Feb. 2, 1943. J. E. SMITH 2,309,678

FREQUENCY MODULATION SYSTEM

Filed Aug. 31, 1940 2 Sheets-Sheet 1

Fig. 1

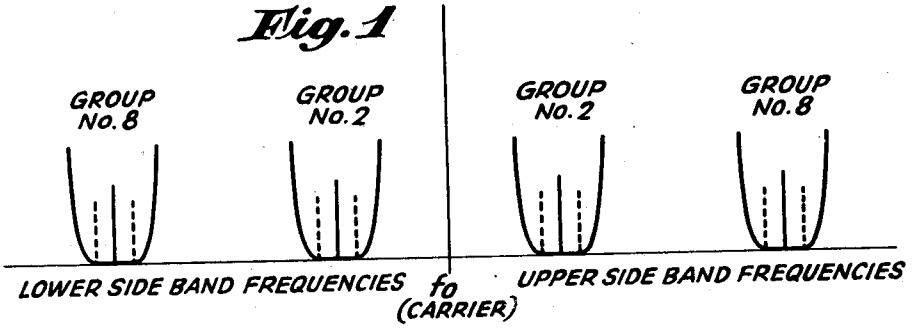
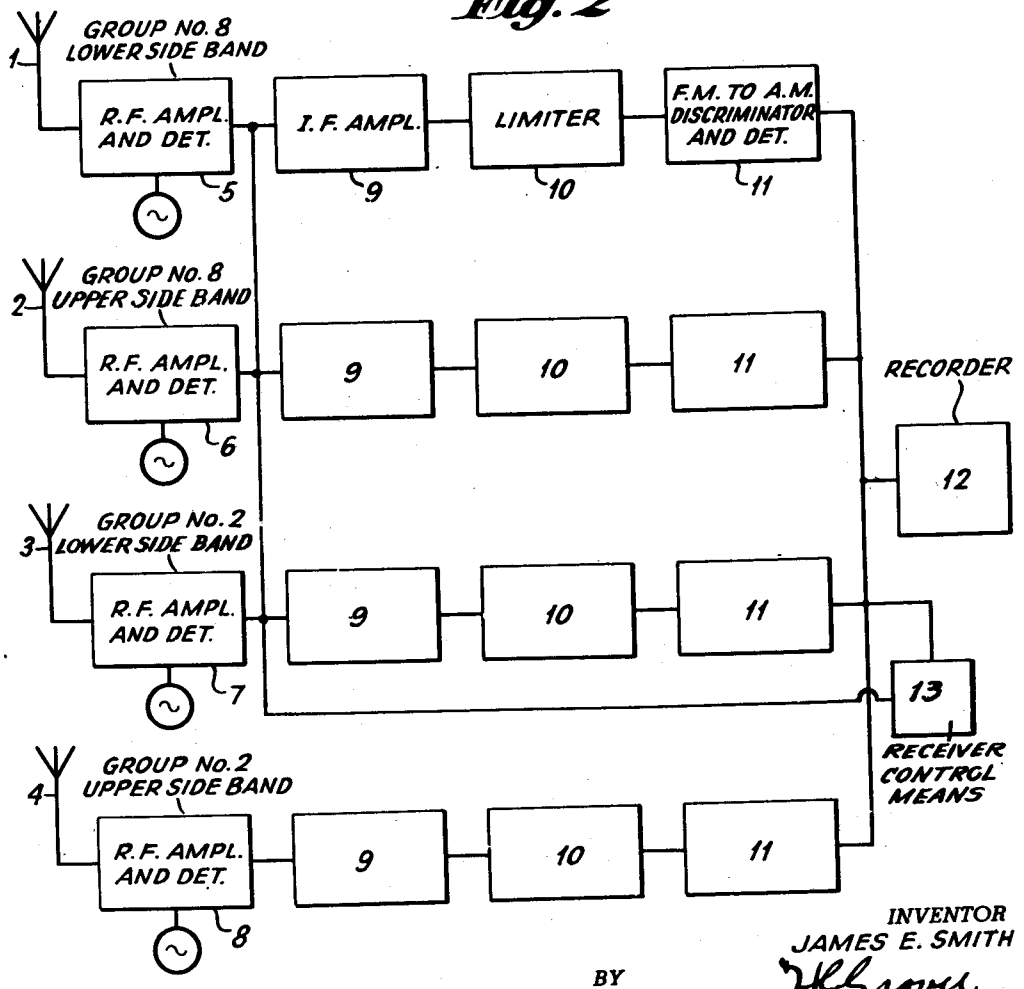


