

Feb. 4, 1941.

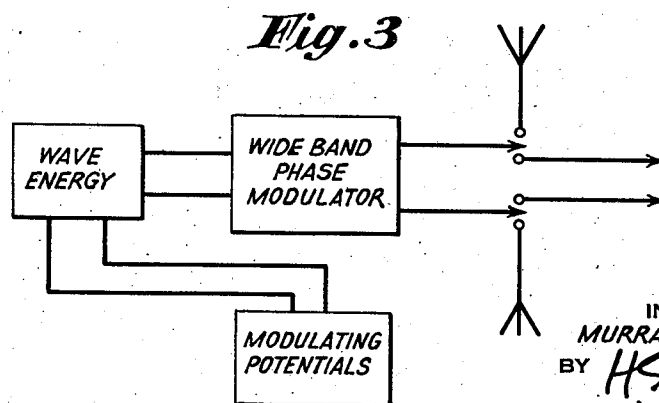
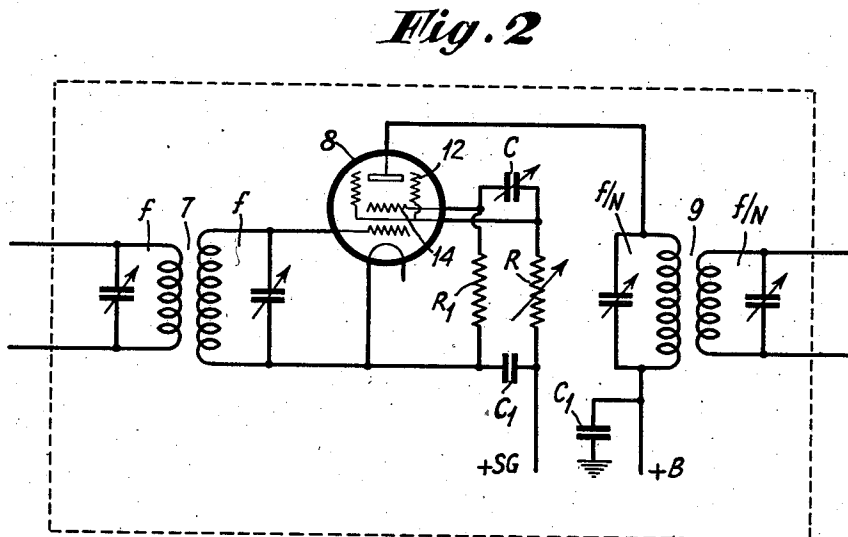
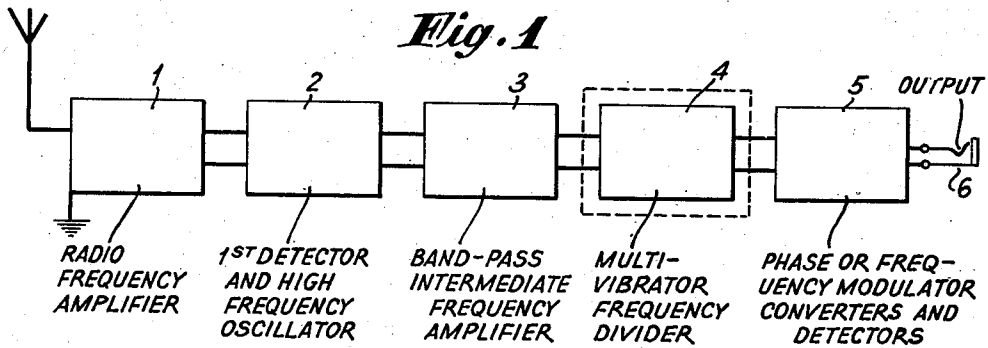
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2,230,232

