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Scott et al.

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[45] **Aug. 19, 1975**

[54] **CONICAL UNBALANCED SPIRAL RADAR MODULATOR**

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[73] Assignee: **The United States of America as represented by the Secretary of the Air Force**, Washington, D.C.

[22] Filed: **Oct. 17, 1973**

[21] Appl. No.: **404,460**

[52] **U.S. Cl.** ..... **343/18 D**; 343/18 B; 343/895

[51] **Int. Cl.**[2] **G01S 9/02**; H01Q 1/38

[58] **Field of Search** ..... 343/18 B, 18 D, 879, 895, 343/859

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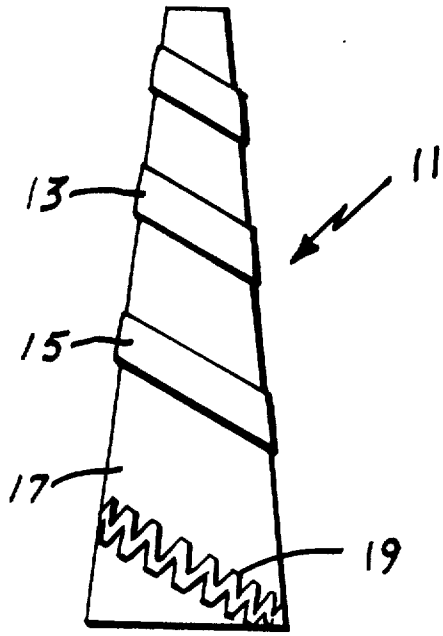
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[57] **ABSTRACT**

A radar reflecting and modulating system using unbalanced spiral conductors. A pair of conductors are wound and interleaved on a conical surface with one spiral terminating in a zigzag configuration at the base of the conical surface. The conductors are connected to a variable impedance load which is controlled by a pair of voltage sources whose outputs have different time dependence. The control voltages provide bias to interconnected varactors which are connected to the spiral conductors.

