United States Patent

Charlton et al.

[15] **3,670,336**

[45] **June 13, 1972**

[54] **ELECTRONIC TECHNIQUE FOR AN ALL-ELECTRONIC CYLINDRICAL ARRAY BEACON ANTENNA**

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[22] Filed: **May 11, 1970**

[21] Appl. No.: **36,050**

[52] **U.S. Cl.** ....**343/106,** 343/100 SA

[51] **Int. Cl.** **G01s 1/44**

[58] **Field of Search** ....343/106, 100 SA

[56] **References Cited**

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3,474,446 10/1969 Shestag et al. ....343/100 SA

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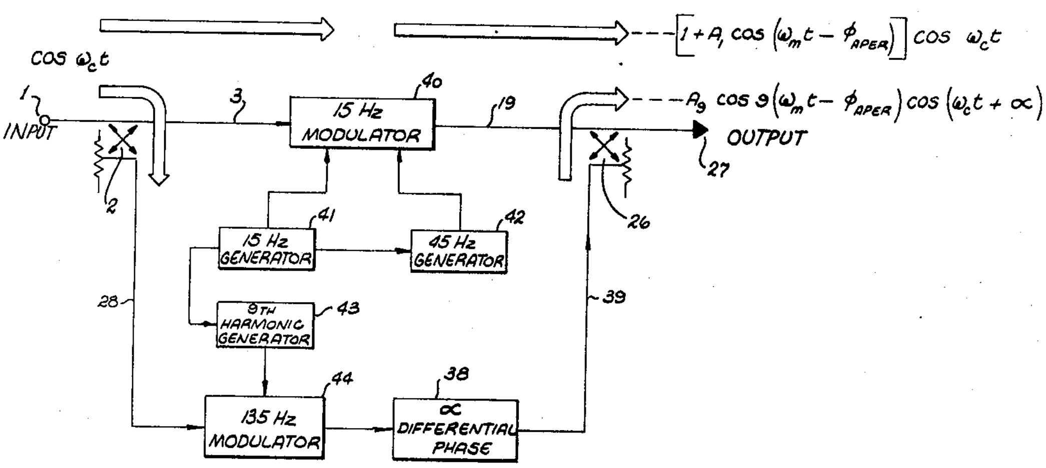
[57] **ABSTRACT**

A system for generating the amplitude modulation functions to apply to the individual columns of radiating elements in a cylindrical array antenna for the TACAN system. Two harmonically related low frequency modulation waveforms are contemplated, and means are provided for adjusting the radio-frequency phase of the higher of these two aperture excitation components relative to the RF phase of the carrier component. The result is broadening of the "operating lobe" of the modulation pattern, permitting operation over a broader band of frequencies and a wider range of elevation angles in a cylindrical array of moderate size.

10 Claims, 12 Drawing Figures



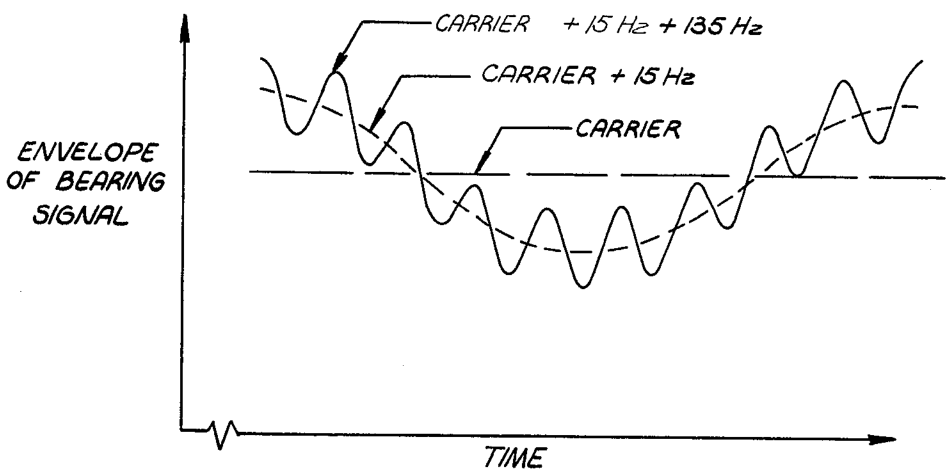


Fig. 1.

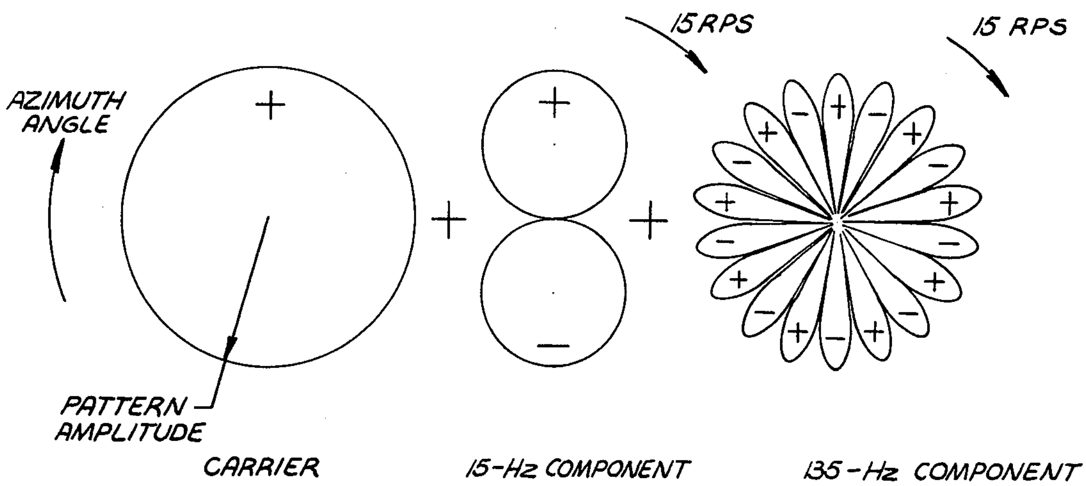


Fig. 2.

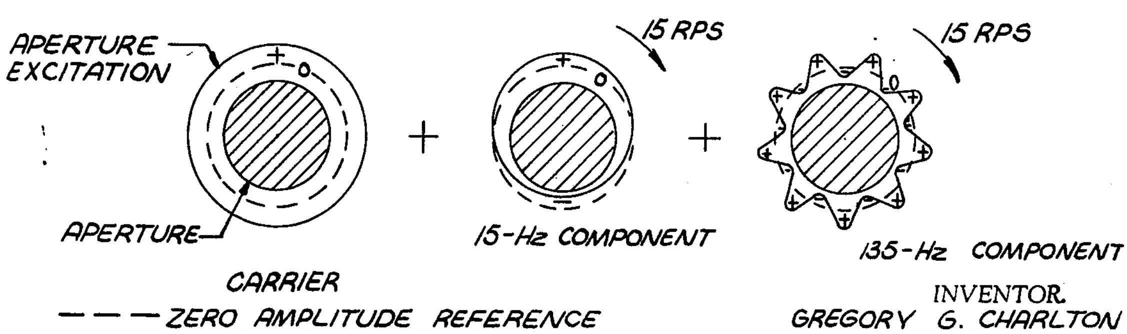


Fig. 3.

