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PATENT SPECIFICATION

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(72) Inventor ERIC JOSEPH ISBISTER

(54) NAVIGATION SYSTEMS

(71) We, SPERRY CORPORATION formerly Sperry Rand Corporation, a Corporation organised and existing under the laws of the State of Delaware, United States of America, of 1290 Avenue of the Americas, New York, New York 10019, United States of America do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to navigation systems and more particularly to detection and identification systems which utilise frequency diversity transmission, for example for the illumination of navigation markers which include retrodirective elements containing non-linear devices which reradiate signals with frequencies that are linear combinations of the frequencies of the received signals, thus providing a means for identifying the markers.

Hitherto, navigational systems have been proposed that employ retro-directive identifiable devices to mark channels or routes to be taken by navigating vehicles. Some of the earlier systems such as that disclosed in U.S. Patent Specifications Nos. 2,461,005 and 2,520,008 provide an identification means by modulating the signal received at the marker prior to retransmitting the signal. However, these systems retransmit frequencies that have been originally transmitted and as such complete with returns from background clutter at the receiver. In many environments, the energy level of the background clutter at the receiver is such that the modulated re-radiated signals may not be detected.

Later systems, such as that disclosed in U.S. Patent Specification No. 3,518,546, provide a non-linear element in the retro-directive device to generate harmonics of the frequency of the received signals and a means for modulating the latter. These harmonic signals are then re-radiated towards a receiver located adjacent the original transmitter. Since signals are re-radiated at harmonic frequency, rather than at the fundamental or received frequency, separation from the fundamental signal returns of the background clutter is theoretically more easily accomplished at the receiver. However, a heterodyning receiver is usually a generator of harmonic signals and some portion of the background clutter fundamental signal is converted to harmonic signals tending to mask the desired externally generated harmonic signals. To minimise this possibility, filters with extremely deep and steep passband characteristics are employed prior to mixing the received harmonic signals with the local oscillator signals. Further, stringent transmitter and local oscillator frequency control is required to maintain the desired signals within the filter and intermediate frequency (i.f.) amplifier passbands.

According to the present invention a detection and identification system comprises transmitter means for producing a multiplicity of signals each having a different frequency with a known frequency separation therebetween; means coupled to the transmitter means for radiating the multiplicity of signals; means at the object to be detected and identified for focussing signals received from the radiating means at a given area; a multiplicity of signal energy collectors positioned to collect the focused signals; a multiplicity of non-linear elements, coupled to the multiplicity of signal energy collectors, wherein signals at frequencies which are linear combinations of the frequencies of the radiated multiplicity of signals are generated, the generated signals being re-radiated by the signal energy collectors via the focussing means in substantially the directions from which the received signals arrived; and means for receiving the re-radiated signals and producing output signals in response to the re-radiated signals whereby the object may be identified.

The present invention provides an improved system which utilizes retro-directive devices that re-radiate signals which are identifiable with respect to signal returns from land, ice, rain and sea clutter. The re-radiated signals are readily detected and can be used to facilitate the identification of route markers in a high clutter enviroment.

In a preferred embodiment, a transmitter and antenna combination radiates two independent signals with a known frequency separation therebetween, the radiated signals propagating to a navigation marker containing a Luneberg lens with an equatorial band of antenna elements thereon. The Luneberg lens directs the illuminating signals to one of the antenna elements, the signal being guided therefrom to a non-linear device wherein signals at the fundamental frequencies and at frequencies which are linear combinations thereof are generated. These generated signals are then guided to the antenna element for re-radiation to the original transmitting location where they are received and the fundamental and linear combination signals are seperated. After separation each linear combination signal is reduced to video and summed with the video of the other linear combination signals while the fundamental signals are correlated in a manner similar to the correlation of a frequency diversity radar system to improve the signal to clutter ratio. Summed video and the correlation video are then coupled to a display unit and to a processing unit for marker tracking and identification.

