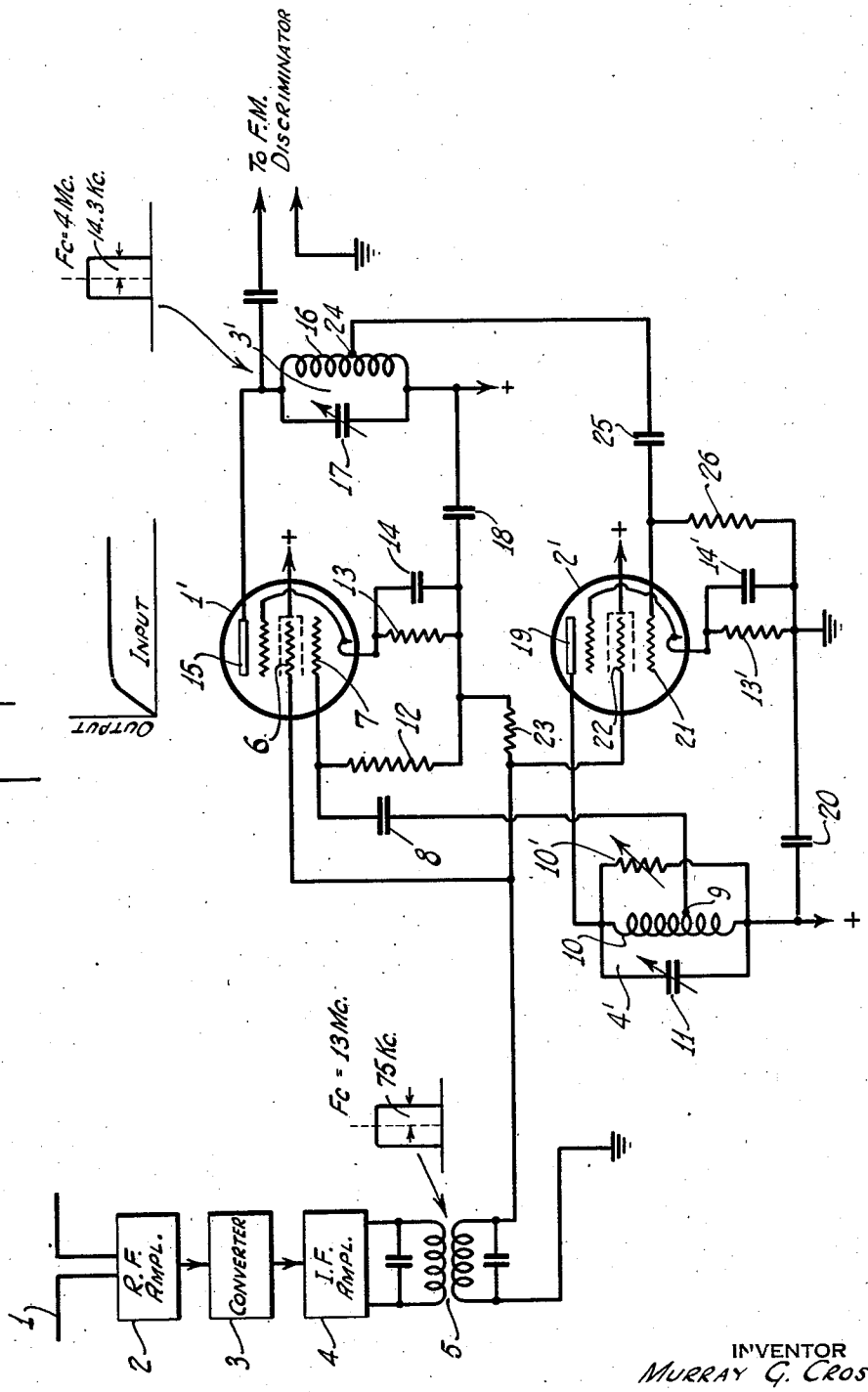
Dec. 14, 1943. M. G. CROSBY 2,336,926

FREQUENCY, OR PHASE, DEVIATION CHANGER CIRCUIT

Filed Feb. 11, 1942 2 Sheets-Sheet 1

Fig. 1.