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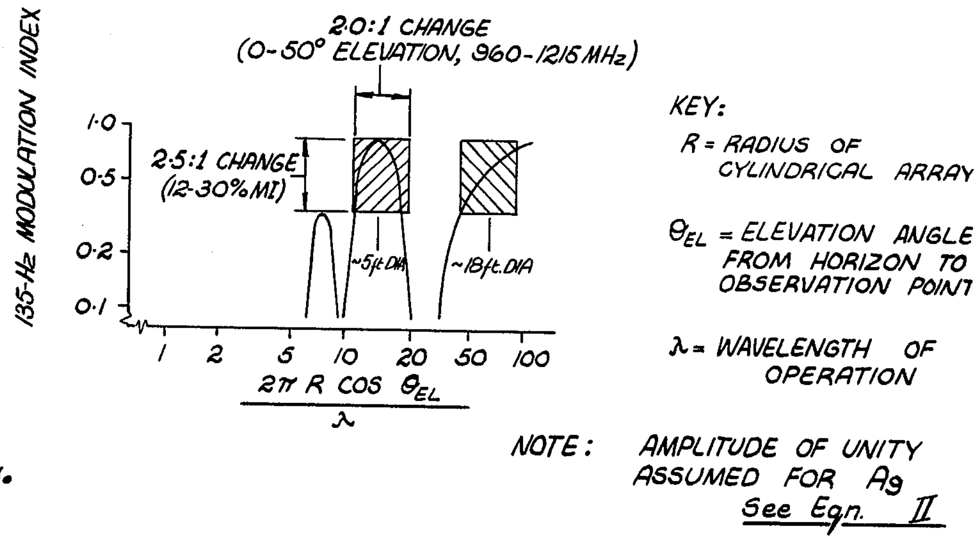

Fig. 4.

$$\left[1+\left(M_9'-JM_9''\right)\cos 9\left(\omega_m t-\phi_{az}\right)\right]\cos\omega_c t$$

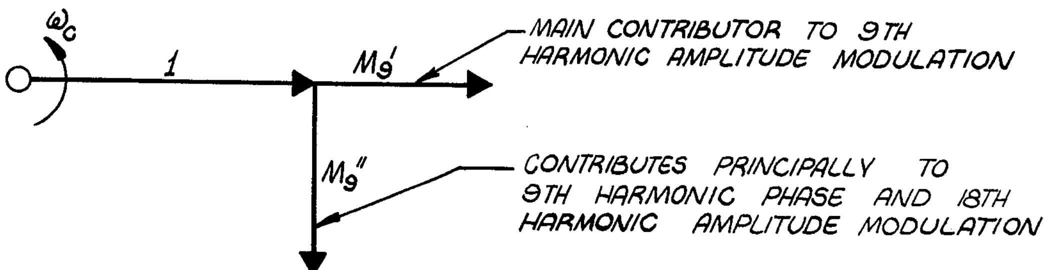

Fig. 5.

$$\left[1+\frac{1}{\sqrt{2}}\left(1+J\right)\left(M_9'-JM_9''\right)\cos 9\left(\omega_m t-\phi_{az}\right)\right]\cos\omega_c t$$

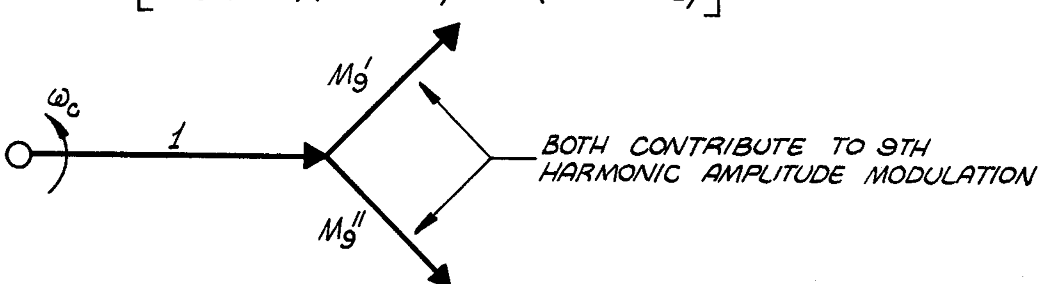

Fig. 6.

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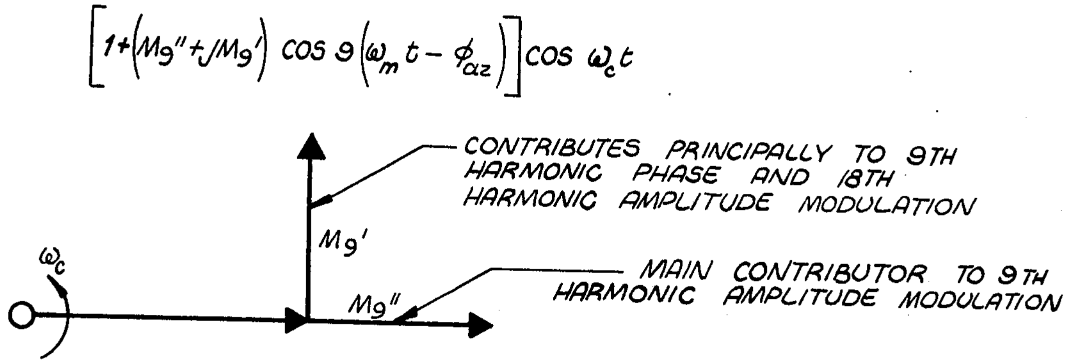

Fig. 7.

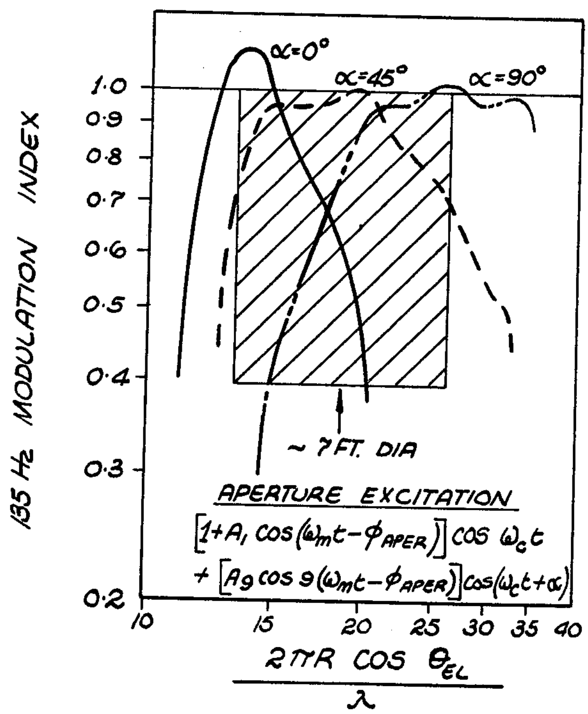

Fig. 8.

