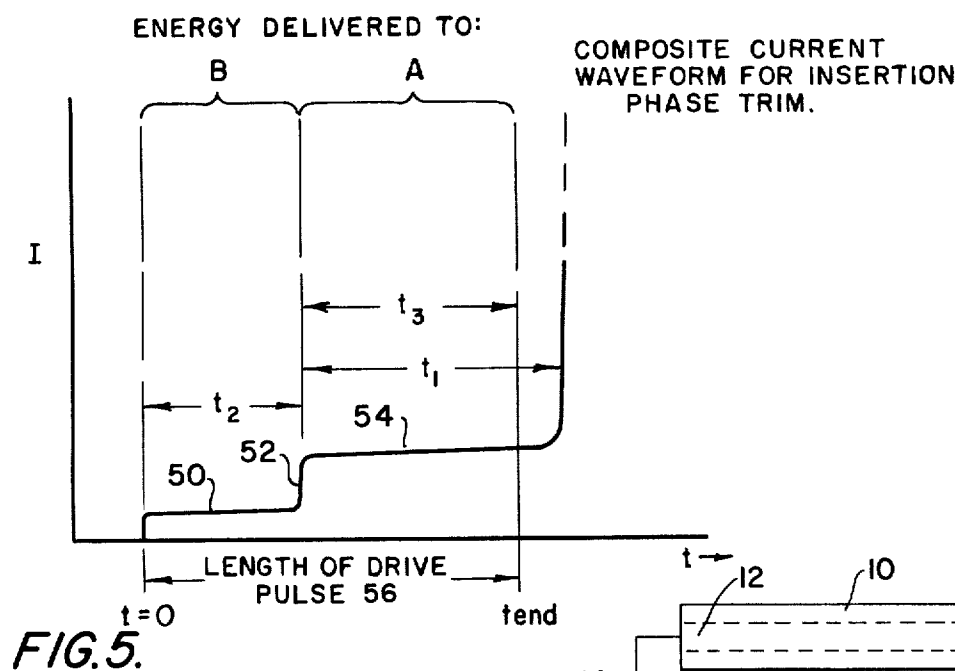
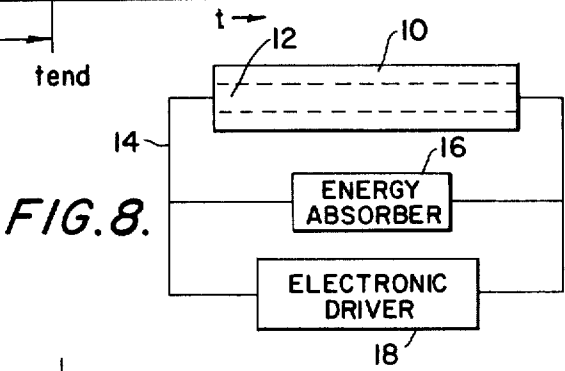
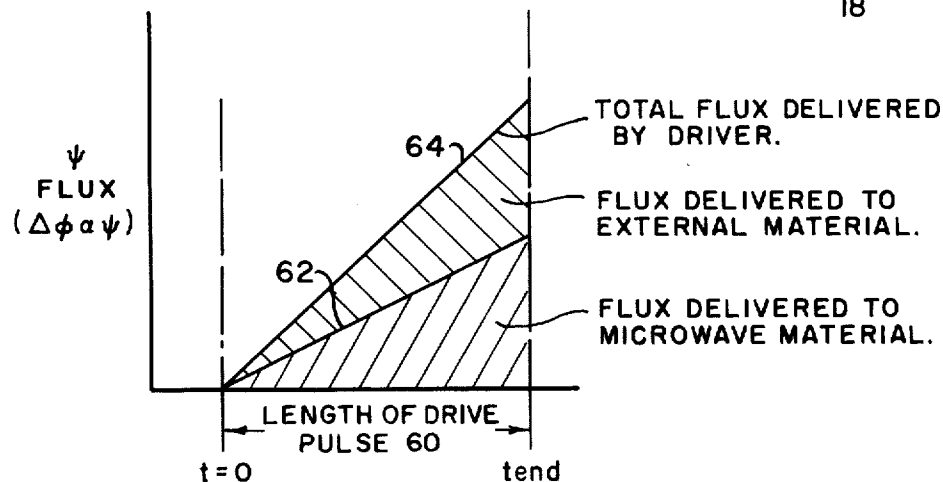


FIG. 6.