1 Claim, 14 Drawing Figures



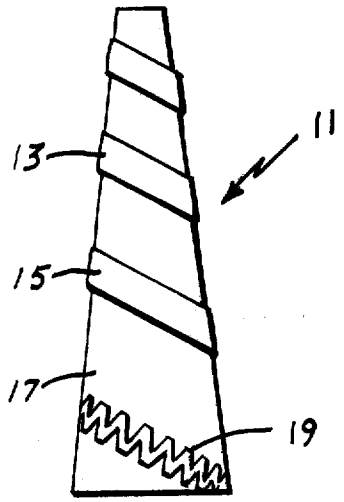


FIG. 1a

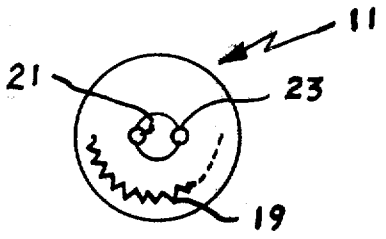


FIG. 1 b

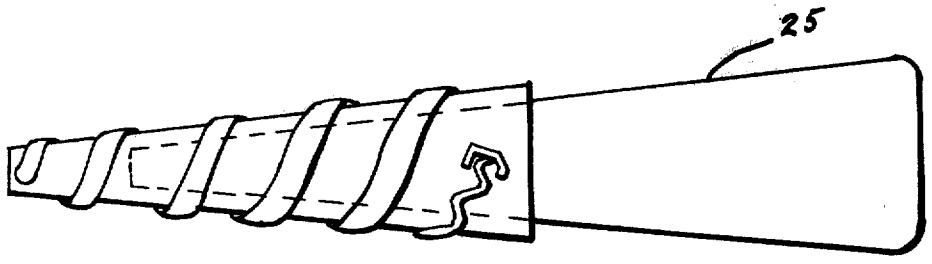


FIG. 2

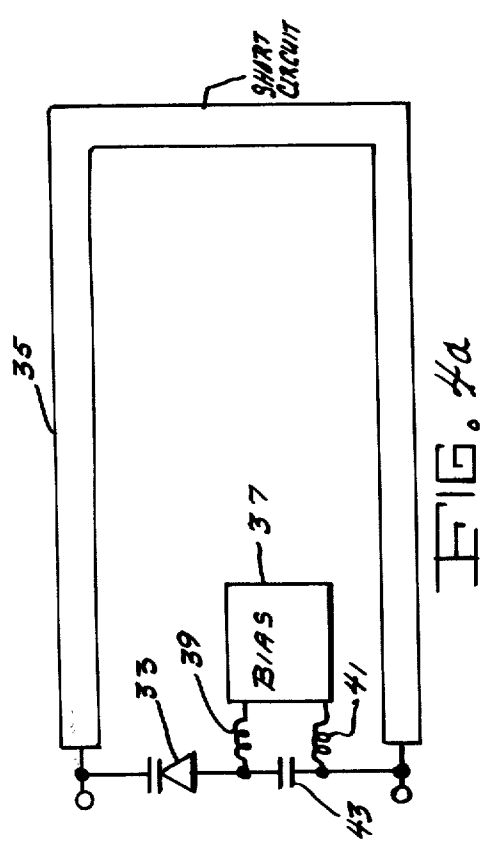


FIG. 4a

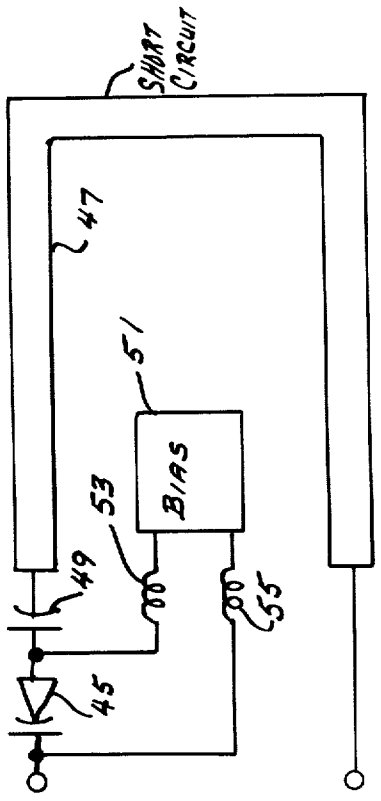


FIG. 4b

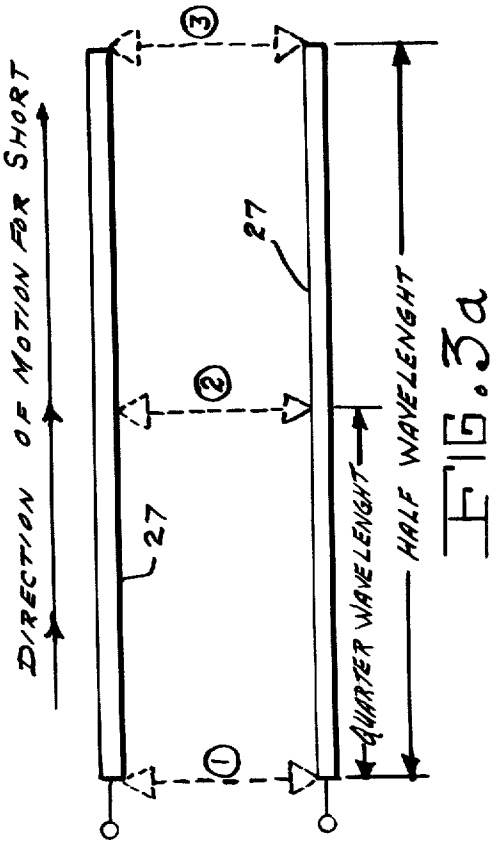


FIG. 3a

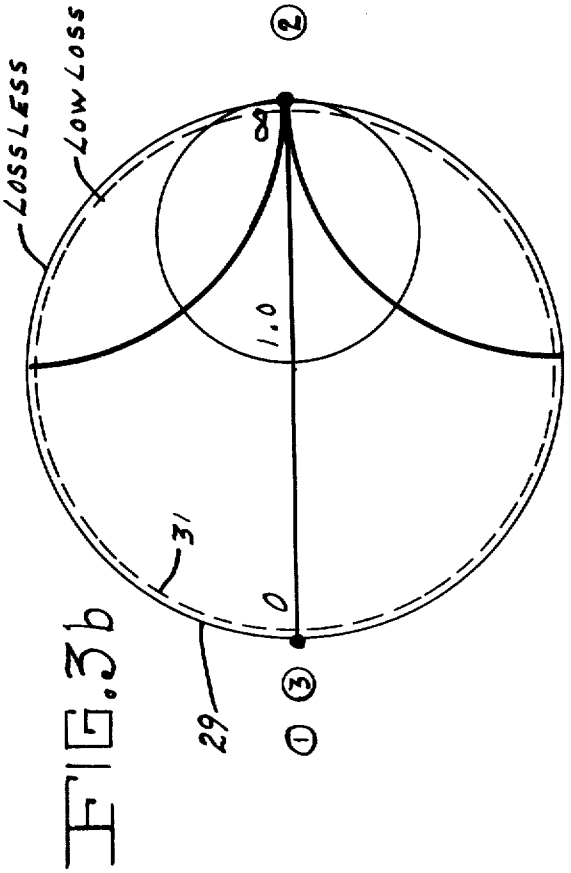


FIG. 3b

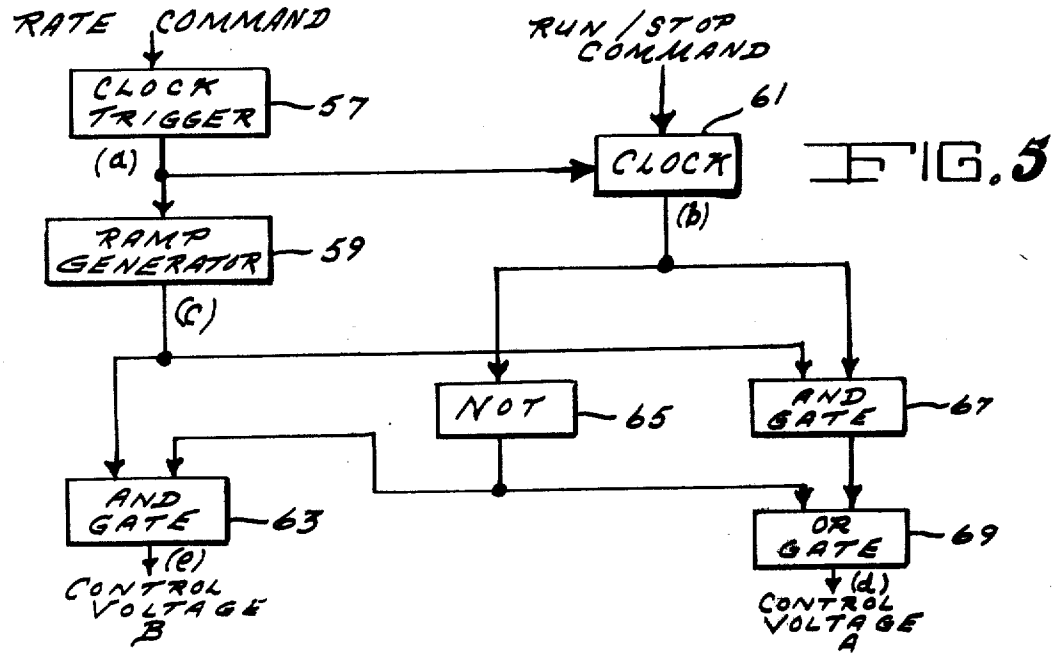


FIG. 5

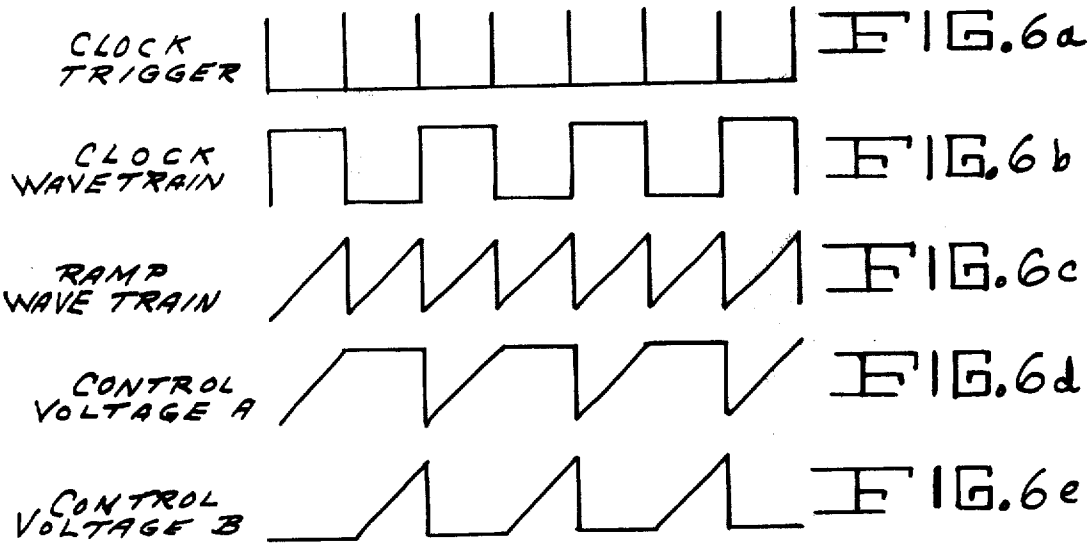


FIG. 6a

FIG. 6b

FIG. 6c

FIG. 6d

FIG. 6e

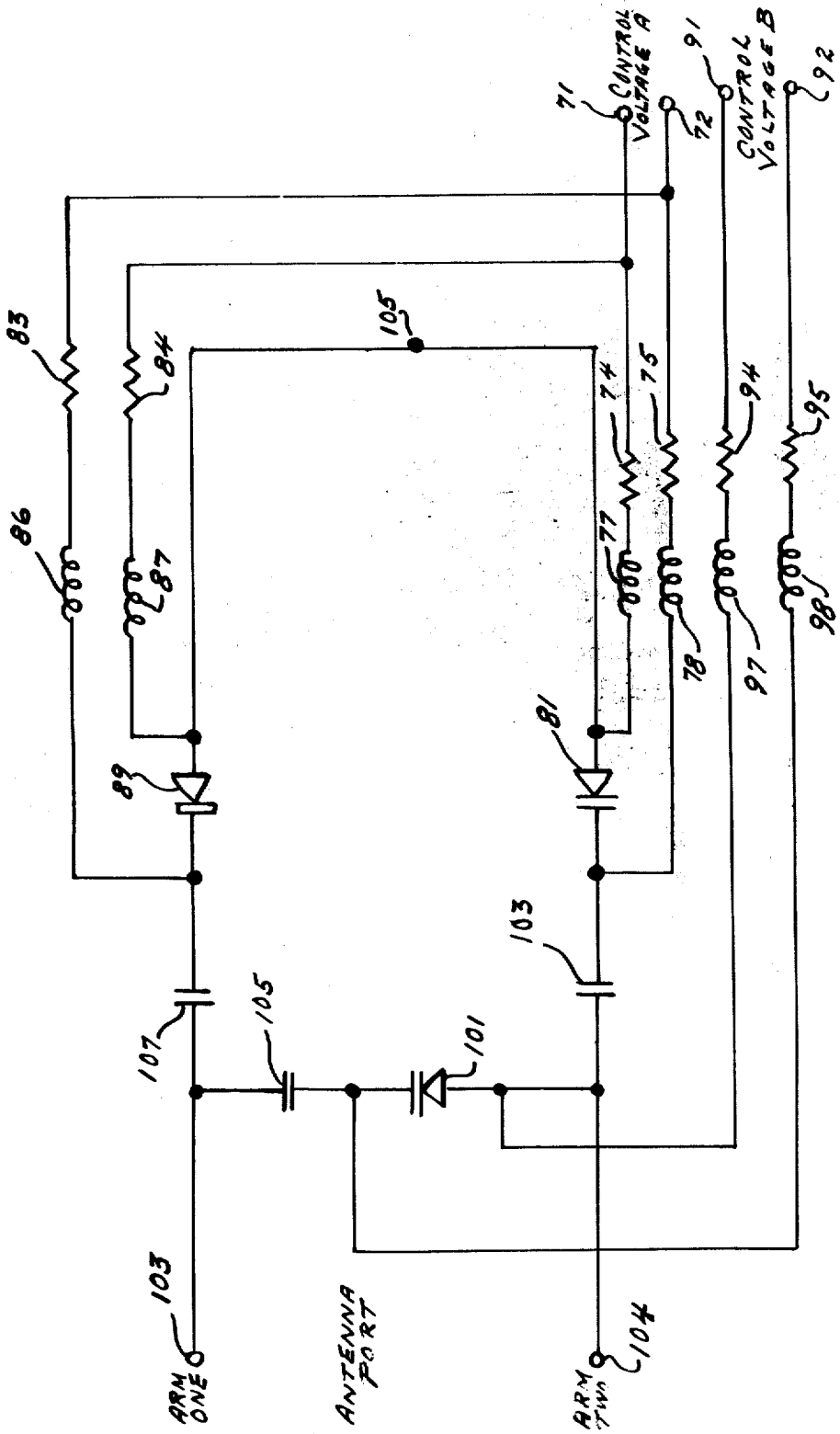

71