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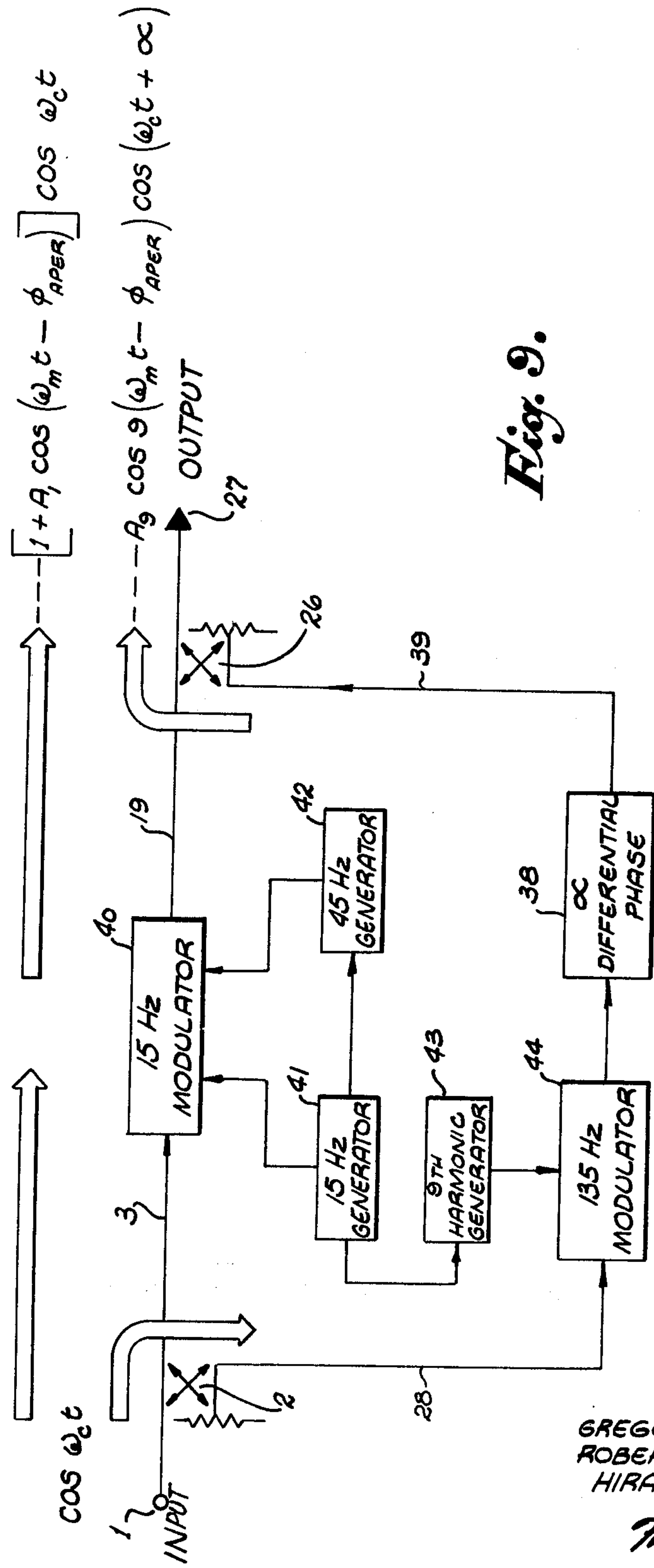

Fig. 9.

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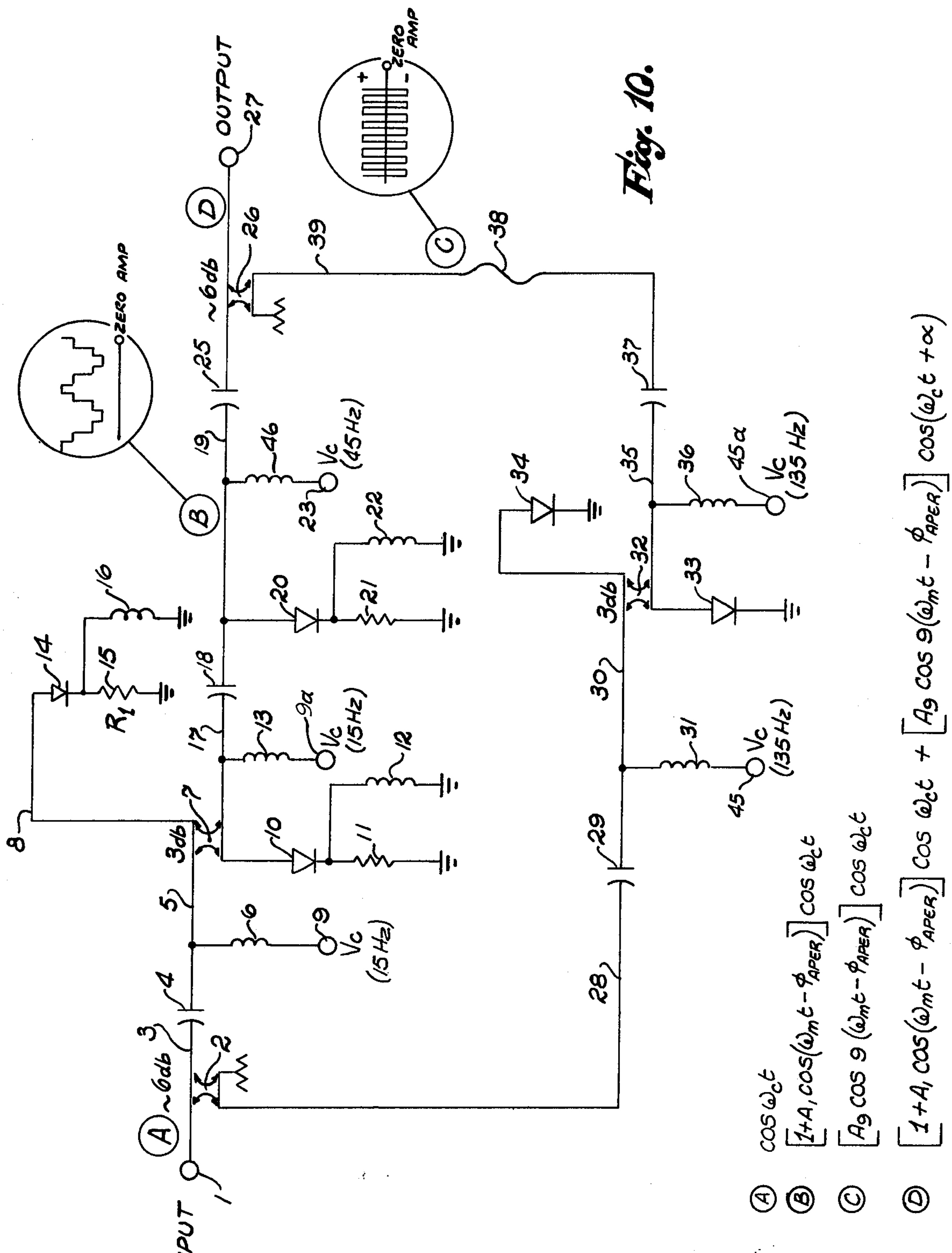