When two signals with different frequencies are received by a non-linear device, such as a crystal diode, a multiplicity of frequencies are generated which are linear combinations of the fundamental frequencies and harmonics thereof. If the frequencies of the signals received by the non-linear device are f_1 and f_2, the generated frequencies will be $mf_1 \pm nf_2$, m and n being integers the value of which are dependent upon the characteristics of the non-linear device and the received signal level. For example, a non-linear device receiving two signals with frequencies f_1 and f_2 operating at a signal level for which a cube term is included in the voltage-current Taylor expansion of the device, will generate signals with frequencies of f_1, f_2, $3f_1$, $3f_2$, $2f_1+f_2$, $2f_2+f_1$, $2f_1-f_2$ and $2f_2-f_1$. Any combination of these frequencies may be employed by the present invention. However, to maintain the overall operation within a reasonable frequency bandwidth, the frequencies utilised are preferably: f_1, f_2, $2f_1-f_2$ and $2f_2-f_1$. Other terms generally exist in the Taylor expansion, resulting in a multiplicity of available harmonic combinations that may be selected along with f_1 and f_2 to maintain a reasonable operating bandwidth. While the preferred embodiment of the invention will be described in terms of a system in which a non-linear device is illuminated by a composite signal containing two frequencies, it will be apparent that the invention may be implemented with a greater number of illuminating frequencies with a concomitant increase in available linear combinations of generated frequencies.

The invention will now be further described, by way of example, with reference to the accompanying drawings, in which:—

Figure 1 is a block circuit diagram of a preferred system according to the invention,

Figure 2 shows a retro-directive antenna which may be used in the system of Figure 1,

Figure 3 shows an alternative antenna to that of Figure 2,

Figures 4*a* and 4*b* show two alternative antenna elements either of which may be used in the antenna of Figure 3, and

Figure 5 shows a further alternative antenna.

Figure 1 illustrates an embodiment of the invention in which two signals with frequencies f_1 and f_2, wherein $f_2=f_1+\Delta f$, are transmitted by a transmitter 10 which includes a signal generator 11 for generating a signal at a frequency f_1 and a signal generator 12 for generating a signal at a frequency f_2. The output signals from signal generators 11 and 12 are coupled to an antenna 13 via transmission lines 14, 15 and 16 and a TR device 17, these signals being radiated from the antenna 13 to illuminate subsequently a retro-directive antenna 18, yet to be described. The antenna 18 contains a non-linear device for the generation of signals at frequencies which are linear combinations of the frequencies f_1 and f_2. Since the signals at linear combinations of f_1 and f_2 can only emanate from the antenna 18 which contains a non-linear device, they may be more easily detected in a clutter environment than can the signals at frequencies f_1 and f_2. Signals with frequencies f_1, f_2 and the linear combinations thereof are re-radiated from the antenna 18 and received by the antenna 13, from which they are coupled through the TR device 17 to a pre-amplifier 21 wherein the total received signal, comprising components at frequencies f_1, f_2 and linear combinations thereof, is amplified and then coupled to a first mixer 22 to which a first local oscillator 23, operating at a frequency f_{LO} is also coupled. Though a single antenna and a TR device, to accomplish energy transmission and reception, is described in this embodiment, it should be understood that these functions could also be performed by two seperate antennae: a transmitting antenna directly coupled to the transmitter 10 and a receiving antenna directly coupled to the peramplifier 21.

The first mixer 22 and the local oscillator 23 are included in a receiver 24 which also includes a frequency selection unit 26, a second mixer 27, a detector 28, a second local oscillator 29, an IF amplifier unit 30, a video sum unit 33, a video amplifier 34, a correlator 37 and a video amplifier 38. The composite signal at the output terminals of the first mixer 22 is then coupled to the frequency selection unit 26 which contains tuned amplifiers 26*a*, 26*b*, 26*c* and 26*d* wherein signals having frequencies f_{IF}, $f_{IF}+\Delta f$, $f_{IF}+2\Delta f$, and $f_{IF}+3\Delta f$ are selected and amplified.

Where:—

$$f_{IF}=2f_1-f_2-f_{LO};$$
$$f_{IF}+\Delta f=f_1-f_{LO};$$
$$f_{IF}+2\Delta f=f_2-f_{LO};$$

and

$$f_{IF}+3^{\delta}f=2f_2\alpha f_1\alpha f_{LO}.$$

though a series of tuned amplifiers are employed for frequency separation in this embodiment of the invention, it should be apparent that passive filters may be utilised to perform this frequency separation.