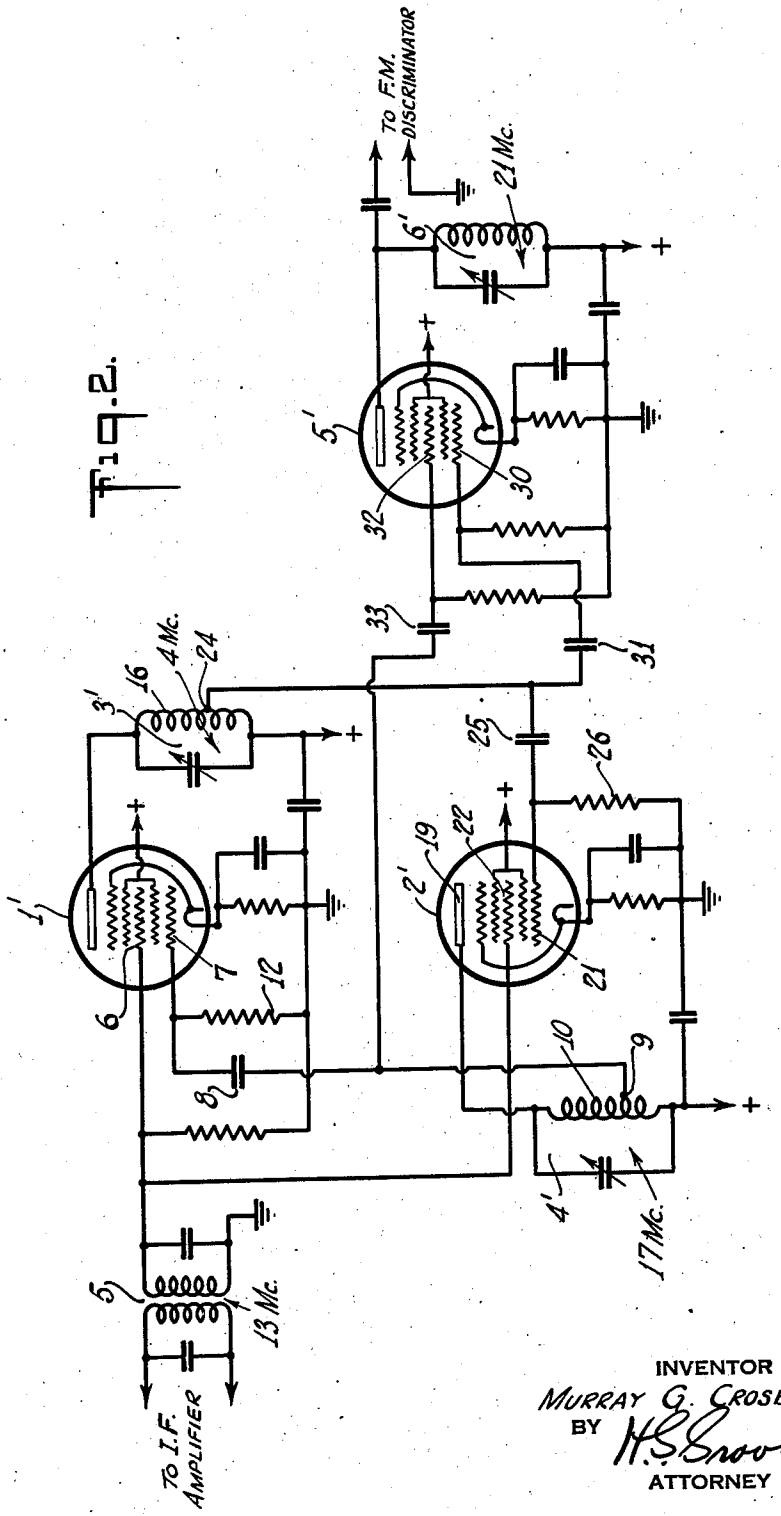
INVENTOR
MURRAY G. CROSBY
BY H. G. Grover
ATTORNEY

Dec. 14, 1943. M. G. CROSBY 2,336,926

FREQUENCY, OR PHASE, DEVIATION CHANGER CIRCUIT

Filed Feb. 11, 1942 2 Sheets-Sheet 2

Fig. 2.



INVENTOR
MURRAY G. CROSBY.
BY H. S. Snover
ATTORNEY

Patented Dec. 14, 1943

2,336,926

UNITED STATES PATENT OFFICE

2,336,926

FREQUENCY, OR PHASE, DEVIATION CHANGER CIRCUIT

Murray G. Crosby, Riverhead, N. Y., assignor to Radio Corporation of America, a corporation of Delaware

Application February 11, 1942, Serial No. 430,348

18 Claims. (Cl. 250—20)

My present invention relates generally to circuits for changing the frequency, or phase, deviation of frequency modulated, or phase modulated, carrier waves respectively, and more especially the invention relates to deviation changer circuits of the type wherein a pair of frequency converters are arranged in an oscillating system wherein an incoming modulated carrier wave is utilized as one of the sources of heterodyning oscillations.

In the prior art of frequency and phase modulation the process of frequency multiplication has been used to increase the degree of modulation, while the process of frequency division has been employed to decrease the degree of modulation of the carrier wave. It is, also, known to reduce frequency, or phase, deviation by a locked-in oscillator method. In this method an oscillator at a sub-harmonic frequency is held in step with the applied modulated carrier waves; automatic frequency control may be applied to the oscillator to aid the oscillator in following the applied modulated carrier waves. In such a system a beat note may be effected at the instant the applied modulated waves lose control of the local oscillator, the beat note being effected between the applied waves and the oscillator frequencies which may be slightly different. My present system eliminates the possibility of such beat note being produced, since the local oscillations are not produced at the instant the applied signals lose control.