CONTROL VOLTAGE A
72
91
CONTROL VOLTAGE B
92
83
84
105
74
75
94
95
96
87
77
78
97
98
89
81
103
107
105
101
103
ARM ONE
ANTENNA PORT
ARM TWO
104

FIG. 7

CONICAL UNBALANCED SPIRAL RADAR MODULATOR

BACKGROUND OF THE INVENTION

This invention relates to radar reflectors, and more particularly to radar cross-section modulated conical spiral antennas.

The conical unbalanced spiral antenna is an evolvement of the well-known conical spiral antenna developed by the University of Illinois. The purpose of the present invention is to extend the lowest frequency of the operating range of the standard conical spiral by the generation of an additional radiation mode.

The details of the spiral arm design including a zigzag (slow wave) electrical unbalancing section product certain electrical effects for prior art antennas but different effects for the radar reflector function of the present invention.

In the prior art antennas the special balun (balance-to-unbalance transformer) is used. The operation of the balun, along with the unbalanced antenna arm design produces a specific current distribution on the antenna as well as a low and frequency insensitive input impedance at balun input terminals. Such impedance constancy permits easy coupling of the antenna to a transmitter or receiver. The antenna impedance frequency sensitivity is much less than that of a conventional conical spiral antenna of comparable size. In the prior antennas the bifilar spiral arms are mounted around a smaller metal cone (called the conducting cone). The cone is nearly as large as the conical surface containing the antenna arms; the spacing from antenna arms to surface of the cone is less than 0.02 λ_1, where λ_1 is the maximum wavelength of antenna operation.