INSERTION AND DIFFERENTIAL PHASE-TRIM METHOD

BACKGROUND OF THE INVENTION

1. Field of Invention

The present invention relates generally to microwave phase-shifters and in particular to antenna phase-shifters utilizing ferrimagnetic materials.

2. Description of the Prior Art

Ferrimagnetic phase-shifters have been widely used for some time, most notably in antenna array applications. Typically, such arrays comprise thousands of small ferrite phase-shifters spaced $\frac{1}{2} \lambda$ apart to form a beam. In order to generate the proper beam shape, each phase shifter is set to a different predetermined phase. This is only possible if at some reference current all the phase-shifter units have an identical insertion-phase length. Prior art methods for obtaining a common-reference insertion-phase initialization are costly and time-consuming. The present invention provides a method and a means to alleviate the basic problems encountered in the prior art in initialization the insertion-phase.

Generally, ferrite phase-shifters comprise a rod of ferrimagnetic material mounted within a waveguide section and means for producing a magnetic field within the material. By varying the strength of this magnetic field, the phase-shift due to the ferrimagnetic rod can be varied.

In the phase-shifter used to illustrate the present invention, a hollow rectangular ferrimagnetic toroid is mounted longitudinally within a rectangular waveguide. A wire mounted in a dielectric slab is inserted in the space within the hollow ferrimagnetic toroid. The phase is varied by sending a current pulse through the wire which acts to induce a magnetic flux in the toroid. When the current pulse has dissipated, and thus $H=0$, there will still be some remanent magnetic flux density B in the toroid due to hysteresis effects. This remanent flux density change will cause a change in the propagation constants in the toroid. Thus the microwave signal will pass through the ferrimagnetic toroid either faster or slower depending on whether the flux density is increased or decreased from its preceding level. This change in the electrical length of the toroid will cause the phase-shift in the microwave signal. The flux density is proportional to the size of the current pulse through the wire. Thus the phase-shift can be varied by varying the size of the current pulse.

Since neither the ferrimagnetic cores nor the waveguide sections can be manufactured to have exactly identical physical properties, each phase-shifter must be trimmed to a reference phase when under a reference condition. Mechanical, as well as electrical, methods have been previously used to obtain the desired trim to give each unit the same electrical length under a reference condition. The reference condition is usually a pulse, having a certain strength and a certain time period, through the drive wire contained within the ferrimagnetic toroid core.

The electrical method of insertion trimming comprises varying the strength of the current pulse and its time period through the drive-wire. By properly varying the reference-current pulse strength and time, the electrical length, and thus the phase-shift, may be varied to any value.

The basic problem with this method is that, after this reference calibration, the electronic circuitry for that driver must always be used with that phase-shifter. Due to this mating requirement, if there is a malfunction of the phase-shifter or the driver circuitry when located in the phase-shifter array, both the phase-shifter and the driver circuitry must be replaced.

Mechanical methods of insertion trimming generally comprise the insertion of something inside the waveguide to change the R.F. propagation characteristics of the waveguide. The something inserted is usually a machined piece of dielectric or metal. Slots must be cut into the sides of the waveguide in order to permit this insertion. The machining, inserting, evaluating and testing required in such a method make it very expensive and time-consuming.