Fig. 10.

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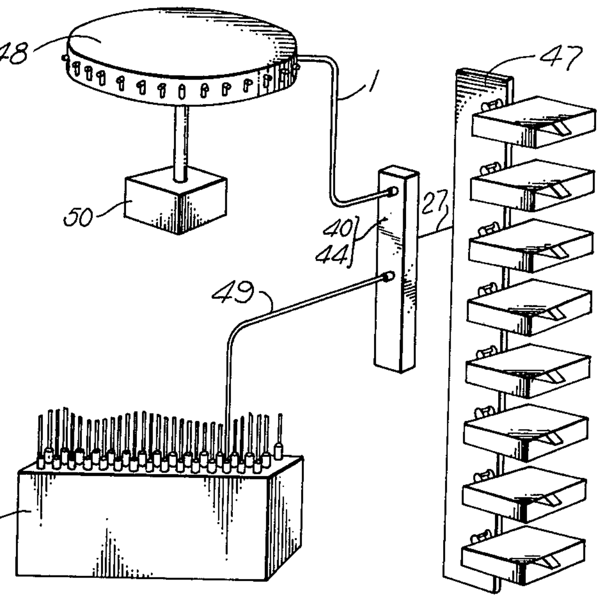

Fig. 12.

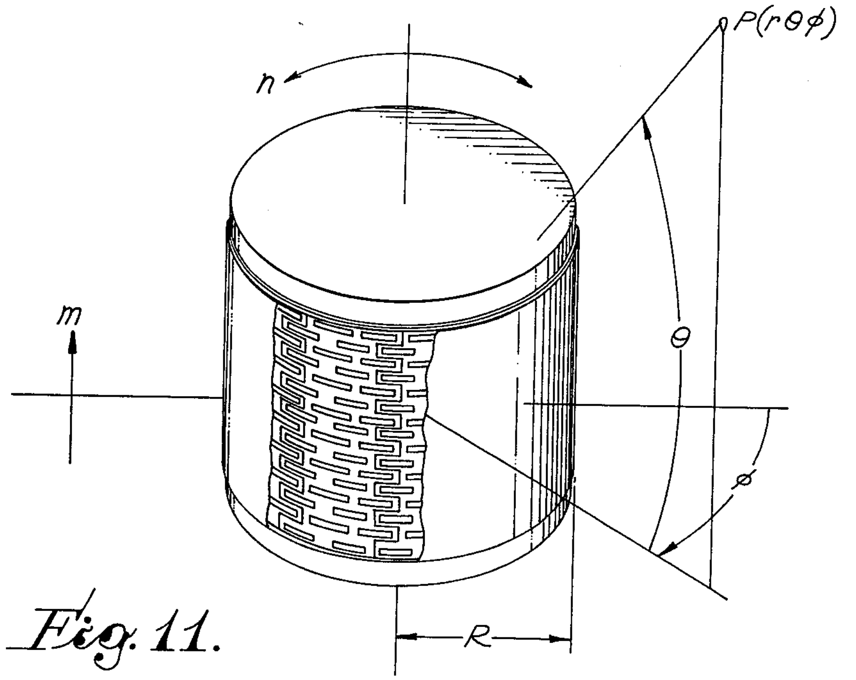

Fig. 11.

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ELECTRONIC TECHNIQUE FOR AN ALL-ELECTRONIC CYLINDRICAL ARRAY BEACON ANTENNA

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to modulation systems and techniques for providing electronic scanning from a cylindrical array. More particularly, the invention relates to an improved electronic modulation technique and apparatus for an all electronic beacon antenna system such as for the so called TACAN system.

2. Description of The Prior Art

In the prior art there have been a number of systems for radiating prescribed patterns similar to those of which the present invention is capable. The particular system instrumentation described herein was developed in contemplation of a rotating gear shaped pattern as required by the so-called TACAN system, a navigational guidance system for aircraft use. This system is described in detail in Chapter 12 of "Electronic Avigation Engineering" by Peter C. Sandretto, a reference handbook published in 1958 by International Telephone and Telegraph Corporation, New York. In that reference, a typical prior art antenna system for the TACAN ground transmitter is described. In that prior art instrumentation, as well as in some other prior art techniques for scanning the radiation pattern from a cylindrical array, mechanical means are used to obtain the desired pattern rotation (scanning).

Of most particular relationship to the present invention is the system described in U. S. Pat. No. 3,474,446, entitled "-Cylindrical Array Antenna System With Electronic Scanning". The present invention is, in fact, an improved modulation technique and apparatus applicable to the system of that reference.

In the aforementioned U.S. Pat. No. 3,474,446, the modulation pattern presented is that required in TACAN beacon antennas. Those patterns are typically formed by exciting a cylindrical antenna aperture circumferentially with appropriate amplitude modulation functions; in particular, three modulation components, consisting of a carrier of uniform amplitude and phase, and 15 and 135 Hz sinusoidal waves superimposed thereon. Each column of radiating elements around the circumference of the array is individually excited, the modulation phase varying progressively over the said columns about the circumference of the array, so that time rotation of the net pattern is effected. Simple amplitude modulation of the excitation to each of these columns is then possible.

The shortcomings of the aforementioned modulation technique are two, as follows: (1) an inability to develop, in a practical-sized antenna, the required 135 Hz modulation of the bearing signal over the full TACAN frequency band of 960 to 1,215 MHz and simultaneously over an elevation angle extending from the horizon up to at least 50°; and (2) an inability to develop the 135 z modulation in a manner that is insensitive to the parameters of the antenna. These shortcomings will be more clearly understood as this specification proceeds and description is undertaken in respect to the drawings presented. Also, the manner in which the present invention solves these prior art problems will be understood as this specification proceeds.