In the present radar reflector the inner metal cone is not necessarily required. Also, the use of a two-wire transmission line feed and the use of the continuously variable load impedance results in a different current distribution on the antenna than in the prior antenna. Also, the terminals of the radar reflector are the terminals of the antenna (reflector) whereas in the prior antennas the terminals are at the end of the balun. This latter difference results in a radar reflector terminal impedance which, when used with the variable impedance load, provides control over the radar cross section. At frequencies below the normal mode cutoff the balanced conical spiral behaves as an open circuited transmission line, due to the small separation (in wavelengths) between the two arms. As in the case of a balanced two-wire transmission line, radiation from one arm is effectively cancelled by that from the other arm due to the equal magnitude, opposite phase, relationship between the currents in the two arms and their near proximity. This is true for both incident and reflected current components as long as the system remains balanced. If, however, the electrical symmetry is disturbed resulting in a net current flow, appreciable radiation can occur. The function of the design of the present invention is to provide the unbalance necessary to result in useful operation of the antenna as a reflector below the normal conical spiral mode cutoff. The unbalance can be provided by a slow wave zigzag structure which comprises the end of one of the antenna arms in the base region of the cone. Note that this does not affect the higher frequency (normal conical spiral mode) operation since currents associated with the mid and high frequency ranges of the antenna are radiated off before reaching the base region. The broadband characteristic of the invention as an antenna provide broadband operation of the structure as a reflector.

SUMMARY OF THE INVENTION

The invention is a semi-active radar reflector device called CUSP (conical unbalanced spiral) for producing time varying modulation of the radar signal over a wide band of frequencies scattered from a small radar decoy vehicle or from a reentry warhead vehicle during the midcourse and reentry portions of the ballistic missile trajectory. The CUSP consists of an electrically small wide band radar reflector of conical shape and a very much smaller battery operated control box called a variable impedance load (VIL). The device is termed semi-active because the battery power is used only to vary the passive scattering properties of the reflector. No battery energy is added to the scattered radar signal. The CUSP may be used in two basic ways, mounted in a small dielectric shell as a small separate modulated radar decoy for a larger ballistic missile reentry vehicle as a radar cross-section (RCS) modulator.

It is therefore an object of the invention to provide a radar reflector whose dimensions are a small fraction of wavelength and which serves as a decoy for ballistic missiles.

It is another object to provide a radar reflector which extends a low frequency range of a standard conical spiral antenna by generating an additional radiation mode.

It is still another object to provide a radar reflector that offers large and time varying cross-sections over wide wavelength bands for ballistic missiles.

These and other objects, advantages and features of the invention will become more apparent from the following description taken in connection with the illustrative embodiment in the accompanying drawings.

DESCRIPTION OF THE DRAWINGS

FIG. 1*a* is a side elevation view of the reflector used as a radar decoy;

FIG. 1*b* is a top plan view of that shown in FIG. 1*a*;

FIG. 2 is a side elevation view of the reflector used together with a reentry vehicle;

FIG. 3*a* is an analogous diagram used to explain the variation of reactances obtained from a variable impedance load;

FIG. 3*b* is a Smith Chart showing the reactance obtained from the procedure shown in FIG. 3*a*;

FIG. 4*a* is a schematic diagram showing a shunt tuned variable impedance load;

FIG. 4*b* is a schematic diagram showing a series tuned variable impedance load;

FIG. 5 is a basic block diagram showing a possible source of control voltage;

FIGS. 6*a*–6*e* show timing waveforms used in the explanation of FIG. 5; and

FIG. 7 is a circuit diagram showing the variable impedance load.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The invention consists of two major electrical systems which are mounted within a thin-walled dielectric support frustum of a cone.

As shown in FIGS. 1*a* and 1*b*, radar reflector **11** includes a pair of thin metallic foil interleaved conical spiral conductors **13** and **15**. This bifilar spiral conductor set is bonded onto the surface (inner or outer) of dielectric support cone **17**. The detailed shapes of the two spiral conductors are different from each other providing an electrical "unbalancing" effect to the reflector operation. At the base of one of the spirals the conductor assumes a zigzag configuration shown at **19** and this unbalancing operation permits long wavelength operation. The two ends of the spiral reflectors at the small ends of the frustum (hereinafter referred to as the "tip" of the cone) are the electrical terminals **21** and **23** of the reflector. At the longest wavelength of operation (λ_1) the base of CUSP is 0.1 λ_1 in diameter, and its axial length is 0.3 λ_1. The diameter of the tip of the cone is 0.03 λ_1. In spite of its small electrical size, CUSP provides large and time varying values of radar cross-section over wide solid angles about the forward axis of the cone and over a wide frequency band.