Fig. 2



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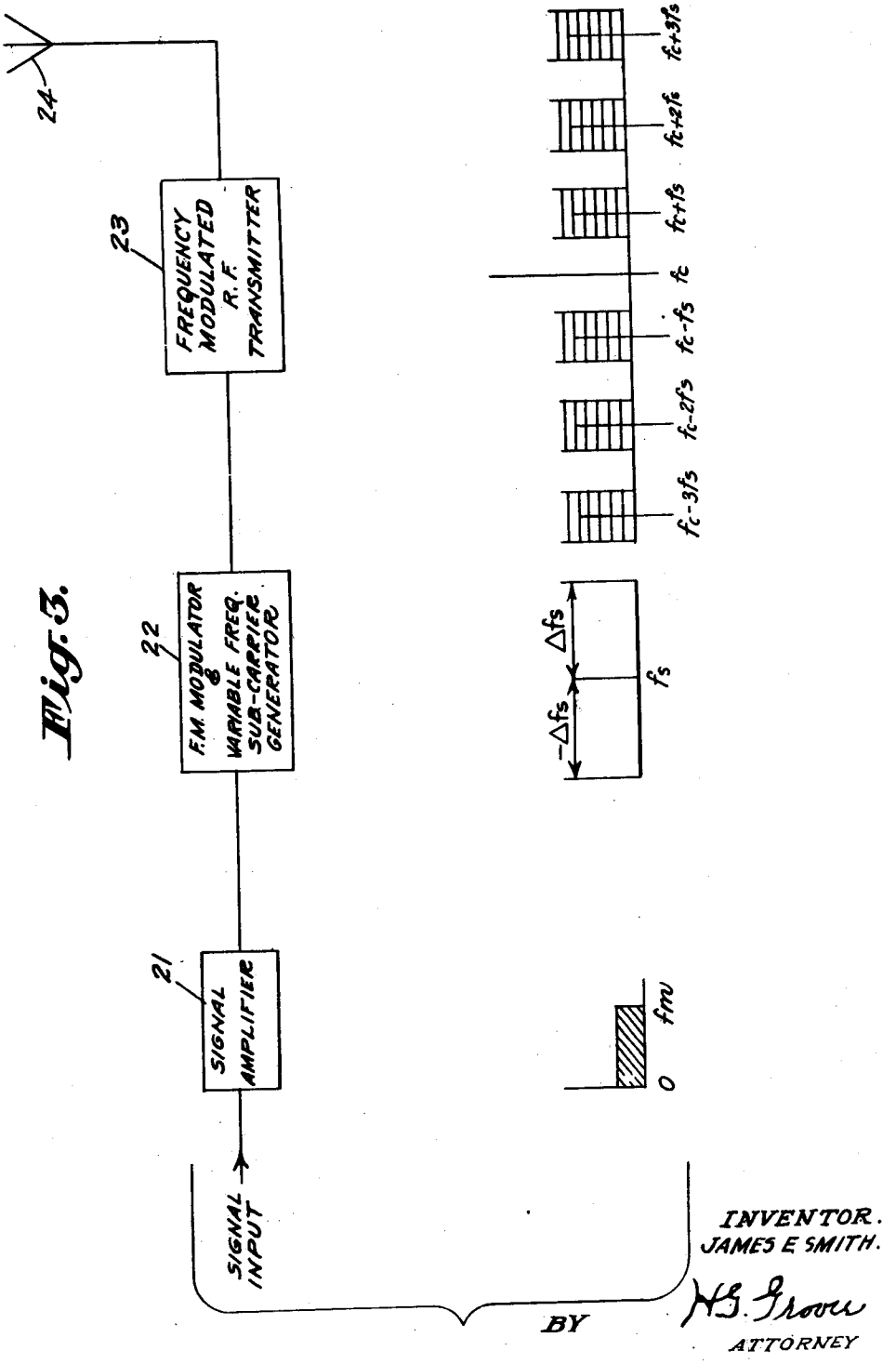


Fig. 3.