SUMMARY OF THE INVENTION

In the description to follow, the invention will be described in connection with the TACAN system, since it is in that connection that it is particularly useful. Hz

It may be said that the general objective of the present invention was the provision of a cylindrical array modulation technique and apparatus providing broad frequency band and extended elevation angle coverage in an antenna of moderate size. In essence, the improved aperture modulation technique that is the basis of this invention overcomes the aforementioned shortcomings by broadening the desired "operating lobe" of the modulation pattern. The specific result in one embodiment was the achievement of the required 135 Hz modulation of the bearing signal in a cylindrical array used with a TACAN system over the full frequency band of 960 to 1,215 MHz, and simultaneously over an elevation angle extending upward from the horizon to at least 50°. The so-called "operating lobe" will be defined in more detail later in this description; however, for the moment, it may be considered to be an expression relating the radius of a given cylindrical array, the elevation angle and the frequency.

As described in the aforementioned U.S. Pat. No. 3,474,446, the desired TACAN radiated signal is a gear shaped rotating pattern which is decodeable in an airborne receiver to obtain a demodulated signal of significance described in the aforementioned reference entitled "Electronic Avigation Engineering", by P. C. Sandretto.

Basically, broadening of the desirable "operating lobe" in a cylindrical array according to the present invention is achieved by shifting the radio-frequency phase of the energy which is modulated by the 135 Hz component of modulation. Stated otherwise, it may be said that the RF phase of the 135 Hz component of the aperture excitation is shifted relative to the RF phase of the remaining components, resulting in a complex audio amplitude and phase modulation of the antenna aperture excitation. This is in contrast to the prior art technique in which the RF phases of the 135 Hz and other components are identical, resulting in simple audio amplitude modulation of the antenna aperture excitation.

BRIEF DESCRIPTION OF THE DRAWINGS

In describing the present invention in a representative way, drawings have been provided as follows:

FIG. 1 is a representation of the envelope of the bearing signal required at a point in space in accordance with the requirements of a typical utilization system for the present invention.

FIG. 2 depicts the generation of the required bearing signal by rotating azimuthal radiation patterns, also in relation to a typical utilization system for the present invention.

FIG. 3 depicts the physical significance of the generation of required azimuthal radiation patterns by amplitude modulation of the aperture excitation, a concept pertinent to the present invention.

FIG. 4 represents a graph of a typical modulation pattern of a cylindrical array antenna, especially for operation of the present invention in a TACAN system.

FIG. 5 is a phasor representation of 135 Hz modulation of the bearing signal for in-phase aperture excitation.

FIG. 6 is a phasor representation of 135 Hz modulation of the bearing signal for 45° phase aperture excitation.

FIG. 7 is a phasor representation of 135 Hz modulation of the bearing signal for quadrature phase aperture excitation.

FIG. 8 graphs typical "modulation patterns" of a cylindrical array antenna with α phase aperture excitation.

FIG. 9 illustrates the form of an amplitude modulator for α phase aperture excitation.

FIG. 10 illustrates an example of a typical strip-line PIN diode modulator for α phase aperture excitation.

FIG. 11 is a pictorial drawing of a cylindrical array of known type to which the present invention is applicable.

FIG. 12 is a block diagram of a known column feed arrangement for the cylindrical array of FIG. 11 used with the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

As indicated previously, the principal use of the present invention is in connection with the so-called TACAN system, the present antenna and scanning system constituting a ground beacon station therefor. In that connection, the utility of the present invention is essentially the same as that provided by the device of the said U.S. Pat. No. 3,474,446, the present invention constituting an improvement thereover.

Referring now to the drawings, it will be seen that the envelope of the composite bearing signal required to be generated in space by a TACAN beacon antenna system is illustrated in FIG. 1. This instantaneous bearing signal is expressed mathematically as follows:

$$\underbrace{\underbrace{[1}_{\text{CARRIER}} + \underbrace{M_1 \cos(\omega_m t - \phi_{AZ})}_{\text{15-Hz COMPONENT}} + \underbrace{M_9 \cos 9(\omega_m t - \phi_{AZ})]}_{\text{135-Hz COMPONENT}}}_{\text{AUDIO MODULATION OF RF CARRIER}} \underbrace{\cos \omega_c t}_{\text{RF CARRIER}} \qquad \text{Eq. I}$$

Where:

M_1 = Modulation Index of 15–Hz Component
M_9 = Modulation Index of 135–Hz Component
ωm = Radian Modulation Frequency = $2\pi \times 15$
ω_c = Radian Carrier Frequency
t = Time
ϕ_{AZ} = Azimuthal Space Angle

From FIG. 1 and the above equation I, it will be seen that the bearing signal required consists of three distinct components; namely, a bias or carrier level, a 15 Hz component of audio modulation and a 135 Hz component of audio modulation. As indicated previously, such a bearing signal has been typically generated by rotating a multilobed azimuthal radiation pattern from the beacon antenna. FIG. 2 further illustrates these three components of the composite azimuthal pattern, corresponding to the three components of the bearing signal. In the context of space, the three components are: an omnidirectional "carrier" pattern, a dual-lobed "15 Hz" pattern and an 18-lobed "135 Hz" pattern, all with relative radio-frequency phases as indicated by + and − markings on FIG. 2. Time rotation of the latter two components at an effective rate of 15 revolutions per second develops the 15 and 135 Hz audio components of the bearing signal, as the said bearing signal would be received by an airborne receiving station.

Basically, in order to effect the azimuthal radiation patterns illustrated in FIG. 2, the cylindrical antenna aperture is excited circumferentially with similar-appearing amplitude functions.

FIG. 3 illustrates, and equationII expresses mathematically, the three components of circumferential aperture excitation corresponding to the three radiation patterns of FIG. 2. These are a uniform amplitude and phase "carrier" excitation, a single cycle "15 Hz" excitation, and a nine cycle "135 Hz" excitation. Time rotation of the latter two components is again implied.

It will be noted from the expression of equation II that the RF phase is identical for all three components and simple audio amplitude modulation of the antenna aperture therefore results. Such a system of excitation could be said to describe the prior art, particularly that represented in U.S. Pat. No. 3,474,446. The disadvantages of the aforementioned modulation technique have already been set forth.

For purposes of reference to the prior art and description of the invention, the term "modulation pattern" means variation in the modulation index of the 135 Hz component of the bearing signal, M_9 (equation I), graphed against a numerical parameter including the radius of the cylindrical antenna, the elevation angle from the horizon to the observation point, and the wavelength of operation.