It is one of the main objects of my present invention to provide a frequency, or phase, deviation changing circuit wherein a pair of frequency converters are arranged in an oscillating system, and the applied modulated waves act as the source of local oscillations of one of the converters; the converters being arranged to be re-entrant so that oscillations are sustained.

Another important object of my invention is to provide a pair of frequency converters in a re-entrant oscillation system; the system functioning to remove amplitude modulation from applied angular velocity-modulated carrier waves without the aid of a limiter network per se.

Another important object of the invention is to provide a system for reducing the frequency deviation of a frequency modulated carrier wave, the deviation reducing system comprising an oscillation network under the control of the applied modulated waves, and wherein sustained oscillations of the oscillation network cease when the applied modulated waves lose control thereby permitting adjustment such that only applied waves above a predetermined intensity may be transmitted.

Still another object of the invention is to provide a network for reducing the frequency deviation of applied angular velocity-modulated carrier waves; there being utilized at least two frequency converters arranged in a re-entrant circuit so that oscillations are sustained, and the applied modulated waves act as the source of local oscillations for one of the converters thereby enabling inter-station noises to be eliminated by virtue of adjustment such that only applied modulated carrier waves above a predetermined noise level may be received.

Still other objects of the invention are to improve generally the efficiency and reliability of frequency, or phase, deviation changer circuits, and more especially to provide receivers of angular velocity-modulated carrier waves which are economically manufactured and assembled.

The novel features which I believe to be characteristic of my invention are set forth in particularity in the appended claims; the invention itself, however, as to both its organization and method of operation will best be understood by reference to the following description taken in connection with the drawings in which I have indicated diagrammatically several circuit organizations whereby my invention may be carried into effect.

In the drawings:

Fig. 1 shows a receiving system embodying one form of the invention,

Fig. 2 illustrates a modification of the deviation changer circuit.

Referring, now, to the accompanying figures, wherein like reference characters in the two figures designate similar circuit elements, Fig. 1 shows a receiver system of the superheterodyne type. In general, it may embody a signal collector device 1, which may be a di-pole, a grounded antenna circuit, or even an ultra-high radio frequency distribution line. The collected signals, which may be frequency modulated, or phase modulated, carrier waves, are applied to the radio frequency amplifier 2. Amplifier 2 may embody one or more stages of tunable radio frequency amplification. The generic term "angular velocity-modulated carrier wave" is to be understood as denoting carrier waves which have been frequency modulated or phase modulated. Those skilled in the art are fully aware of the fact that a frequency modulated carrier wave (FM) has its carrier, or mid-band, frequency F_c instantaneously varied, or deviated, in fre-

quency value in accordance with the amplitude of the modulating voltage at the transmitter. The rate of frequency deviation depends upon the modulation frequencies per se. In phase modulation (PM) the frequency is deviated to a greater extent at the higher modulation frequencies; otherwise, this form of modulation is similar to frequency modulation. It will be understood that the term "deviation" refers to the maximum applied frequency deviation in the case of a frequency modulated wave, and to the maximum applied phase deviation in the case of a phase modulated wave.

In so far as the channel width of each station is concerned, it will be understood that the frequency deviation may be high or low. The present practice in FM broadcast transmission is to employ carrier frequencies in the range of 42–50 megacycles (mc.). The carrier frequency is deviated a maximum of 75 kilocycles (kc.) to either side, and each channel width is 200 kc. That is, the maximum overall frequency swing is 150 kc., whereas the allotted channel width is 200 kc. It is to be clearly understood that these are purely illustrative values, and can be varied depending upon the circumstances which face the receiver designer. Assuming, however, for the purpose of this application that the frequency deviation is 75 kc., and that the carrier is chosen from the 42–50 mc. band, the amplified modulated carrier waves are applied to a converter **3** to reduce the carrier, or mid-band, frequency of the modulated waves to the operating intermediate frequency (I. F.) value. Those skilled in the art are fully aware of the manner of constructing the converter stage, and it is to be understood that it may utilize a separate local oscillator and a separate first detector, or the converter may be a combined local oscillator-first detecter stage which uses the well known pentagrid converter tube.

By way of illustration the I. F. value is chosen as 13 mc. The I. F. amplifier **4** may comprise one or more stages of amplification. The numeral **5** denotes the I. F. output transformer whose primary and secondary circuits are each tuned to 13 mc., which is the carrier frequency of the modulated waves. Adjacent to the transformer **5** there is shown in a purely pictorial manner the appearance of the response characteristic of transformer **5**. It will be seen that the transformer, as well as its prior circuits, produces a flat-topped band pass characteristic having an over-all band width of 150 kc. with F_c at 13 mc. The frequency deviation is represented as being 75 kc.