PHASE AND FREQUENCY MODULATION

Original Filed Oct. 24, 1936

3 Sheets-Sheet 1



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Fig. 4

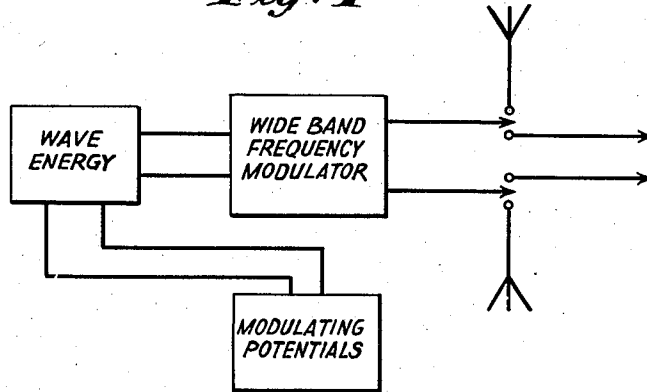


Fig. 5

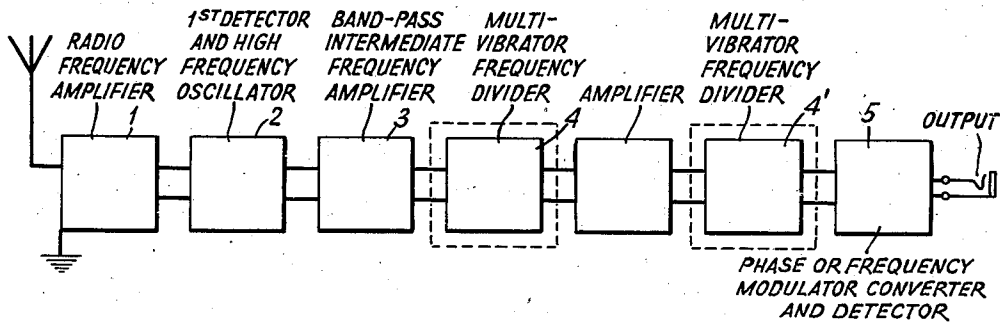
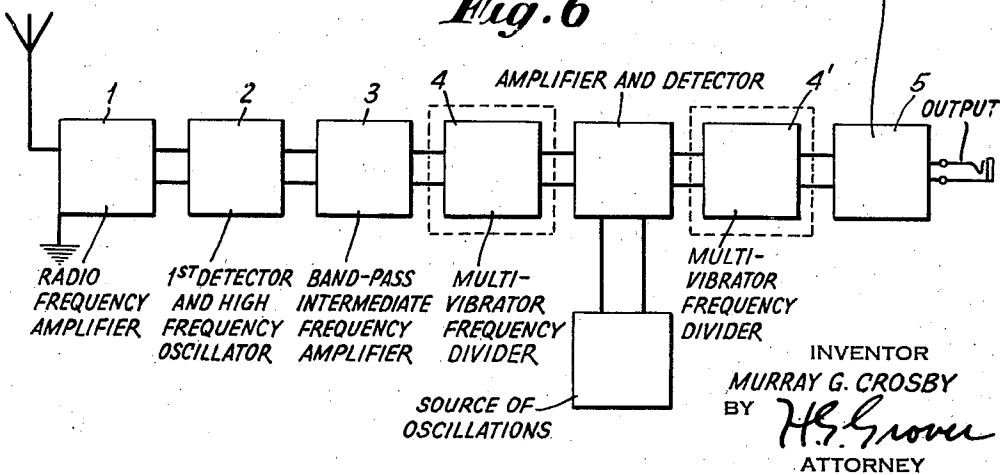


Fig. 6



UNITED STATES PATENT OFFICE

2,230,232

PHASE AND FREQUENCY MODULATION

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Original application October 24, 1936, Serial No.
107,333. Divided and this application Febru-
ary 7, 1940, Serial No. 317,617

11 Claims. (Cl. 250—20)

This is a division of my application Serial No. 107,333, filed October 24, 1936. This invention concerns a method of and means for signalling by transmitting and receiving wave energy modulated in frequency or phase wherein high frequency or phase deviation is accomplished in accordance with the modulating potentials. At the transmitter I may use any of the known means for producing high frequency or phase deviations of the wave energy in accordance with signals and for propagating the same either by way of natural mediums or by conductors to a point at which they are to be received and demodulated. A frequency divider is employed at the receiver to reduce the frequency or phase deviation of the received wave so that the devices for converting the phase or frequency modulation into amplitude modulation, operate on a wave whose degree of frequency or phase deviation is reduced with respect to the deviation of the propagated and received wave. This process has special application to phase modulation reception since it enables the reception of wide-band phase modulation on certain types of phase modulation receivers which are normally limited to the reception of phase modulation using a maximum phase deviation of less than 90°.