Additionally the cutting of slots and the insertion of dielectric or metallic materials change the slope of the electrical length (phase-shift) vs. frequency curve. Thus this phase-shifter can only properly be trimmed at one frequency, usually the center of a band. At the end of the band, due to the different slope in each of the phase-shifters, there is a large phase-shift error.

SUMMARY OF THE INVENTION

Briefly, the invention resides in the external coupling of a second ferrimagnetic material to the drive-wire used for driving a ferrimagnetic phase-shifter located in a waveguide, for the purpose of absorbing a sufficient portion of the energy normally applied to set the phase-shift characteristics of the phase-shifter so that the ferrimagnetic core of this phase-shifter is driven only to some predetermined phase-shift or phase-shifts and not beyond.

OBJECTS OF THE INVENTION

An object of the present invention is to phase-trim a phase-shifter at its toroid core rather than its driver.

A further object of the present invention is to make all phase-shifters in an array function within close unit-to-unit tolerances independent of the driver, thus eliminating system performance errors.

A still further object is to allow variable phase-trimming such that both the insertion and the differential phase-shift may be trimmed.

Other objects, advantages, and novel features of the present invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of basic phase-shifter system of the present invention.

FIG. 2 is a graph of phase-shift vs. pulse energy in an insertion phase trimming situation.

FIG. 3a is a typical ferrimagnetic material B/H loop characteristic.

FIG. 3b is the current vs. time curve for the B/H loop of FIG. 3a.

FIG. 4a is the B/H loop for the microwave material of the phase-shifter core.

FIG. 4b is the B/H loop for the insertion material.

FIG. 4c is the current vs. time curve for the B/H loop of FIG. 4a.

FIG. 4d is the current vs. time curve for the B/H loop of FIG. 4b.

FIG. 5 is a composite graph of the current vs. time waveform.

FIG. 6 is a graph of the phase-shift vs. time in a differential trim situation.

FIG. 7 is the flux vs. time curve in a differential phase-trimming situation.

FIG. 8 is a block diagram of the phase-shifter system of the present invention with the external energy-absorbent material connected in parallel.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 is a block diagram of the basic system of the present invention. The microwave waveguide 10 is shown with a ferrimagnetic toroid 12 fitted within it. The drive-wire 14 runs through the center of the toroid 12 and comes out at each end of the toroid to connect to the electronic driver circuitry 18. This is the well-known phase-shifter configuration normally used in antenna arrays and will be used to illustrate the present invention.

As previously stated, due to the many and varied kinds of phase-shifters and electronic drivers in current use, it is very desirable to use a method of trim applicable to both differential and/or insertion phase independent of the microwave, electronic, driver hardware employed.

When either the insertion or the differential phase of the phase-shifter exceeds predetermined reference values, trimming is required. The method used in the present invention to effect a phase-shift trimming comprises the insertion of an energy-absorbing material 16 into the electrical circuit with the toroid core 12. The energy-absorbing material 16 is chosen and then shaped to absorb a sufficient amount of the constant-voltage, pulse energy applied by the electronic driver 18 to the phase-shifter toroid 12 so that this toroid 12 can only be driven up to a certain flux value or values upon the application of a reference voltage pulse or a set of pulses. The only requirement made on the electronic driver by this method is that it operate in some form of a flux mode rather than a current saturation mode. (A flux mode generally entails the use of a constant voltage pulse for generating a magnetic flux in a ferrimagnetic material).

The application of the present method to insertion phase trimming will first be treated. FIG. 2 illustrates the normal insertion phase trimming situation. Point 20 on the curve 19 is the predetermined reference phase-shift value that is desired for a given constant-voltage pulse applied by the driver 18 for a set period of time. Since phase-shifter, toroid cores cannot be manufactured to exactly fit specifications, the phase-shift generated by a toroid core rarely hits the desired value when the reference voltage pulse length is applied. For purposes of illustration, the phase-shift of this particular toroid 12 is shown as point 22 in FIG. 2 after the reference voltage pulse is applied.