The CUSP spiral reflector arms comprise a radar reflector with an unusual reflecting characteristic when the wavelength of the electromagnetic waves incident upon the reflector is longer than the dimensions of the reflector. This characteristic is the relationship of the radar cross-section of the CUSP reflector in the tip direction to the value of RF impedance connected to the reflector terminals. At long wavelengths the radar cross-section is variable through a large range of values by changing the value of the complex impedance load attached to the reflector terminals.

As shown in FIG. **2**, conical reflector **11** can be mounted about a large conical reentry vehicle **25** as a radar cross-section modulator. Reflector **11** can be mounted on a thin teflon support shell and over a conducting reentry vehicle skin which is spaced a certain distance from the reflector arms.

The variable impedance load is a device which is connected to the terminals of CUSP and can be continuously varied to produce a wide range of terminal impedances over a wide wavelength band. This impedance will typically be reactive but may be complex for certain applications where reduced maximum RCS is desired.

There are a number of ways of building this device. One of the simplest is a transmission line terminated in a movable reactive load. As the position of the reactive load is changed through a half wavelength on the line, the input impedance at the end of the line varies through all possible reactances. The variable impedance load could also comprise a wide band variable phase shifter terminated in a reactive load. In this case the phase shifter performs the same function as the variable length transmission line in the previous example and the impedance again varies through all reactive values. In such cases a variable capacitance or inductance together with an impedance transformer may suffice. The variable capacitance could be produced by a varactor diode or similar device and the transformer could be the junction of two transmission lines of different characteristic impedance. Thus a relatively small change in capacitive reactance load in the line of higher impedance can produce a relatively large change in the input impedance to the line of lower characteristic impedance.

The variable impedance load for the CUSP antenna consists of an RF circuit and a control circuit. For radar cross-section modulation, it may be desirable to cause the terminal impedance to vary in a specific way with time which may or may not be periodic. This can be accomplished by proper design as will be explained below. For explanatory purposes, the remainder of this section will discuss a periodic time function for the impedance.

The terminals of the RF circuit present the antenna terminals with a reactance varying from short to open circuit through all inductive and capacitive reactance values. This nearly lossless reactance approximates the impedance variation obtained by sliding a short circuit along lossless transmission line **27** over a distance of at least a half wavelength as shown in FIG. 3*a*. A convenient way of expressing this variation is by means of a Smith Chart. The reactance values follow the outer circumference of a Smith Chart as indicated in FIG. 3*b*.

When the short circuit (zero impedance) is located at point **1**, the imput reactance is zero. When the short circuit is moved to point **2** (one-quarter wavelength) the reactance at the terminals is open circuit (infinite impedance). It can therefore be seen that the input reactance follows the outer circumference **29** of the Smith Chart as the short circuit is moved from point **1** to point **2** and on to point **3**. If the transmission line has some loss, the reactance values will fall at points inside the circumference as indicated by dotted circle **31** of FIG. 3*b*.