In the prior art of phase modulation reception on the filtered or synchronized carrier type of receiver, maximum phase deviation has been limited to approximately 90°. Since this type of reception was accomplished by combining a locally synchronized carrier, or carrier from which the signal modulations have been stripped, with the incoming modulated carrier to detect the amplitude changes of the resultant, a phase deviation of 90° would vary the amplitude of the resultant between zero and twice its unmodulated amplitude.

My method of overcoming these limitations as to the phase deviation of phase modulation consists in the application of frequency division at the receiver. This permits the transmission or propagation of wave energy of extremely high phase deviation at signal frequencies. Means for producing a high degree of phase modulation has been shown in my United States application #588,309 filed January 23, 1932, Patent #2,081,577 dated May 25, 1937. As to the means for producing the division at the receiver, it is well known that an oscillator, preferably a multivibrator oscillator, may be held in step with an external alternating voltage of a frequency an integral multiple lower than the frequency of the multivibrator, as illustrated by the constants of its circuits. Thus, a 100 kc. multivibrator may be held in synchronism with a 300 kc. voltage. This method of frequency division has properties in common with frequency multiplication in that the phase or frequency deviation of the

wave which is frequency divided is divided by the order of frequency division. Hence, a 300 kc. voltage with a phase deviation of 180°, when divided to a 100 kc. voltage, will have a phase deviation of 60°. Thus, the original phase deviation has been reduced to one-third the original deviation. Similarly the 300 kc. voltage with a frequency deviation of 3 kc. when frequency divided to 100 kc., will have a frequency deviation of 1 kc. This can be seen when it is considered that the process of frequency division consists of the holding in step of the harmonic of the multivibrator wave with the fundamental of the wave to be frequency divided. Thus, the third harmonic of the 100 kc. wave from the multivibrator is held in step with the 300 kc. to be divided. Consequently, if the third harmonic of the multivibrator were shifted 3 kc., the fundamental would have to be shifted 1 kc. to remain in harmonic relation. The same is true with respect to phase deviation when the phase deviated wave is divided as to frequencies.

It might be argued that frequency division at the receiver has no advantage, since in the division process the carrier has not been raised with respect to the noise coming in on the antenna, or other receiving circuit. However, while the phase modulated wave with the higher phase deviation has not been changed with respect to the incoming signal-to-noise amplitude ratio, the ratio of the phase deviation of the modulated wave to the phase deviation produced by the noise has been changed. That is to say, the signal-to-noise ratio of a wave, the phase deviations from the signal frequency of which is high, is higher than the signal-to-noise ratio of a wave of small phase deviation at signal frequency. Since the receiver receives only phase modulations, the effective phase deviation produced by the combination of the signal and the noise must be considered. Thus, the signal-to-noise ratio at the receiver output depends upon the signal phase deviation to noise phase deviation ratio. For a given signal-to-noise amplitude ratio, the effective phase deviation produced by the noise is constant. Consequently, the higher the phase deviation of the signal wave is made, the higher will be the signal-to-noise ratio at the receiver output terminals. Hence, in applying a high phase deviation at the transmitter, when this phase deviation is reduced to the proper value for detection, the noise is reduced in the same ratio and the signal phase deviation to noise phase deviation ratio remains high. The improvement that may be effected in this manner is, therefore, proportional to the degree of frequency division applied at the receiver. That is, a frequency division of "N" times would make the signal-noise ratio "N" times as great or would effect a power improvement of "N" squared.