In order to trim this phase-shift to the desired reference point 20, the drive-wire 14 is run through an absorbing material which completely absorbs all of the driver, voltage-pulse energy for an initial portion of the constant-voltage-pulse time period. Thus part of the drive pulse is absorbed before it reaches the microwave core 12 and thus the microwave core phase-shift is trimmed. This insert 16 should be located external to the waveguide 10 to avoid affecting the waveguide R.F. signal.

This energy-absorbing material used for insertion phase trimming will now be discussed. A typical B/H loop for a ferrimagnetic material is shown in FIG. 3a and its current variation with time is shown in FIG. 3b. The normal material starting-point or rest-point is the $H=0$ point 30. Since H is proportional to the current I , the current I is zero also (FIG. 3b). During the section 32 of the B/H curve coinciding with a rapid increase in current (FIG. 3b) there is only a small change in flux (B field). Thus little energy is absorbed by the material. As the section 34 of the B/H curve is reached the current (H field) increases slowly but the flux (B field) in the toroid changes rapidly. Thus a substantial amount of energy is absorbed by the material during this portion of the curve to support this material flux increase. When the saturation section 36 of the B/H curve is reached, the current again increases rapidly with only small increases in flux.

From the above discussion it can be seen that the flux variation section 34 of the B/H curve performs the energy absorption. In order not to effect the slope of the microwave core phase-shift vs. pulse-energy curve the energy must be absorbed in one packet at the beginning before the toroid is driven to the fast-rising flux section 34 of its B/H loop. To accomplish this, the flux excursion of the inserted material must be completed before the beginning of the flux excursion of the toroid B/H loop. Thus the inserted energy absorbing material is chosen to have a square or rectangular B/H loop and a lower coercive field than the toroid core 12.

FIG. 4a shows a typical B/H loop of a microwave material that may be used in the toroid core 12. FIG. 4b shows a B/H loop that may be used for insertion trimming. As can be seen from the figures, the insertion material loop is essentially rectangular and its coercive field point 42 occurs at a much lower H field strength (current) than the toroid material coercive field 40. Thus the inserted material flux excursion is completed before the beginning of the toroid core 12 flux excursion. (Thus the H field at point 46 is less than the H field at point 44).

FIG. 4c is a graph of the current vs. time curve for the B/H loop of FIG. 4a used in the toroid core 12. The current is held to a constant value 48 during the flux excursion of FIG. 4a. The time t_1 during which this current is constant (the flux excursion) is the time during which the material absorbs energy prior to saturation.

Likewise, FIG. 4d is a graph of the current vs. time curve for the B/H loop of FIG. 4b used in the energy absorbing insert 16. The current is again held constant, but to a value 50 much lower than constant current 48 of the toroid core 12. The time t_2 is the time during which energy is absorbed by this insert prior to saturation.

The longer the times t_1 and t_2 , the more energy is absorbed by their respective materials. These energy-absorption times (the time it takes for the material to go from a rest state to flux saturation) for a given uniform core depend on (a) the B/H loop of the material chosen; (b) the length of the drive-wire loop around the toroid; (c) the number of turns this drive-wire makes around the toroid; and (d) the smallest cross-sectional area of the toroid core. All these characteristics of the insertion core 16 are chosen so as to give the desired energy absorption time t_2 . Generally, in microwave applications, the cross-sectional area of the core

16 is used to control the time t_2 and the other three variables are kept constant.

This control is accomplished as follows. When the cross-sectional area of the core is decreased at one point, the flux running through the core is bunched together at this point into a smaller area thus changing the flux density at this point. Since the whole ferrimagnetic core saturates if any part of the material saturates, the material goes into saturation and stops absorbing energy when the material at the reduced-cross-sectional point reaches saturation. Thus the material absorption time may be controlled accordingly.