Varactor diodes can be used to provide a circuit capable of being tuned electronically that exhibits the above properties. The tuning varactor is a semiconductor diode designed to optimize variations in junction capacitance as a function of junction bias voltage. This type of diode can be used to capacitively load a transmission line and result in a circuit which characterizes the properties of the transmission line previously mentioned. In FIG. 4*a* the capacitance of diode **33** and the length of transmission line **35** together with bypass capacitor **43** are selected to cause the combination to achieve parallel resonance at the midrange of the varactor capacitance. The resulting terminal impedance will be high (e.g., open circuit). As the bias voltage source is varied, changing the value of the varactor capacitance to a higher or lower value, the input reactance of the network will become inductive or capacitive. The distance traveled on the Smith Chart is dependent upon the total capacitance change possible by varactor **33** as the bias is changed. In FIG. 4*b* the midrange capacitance of diode **45** and the length of transmission line **47** and capacitor **49** are selected to cause the combination to become series resonant resulting in a terminal impedance which is very low (e.g., short circuit). As the varactor bias voltage from source **51** is varied, changing the value of the capacitance to a higher or lower value, the reactance at the terminals of the network, once again, become capacitive or inductive. As before, the distance traveled on the Smith Chart depends on the total capacitance variation possible for the varactor.

Impedances represented by the entire circumference of the Smith Chart are generated by combining these series and parallel varactor diode networks. Varactor diodes having a minimum Q of 100 and a capacitance variation of 4 to 1 are needed in this application to effect low loss variable impedance load.

Impedance modulation, i.e., variation around the circumference of the Smith Chart as a function of time, is achieved by varying the varactor bias values. Varying the bias voltages as functions of time causes the terminal impedance of the variable impedance load, and thus the radar reflecting properties of CUSP, to vary with time. The desired time variation, or modulation, of the radar reflections from CUSP is thus obtained by appropriate design of the bias voltage modulation for the variable impedance load. These time functions can be either periodic or random.

FIG. 5 presents a block diagram of the timing circuitry and FIG. 6 presents related timing waveforms for a specific form of bias voltage modulation. The lower case letters in parenthesis in FIG. 5 refer to the waveforms shown in FIG. 6. Clock trigger 57 activates both ramp generator 59 and clock 61. AND gate 63 gates the output of ramp generator 59 as enabled by clock 61 after negation by NOT circuit to produce control voltage B. Ramp generator 59 is also gated in AND gate 67 as enabled directly by clock 61. The output of AND gate 67 and NOT circuit 65 is fed to OR gate 69 to obtain control voltage A. Thus, two control voltages are obtained for Smith Chart rotation, one for shunt variable reactance action and the other for series variable reactance load.

The bias voltage modulation shown in FIGS. 5 and 6 and described above will cause the terminal impedance to vary with time in such a way that, when plotted on a Smith Chart, a uniform angular rotation around the chart is achieved. This represents only one of an indefinite number of possible modulation types.

Referring to FIG. 7, control voltage A is fed to points 71 and 72 through resistors 74 and 75 and RF chokes 77 and 78 to bias varactor 81. Control voltage A is also fed through resistors 83 and 84 and RF chokes 86 and 87 to varactor 89. Control voltage B is fed at points 91 and 92 through resistors 94 and 95 and RF chokes 97 and 98 to bias varactor 101. Bypass capacitor 103 connects varactors 81 and 101 and bypass capacitors 105 and 107 connect varactors 89 and 101. The outputs for connecting the arms of the spiral conductor are taken at points 103 and 104. A tuning stub (not shown) can be inserted at point 105.

What is claimed is:

1. A system for modulating and reflecting radar signals comprising:
   a. a conical surface;
   b. a first spiral conductor mounted on the conical surface;
   c. a second spiral conductor mounted on the conical surface interleaved between the first spiral conductor and having a zigzag configuration at the wide base of the conical surface; and
   d. a variable impedance load connecting the first and second spiral conductors and including
      1. first and second sources of time varying voltages,
      2. a first varactor having the terminals thereof inductively connected to the first voltage source,
      3. a second varactor having the terminals thereof inductively connected to the first voltage source,
      4. a third varactor having the terminals thereof inductively connected to the second voltage source,
      5. first and second capacitors in series connecting the second and third varactors with the junction of the first and second capacitors being connected to one spiral conductor, and
      6. a third capacitor connecting the first and third varactors with the junction of the third varactor and the third capacitor being connected to the other spiral conductor.

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