Although the above explanation is specific to phase modulation, it will be understood that due to the similarities of frequency and phase modulation, the words "phase modulation" and "frequency modulation" may be interchanged. For purposes of convenience the words "wavelength modulation" will be used and when used, will denote modulation in phase of frequency even though phase modulation and frequency modulation, as is well recognized, each have separate and distinct characteristics, as well as characteristics in common. Thus, frequency modulation may be transmitted with a high frequency deviation and frequency division may be applied at the receiver to reduce the frequency deviation of the modulated wave and the frequency deviation of the noise at the same time, while preserving the high ratio of their respective frequency deviations. For instance, a frequency deviation of 100 kc. at signal frequency may be applied to the wave energy to be propagated and a frequency division of 10 to 1 may be applied at the receiver to the received wave to reduce the deviation at signal frequency to 100 kc. The selectivity channels preceding the frequency divider may then be 200 kc. wide and those following the divider need be only 20 kc. wide. The sloping filter under these circumstances would be required to convert a 10 kc. frequency deviation at signal frequency, into amplitude modulation instead of a 100 kc. frequency deviation.

This type of reception may also take advantage of the inherent limiting properties of a multivibrator wherein its output amplitude is constant even though the input amplitude varies over a rather wide range. Hence, the multivibrator may take the place of the amplitude limiter normally required in a frequency or phase modulation receiver. The use of the multivibrator for a limiter also has the advantage that when the signal fades, the noise does not rise to prohibitively high values as it does in the case of the over-loading type of amplitude limiter and in the automatic volume control type of limiter. This is due to the fact that when the signal fades it merely loses control of the multivibrator whereas with the over-loading type of limiter and automatic volume control type of limiter, when the signal fades the noise is amplified to extremely high values.

In describing specific embodiments of my invention reference will be made to the attached drawings wherein;

Figure 1 illustrates diagrammatically the essential elements of a receiver arranged in accordance with my invention. The various receiver units have been shown as rectangles since the circuits per se of some of the units form no part of the present invention;

Figs. 1a and 1b illustrate frequency and phase modulated wave demodulating means respectively which can be supplied by wave energy which has, in accordance with this invention, been reduced in frequency and phase.

Fig. 2 illustrates the details of a multivibrator suitable for use as one of the units of the receiver of Fig. 1;

Fig. 3 illustrates a wide band phase modulator;

Fig. 4 illustrates a wide band frequency modulator. Here again, as in Fig. 1, units of the transmitter are shown as rectangles since the details of the said unit per se form no part of the present invention;

Fig. 5 illustrates a modification of the receiver of Fig. 1;

Fig. 6 illustrates a modification of the circuits of Figs. 1 and 5. Fig. 6 shows how to increase the amount of division possible. The divided wave energy is heterodyned to a higher frequency and again divided.

Fig. 1 illustrates by block diagram, how frequency division may be applied to a phase or frequency modulation receiver. The signal to be demodulated is fed from the antenna to a radio frequency amplifier 1 where it is amplified. The amplified signal is then fed to a first detector and high frequency oscillator into which it is beat down to an intermediate frequency and amplified if desired. The intermediate frequency energy is then impressed on band pass intermediate frequency amplifier 3, which amplifies and selects the intermediate frequency energy. 4 is a frequency divider which, as stated, may be a multivibrator and has its input connected to the output of the intermediate frequency amplifier 3. The unit in 4 may take the form of an unstable oscillator which is unstable enough to follow the frequency or phase deviations of the modulated wave, or it may take the form of a multivibrator as shown in Fig. 2, which will be described in detail later. The output of 4, e. g., the divided wave energy, is impressed on the input of a unit 5 which contains any form of frequency modulation or phase modulation receiver known in the art. If frequency modulated waves are being received, the unit 5 may employ principles of receiving frequency modulation such as described in

Crosby U. S. application #618,154, filed June 20, 1932.

Crosby U. S. application #703,770, filed Dec. 23, 1933, Patent #2,060,611, dated Nov. 10, 1936.

Crosby U. S. application #25,231, filed June 6, 1935, Patent #2,087,429, dated July 20, 1937.

Crosby U. S. application #45,409, filed Oct. 17, 1935, Patent #2,071,113, dated Feb. 16, 1937.

Crosby U. S. application #114,894, filed Dec. 9, 1936, Patent #2,154,398, dated Apr. 11, 1939.

Crosby U. S. application #144,778, filed May 26, 1937, Patent #2,138,341, dated Nov. 29, 1938.