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Patented Feb. 2, 1943 2,309,678

UNITED STATES PATENT OFFICE

2,309,678

FREQUENCY MODULATION SYSTEM

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Application August 31, 1940, Serial No. 354,984

10 Claims. (Cl. 250—6)

This invention relates to improvements in frequency modulation systems, and has for one of its objects a method of and apparatus for overcoming selective fading in radio communication.

Known frequency modulation systems deviate the frequency of the transmitted instantaneous carrier directly according to the modulating signal amplitude variations. At the receiver, there is employed a single frequency-to-amplitude demodulator or converter having a band width conversion characteristic at least equal to the total swing or peak-to-peak deviation of the carrier. Such systems are subject to distortion due to selective fading, and in fact this distortion is sufficiently severe to preclude the use of frequency modulation transmissions at normal short-wave long-distance radio communication circuits.

The system of the present invention, broadly speaking, overcomes the foregoing defect by breaking up or segregating the transmitted signal side bands into individual frequency groups, each group of which contains all of the necessary intelligence, and then receiving and detecting certain ones of these groups of side bands separately. The receiver outputs of the system of the present invention are then combined in accordance with the usual diversity receiving methods. The effects of selective fading are thus minimized.

A better understanding of the invention may be had by referring to the following description in conjunction with the accompanying drawings, wherein:

Fig. 1 illustrates graphically desirable side band groups which can be selected from a particular table and used for the purpose of the invention;

Fig. 2 illustrates one form of receiving system which may be used in the practice of the invention; and

Fig. 3 illustrates diagrammatically one means for transmitting signals in accordance with the invention.

For purposes of exposition, the principles underlying the present invention will now be described.

It is known that a frequency modulation radio frequency carrier, when modulated by a single sub-carrier tone, is equivalent to a carrier and an infinite number of sinusoidal primary side band carriers above and below the radio frequency carrier and having frequency spacings equal to the sub-carrier frequency. Normally, the side band components greatly removed from the radio frequency carrier are of small amplitude and may be neglected. The spread of the pertinent side band carriers, i. e., those having considerable amplitude, is a function of the modulation index (ratio of peak radio frequency carrier deviation to sub-carrier frequency in this case). If the sub-carrier frequency is now varied, each of the foregoing primary side bands will vary in frequency in direct correspondence with the variation of the sub-carrier. Each of these varying primary side band carriers is actually composed of a group of frequency components including a secondary sub-carrier and secondary upper and lower side bands, determined by the modulating signal intelligence. The position of the primary side band carriers relative to the radio frequency carrier is determined by the frequency of the sub-carrier, and the amplitude of the primary side band carriers is determined by the amplitude of the sub-carrier. The position of the secondary side bands with respect to the secondary sub-carrier in each group is determined by the frequency components of the intelligence, and the amplitude of these secondary side bands is determined by the amplitude of the frequency components of the intelligence. However, the amplitudes of the varying primary side band carriers constituting each group is a function of the modulation index and for a particular amplitude of the sub-carrier certain primary side band carriers may have their amplitudes decreases to zero or to a reverse polarity when the frequency of the sub-carrier is varied. Such side band groups whose amplitudes decrease to zero cannot be satisfactorily limited. Other side band groups, on the other hand, will have sufficient amplitudes for a fixed modulation index to permit satisfactory limiting. These last wave groups may be demodulated separately and in accordance with the invention then combined in the usual diversity receiving fashion. Selective fading may submerge one entire signal group in the noise, but if three or more groups are employed in the diversity system of the invention, the probability that they will all fade simultaneously is extremely small. Following the principles just described, the present invention achieves communication by frequency modulation by varying or shifting the sub-carrier frequency in accordance with the intensity or amplitude of the modulating signal.