In the prior art it has been customary to apply the output of the I. F. amplifier to an amplitude limiter stage. This was done in order to remove any amplitude modulation components which may have been produced on the carrier. Such components are generally due to fading effects, noise in the tubes and circuits, and the "round-topped" effect of cascaded tuned transformers. The limiter stage of the prior art is a special tube, often constructed in the manner of a readily saturatable amplifier, which has an input-output characteristic which is flat above a predetermined wave input amplitude. According to my invention, however, such a special limiter stage is eliminated. Prior to the usual discriminator-rectifier network there is employed a network for reducing the deviation band width of the energy output of transformer **5**. Concurrently, this deviation reducing network effects a limiting action.

Referring to the diagram in Fig. 1, it will be seen that tubes **1'** and **2'** are each pentagrid tubes. Tube **1'** has its third grid **6** connected to the high potential side of the secondary circuit of I. F. transformer **5**, the low potential side of the secondary circuit being grounded. The first grid **7** is connected by grid condenser **8** to an intermediate tap **9** on the coil **10** of resonant circuit **4'**. The condenser **11** in shunt with coil **10** resonates circuit **4'** to a frequency of 17 mc. The grid leak resistor **12** connects the grid **7** to the grounded end of biasing resistor **13**, the latter being by-passed by condenser **14** for I. F. currents. The plate **15** of tube **1'** is connected to the high potential side of resonant output circuit **3'**. The latter comprises a coil **16** shunted by tuning condenser **17**.

The low potential side of tuned circuit **3'** is connected to the positive terminal of the direct current energizing source, the condenser **18** by-passing the low potential side of circuit **3'** to ground for radio frequency currents. The circuit **3'** is resonated to a frequency of 4 mc., and the circuit is given a pass band of 28.6 kc. The response characteristic of circuit **3'** is depicted adjacent to it. The plate **19** of tube **2'** is connected to the high potential side of resonant circuit **4'**, while the low potential side thereof is connected to the positive terminal of a direct current energizing source. It will be understood that a common direct current energizing source may be used for the cold electrodes of converter tubes **1'** and **2'**. The condenser **20** may by-pass the energizing connection to plate **19** for radio frequency currents, and biasing resistor **13'**, shunted by I. F. by-pass condenser **14'**, may function to provide the grid bias for the spaced control grids **21** and **22** of tube **2'**.

The third grid **22** is connected to the high potential side of the secondary circuit of I. F. transformer **5**. The direct current voltage developed across resistor **13'** provides the normal grid bias for grid **22**. The grid **21**, which is the first grid of converter tube **2'**, is connected to an intermediate tap **24** on coil **16** of circuit **3'**. Grid condenser **25** is inserted in the connection of tap **24**. The resistor **26** provides the direct current voltage biasing path for grid **21**.

It will be noted that the output of converter **1'**, which is developed across resonant circuit **3'**, is fed to the input electrode **21** of converter tube **2'**. Furthermore, the output voltage of converter tube **2'**, which is developed at resonant circuit **4'**, is applied to the grid **7** of converter tube **1'**. The applied modulated carrier waves are fed to the grids **6** and **22** of both converter tubes, and is the I. F. energy developed by the I. F. transformer **5**. This arrangement is proper for the production of a heterodyne output between the applied signal waves and the oscillations on the spaced control grids of each of the converter tubes.

With the resonating of tuned circuits **3'** and **4'** as described, the system including tubes **1'** and **2'** is re-entrant so that oscillations will be sustained. The conversion gain of the converter tubes is assumed to be greater than unity. Hence, a pulse of voltage within the circuits causes a component to appear, for instance at 17 mc., in tuned circuit **4'**. Such a pulse of voltage is the same type of starting impulse that stimulates the conventional oscillator to maintain oscillations. It usually is supplied by the surge of current which takes place when the oscillator is turned on. The 17 mc. voltage across **4'** heterodynes with the 13 mc. signal voltage in tube **1'**,

fed to grid 6, thereby producing a 4 mc. component in tuned circuit 3'. The 4 mc. component heterodynes with the 13 mc. signal voltage in tube 2', fed to grid 22, to produce an amplified 17 mc. component across tuned circuit 4'. In this way oscillations are built up until some part of the re-entrant circuit limits the amplitude at its sustained oscillation value. The result is a system which is in oscillation at the two frequencies of tuned circuits 3' and 4', i. e., 4 mc. and 17 mc. respectively, for the case of the example assumed here.