Crosby U. S. application #171,820, filed Oct. 30, 1937, Patent #2,163,747, dated June 27, 1939.

Hansell Patent #1,813,992, dated June 14, 1931.

Usselman Patent #1,794,932, dated March 3, 1931.

Hansell Patent #1,867,567, dated July 19, 1932.

In general, the unit 5 may contain a limiter, sloping filter, and detector. The limiter may be eliminated if sufficient limiting is obtained inherently in the multivibrator in the unit 4. If phase modulation is being received, unit 5 may employ principles of receiving phase modulation as are described in

Crosby U. S. application #588,309, filed Jan. 23, 1932, Patent #2,081,577, dated May 25, 1937.

Crosby U. S. application #565,005, filed Sept. 25, 1931, Patent #2,114,335, dated Apr. 19, 1938.

Crosby U. S. application #618,154, filed June 20, 1932.

Crosby U. S. application #616,803, filed June 13, 1932, Patent #2,065,565, dated Dec. 29, 1938.

Crosby U. S. application #704,257, filed Dec. 28, 1933, Patent #2,112,881, dated Apr. 5, 1938.

Crosby U. S. application #46,285, filed Oct. 23, 1935, Patent #2,076,175, dated Apr. 6, 1937.

Crosby U. S. application #47,933, filed Nov. 2, 1935, Patent #2,085,008, dated June 20, 1937.

If, for instance, the principles of demodulation disclosed in my United States application #47,933, filed Nov. 2, 1935, Patent #2,085,008,

dated June 20, 1937, are applied, the frequency divided energy is fed through an unneutralized crystal filter and detected. If automatic frequency control is applied, the audio frequency energy obtained from the output of 5 may be used to control the frequency of the high frequency oscillator in unit 2. The audio frequency control energy derived from the output of 5 may also be applied to control the frequency of a second oscillator of a triple detection superheterodyne receiver.

Obviously, my system is applicable to many phase and frequency modulation systems known in the art today. For example, as pointed out above, my invention is adapted to be used with the phase and frequency modulated wave receivers as disclosed in my United States application #618,154, filed June 20, 1932, and to my phase modulated wave receivers as disclosed in my United States application #588,309, filed June 23, 1932, now Patent #2,081,577, dated May 25, 1937. In Fig. 1a, I have illustrated the use of my frequency and phase divider scheme with a frequency or phase modulated wave demodulator as illustrated in Fig. 1 of my United States application #618,154 of June 20, 1932, referred to above, while in Fig. 1b, I have illustrated the manner in which the frequency and phase reducer scheme of the present invention supplies energy for demodulation purposes to a demodulator as disclosed in Fig. 8 of my Patent #2,081,577 referred to above.

In Fig. 1a, elements 1 to 4 inclusive, may be as disclosed heretofore in connection with Fig. 1 and the circuits of these elements supply wave energy of reduced frequency and reduced modulation degree to demodulating means. Of course, if desired, an additional heterodyne detector and additional divider 4' as shown in Fig. 6 may precede the demodulator circuits. The demodulator circuits are represented by the block 5 in Figs. 1 and 6. The output energy of 4 is supplied to a transformer 17 and from the transformer 17 to a potentiometer resistance P1 having a movable point thereon connected to the grid of an amplifier tube A. The amplifier tube A has its anode connected to a transformer primary winding T, the secondary of which is coupled to a rectifier tube RT. The output of frequency divider and modulation degree reducer 4 is also supplied by leads 26 to a transformer 28, the secondary winding of which is connected with a line I comprising series inductance L and shunt capacities SC. The line is terminated by a resistance R, while a potentiometer P2 is connected to the low potential side of the line I on the one hand, and to a movable point on the line I by lead 30, on the other hand. A coupling tube B has its grid connected to the movable point 33 on the potentiometer P2 and its anode connected to the primary winding of transformer T. Thus, we see that wave energy of reduced frequency from the frequency reducer 4 is supplied to the primary winding of transformer T over two paths one of which is substantially direct including transformer 17, and the other of which is by way of a network I of appreciable reactance. The path including appreciable reactance may comprise a network or a line as shown or a filter or equivalent means.