The signal of the first local oscillator 23 is also coupled to an automatic frequency control (AFC) unit 32 contained within the transmitter 10. Frequency control signals from the AFC unit 32 are coupled to the frequency generators 11 and 12 as reference signals for maintaining the frequency separation Δf between the frequencies f_1 and f_2 and for maintaining frequencies f_1 and f_2 within limits which ensure that the frequencies of the component signals at the output terminal of the mixer 27 are within the passbands of the tuned amplifiers 26*a* to 26*d*.

After frequency separation and amplification, the signals at the output terminals of the amplifiers 26*a*, 26*b* and 26*c* are respectively coupled to mixer units 27*a*, 27*b* and 27*c* of the second mixer 27 and a signal at the output terminal of the amplifier 26*d*, which is at a frequency f_{IF}, is coupled to a detector unit 28*d* of the detector 28. The second local oscillator 29 couples a signal with frequency Δf to the mixer unit 27*a*, a signal with frequency of $2\Delta f$ to the mixer unit 27*b*, and a signal with frequency $3\Delta f$ to the mixer unit 27*c*. These local oscillator signals mix with the signals coupled from the mixer units 27*a*, 27*b* and 27*c* to produce signals with frequencies f_{IF} at the output terminals of the mixer units 27*a*, 27*b*, and 27*c*. The signal at the output terminal of the mixer unit 27*c* is then coupled to the detector unit 28*c* of detector unit 28 via the IF amplifier 30*c*. The video signals at the output terminals of the detector units 28*c* and 28*d* which correspond to the received signals having frequencies of $2f_2-f_1$ and $2f_1-f_2$ are coupled to the video sum unit 33 and added therein, the sum provided to the video amplifier 34 from which the amplified video is coupled to a display unit 35 and a processor unit 36. The signals at the output terminals of the mixer units 27*a* and 27*b* which correspond to the received signals with frequencies f_1 and f_2 are coupled to the correlator 37 via the IF amplifiers 30*a* and 30*b* wherein they are combined with some logic technique providing a video signal at the output terminal representative of the correlation of the two signals. This video is coupled to the video amplifier 38, the video signal output of which is coupled to the display unit 35 and the processor unit 36.

The processor unit 36 is made automatically to track the position of the retro-directive antenna 18 by means of the azimuth data coupled from the antenna 13 via a line 70 and the range information derivable from the video received from either the correlator 37 or the video amplifier 34. Since the signals with frequencies f_1 and f_2 must complete with clutter, in many environments the combination of signal and clutter received at the antenna 13 does not permit the detection of the desired signals by the correlator 37. In these situations, the signals at frequencies which are linear combinations of f_1 and f_2 and can only emanate from the retrodirective antenna 18, as explained heretofore, are used for range tracking. When the system is operating in an environment in which the signals at f_1 and f_2 may be detected by the correlator 37, the signals at frequencies that are linear combinations of f_1 and f_2 are used as identifying markers on the display unit 35, thus ensuring that the signals being used for tracking emanate from the retro-directive antenna 18.

The retro-directive antenna (shown at 18 in Figure 1) may be as shown in Fig. 2 which shows an antenna 40 comprising electrical conductors 42 which form a dipole, the terminals of which are connected to the respective cathode and anode terminals of a diode 41, the overall length L of the entire assembly approximating a half wavelength at the central frequency of the operating bandwidth. The antenna resulting from the diode 41 and the conductors 42 receives signals at frequencies f_1 and f_2 radiated from the antenna 13 and applies these signals to the diode 41 wherein the aforementioned composite signal containing a multiplicity of frequencies is generated due to the non-linear characteristics of the diode 41. This composite signal is then omni-directionally re-radiated and subsequently received at the antenna 13 and coupled to the preamplifier 21 of Fig. 1.