To illustrate a specific embodiment of the invention, given by way of example only, let us suppose that a carrier in the frequency modulation transmitter is modulated by a one kilocycle tone and the amplitude of the tone deviates the

radio frequency carrier plus and minus ten kilocycles. The modulation index which, as mentioned before, is the maximum devivation (to one side of the carrier) divided by the maximum audio frequency transmitted is then $m=10$ and the resulting side bands are shown in the table given below. This table shows different side-band amplitudes and phases for three different modulation indices. If the tone frequency of one kilocycle is now changed to 900 cycles, but its amplitude maintained constant as before and of the same value, the modulation index will then be $m=11.1$. Further, if the frequency of the tone is changed to 1100 cycles without varying its amplitude, the modulation index becomes $m=9.08$. The following table shows the side band amplitudes and phases (plus and minus) for these three conditions which represent a case where the sub-carrier frequency is frequency modulated from 900 cycles to 1100 cycles by the signal intelligence.

	Groups									
		#1	#2	#3	#4	#5	#6	#7	#8	#9
m	$J_0(m)$	$J_1(m)$	$J_2(m)$	$J_3(m)$	$J_4(m)$	$J_5(m)$	$J_6(m)$	$J_7(m)$	$J_8(m)$	$J_9(m)$
9.08	−1.13	2.33	1.62	−1.6	−2.7	−.8	1.83	3.22	3.1	
10	−2.47	.43	2.53	.57	−2.18	−2.34	−.17	2.16	3.19	
11.1	−1.5	−1.9	1.17	2.34	0	−2.75	−2.13	0	2.1	

If the 900 to 1100 cycle tones in the foregoing example are the extreme or peak deviation frequencies of an actual frequency modulating system in accordance with the invention, it will be evident that as the sub-carrier tone varies in frequency between these limits in accordance with the intensity or amplitude of the modulating signal there will be instantaneous side bands lying between the extreme values for the individual frequency groups given in the table.

In accordance with the invention, one or more of those side band groups (such as numbers 2, 5 and 8 of the table) which will permit limiting, are detected individually and then combined. Side band groups such as numbers 1, 4 and 7 of the above table are not used since the side band amplitudes in these groups become zero during continuous sub-carrier frequency modulation. By selecting channels or groups such as numbers 2 and 8 of the above table, the degree of amplitude modulation of the radio frequency side bands is well within the operating range of normal limiters. Both the upper and lower side band groups **2** and **8** could be used individually in the receiver of the invention. Further, the selected groups for detection are well separated in the frequency spectrum so that selective fading would not normally affect all groups simultaneously. Selective fading of the radio frequency carrier or any of the components outside the chosen bands thus does not destroy the received signal. This is one important advantage which the present invention has over frequency modulation systems employing a common detector for the entire radio frequency band.

Fig. 1 shows the desired side band groups or channels to be detected and combined. These are shown without regard to the actual phases of the components since only the relative phases within a group are of importance. In each group there are shown a solid vertical line and two slightly smaller vertical dash lines on opposite sides of the central solid line. The solid line represents the subcarrier when unmodulated by frequency modulation, while the smaller dash lines represent the extreme positions of the sub-carrier when frequency modulated. Of course, only one of these lines will exist at any one moment of time.