Since the line L is of appreciable length for a given frequency at a higher frequency, the electrical length will be greater and for a lower frequency the electrical length of the line will be less. The fact that the electrical length of the

line I does change with frequency makes the phase at the output of the line, say at lead 30, change with respect to the phase of the wave energy at the input of the line, say in leads 26. Consequently, if the phase or frequency modulated wave energy is supplied by leads 26 to the line and by leads 13 directly to the coupling tube A, an adjustment of the line may be made so that the phase difference between the voltage of the signal impressed on the input of the line and the voltage of the signal at the output of the line increases as the degree of frequency modulation increases. Since the wave energy supplied over the path 17 and that over the line I which is of phase which changes with change of frequency are combined in T, the changes in phase will cause a variation in the amplitude of the combined resultant supplied to the rectifier tube RT and said variation in amplitude is truly characteristic of the frequency variations of the wave supplied from 4. The variations in amplitude are rectified by RT and supplied to any utilization circuit from a jack directly in the case frequency modulation is received and by way of a correction circuit 35 when phase modulated waves are being received. The correction circuit is such that the amplitude of the output varies substantially inversely proportional to the frequency of the modulation potentials at the input thereof.

In the circuit of Fig. 1b the elements 1 to 4 inclusive may be as described above in connection with Fig. 1. The output of the multivibrator 4 in this case is supplied to a demodulating means as disclosed in Fig. 8 of my United States Patent #2,081,577 referred to above. Here the wave energy of reduced frequency and reduced modulation deviation is supplied to a carrier filter 50 and from the carrier filter 50 to a carrier limiter or automatic volume control means 52 and from 52 to a phase adjuster 54 and to the primary winding 56 of transformer 58. In this path the carrier of the phase modulated wave energy is isolated in 50, limited in 52 and adjusted as to phase in 54. Phase modulated wave energy of reduced phase deviation and reduced frequency is also supplied directly to the primary winding of a transformer 60 and from the secondary winding of the transformer 60 is impressed in phase on the control grids 61 and 63 of a pair of detector tubes 62 and 64.

In this phase modulated wave detector, phase modulated wave energy of reduced phase deviation and frequency is supplied cophasally to the grids of detector 62 and 64, while filtered carrier energy is fed to the control electrodes 61 and 63 of the detectors 62 and 64 180° out of phase or in phase opposition. As the phase of the energy supplied cophasally to the detector grids shifts in accordance with the signal potentials thereon, the resultants of the cophasal energies and phase opposed energies on the control grids vary in amplitude and these amplitude variations are detected in the tube 62 and 64 to supply by way of transformer 68 variations representative of the signals used in phase modulating the wave energy. The signals may be amplified in amplifier 70 and supplied to utilization means.

The multivibrator of Fig. 2 is of the negative transconductance pentode type. The values of resistance R and condenser C determine the time constants of the circuit and consequently the frequency at which the multivibrator oscillates. R₁ is a grid leak and C₁ is a bypass condenser. The energy to be frequency divided is fed to the grid of the pentode 8 by way of transformer 7. 75

The divided energy is taken from the plate circuit of the pentode by way of transformer 9.

This type of multivibrator which is of the negative transconductance type will now be described. Briefly, the oscillations take place by virtue of the negative resistance characteristic existing between the suppressor grid 12 and screen grid 14 of the tube 8 when proper element voltages are applied. With a resistance R in the screen-grid circuit and a condenser C coupling the screen grid to the suppressor, approximately square wave form oscillations will take place at a frequency depending upon the time constant of the combination of resistors R and R_1 and the capacity C. Due to the fact that these oscillations are quite unstable as to frequency, an alternating voltage fed to the control grid 16 of the tube, for instance, by means of transformer 7 of Fig. 2, will cause the oscillations to lock in step with the applied alternating voltage at a frequency which is an integral multiple or sub-multiple of the applied alternating voltage frequency. By using the sub-multiple lock-in frequency division is obtained. The frequency divided energy may be taken directly from the resistor and condenser circuits R, R_1 and C, but may be conveniently taken from the plate circuit by taking advantage of electron coupling. Since the electron stream within the tube may be modulated by the oscillations of the multivibrator circuit, the plate current will vary in accordance with these oscillations. Consequently the output may be taken from the plate circuit by inserting an output circuit such as the transformer 9 in Fig. 2. It will be noted that since the anode is coupled to the other electrodes in the tube and in particular, the auxiliary electrodes in the circuit RC, by way of the electron stream only of the tube, changes in load cannot affect the input and auxiliary electrodes or the circuits connected therewith.