The antenna 40 exhibits a radar cross-sectional area approximately equal to $0.2\lambda^2$. This radar cross-section in combination with other system parameters determines the operating range of overall system. With other system parameters remaining equal, an appreciable increase in range may be achieved with the antenna 43 shown in Fig. 3 which comprises a Luneberg lens 44 with an antenna belt 45 circumferentially disposed about the equator. An electro-magnetic wave illuminating the antenna 43 at an elevation angle within a specified band above and below the equator, which is determined by the width of the antenna belt 45, will be focused onto the antenna belt to an area diametrically opposite from the approaching wave where the signal energy is collected by at least one of a multiplicity of antennae elements 46 comprising the antenna belt. The antenna element 46 (containing a diode or other non-linear device) re-radiates a composite signal which possesses frequencies which are linear combinations of the two received signals f_1 and f_2. The antenna belt 45 may comprise a multiplicity of dipole-diode antennae, such as the antenna 40 shown in Fig. 2, circumferentially disposed within a number of bands 47 with the dipole spacing within each band adjusted to provide continuous coverage in the azimuthal sector of interest, whereas the number of bands contained within the belt is determined by the elevation coverage desired.

Other configurations, two of which are shown in Figs. 4*a* and 4*b* may be employed as the antenna elements 46 of the antenna belt 45. In Fig. 4*a*, the antenna element comprises a horn 50, the throat end of which is connected to a chamber comprising a waveguide extension 51 of the horn, a metallic iris diaphragm 52, a metallic piston reflector 53 and a diode 54 mounted in the waveguide between the iris 52 and the movable piston reflector 53, with the cathode and the anode of the diode 54 respectively connected to the top and bottom walls of the waveguide via two wires 55. The chamber is made resonant at some desired frequency, determined by its proportions, that is when the operating frequency band includes transmitted frequencies f_1 and f_2 and the desired linear combinations thereof. The various parameters of the chamber can be so correlated that substantially all of the wave power of frequencies within the given bandwidth incident on the iris diaphragm 52 enter the chamber; when the transmitted signals with frequencies f_1 and f_2 enter the chamber they are received by diode 54 which proceeds to generate the linear combinations of f_1 and f_2 mentioned heretofore. As a result of these generated signals, currents are conducted to the walls of the waveguide extension 51. These currents will excite the chamber and cause resonance therein, only for frequencies that are within the aforementioned bandwidth. These resonating signals will then be coupled through the iris diaphragm 52 to the horn 50 to be retro-directionally radiated from the Luneberg lens 43.

In the modification of Fig. 4*a* that is illustrated in Fig. 4*b*, an additional chamber preceding the chamber containing the diode 54 is formed by a second iris diaphragm 56 spaced apart from the iris diaphragm 52 a known distance such that the two chambers constitute a bandpass filter. This arrangement may be used either to provide a narrower bandwidth by synchronously tuning the two chambers or a boarder bandwidth by stagger tuning the two chambers. In the latter case, additional linear combinations of f_1 and f_2 may be retro-directionally radiated.

As stated previously, the elevation coverage of the spherical retro-directive antenna may be increased by widening the equatorial antenna belt 45. However, this increase in width causes an increase in aperture blockage resulting in a decrease in the radar cross-sectional area of the spherical retro-directive antenna, the ratio of the cross-sectional area σ_2 with blockage to the theoreticly maximum cross-sectional area σ_1 being:

$$\frac{\sigma_2}{\sigma_1} = \left[1 - \frac{2}{\pi}\left(\sin^{-1}\alpha + \alpha\sqrt{1-\alpha^2} \right) \right]^2$$

where $\alpha = a/R$ *a* being the half width of the antenna belt 45 and R being the radius of the sphere of the Luneberg lens 43. Thus, a compromise has to be made between the maximun operating range of the system and the elevation coverage.