The existence of these oscillations is dependent upon the presence of the signal input voltage, since without the latter there would be no heterodyning action. It is, also, dependent upon the frequency of the signal voltage, since a shift in frequency of the latter will require that the tuned circuits be operated on the side of the selectivity curves instead of at resonance. However, oscillations will be maintained as long as the frequency is such that the resultant conversion gains effect enough amplification to make the re-entrant effect cumulative. The point of loss of the cumulative effect will occur when the circuits have become so far detuned that the combination of the gain and phase conditions causes each re-entrant circulation to be less than the preceding one. Thus, it will be apparent that the signal input frequency may vary over a range which is appreciable, as long as it does not cause the tuned circuits to be detuned too far.

As the signal input frequency is varied, the frequency of the oscillations in both tuned circuits 3' and 4' will also vary. The amount that each varies will depend upon the selectivity of its tuned circuit. In order clearly to point out the functioning of the re-entrant system a mechanical analogy is herein presented. The analogy is purely illustrative. The system is analogous to the drive of two flywheels of different size by means of a differential drive gear. For instance, assume that the rear axle of an automobile is jacked up, and that one rear wheel is replaced by a heavy flywheel and the other by a light flywheel. At a given motor speed both flywheels will turn, but the lighter one will turn the fastest. If the motor speed is increased, the lighter flywheel will take most of the increase. The heavier flywheel would be considered the most stable of the two, and would have the least speed variation. Now, in the case of the oscillating converters 1' and 2', the low-frequency tuned circuit 3' will normally have the highest selectivity which is analogous to the heavy flywheel effect. Consequently, when the frequency of the input signal is changed, the larger part of the change will take place on the higher-frequency tuned circuit 4' since its flywheel effect is less.

Another way of describing the operation is as follows: If both tuned circuits had equal values of "Q" the low-frequency circuit 3' would have the highest degree of selectivity, since a given frequency change in cycles would represent a larger percentage frequency change in that circuit. When the input signal frequency is changed, both circuit frequencies will change. However, since the oscillation follows the path of least resistance and assumes the frequency which is a compromise between the maximum possible gain and the best phase position, the lower frequency will shift to approximately the same amplitude and phase on its tuned circuit that the higher frequency does. For this to be the case the lower frequency cannot shift as far in frequency, since it is relatively more selective.

In the numerical example, assume that the 13 mc. signal frequency shifts 75 kc. higher. If the selectivities of the tuned circuits 4' and 3' were the same (by having values of "Q" proportional to their frequency) the 4 mc. voltage would shift to 4 mc. minus 37.5 kc. and the 17 mc. voltage would shift to 17 mc. plus 37.5 kc. This would be the equilibrium condition. However, if the values of "Q" of the circuits were equal, so that the 4 mc. circuit was 1¾ times as selective as the circuit 4', then the two frequencies would shift in the ratio of 4 to 17. This would make the 4 mc. circuit shift approximately 14.3 kc., and the higher frequency would shift approximately 60.7 kc.

From the above it can be seen that the frequency deviation of the input signal has been reduced in the case of both of the resulting oscillations. The lower frequency oscillations have been reduced approximately 4:1, whereas the carrier frequency would be reduced in the ratio of 17:4 or 4.25 to 1. Thus, a reduction of frequency deviation is effected which is even greater than the reduction of the carrier frequency. In the case of the usual type of frequency multiplication or division, the frequency deviation change is the same as the order of the frequency multiplication or division. According to the present method of reducing the degree of deviation, however, such reduction can be carried to any desired degree by adjusting the relative selectivities of circuits 4' and 3'. Such an adjustment may be effected by varying the damping of the two tuned circuits. Thus, if it were desired to decrease the deviation of the circuit 3', the damping of the circuit 4' could be increased by lowering the shunt resistance across circuit 4', or by increasing the series resistance in circuit 4'.

In experimental work with this circuit, it has been observed that the direction of the frequency deviation is opposite on the two oscillation frequencies. This furnishes a means of reversing the direction of a frequency, or phase, modulation deviation. Experimental work has, also, shown that once the oscillations have started in the re-entrant system, the amplitude of oscillations is quite insensitive to amplitude variations of the modulated carrier wave input. As the wave input is brought up oscillations start and increase in amplitude for a small range, but limit to a constant value. Thus, the system has the property of passing only the frequency, or phase, variations of the input waves thereby eliminating amplitude variations. Hence, there is shown above tube 1' a characteristic which shows a typical limiting characteristic relating input and output wave amplitude.

In the receiving system the voltage developed across tuned circuit 3', which would have the carrier frequency of 4 mc. and a maximum frequency deviation of 14.3 kc. instead of 75 kc., would be fed to a succeeding demodulation network. Such a demodulation network could be of any type well known to those skilled in the art. Usually it comprises a discriminator-rectifier, and the discriminator would have its input circuit tuned to a frequency of 4 mc., and would be adjusted to handle a maximum deviation of 14.3 kc. It is not believed necessary to show the specific details of any discriminator network, since the various types of demodulator networks are well known to those skilled in the art. For example, there may be utilized the type of discriminator-rectifier

shown by S. W. Seeley in his U. S. Patent 2,121,103, granted June 21, 1938. It will be noted that the demodulator is not responsive to the full frequency variations of the wave as collected by the signal collector. Further, no limiter per se need be used prior to the demodulator. Additionally inter-channel noise squelching is secured.