The primary and/or secondary winding of transformer 7 may be tuned to a frequency f , e. g., the frequency of the wide band phase or frequency modulated energy to be demodulated. The primary and/or secondary winding of the transformer 9 may be tuned to a frequency

$$\frac{f}{N}$$

where N equals the number of times it is desired to reduce the incoming frequency. The multivibrator of Fig. 2 is included in the unit 4 as shown by the dotted lines enclosing said unit and enclosing Fig. 2. The incoming wave energy excites the control grid of 8 and locks in step the oscillations which are produced therein of a frequency determined by R and C. By adjusting R and C to the proper values the desired order of frequency division may be obtained. The signal carrying energy of reduced frequency appears in 9 and is impressed on 5. This type of pentode negative transconductance multivibrator is particularly suited for such operation, since the control grid is available to apply the energy and the electron coupled output may be taken from the plate circuit. However, any other type of multivibrator may serve the purpose equally well.

The process of frequency reduction employed in this receiver is not limited to the use of a single frequency dividing oscillator. I contemplate the use of several multivibrators cascaded so that each one performs a part of the frequency dividing. Such a system has been illustrated in Fig. 5 wherein the rectangles 4 and 4' designate

two frequency dividing units in cascade. For instance, if a 600 kc. intermediate frequency wave is to be divided to 100 kcs., the 600 kc. energy may be fed to the first frequency dividing oscillator in 4 where it will be divided by a ratio of 3 to 1 or to 200 kc. This 200 kc. energy may then be fed to the frequency dividing oscillator in 4', which may apply a frequency division of 2 to 1 so as to divide the frequency to 100 kc. Such multi-stage dividing has the advantage of greater stability since the lower ratios of frequency division hold "in step" more easily. Amplification may also be applied between limiting stages to further improve the stability. An amplifier has been shown connected between the stages 4 and 4' of Fig. 5.

For high ratios of frequency division the process of frequency division and heterodyning may be combined. Thus, in the instance of the frequency division of the 600 kc. intermediate frequency energy, if a greater frequency division ratio than 6 to 1 were desired with a final frequency of 100 kc., a frequency division of 3 to 1 may be first applied to divide the frequency to 200 kc. This 200 kc. energy may then be heterodyned to, for instance, 1000 kc. The 1000 kc. energy may then be applied to another frequency dividing system to obtain a frequency division from 1000 to 100 kc. A total frequency division of 30 to 1 is in this manner obtained in the whole process of division and heterodyning. By further heterodyning and division the process of frequency division may be carried to any degree desired. As has been described in various copending applications, the process of heterodyning phase or frequency modulated waves does not alter the degree of phase or frequency modulation of the wave, whereas the process of dividing the phase or frequency modulated wave also divides the phase or frequency modulations of the wave. A receiver including the heterodyning means described above has been illustrated in Fig. 6 of the drawings.

In Figs. 3 and 4 I have shown diagrammatically wide band frequency modulation transmitters and wide band phase modulation transmitters respectively. These modulations may be of any type known in the art. For example, I may use the wide band phase modulation of Crosby United States application #588,309, filed January 23, 1932, Patent #2,081,577, dated May 25, 1937, or the wide band frequency modulation of United States application #13,886, filed March 30, 1935, Patent #2,121,158, dated June 21, 1938.

I claim:

1. A receiver for carrier wave energy the phase of which has been shifted or deviated more than 90° in accordance with signals comprising, means for receiving wave energy varying in phase more than 90°, means for amplifying the received wave energy, means for frequency dividing the amplified wave energy to obtain wave energy of reduced frequency and reduced phase deviation, means for heterodyning the wave energy of reduced frequency to a higher frequency, means for frequency dividing the higher frequency wave energy to wave energy of a lower frequency and of phase deviation less than 90°, and means for translating said last mentioned phase deviations in the wave energy to derive the signal.