Retro-directive antennae as heretofore described are relatively complex, heavy and costly. In Fig. 5 is shown an antenna that provides retro-directivity at an appreciable reduction in complexity, weight and cost. The retro-directive antenna shown in Fig. 5 generally comprises two parts. A cylindrical antenna ring 61 and a spherical shell 62 disposed concentrically about the antenna ring 61. The spherical shell 62 may be constructed in accordance with the disclosure of such prior art as U.S. Patent Specification No. 2,510,020 or an article by J. Croney et al that appeared in the

Microwave Journal of March 1963. In accordance with these prior disclosures, the spherical shell 62 comprises a mutiplicity of wire or rod like conductors 63 which form an angle of substantially 45 degrees with the horizontal at substantially all latitudes. Thus, an observer at the centre of the sphere looking outwards sees wires at 45 degrees on all azimuths but an observer outside looking through the sphere sees wires at 45 degrees on the front surface and at an orthogonal angle of −45 degrees on the rear surface. Consequently, rays 64 of a plane wave, each possessing a polarization of −45 degrees, incident on the front surface of the shell 62 at points 65 each will pass through the mesh of wires without significant loss until each reaches the inner surface at the points 66 where they will be focused by the curved surface to apoint 67 on the antenna ring 61 and received thereat by antenna elements 68. The antenna elements 68 are similar to those described for the antenna belt 45 shown in Fig. 3. Each antenna element 68 contained in the antenna ring 61 is appropriately polarized to receive the signals reflected from the inner surface and to generate linear combinations of frequencies f_1 and f_2. The rays of the wave being radiated from the antenna element located at point 67 illuminate the inner surface of the sphere, are reflected therefrom and travel along a path parellel to the incident rays 64. Polarization of the re-radiated wave is such that it passes through the spherical surface at the front of the shell 62 and continues in the direction of the original source.

Polarization other than at an angle of −45 degrees causes a loss of radar cross-sectional area. For horizontal, vertical and circular polarization, this loss results in a radar cross-sectional area that is approximately 25% of the projected area. However, the radar cross-sectional of the antenna of Figure 5 is directly proportional to the fourth power of the diameter (i.e. D^4) and consequently an increase in diameter of 40% will compensate for the polarization loss.

WHAT WE CLAIM IS:—

1. A detection and identification system comprising transmitter means for producing a multiplicity of signals each having a different frequency with a known frequency separation therebetween; means coupled to the transmitter means for radiating the multiplicity of signals; means at the object to be detected and identified for focussing signals received from the radiating means at a given area; a multiplicity of signal energy collectors positioned to collect the focused signals; a multiplicity of non-linear elements, coupled to the multiplicity of signal energy collectors, wherein signals at frequencies which are linear combinations of the frequencies of the radiated multiplicity of the signals are generated, the generated signals being re-radiated by the signal energy collectors via the focussing means in substantially the directions from which the received signals arrived; and means for receiving the re-radiated signals and producing output signals in response to the re-ɪadiated signals whereby the object may be indentified. That from which the received signals arrived.

2. A detection and identification system according to claim 1 wherein the focussing means is a spherical Luneberg lens with the focused signal receiving means equatorially disposed thereabout.

3. A detection and identification system according to claims 1 or 2, wherein the signal energy collectors are metallic horn antennae.

4. A detection and identification system according to claim 1 or 2, wherein the signal energy collectors are dipole antennae.

5. A detection and identification system according to any of the preceding claims, wherein the non-linear elements are crystal diodes.

6. A detection and identification system according to any of the preceding claims, wherein the focussing means comprise a spherical shell made of conductive wires each inclined at an arc of 45 degrees to the horizontal at all latitudes with the focused signal receiving means concentrically contained therein.

7. A detection and identification system according to any of the preceding claims, wherein the receiving means include energy collecting means for collecting energy re-radiated from the signal generating means, a first mixer coupled to the energy collecting means, a first local oscillator coupled to the first mixer and providing a signal to the first mixer that is at a predetermined frequency separation from a preselected one of the signal frequencies produced by the signal generating means, the frequency separation being an intermediate frequency, the frequency differences between the local oscillator signal frequency and other signal frequencies produced by the signal generating means being at a frequency separation from the intermediate frequency predetermined for each of the other signal frequencies, whereby the first mixer provides a combined output signal which includes a signal at the intermediate frequency and a multiplicity of signals at the predetermined frequency separations therefrom, each signal in the combined output signal corresponding to one of the signals produced by the signal generating means, filter means including a multiplicity