Fig. 2 illustrates, by way of example only, a diversity receiving system having separate intermediate frequency stages and detectors for receiving the selective groups of side bands radiated at a transmitter for subsequent utilization by a recorder or other translating devices. Referring to Fig. 2, the upper and lower side bands of the selected groups **2** and **8**, taken as an illustration from the foregoing table, are individually collected by antennas **1**, **2**, **3** and **4** which are located at geographically spaced points where the signal does not fade similarly. Observations have shown that the receiving antennae need only be separated from one another by a distance of a few hundreds of feet, and less, in order to get this effect. These antennae may be polarized in the same plane or in different planes, and if desired, be of the steerable directive type in order to insure optimum reception. The radio frequency voltages from the antennae **1**, **2**, **3** and **4** are respectively fed to the inputs of radio frequency amplifiers and detectors **5**, **6**, **7** and **8** where they are converted to an intermediate frequency and passed on to suitable intermediate frequency amplifiers **9**, **9**. The receiver constituting radio frequency amplifier and detector **5** is selective by means of filters or other suitable circuits to the lower side band frequencies in group 8, while the receiver constituting the radio frequency amplifier and detector **6** is selective to the upper side band frequencies of group 8. Similarly, the receivers constituting amplifiers and detectors **7** and **8** are respectively selective to the lower and upper side band frequencies of group 2. The outputs from the intermediate frequency amplifiers **9**, **9** may, if desired, be reduced to a still lower intermediate frequency before being individually passed on to limiters **10**, **10**. The effect of the limiter **10** is to yield a constant amplitude output regardless of the amplitude variations of the voltage fed into the limiter. The output from each limiter **10** is passed to an analyzing detector or so-called frequency modulation-to-amplitude modulation discriminator circuit and detector **11**, which converts the frequency modulation signals to amplitude modulated signals of an audio frequency character to which the recorder or translator **12** is responsive. These amplitude modulated signals are a true reproduction of the original frequency modulation. Analyzing detector **11** may be of the balanced type shown in Seeley Patent No. 2,121,103, granted June 21, 1933, and in Usselman Patent No. 1,794,932, granted March 3, 1931; or an unbalanced detector operating on one side of the operating range of frequencies, as shown in Fig. 3 of Hansell Patent No. 1,803,504, granted May 5, 1931. Translator **12** may be a

loudspeaker, headphones, or a suitable recording device. It is preferred, in accordance with known practice, though not essential, that the diversity receiver of Fig. 2 be provided with circuit arrangements for selecting for ultilization in the translator **12** that receiver of the diversity receiving system giving the best results, while at the same time those receivers which have received feeble or unsatisfactory signals are effectively ignored or disassociated from the translator **12**.

Such a circuit arrangement may constitute a suitable receiver control means, labeled **13**. Reference is herein made to United States Patents Nos. 1,888,065, granted November 15, 1932, to H. H. Beverage, and 1,913,428, granted June 13, 1933 to E. Bruce, showing circuits for selecting the strongest signal for utilization in a diversity system.

Fig. 3 illustrates one type of transmitter which can be employed in the practice of the invention. The various operations have been divided into three stages, and below the block diagrams representing the various stages I have shown the frequency characteristics which pass through each portion of the equipment. The transmitter includes a suitable signal amplifier **21** to whose input is applied the signal intelligence having any suitable range of frequencies from zero to f_m. The output of the signal amplifier is then applied to apparatus **22** representing a frequency modulator and a variable frequency sub-carrier generator. The sub-carrier frequency is represented by f_s and the limits to which the sub-carrier is modulated is represented by $\pm\Delta f_s$. The modulation index is given by the formula

$$\frac{\Delta f_s}{f_m}$$

The output of apparatus **22** is used to frequency modulate the radio frequency transmitter **23**. This radio frequency transmitter includes a suitable radio frequency carrier generator whose frequency is represented by f_c. The output of apparatus **23** which is radiated from antenna **24** includes a plurality of frequency modulated carriers each of which is composed of a group of side bands, each group containing the same intelligence. These frequency modulated carriers are represented by the characters f_c+f_s, f_c+2f_s, f_c+3f_s, on one side of the radio frequency carrier f_c, and frequency modulated carriers f_c-f_s, f_c-2f_s, f_c-3f_s on the other side of the radio frequency carrier f_c.

In the transmitter of the invention it is also contemplated that, if desired, those side band groups which extend beyond the useful range may be suppressed in order to reduce interference on an adjacent radio frequency channel.

Another advantage of the present invention is that it increases the range of reliable communication by frequency modulation way beyond the optical range. The invention enables the use of communication by frequency modulation on carrier frequencies which reach and are reflected from the ionosphere, such as those now used on long distance short wave radio circuits.

What is claimed is:

1. The method of communicating which includes modulating the frequency of a carrier by a sub-carrier, shifting the frequency of the sub-carrier in accordance with the amplitude of the modulating signal to produce a wave having a plurality of spaced frequency modulated carriers each composed of a group of side bands containing the same intelligence, radiating the said frequency modulated carriers, receiving separately from one another certain ones of said frequency modulated carriers, separately limiting and detecting said received frequency modulated carriers, and combining the resultant detected energies.