Referring now to FIG. 4, the above mentioned numerical parameter is employed as the abscissa of a curve of a typical modulation pattern. For convenience, unity amplitude has been assumed for the aperture modulation coefficient of the 135 Hz component, A_9 (equation II). Superimposed on the graph of FIG. 4 are "boxes" illustrating the extent of acceptable modulation indices established by MIL-STD-291B for a standard TACAN signal; the extent of the horizontal axis parameter corresponds to operation from 960 to 1,215 MHz and from 0° to 50° elevation.

From FIG. 4 it will be perceived that a very large antenna (approximately 18 feet in diameter) is required if the specified index of 135 Hz modulation is to be obtained over the frequency band and range of elevation angles simultaneously using the prior art modulation technique. A smaller more practical sized antenna of the type described in U.S. Pat. No. 3,474,446 is satisfactory only if a reduced frequency band and/or coverage of elevation angles is acceptable, or if a greater variation in modulation index is considered acceptable.

As has been previously indicated, such a smaller antenna utilizing the prior art aperture excitation technique is extremely sensitive to variation of antenna parameters. For example, a small change in electrical radius of the antenna, from whatever cause, can reduce the 135 Hz component of the bearing signal to zero at particular elevation angles and frequencies, or it can cause a 180° audio phase shift of the 135 Hz component, giving rise to an intolerable bearing error.

The variation of the said parameter (which is the abscissa of FIG 4) over acceptable modulation index limits may be termed the "operating lobe" of the modulation pattern. It has been determined that, in accordance with the technique and instrumentation of the present invention as herein described, broadening of the so-called "operating lobe" of the modulation pattern is achieved at the expense of only a very modest increase in antenna size. It has also been determined that the technique of the present invention makes the entire antenna much less sensitive to variations of antenna parameters. Broadening of the desirable "operating lobe" is achieved in accordance with the present invention by shifting the radio-frequency phase of the 135 Hz component of the aperture excitation relative to the RF phase of the carrier component. The result is a complex audio amplitude and phase modulation of the antenna aperture excitation. As also indicated previously, this technique is in contrast with the in-phase modulation technique of the prior art. Mathematical expressions for the circumferential aperture excitation and resulting bearing signal for three different RF phase shifts of the 135 Hz modulated component of the aperture excitation relative to the RF phase of the carrier component have been written. These values are zero, 45° and 90° respectively, the zero value corresponding to simple audio amplitude modulation as described previously in connection with the prior art analysis. For the zero phase shift situation, equation II represents the aperture excitation and equation III the resulting bearing signal, as follows:

$$\underbrace{\underbrace{[1}_{\text{CARRIER}} + \underbrace{A_1 \cos(\omega_m t - \phi_{APER})}_{15\ H_z\ \text{COMPONENT}} + \underbrace{A_9 \cos 9(\omega_m t - \phi_{APER})]}_{135\ H_z\ \text{COMPONENT}}}_{\text{AUDIO MODULATION OF AZIMUTHAL APERTURE EXCITATION}} \underbrace{\cos \omega_c t}_{\text{RF CARRIER}} \qquad \text{Eq. II}$$

Where:

A_1 = Aperture Modulation Coefficient of 15–Hz Component

A_9 = Aperture Modulation Coefficient of 135–Hz Component

ϕ_{APER} = Circumferential Aperture Coordinate

by the 135 Hz signal at **44** and then re-injected through a directional coupler **26** into the primary line to output **27**. The required differential RF phase shift between the carrier and the 135 Hz components of the aperture excitation is provided by the differential phase device **38**. Actually, the transmission line length differential around the loop, including **28**, modula-

BEARING SIGNAL

$$+\ M_1 \text{ COS } (\omega_m t-\phi_{AZ})\ +\ \underbrace{M_9}_{M_9'-jM_9''} \text{ COS } 9\ (\omega_m t-\phi_{AZ})]\text{ COS } \omega_c t \qquad \text{Eq. III}$$

In equation III, the coefficient of the 135 Hz bearing signal, M_9, is shown to be a complex number, $M_9' - jM_9''$. The existence of the imaginary term, jM_9'', is peculiar to the higher harmonics of the aperture excitation formed by the 135 Hz component, A_9. It is through the use of this imaginary term that the RF phase shift of the 135 Hz component will provide broadening of the "operating lobe".

For the 45° phase shift condition, equations IV and V describe the aperture excitation and resulting bearing signal respectively, as follows:

tor **44** and **39**, vis-a-vis the path **3**, **40**, **19** can be designed to provide the necessary differential phase shift. In that case, the element **38** is symbolic only.

Referring now more specifically to FIG. **9**, the essential elements of an amplitude modulator and their operation providing the α - phase aperture excitation required will be described.

The radio-frequency power for a single column is applied at input **1** and then separated between lines **3** and **28** by means of a directional coupler **2**. A 15 Hz generator **41** provides a

APERTURE EXCITATION

$$[1+A_1 \text{ COS } (\omega_m t-\phi_{APER})] \text{ COS } \omega_c t+[A_9 \text{ COS } 9\ (\omega_m t-\phi_{APER})] \text{ COS } (\omega_c t+45°) \qquad \text{Eq. IV}$$

BEARING SIGNAL

$$[1+M_1 \text{ COS } (\omega_m t-\phi_{AZ})+\underbrace{M_9}_{\frac{(1+j)}{\sqrt{2}}(M_9'-jM_9'')} \text{ COS } 9\ (\omega_m t-\phi_{AZ})] \text{ COS } \omega_c t \qquad \text{Eq. V}$$

Finally, equations VI and VII will be seen to represent the aperture excitation and resulting bearing signal for the 90° phase shift condition, as follows:

modulation signal, hereinafter sometimes referred to as a first modulation signal, to the modulator **40**. The output of the modulator **40** automatically contains the carrier component il-

APERTURE EXCITATION

$$[1+A_1 \text{ COS } (\omega_m t-\phi_{APER})] \text{ COS } \omega_c t+[A_9 \text{ COS } 9\ (\omega_m t-\phi_{APER})] \text{ COS } (\omega_c t+90°) \qquad \text{Eq. VI}$$

BEARING SIGNAL

$$[1+M_1 \text{ COS } (\omega_m t-\phi_{AZ})+\underbrace{M_9}_{M_9''+jM_9'} \text{ COS } 9\ (\omega_m t-\phi_{AZ})] \text{ COS } \omega_c t \qquad \text{Eq. VII}$$

FIGS. **5**, **6** and **7** are self explanatory phasor representations of the signal components contributing to the 135 Hz modulation of the bearing signal, corresponding respectively to the three discrete values of RF phase shift. Introduction of the indicated RF phase shifts changes the phase relationship of the "real" and "imaginary" components of the 135 Hz modulation index, M_9 (equation I), relative to the carrier component.