of output terminals, coupled to the first mixer, for separating the combined output signals into signals at the intermediate frequency and signals at preselected difference frequencies from the intermediate frequency, the signal at the intermediate frequency and the signals at preselected difference frequencies there from corresponding to signals produced by the frequency generating means, the signal at the intermediate frequency being coupled to one of the multiplicity of output terminals and other output terminals of the multiplicity of output terminals having one of the preselected signals coupled thereto, a second mixer including a multiplicity of input terminals each with a corresponding output terminal, each of the input terminals being coupled to one terminal of the multiplicity of output terminals of the filter means, a second local oscillator coupled to the second mixer and providing signals at frequencies equal to the predetermined frequency differences from the intermediate frequency, whereby signals at the intermediate frequency are coupled to the output terminals of the second mixer, each signal corresponding to one of the signals produced by the signal generating means, means coupled to the intermediate frequency terminal of the filter means and to the output terminals of the second mixer corresponding to the signals at linear combinations of the frequencies of the multiplicity of radiated signals for reducing signals coupled thereto to video providing the sum thereof, and means coupled to the output terminals of the second mixer corresponding to the multiplicity of radiated signals, for correlating signals at the output terminals of the second mixer corresponding to the multiplicity of radiated signals and for reducing to video the correlated signal thereby obtained.

8. A detection and identification system according to any of the preceding claims, wherein the transmitter means comprise a multiplicity of signal generators, each for the generation of a signal at a predetermined frequency and each coupled to the radiating means, and means for controlling each signal generator of the multiplicity of signal generators to maintain the signal frequency of each of the signal generators within a given frequency band about each of the predetermined frequencies and for maintaining the frequency separation therebetween within a preselected frequency range.

9. A detection and identification system constructed and arranged substantially as herein particularly described with reference to Figure 1, or as modified by any of Figures 2 to 5, of the accompanying drawings.

Agents for the Applicants
J. SINGLETON
Chartered Patent Agent

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3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