The amount of energy that must be absorbed to effect a trimming may be determined with either a measurement, or an actual substitution of variously sized insert cores in the drivewire 14 circuit of FIG. 1. Upon determination of the required energy absorption, the cross-sectional area of the energy-absorbing insert 16 may be set so that the insert 16 absorbs exactly that amount of energy.

The actual operation will now be described. When a constant-voltage pulse is applied on the drive-wire 14, the current in the wire 14 begins to rise. Since the insert 16 is chosen to have a low coercive field point 42, the H field in this insert material quickly reaches the rapid flux excursion section of its B/H loop and its flux begins to rise rapidly toward saturation. Substantially all of the energy of the voltage pulse occurring during this insert flux-excursion is absorbed. During this time the current is held at the constant level 50 (FIG. 4d). This is shown in the composite current vs. time graph of FIG. 5. Upon reaching saturation the ferrimagnetic material of the insert 16 stops drawing energy from the voltage pulse and essentially drops out of the circuit.

Since the insert 16 is no longer drawing energy, the current is no longer held to a constant. Thus the current and the H field begin to rise. This is shown as section 52 on the composite curve of FIG. 5. When the H field in the toroid core 12 reaches the rapid flux excursion section of its B/H loop (FIG. 4a), it begins to absorb energy. The remaining energy of the constant voltage pulse is absorbed by the core 12 during the time t_3 . This section of the curve is represented as the numeral 54. The total pulse length is represented by the distance 56.

As can be seen from FIG. 5 the remaining energy left to be absorbed by the core 12 is varied by varying the time t_2 . Thus the energy-delivery time t_3 to the core 12 may be varied over its total possible energy absorption time t_1 (FIG. 5 and FIG. 4c) of the core 12 merely by varying the absorption time t_2 .

Thus, the beginning of the core 12 absorption is merely delayed, as shown by the curve 21 of FIG. 2. The energy remaining in the voltage pulse when the core 12 reaches its flux excursion is sufficient to drive its phase-shift only to the point 24. Thus the voltage pulse that the toroid core 12 sees is essentially shortened.

Stated from an impedance point of view, due to its low coercive field the insert has reached its rapid flux excursion first, and thus presents a high impedance across which most of the energy of the voltage pulse is dissipated. Upon reaching saturation, the insert impedance drops to zero and essentially zero energy is dissipated across the insert. Since the impedance is no longer high, the current begins to rise. When the toroid

core 12 reaches its flux excursion point, the remaining pulse energy is dissipated across it.

The actual trimming is accomplished by using the following method steps:

1. determining the amount of toroid phase-shift overshoot of the reference;
2. determining the portion of the voltage-pulse (energy) which must be absorbed before it is applied to the toroid core 12 in order that the core is driven only to its reference phase-shift;

3. varying the shape (cross-sectional area and length) and the electrical coupling of the ferrimagnetic-material insert so that the amount of energy absorption required by the material to attain flux saturation from a previously remanent state is varied. Since the portion of the voltage-pulse energy that is required to be absorbed from the voltage pulse is known from step 2, the saturation point of the insert material may be varied until exactly that portion of the voltage-pulse is absorbed in driving the insert material to saturation.

Any ferrimagnetic material with a square B/H loop and a low coercive field may be used in this application, including the low quality video materials such as the 0-5, 0-6, and 0-3 series put out by Indiana General Corporation.

The following design equations may be used in choosing the material variables.

$\Delta B_{SL} A_L$ = energy needed to be absorbed to obtain the desired phase-shift at reference conditions.

$$\frac{C_L L_L}{N_L} \ll \frac{C_M L_M}{N_M}$$

N_L = turns through non-microwave (inserted material) load.

N_M = turns through microwave (toroid core) load.

C_L = coercive field of non-microwave load.

C_M = coercive field of microwave load.

ΔB_{SL} = change in flux of non-microwave load in order to attain saturation from a previously remanent state.

A_L = cross section of non-microwave load.