2. The method of receiving a frequency modulated wave having a plurality of frequency modulated side bands on both sides of said wave and containing the same intelligence, which includes receiving separately from one another certain ones of said frequency modulated side bands whose amplitudes do not decrease to zero, separately limiting and detecting said received frequency modulated side bands and combining the resultant detected energies.

3. The method of receiving a frequency modulated wave having a plurality of frequency modulated side bands on both sides of said wave and containing the same intelligence, which includes receiving separately from one another at least two frequency modulated side bands whose amplitudes do not decrease to zero, separately amplifying, limiting and detecting said received frequency modulated side bands, and translating the resultant detected energy from that frequency modulated side band having the largest voltage.

4. In a frequency modulation system, means for modulating the frequency of a carrier by a sub-carrier, means for shifting the frequency of the sub-carrier in accordance with the amplitude of the modulating signal to produce a plurality of spaced frequency modulated carriers each composed of a group of side bands containing the same intelligence, means for radiating said frequency modulated carriers, means for receiving certain ones of said frequency modulated carriers separately from one another and for separately limiting the amplitudes thereof, means for separately detecting the resultant energies, and signal translating means responsive to said detected energies.

5. In a frequency modulation system wherein means are provided for modulating the frequency of a carrier by a sub-carrier, and means are provided for shifting the frequency of the sub-carrier in accordance with the amplitude of the modulating signal to produce a plurality of spaced frequency modulated carriers each composed of a group of side bands containing the same intelligence, there also being provided means for suppressing certain undesired frequency modulated carriers, and means for radiating the non-suppressed frequency modulated carriers, a receiving system having a plurality of differently selective receivers for passing the received frequency modulated carriers, and a common utilization circuit for said receivers.

6. In a frequency modulation system, means for modulating the frequency of a carrier by a sub-carrier, means for shifting the frequency of the sub-carrier in accordance with the amplitude of the modulating signal to produce a plurality of spaced frequency modulated carriers each composed of a group of side bands containing the same intelligence, means for radiating said frequency modulated carriers, means for receiving separately from one another certain frequency modulated carriers whose amplitudes do not become zero, means for separately limiting the amplitudes of said received selected frequency modulated carriers, means for separately detect-

ing the resultant energies, and signal translating means responsive to said detected energies.

7. The method of communication which includes modulating the frequency of a carrier by a sub-carrier, shifting the frequency of the sub-carrier in accordance with the amplitude of the modulating signal to produce a wave having a plurality of spaced frequency modulated carriers each composed of a group of side bands containing the same intelligence, radiating the said frequency modulated carriers, receiving separately from one another certain frequency modulated carriers whose amplitudes do not become zero, separately limiting and detecting said received frequency modulated carriers, and utilizing the detected energies.

8. The method of overcoming selective fading in radio communication which includes modulating the frequency of a carrier by a sub-carrier, shifting the frequency of the sub-carrier in accordance with the amplitude of the modulating signal to produce a wave having a plurality of spaced frequency modulated carriers each composed of a group of side bands containing the same intelligence, radiating the said frequency modulated carriers, receiving separately from one another certain ones of said frequency modulated carriers, and utilizing said received carriers.

9. In a frequency modulation system for overcoming the effects of fading, means for modulating the frequency of a carrier by a sub-carrier, means for shifting the frequency of the sub-carrier in accordance with the amplitude of the modulating signal to produce a plurality of spaced frequency modulated carriers each composed of a group of side bands containing the same intelligence, means for radiating said frequency modulating carriers, a receiving system having separate antennas for collecting certain ones of said carriers, and means coupled to said antennas for impressing the intelligence of one or more of the received carriers upon a signal translation circuit.

10. The method of communication which includes modulating the frequency of a carrier by a sub-carrier, shifting the frequency of the sub-carrier in accordance with the amplitude of the modulating signal to produce a wave having a plurality of spaced frequency modulated carriers each composed of a group of side bands containing the same intelligence, radiating the said frequency modulated carriers, receiving certain ones of said frequency modulated carriers, separately limiting and detecting said received frequency modulated carriers, and combining the resultant detected energies.

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