It will be apparent that this same type of deviation reducing circuit may be applied to a PM receiver. The use of such a deviation reducing system in a PM receiver has the advantage that higher values of phase deviation may then be used without overloading the phase detector. The function of the deviation reducing network in such case, and also in the case of an FM receiver, is the same as that of the frequency divider disclosed in my U. S. Patent 2,230,231. For the case of phase modulation reception, the use of such a frequency division increases the phase deviation capabilities of a phase modulation receiver which is normally limited to a maximum phase deviation of one radian. Receivers of the crystal filter type, and others, have this limitation. Hence, by the inclusion of frequency division high-deviation, phase modulation is made possible on these types of receivers.

Where it is desired to obtain extreme reduction of deviation, the circuit of Fig. 2 may be employed. In this arrangement a third converter tube 5' is provided which produces a heterodyne output which is the sum of the two oscillation frequencies. That is, the output of converter 5' will be the sum of the oscillations produced across circuits 4' and 3'. Therefore, the heterodyne output would be equal to 21 mc., and would be developed across tuned circuit 6' arranged in the plate circuit of converter tube 5'. The output of circuit 6' will be constant in frequency, if the selectivities of the oscillation circuits 3' and 4' are the same. The reason for this is that the deviation of the output of circuit 6' is the difference of the deviation present in the oscillation circuits 3' and 4'.

For instance, in the case of the previously-mentioned example for equal values of selectivity in circuits 3' and 4', the 13 mc. input deviated 75 kc. higher, the lower frequency deviated 37.5 kc. lower, and the higher frequency deviation 37.5 kc. higher. The sum of 4 mc. minus 37.5 kc. and 17 mc. plus 37.5 kc. is 21 mc. The sum frequency would also have been 21 mc., if the 13 mc. signal had not deviated at all. For the other example, in which the lower frequency deviated 14.3 kc. and the higher frequency deviated 60.7 kc. higher, the sum of the two oscillation frequencies would be 21 mc. plus 46.9 kc. For this case a deviation of 75 kc. in the signal frequency produced a 46.4 kc. deviation in the output frequency.

Hence, in the system of Fig. 2 as the selectivities of the two oscillation circuits 3' and 4' are made more unequal, the sum frequency output developed across circuit 6' and converter 5' has a larger deviation. Consequently by adjustment of the selectivity of the two oscillation circuits 3' and 4', the deviation may be controlled from a value of zero up to approximately the same deviation as the signal. It will, therefore, be seen that the nearer to equality that the two selectivities are, the greater is the reduction of the deviation. In the circuit of Fig. 1 the opposite is true. That is, the greater the difference in the selectivities, the greater the deviation reduction.

Considering the system shown in Fig. 2, it will be noted that the circuits of converter tubes 1' and 2' are the same as those in Fig. 1. The converter tube 5' has its first grid 30 coupled through condenser 31 to tap 24 of coil 16. The third control grid 32 is connected by condenser 33 to the tap 9 on coil 10 of circuit 4'. Grids 32 and 30 are returned by resistors to the grounded end of the biasing resistor arranged in the cathode circuit of converter tube 5'. Of course, heterodyne output voltage developed across resonant circuit 6' is transmitted to any well known type of FM discriminator as explained in connection with Fig. 1.

In both Figs. 1 and 2 the taps 24 and 9 serve to reduce the overall gain of the cascaded converters. They, also, have the effect of preventing the grid circuits, which the taps feed, from loading the tuned circuits so as to reduce their selectivity. The overall gain is usually much higher than is required for sustained oscillations so that tapping down, with its advantage of improved selectivity, may be employed.

There are other uses to which the re-entrant system shown in this application is applicable. One of these is for a tone keyer for telegraph reception. The threshold effect and the self-limiting feature are both ideally suited for this operation. In this usage the keyed signal is fed to the signal input, and the frequency variations are removed by the deviation-reducing effect of the re-entrant system.

While I have indicated and described several systems for carrying my invention into effect, it will be apparent to one skilled in the art that my invention is by no means limited to the particular organizations shown and described, but that many modifications may be made without departing from the scope of my invention, as set forth in the appended claims.

What I claim is:

1. In a system of frequency, or phase, deviation reduction, the method which includes heterodyning original frequency, or phase, modulated carrier waves of a given mid-band frequency and frequency deviation with oscillations of a higher frequency than said mid-band frequency, deriving from the heterodyne energy modulated waves whose mid-band frequency is equal to the difference of said given frequency and higher frequency and whose deviation is substantially less than said given deviation, and heterodyning said derived modulated waves with said original waves thereby to produce said oscillations of higher frequency.