L_L = path length of non-microwave load.

L_M = path length of microwave load.

The application of the present invention to differential phase trimming will next be discussed. FIG. 6 illustrates the normal differential phase trimming situation. The curve 30 has the desired slope (differential phase) for the phase-shift response. Again, since phase-shifter toroid cores cannot be manufactured to exactly fit specifications, the actual slope of the phase-shift response will rarely hit the desired reference value for a timed-period, constant-voltage pulse. For purposes of illustration the phase-shift curve of this particular toroid 12 is shown as curve 32.

In order to trim the phase-shift to the desired response (curve 30 in FIG. 6), the drive-wire 14 is run through a ferrimagnetic energy-absorbing material. This material will absorb a linearly increasing (with time) amount of energy from the drive-wire 14. It may be connected so that it is in either electrical series or parallel (shown in FIG. 8) with the microwave toroid core 12. This insert material 16 should be located external to the wave-guide 10 to avoid affecting the wave-guide R.F. signals. Since this insert is in the electrical circuit with the core 12, and since the insert is absorbing an amount of energy linearly increasing with time,

the energy actually applied to the core 12 is reduced by an amount linearly decreasing with time.

FIG. 7 is a FLUX (energy) vs. time curve. The length of the drive voltage pulse is shown as 60. The total energy delivered by the voltage pulse at any given time is shown by the curve 64. The energy that is desired to be applied to the toroid core 12 to provide the desired reference phase-shift is shown as the curve 62. If the energy-absorbing insert is designed to absorb this excess energy between the two curves 62 and 64, then only sufficient energy to drive the core 12 to the reference phase-shift response curve 30 (FIG. 6) is applied to the core 12. Thus the phase-shift vs. energy-curve slope is trimmed to the desired value.

In order to effect this type of differential phase-trimming over the entire voltage pulse time period, a ferrimagnetic material with the following B/H loop characteristics is required for the insert 16. The B/H loop must have approximately the same shape as the toroid core 12 B/H loop and the coercive fields of the insert 16 and the toroid core 12 materials must be approximately the same. This requirement of approximate B/H loop coincidence is due to the fact that the insert 16 must be absorbing energy simultaneously with the core 12 during the entire pulse period in order to effect a uniform trimming of the energy applied to the core 12. Obviously, in order to have an energy absorption over the entire length of the voltage pulse, the insert material must also not be driven into saturation at any time during this pulse. Thus the saturation point of the insert material should be higher than the saturation point of the toroid core 12 material.

The amount of flux (energy) absorbed at any one time from a constant voltage pulse may be varied in the same manner as was done for insertion trimming. Thus by judiciously choosing the cross-sectional area of the insert material 16, the number of loops the drive-wire takes through the insert 16, the length of the flux path around the insert 16, and the type of material used, the amount of energy absorbed may be varied.

Using the above-stated methods, the slope of the energy absorption vs. pulse time curve for the insert 16 may be varied to any desired value. Thus in order to remove the excess energy from the pulse reaching the toroid core 12, the slope of the flux vs. time curve for the insert 16 may be varied so that it absorbs exactly the amount of flux (energy) at any given time during the pulse so that the flux vs. time slope for the core 12 is trimmed down to the curve 62 (the reference flux vs. time curve). This trimming of the core 12 flux vs. time slope in turn trims the phase-shift vs. time curve of FIG. 6 down to the curve 30.

Any ferrimagnetic materials that have coercive fields and shapes approximating those of the microwave toroid core 12 material may be used. Since magnesium-manganese or garnet materials are generally used for microwave cores, such materials may also be used as the insert 16 material. Also the cheaper video materials such as those made by Indiana General Corporation may be used in this application.

The following design equations may be used to select a material for differential phase trimming. The variables were defined previously.

$$\frac{C_L L_L}{N_L} = \frac{C_M L_M}{N_M}$$

$\Delta B_{SL} A_L$ saturation flux of the toroid core.