2. In a system for demodulating transmitted wave energy the wave length of which has been modulated through a wide range or degree in accordance with signals to obtain a favorable

signal-to-noise ratio in the said transmitted wave energy, means for receiving and amplifying said wave energy the wave length of which has been modulated through a wide range or degree, a frequency divider having an input coupled to said amplifying means, said frequency divider having an output circuit wherein wave energy of reduced frequency and reduced modulation range or degree, characteristic of said received wave energy, is caused to flow, a plurality of paths coupled to said frequency divider output circuit, said paths passing energy of all frequencies appearing in said output circuit, and means for combining and detecting wave energy which has passed through said paths.

3. In a system for demodulating transmitted wave energy the wave length of which has been modulated through a wide range or degree in accordance with signals to obtain a favorable signal-to-noise ratio in the transmitted wave energy, means for receiving and amplifying said wave energy the wave length of which has been modulated through a wide range or degree, a frequency divider having an input coupled to said amplifying means, said frequency divider having an output wherein wave energy of reduced frequency and reduced modulation range or degree, characteristic of said received wave energy, is caused to flow, signal detecting means, a first path connecting said frequency divider output to said signal detecting means, and a second path, the electrical length of which in terms of wave length of said wave energy of reduced frequency is greater than the electrical length of said first path, connecting said frequency divider output to said signal detecting means.

4. In a system for demodulating transmitted wave energy the wave length of which has been modulated through a wide range or degree in accordance with signals to obtain a favorable signal-to-noise ratio in the transmitted wave energy, means for receiving and amplifying said wave energy the wave length of which has been modulated through a wide range or degree, a frequency divider having an input coupled to said amplifying means, said frequency divider having an output wherein wave energy of reduced frequency and reduced modulation range or degree, characteristic of said received wave energy, is caused to flow, signal detecting means, a first path connecting said frequency divider output to said signal detecting means, a second path connecting said frequency divider output to said detecting means, a sharply resonant filter in one of said paths and phase adjusting means in one of said paths.

5. The method of reducing the degree of phase or frequency modulation of a phase or frequency

modulated wave which includes heterodyning the phase or frequency modulated wave to a different mean frequency and frequency dividing the wave of different mean frequency.

6. The method of reducing the degree of phase or frequency modulation of a phase or frequency modulated wave which includes heterodyning the phase or frequency modulated wave to a higher mean frequency and frequency dividing the wave of higher mean frequency.

7. The method of reducing the degree of phase or frequency modulation of a phase or frequency modulated wave which includes heterodyning the wave to a different mean frequency dividing the frequency of the different mean frequency derived from the heterodyning process, further heterodyning the divided energy and frequency dividing the last mentioned heterodyned energy.

8. The method of reducing the degree of phase or frequency modulation of a phase or frequency modulated wave which includes heterodyning the wave to a higher frequency, dividing the frequency of the higher frequency wave, heterodyning the divided frequency wave energy to a relatively higher frequency and frequency dividing the last mentioned heterodyned wave energy.

9. The method of changing the phase or frequency modulated wave of mean frequency F to a wave of the same or lower frequency but with a degree of modulation equal to the original degree divided by N where N is any number greater than 1 which includes heterodyning and frequency dividing the wave energy until the combined heterodyning and frequency dividing process results in the wave of desired frequency and degree of modulation.

10. The method of reducing the frequency of a wave of frequency F having an undesired degree of phase or frequency modulation to a wave of frequency f having a degree of phase or frequency modulation of a value equal to 1 divided by N of that in the wave F where F divided by N would not equal f , which includes heterodyning the wave F to a higher frequency and frequency dividing the heterodyned wave a sufficient number of times such that the resultant wave is of frequency f and has a degree of modulation equal to 1 divided by N times the degree of modulation of the wave F .

11. The method of receiving a phase or frequency modulated wave which includes frequency dividing energy derived from the received waves in order to reduce the degree of phase or frequency modulation, separating the divided energies into two portions, producing a relative phase shift in the portions and combining and detecting the phase shifted energy portions.

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