2. In a system of frequency, or phase, deviation reduction, the method which includes heterodyning original frequency, or phase, modulated carrier waves of a given carrier frequency and deviation with oscillations of a higher frequency than said carrier frequency, deriving from the heterodyne energy modulated waves whose carrier frequency is equal to the difference of said given frequency and higher frequency and whose deviation is substantially less than said given deviation, heterodyning said derived modulated waves with said original waves thereby to produce said oscillations of higher frequency, and finally combining said higher frequency oscillations with said derived waves to produce a second heterodyne voltage which is the sum of the combined frequencies.

3. In a system of frequency, or phase, deviation reduction, the method which includes heterodyning original frequency, or phase, modulated carrier waves of a given frequency and frequency swing with oscillations of a higher frequency than said given frequency, deriving from the heterodyne energy modulated waves whose frequency

is equal to the difference of said given frequency and higher frequency and whose frequency swing is substantially less than said given frequency swing, heterodyning said derived modulated waves with said original waves thereby to produce said oscillations of higher frequency, and maintaining said derived waves and said higher frequency oscillations at different degrees of damping.

4. A method of reducing the frequency deviation of original angular velocity-modulated carrier waves of a pre-determined frequency and a given frequency deviation, which includes deriving from said modulated waves similar modulated carrier waves whose frequency is higher than said predetermined frequency but whose frequency deviation is lower than said given deviation, combining said original waves with the derived waves thereby to produce resultant modulated waves at a reduced frequency equal to the difference of said predetermined and higher frequencies and whose frequency deviation is reduced from said given deviation, and deriving from the combination of said original waves and said resultant waves said higher frequency modulated waves.

5. A method of reducing the frequency deviation of angular velocity-modulated carrier waves of a predetermined carrier frequency and a given carrier frequency deviation, which includes deriving from said modulated waves similar modulated carrier waves whose carrier frequency is higher than said predetermined frequency but whose frequency deviation is lower than said given deviation, combining said original waves with the derived waves thereby to produce resultant modulated waves at a reduced carrier frequency equal to the difference of said predetermined and higher frequencies and whose deviation is reduced from said given deviation to a greater extent than said reduced carrier frequency, and deriving from the combination of said original waves and said resultant waves said higher frequency modulated waves.

6. In combination with a pair of electron discharge tubes each having a pair of input electrodes and an output electrode, means applying signals having a given frequency variation to an input electrode of each tube, a separate resonant circuit connected to each output electrode of each tube, said resonant circuits being tuned to respectively higher and lower frequencies than the mean frequency of said applied signals, a coupling connection from each resonant circuit to the second input electrode of the opposite tube, and means for deriving from the lower frequency-tuned circuit signals whose frequency variations have been reduced relative to said given frequency variation.

7. In combination with a pair of electron discharge tubes each having a pair of spaced control electrodes and an output electrode, means applying signals of a predetermined frequency variation to a control electrode of each tube, a separate resonant circuit connected to each output electrode of each tube, said resonant circuits being tuned to respectively higher and lower frequencies than the mean frequency of said applied signals, a connection from each resonant circuit to the second control electrode of the opposite tube, and means for deriving from the lower frequency resonant circuit signals whose frequency variations have been reduced relative to said predetermined frequency variation, and means for adjusting the relative selectivities of said two resonant circuits.

8. In a system of frequency, or phase, deviation reduction, the method which includes heterodyning original frequency, or phase, modulated carrier wave of a given mid-band frequency and frequency deviation with oscillations of a higher frequency than said mid-band frequency, deriving from the heterodyne energy modulated waves whose mid-band frequency is equal to the difference of said given frequency and higher frequency and whose deviation is substantially less than said given deviation, heterodyning said derived modulated waves with said original waves thereby to produce said oscillations of higher frequency, and providing predetermined unequal damping of said derived waves and last-mentioned oscillations thereby to reduce said given deviation to a predetermined lesser value.

9. A method of reducing the frequency deviation of angular-velocity-modulated carrier waves of a predetermined carrier frequency and a given carrier frequency deviation, which includes deriving from said modulated waves similar modulated carrier waves whose carrier frequency is higher than said predetermined frequency but whose frequency deviation is lower than said given deviation, combining said original waves with the derived waves thereby to produce resultant modulated waves at a reduced carrier frequency equal to the difference of said predetermined and higher frequencies and whose deviation is reduced from said given deviation to a greater extent than said reduced carrier frequency, deriving from the combination of said original waves and said resultant waves said higher frequency modulated waves, and maintaining said resultant waves and higher frequency waves at predetermined different dampings.