Using these disclosed trimming methods the phase-shift characteristics may only be trimmed down. Thus a set of low, reference-phase-shift characteristics is desired. Each toroid core could be purposely designed to provide 10% more phase-shift than a desired reference. Then each toroid core could be trimmed using the above disclosed methods.

It is to be understood, of course, that both differential phase (slope of phase response) and the insertion phase may be adjusted in the same phase-shifter by the proper series connection of several ferrimagnetic material loads of different properties with the microwave toroid core 12.

Also, it should be understood that if linearity as a function of flux is not a requirement, then the use of either method of phase trim (insertion or differential) is possible for effectively attaining differential phase trim.

Obviously, many modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that, within the scope of the appended claims, the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. An apparatus for shifting the phase of the energy propagating through a waveguide comprising:
phase-shift means with a ferrimagnetic core positioned within said waveguide;
electrical driving means coupled to said phase-shift means for setting the phase-shift in said ferrimagnetic core; and
energy-absorption means coupled to said electrical driving means external to said waveguide for limiting the amount of energy supplied by said electrical driving means to said ferrimagnetic core to a value such that the phase-shift characteristics of said phase-shift means approximate a predetermined value or set of values, said energy-absorption means being made of ferrimagnetic materials.
2. An apparatus as defined in claim 1, wherein said electrical driving means comprises:
an electronic voltage-pulse generator for generating a constant-voltage pulse, and
a drive-wire running from said voltage-pulse generator through both said ferrimagnetic core and said ferrimagnetic energy-absorption means for applying the energy from said constant-voltage pulse to both said ferrimagnetic core and said ferrimagnetic energy-absorption means.
3. An apparatus for trimming the insertion-phase error in a phase-shifting device within a waveguide comprising:
ferrimagnetic-core phase-shifter means positioned within said waveguide;
electrical driving means coupled to said phase-shifter means for applying energy to said phase-shifter means for setting the phase-shift in its ferrimagnetic core;
energy absorption means located external to said waveguide and coupled to said electrical driving means for absorbing initially a block of the energy applied by said electrical driving means to said phase-shifter means before said phase-shifter means reaches the flux excursion section of its B/H loop, wherein said energy-absorption means is made of a ferrimagnetic material with an essentially square B/H loop, with a coercive field that is

less than the coercive field of said phase-shifter means material, and wherein the ferrimagnetic material, the cross-sectional area of the energy absorption means, its length, and its coupling to said electrical driving means are chosen so that the energy absorbed initially by said energy absorption means from said electrical driving means is sufficient so that when said phase-shifter means reaches its rapid flux excursion section of its B/H loop, it is only driven to its reference phase and no higher.

4. An apparatus as in claim 3, wherein said electrical driving means comprises an electronic voltage-pulse generator for generating a constant-voltage pulse and wherein the coupling of said electrical driving means to said phase-shifter means and to said energy absorption means comprises the running of a drive-wire from said electrical driving means through the ferrimagnetic core of said phase-shifter means and through the ferrimagnetic material of said energy-absorption means for applying the energy from said voltage pulse to said phase-shifter means and to said energy absorption means.

5. An apparatus as in claim 4, wherein said phase-shifter means and said energy-absorption means are coupled by said drive-wire to said electrical driving means so that said phase-shifter means and said energy-absorption means are in electrical series with each other.

6. An apparatus for trimming the differential phase of a phase-shifting device within a waveguide comprising:

ferrimagnetic-core phase-shifter means positioned within said waveguide;

electrical driving means coupled to said phase-shifter means for applying a constant voltage pulse to said phase-shifter means for setting the phase-shift in its ferrimagnetic core;

energy absorption means located external to said waveguide and coupled to said electrical driving means for absorbing a steadily increasing amount of energy over the entire constant-voltage pulse-length so as to trim the differential phase of said phase-shifter means, wherein said energy absorption means is made of a ferrimagnetic material with a B/H loop and coercive field almost identical to those for the ferrimagnetic core of said phase-shifter means, but with a saturation point slightly higher than the saturation point of said phase-shifter means, and wherein the ferrimagnetic material, the cross-sectional area, the length, and the electrical coupling of said energy absorption means are chosen so that only enough energy is absorbed over the constant voltage pulse period so that the differential phase of said phase-shifter is trimmed to a predetermined reference.