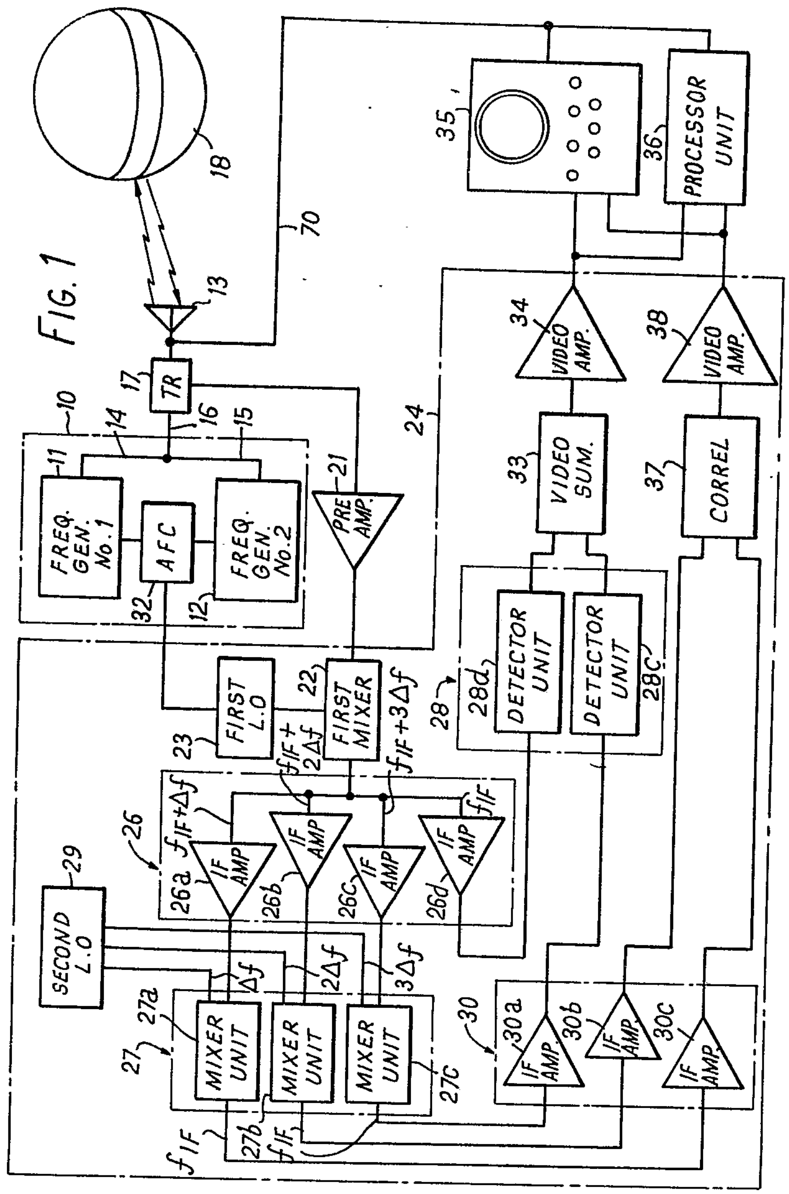


FIG. 1

FIG. 2

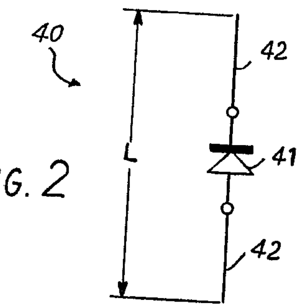
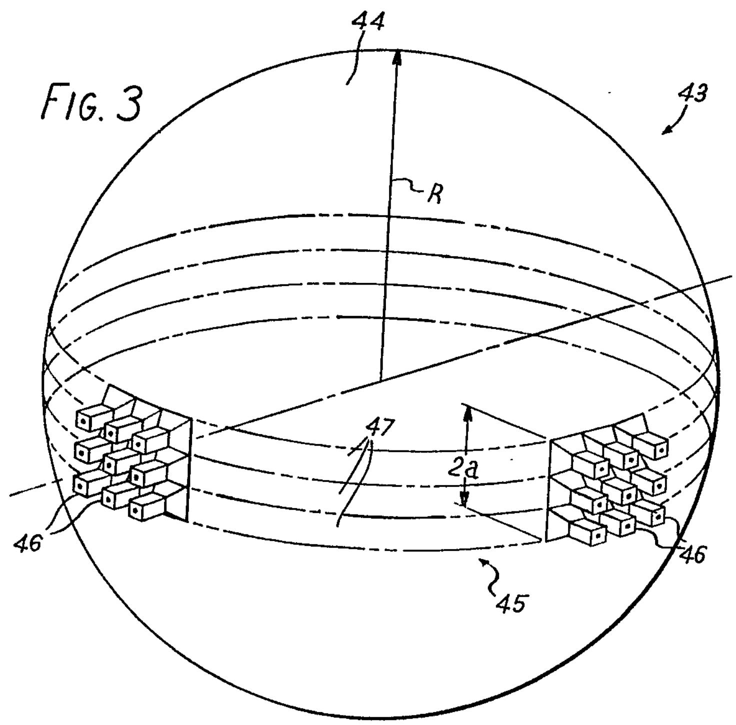


FIG. 3



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3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 3

FIG. 4a

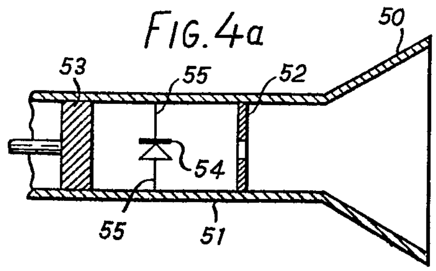

FIG. 4b

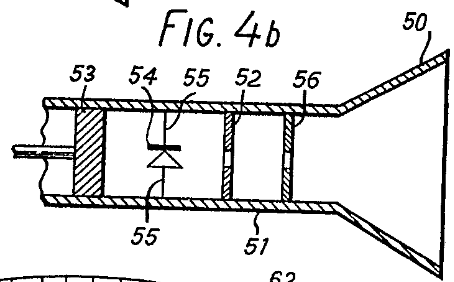

FIG. 5