10. In combination with a pair of electron discharge tubes each having a pair of spaced control electrodes and an output electrode, means applying frequency modulated carrier signals of a given frequency deviation to a control electrode of each tube, a separate resonant circuit connected to each output electrode of each tube, said resonant circuits being tuned to respectively higher and lower frequencies than the mean frequency of said applied signals, a connection from each resonant circuit to the second control electrode of the opposite tube, means for deriving from the lower frequency resonant circuit signals whose frequency deviation has been greatly reduced relative to the given deviation, means for adjusting the relative selectivities of said two resonant circuits, thereby to determine the degree of deviation reduction.

11. In a system of frequency, or phase, deviation reduction, the method which includes heterodyning original frequency, or phase, modulated carrier waves of a given center frequency and frequency deviation with oscillations of a higher frequency than said center frequency, deriving from the heterodyne energy modulated waves whose center frequency is equal to the difference of said given frequency and higher frequency and whose deviation is substantially less than said given deviation, heterodyning said derived modulated waves with said original waves thereby to produce said oscillations of higher frequency, and combining said last oscillations with said derived modulated waves to produce modulated waves of greatly reduced deviation relative to said given frequency deviation.

12. In a system of frequency, or phase, deviation reduction, the method which includes mixing original frequency, or phase, modulated carrier waves of a given center frequency and deviation

with oscillations of a higher frequency than said center frequency, deriving from the mixed energy modulated waves whose center frequency is equal to the difference of said given frequency and higher frequency and whose deviation is substantially less than said given deviation, mixing said derived modulated waves with said original waves thereby to produce said oscillations of higher frequency, and combining said higher frequency oscillations with said derived waves to produce modulated waves whose center frequency is the sum of the combined frequencies and whose frequency deviation is greatly reduced relative to said given deviation.

13. In combination with a pair of electron discharge tubes each having a pair of input electrodes and an output electrode, means applying frequency modulated carrier waves to an input electrode of each tube, separate resonant circuits, connected to each output electrode of each tube, tuned to respectively higher and lower frequencies than the carrier frequency of said applied waves, a coupling connection from each resonant circuit to the second input electrode of the opposite tube, and means for mixing the waves produced across each of the separate resonant circuits to produce resultant frequency modulated waves whose frequency deviation is greatly reduced relative to the frequency deviation of said applied waves.

14. A re-entrant circuit comprising a pair of electron discharge tubes each having a pair of input electrodes and an output electrode, means applying signals having a given frequency deviation to an input electrode of each tube, a separate output circuit connected to each output electrode of each tube, said output circuits being tuned to respectively different frequencies than the mean frequency of said applied signals, a coupling connection from each output circuit to the second input electrode of the opposite tube, and means for deriving from at least one of the output circuits signals whose frequency deviations have been reduced relative to said given frequency deviation.

15. A re-entrant circuit comprising a pair of converters, each converter having an input circuit and an output circuit, means feeding frequency modulated carrier signals to be heterodyned to the input circuit of each converter, said signals having a predetermined frequency deviation, means feeding the heterodyne output of the output circuit of one converter to the input circuit of the second converter, means feeding the heterodyne output of the second converter to the input circuit of the one converter thereby to produce sustained oscillations and the output circuits of said converters being of sufficiently different selectivities whereby the output of said one converter has a greatly reduced frequency deviation relative to said predetermined frequency deviation.

16. A method of producing sustained oscillations in a re-entrant system, which includes separately heterodyning angular velocity-modulated carrier waves of the same mean frequency and same frequency deviation with waves of different mean frequencies and respectively different frequency deviations which differ from said first-named frequency deviation, and deriving each of the last named waves from the heterodyne energy of the opposite heterodyne step.

17. In combination with a pair of tubes each having a pair of input grids and an output electrode, means applying angular velocity-modulated signals of a predetermined frequency deviation to an input grid of each tube, a separate resonant circuit connected to each output electrode of each tube, said resonant circuits being tuned to respectively higher and lower frequencies than the mean frequency of said applied signals, coupling connections from each resonant circuit to the second input electrode of each opposite tube, means for deriving from the output resonant circuit of one of said tubes signals whose frequency deviation is materially reduced relative to said predetermined frequency deviation, and means for adjusting the relative selectivities of said two resonant circuits.

18. A re-entrant circuit comprising a pair of electron discharge tubes each having a pair of input electrodes and an output electrode, means applying signals of a given frequency variation to an input electrode of each tube, a separate output circuit connected to each output electrode of each tube, said output circuits being tuned to respectively different frequencies than the mean frequency of said applied signals, a coupling connection from each output circuit to the second input electrode of the opposite tube, means for deriving from at least one of the output circuits signals whose frequency variation has been reduced relative to said given variation, and said output circuits being of different selectivities, said selectivities being related in a predetermined manner to determine the degree of said frequency variation reduction.

MURRAY G. CROSBY.