FIG. **8** illustrates the effect of the indicated RF phase shifts on the "operating lobe" of the modulation pattern. As already noted, the effect of the indicated RF phase shifts is a broadening of the operating lobe, and the shift of that lobe to the right. The superimposed box on FIG. **8** indicates the extent of specified operating parameter variations, as was the case with FIG. 4. The said parameter limit box is centered about the curve for 45° for illustration. The parameters included in the abscissa of FIG. **8** include the full frequency band of 960 to 1,215 MHz (the full TACAN frequency band), an elevation angle up to 50° over the horizon, and a relatively modest circular array diameter of about 7 feet, the foregoing applying for the said 45° RF phase shift situation as illustrated.

The practical instrumentation of the improved aperture modulation technique of the present invention preferably is achieved through use of a modulator within the RF path "behind" the radiating elements of the antenna in the general form illustrated in FIG. **9**. In that instrumentation, a fraction of the carrier input signal power at input terminal **1** is coupled off by means of a directional coupler **2**, modulated separately

lustrated along with the 15 Hz modulation. Accordingly, a separate injection of unmodulated carrier is unnecessary, the said line modulator output **19** being substantially less than 100 percent modulated and therefore having an appropriate carrier level to afford the same effect.

A frequency tripler **42** acts as a 45 Hz generator operating from **41** to produce a third harmonic component to be impressed on the carrier along with the 15 Hz signal. In a practical instrumentation, it is convenient to use square wave modulation signals, and the 45 Hz component adds to the 15 Hz signal in such a way as to make the net 15 Hz modulation approximate a sine wave. This will be further explained later in this specification in connection with the circuit details of FIG. **10**.

A synchronously generated ninth harmonic of the 15 Hz signal is produced by **43**, controlled by **41**. This ninth harmonic is at 135 Hz, which, like the 15 Hz, is a standard TACAN modulation frequency. Neither of these frequency values or the exact harmonic relationship between them is an absolute requirement of the present invention, however, they are convenient in describing the typical embodiment of the invention as applied in a TACAN system.

The term α-phase aperture excitation has been applied to the present invention wherein the RF energy in the 135 Hz modulated path is phase shifted. As has been pointed out, the phase shift of 45° depicted in FIG. **8** has been found to be near optimum in the aforementioned TACAN antenna application.

Modulation of the energy in the 28 to 39 path is accomplished in modulator 44 and the aforesaid 45° phase shift is introduced by the arbitrary phase shifter 38. At the radio frequencies involved (middle of the band somewhat in excess of 1,000 MHz) it will be apparent that only a relatively minor differential in the length of the RF path 28 through 39, as compared to that of 3 through 19, would provide the 45° shift desired. Thus 38, though illustrated following 44, may equally well be placed ahead of 44, and is not necessarily a discrete component. Rather, 38 is illustrated to represent the required slightly different transmission line path.

The net signal of output 27 is the combination, in directional coupler 26, of the 15 Hz modulated component at 19 with the 135 Hz modulated and RF phase shifted component at 39.

Referring now to FIG. 10, details of a typical modulator arrangement according to FIG. 9 are shown. Input 1 and output 27 will be recognized, as will the input and output directional couplers 2 and 26.

The 15 Hz modulator components include the PIN diodes 10 and 14. Two diodes are used in this modulator to achieve a balanced effect, since it is desirable to minimize RF reflections which could interfere with the proper operation of the device. The inputs 9 introduce the 15 Hz modulation signal from 41 (not shown on FIG. 10) and the components associated with the 15 Hz modulator include inductances 6, 12, 13 and 16, resistances 11 and 15 and the internal 3db directional coupler 7. The capacitances 4 and 18 are of a value so that they readily pass the RF energy passing from lead 3 to lead 5 and from 17 to 19 respectively, but represent substantially open-circuit impedances to the modulation signal frequencies. The converse is true of the inductors 6 and 13. Accordingly, the 15 Hz modulation signals are applied from input 9 through inductor 6 to PIN diode 14. There is conductivity between leads 5 and 8 through the directional coupler 7. Inductor 16 provides a ground for the PIN diode 14 at modulation frequencies, but substantially only the resistance 15 carries the RF passing through diode 14. The value of 15 is selected to regulate the percentage modulation imposed on the RF signal passing through 7 as a result of "switch-on" of diode 14.

The modulation operation of PIN diode 10 (the other side of the balanced modulator) is controlled by the 15 Hz modulation signal introduced at 9*a*. This signal passes through inductor 13 and the conductive path through 7 to control diode 10 in the same manner as 14 was controlled. The resistance 11 and the inductor 12 function the same as 15 and 16, respectively.

It will be recalled that the use of square wave modulating signals was said to be most appropriate, since the PIN diodes are operated only as switches. The RF energy modulated by the 15 Hz modulation signal is extant at 17 and is passed by blocking capacitor 18 to lead 19, where it is further modulated by a single ended shunt type line modulator, comprising the PIN diode 20, resistor 21 and inductors 22 and 46. The operation is comparable to one side of the 15 Hz balanced modulator, i.e., resistor 21, inductor 22 and inductor 46 function in the same manner as hereinabove described for resistor 11, inductor 12 and inductor 13, respectively. A 45° (third harmonic of 15 Hz) modulation signal derived by 42 (FIG. 9) is added to the signal already modulated by the 15 Hz signal. Capacitors 18 and 25 provide the required RF paths with modulation (diode switching) signal isolation. Inspection of the insert waveform at "B" on FIG. 10 depicts the resulting modulation envelope. It will be understood that the sine wave approximation thus effected significantly reduces harmonic content at the output 27.

Considering now the path 28 through 39, it will first be observed that 2 and 26 are both approximately 6db couplers, appropriate for the RF energy apportionment between the basic 15 Hz and the 135 Hz modulation paths beginning at leads 3 and 28, respectively. Having considered the basic 15 Hz modulation process, the 135 Hz channel remains to be studied. The said couplers 2 and 26 provide the RF energy source for the path 28 through 39, and the means for recombining the 15 and 135 Hz modulated energies, respectively.

It will be evident that the modulator components in the aforementioned 28 through 39 path constitute a balanced modulator similar to those of the balanced 15 Hz modulator with the exception that the cathodes of PIN diodes 33 and 34 are directly ground returned and do not have the RL components found associated with 10 and 14. Accordingly, currents flowing in 33 and 34 as a result of the square-wave 135 Hz signals applied at 45 and 45*a*, are limited substantially only by the diode forward resistance and the resistance and inductive reactance of 31 and 36. As previously understood, however, the inductors 31 and 36 operate primarily as barriers to the RF potentials at 30 and 35. Accordingly, this circuit is essentially a 180° phase shifter and produces the modulation envelope depicted in the insert waveform at "C" on FIG. 10. Directional coupler 32 provides modulation signal continuity from terminal 45 to diode 34 and from 45*a* to 33. Blocking capacitors 29 and 37 operate analogously to capacitors 4, 18 and 25, i.e., they pass the RF signals but not the audio frequencies.