7. An apparatus as in claim 6, wherein said electrical driving means comprises an electronic voltage-pulse generator for generating a constant-voltage pulse and wherein the coupling of said electrical driving means to said phase-shifter means and to said energy absorption means comprises the running of a drive-wire from said electrical driving means through the ferrimagnetic core of said phase-shifter means and through the ferrimagnetic material of said energy-absorption means for applying the energy from said voltage pulse to said phase-shifter means and to said energy absorption means.

8. An apparatus as in claim 7, wherein said phase-shifter means and said energy-absorption means are

coupled by said drive-wire to said electrical driving means so that said phase-shifter means and said energy-absorption means are in electrical series with each other.

9. An apparatus as in claim 7, wherein said phase-shifter means and said energy absorption means are coupled by said drive-wire to said electrical driving means such that said phase-shifter means and said energy absorption means are in electrical parallel connection with each other.

10. In a signalling system employing a waveguide containing therein a ferrimagnetic core which is supplied by a drive-wire with electrical pulse energy for effecting a phase-shift of the signals passing through said waveguide, a method for insertion and differential phase trimming comprising the steps of:

determining the phase-shift characteristics obtained from said core in response to the application of a constant electrical energy pulse;

determining a desired set of reference values for said phase-shift characteristics;

placing a ferrimagnetic energy absorbing material in electrical connection with said phase-shifter but external to said waveguide so that an amount of the energy in said electrical energy pulse is absorbed sufficient to drive said ferrimagnetic phase-shifter only to said set of reference values.

11. A method as defined in claim 10, further comprising the steps of:

selecting said energy absorbing material to have a square B/H loop with a coercive field smaller in value than the coercive field of said ferrimagnetic core;

choosing the ferrimagnetic material, the length, the cross-sectional area of the energy absorbing material, and the means of coupling the energy absorbing material to said core so that the energy which said energy absorbing material absorbs from said electrical energy pulse during its flux excursion from a rest state to flux saturation is sufficient so that said ferrimagnetic core is only driven to its reference value phase-shift and not beyond.

12. A method as in claim 10, further comprising the steps of:

selecting said ferrimagnetic energy-absorbing material to have a B/H loop which approximates the B/H loop of the ferrimagnetic phase-shifter core in both shape and coercive field;

choosing the ferrimagnetic material, the length, the cross-sectional area, and the electrical coupling of said energy absorption material so that the portion of the electrical pulse energy continuously absorbed over the flux excursion of said energy absorption material is sufficient so that the remaining energy applied to said ferrimagnetic core only drives up the phase-shift of said ferrimagnetic core at a reference slope rate thus effecting a differential trimming of said phase-shifter.

13. An apparatus for shifting the phase of energy propagating through a waveguide comprising:

means with a ferrimagnetic core positioned with said waveguide for shifting the phase of the energy propagating therein;

electrical driving means coupled by a conductor to said phase-shifting means for generating a voltage pulse and applying it by way of said conductor to

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said phase-shifting means to set its phase shift characteristics; and

energy-absorption means external to said waveguide and surrounding a portion of said coupling conductor for absorbing energy from said voltage pulse as it is applied through said conductor to drive said phase-shifting means in order to decrease the

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phase-shift characteristics of said phase-shifting means to approximate a predetermined value or set of values.

14. An apparatus as defined in claim 13, wherein said energy-absorption means is ferrimagnetic material.

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