As indicated in connection with discussion of FIG. 9, the so-called α - phase aperture excitation is obtained by introduction of an RF phase shift (of 45° near-optimum value in the particular embodiment which is the subject of this discussion) between the 15 and 135 Hz modulated energies. In FIG. 10, the element 38 represents a relatively small change of the transmission-line path length sufficient to provide the required phase shift by virtue of this path length differential. The element 38 is represented as a functional block on FIG. 9; however, this is to be understood to be the same element as indicated on FIG. 10 It is further possible, in the particular TACAN embodiment, to automatically maintain an optimum value of the RF phase shift over the frequency band, by selecting the proper pathlength differential 38. For example, a value of 0° at 960.MHz and a value of 45° at 1,215 MHz may be automatically achieved, without the need for additional circuitry.

The output 27 is appropriate for use as the excitation of a discrete column excitation signal in a cylindrical array, such as contemplated in the aforementioned U.S. Pat. No. 3,474,446. Actually, the modular circuit identified as 309 on FIG. 3 of that reference may be replaced by the circuit of FIG. 10 herewith, the connection being obvious from a study of both structures and their respective descriptions.

FIG. 11 illustrates a known form of cylindrical array of radius R, having n columns each with m elements vertically. The elements of adjacent columns are staggered vertically as shown to permit closer effective azimuthal spacing when the open waveguide radiator elements illustrated are used. Elevation and azimuth coordinate angles, θ and ϕ respectively, are identified.

FIG. 12 summarizes the application of the elements of the combination as the description in relation to the prior art depicts them. One column from FIG. 11 is shown with its distribution network 47 fed at 27 from the modulator block 40 and 44 (see also FIG. 9). The modulator control elements 41, 42 and 43 from FIG. 9 may be packaged together as shown, since these are duplicated for each such column and associated modulator. The lead 49 comprises the leads 9 from each of the blocks 41, 42 and 43 as shown in more detail on FIG. 9. The feed line 1 for this column will be recognized from FIG. 9. The microwave energy source 50 and distributor 48 provides for all columns as does the block marked 41, 42 and 43.

A modulator circuit such as the present FIG. 10 is required for each radiator column in the cylindrical array. The modulation frequencies applied to each column modulator are phase shifted with respect to each other to provide the rotating pattern effect. Accordingly, the same preparation of the modulation tones, as contemplated in FIGS. 5 and 6 of U. S. Pat. No. 3,474,446, is still required, except that the 15 and 135 Hz modulation signals are not mixed as they are at point 606 on

FIG. 6 of that reference, but rather in the present invention they are mixed as described in connection with FIGS. **9** and **10** herewith.

Various modifications are possible within the spirit of the present invention, and these will suggest themselves to those skilled in this art.

Although the modulation circuit of FIG. **10** is more or less typical of PIN diode circuitry, other configurations providing the required function are obviously possible.

The cylindrical array with which this invention is used may contain columns of dipoles or other radiators, as well as the staggered open-waveguide radiators used in U.S. Pat. No. 3,474,446.

Transmission lines of the coaxial or waveguide types may be utilized in the RF transmission circuits.

The materials from which the elements of the present invention may be constructed will be obvious to those skilled in this art. The microwave couplers **2**, **7**, **26** and **32** may be constructed according to well known waveguide component techniques, or may be quite satisfactorily constructed in stripline according to well understood methods.

It is not intended that the present description and drawings should limit the scope of the invention. The drawings and description are illustrative and typical only.

What is claimed is:

1. Apparatus for generating composite modulated radio-frequency signals for energizing each column of radiators in a cylindrical antenna array, comprising:
   - a first modulator for modulating a first fraction of the power from a source of radio-frequency energy with a first modulation frequency;
   - a second modulator for modulating a second fraction of the power from a source of radio-frequency energy with a second modulation frequency which is an integral multiple of said first modulation frequency;
   - phase shift means responsive to the energy modulated by said second modulator for shifting the phase of the radio-frequency power therefrom;
   - and means for combining the outputs of said first modulator and said phase shifted output of said second modulator for producing a discrete composite excitation signal for a corresponding one of said columns of radiators.

2. In an inertialess antenna scanning system including a cylindrical array and a plurality f radiating elements arranged in columns distributed in juxtaposition around at least a portion of the circumference of said cylindrical array, said columns being arranged to be individually excited with radio-frequency energy modulated by a plurality of predetermined modulation signals at predetermined modulation signal phase for each of said columns to produce a radiation pattern equivalent to that which would result from rotation of said cylindrical array about its axis, the combination associated with each of said columns comprising:
   - means for producing said plurality of modulation signals in the form of at least first and second synchronously generated modulating signals, said second modulation signal having a frequency equal to the product of said first modulation signal frequency and a constant greater than unity;
   - means for dividing said radio-frequency energy into a plurality of paths;
   - first modulating means within a first one of said radio-frequency energy paths for modulating the energy therein with said first modulation signal;
   - second modulating means connected within a second one of said radio-frequency paths for modulating the energy therein with said second modulation signal;
   - phase shift means connected within said second radio-frequency path for introducing a predetermined phase shift of said radio-frequency energy in said second path;
   - and means for combining the output energies from said paths, thereby to provide a composite column excitation signal.

3. The invention set forth in claim **2** in which said cylindrical array is oriented such that its axis is substantially vertical.

4. The invention set forth in claim **2** in which said second modulation signal frequency is defined as being an odd multiple greater than unity of the frequency of said first modulation signal.

5. The invention set forth in claim **2** in which said first modulation signal frequency is in the low sub-audio region, and said second modulation signal frequency is the ninth harmonic of said first signal.

6. The invention set forth in claim **5** further defined in that said modulation signals are predetermined to amplitudes such that said composite column excitation signal is modulated less than 100 percent at all times.

7. The invention set forth in claim **6** further defined in that said phase shift means in said second path is inserted after said second modulation means within the circuit of said second path.

8. The invention defined in claim **5** in which said means for dividing said radio-frequency energy comprises a separate directional coupler for coupling from a radio-frequency source into said first and second paths, and said means for combining the output energies from said paths comprises an additional separate directional coupler from the output of each of said first and second paths to form an output for said composite column excitation signal.

9. The invention defined in claim **8** in which said first and second modulation signals are 15 and 135 Hz, respectively.

10. The invention set forth in claim **7** in which said phase shift means in said second path introduces 45° of carrier phase shift measured at a predetermined radio frequency within the operating range of said antenna scanning system.

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