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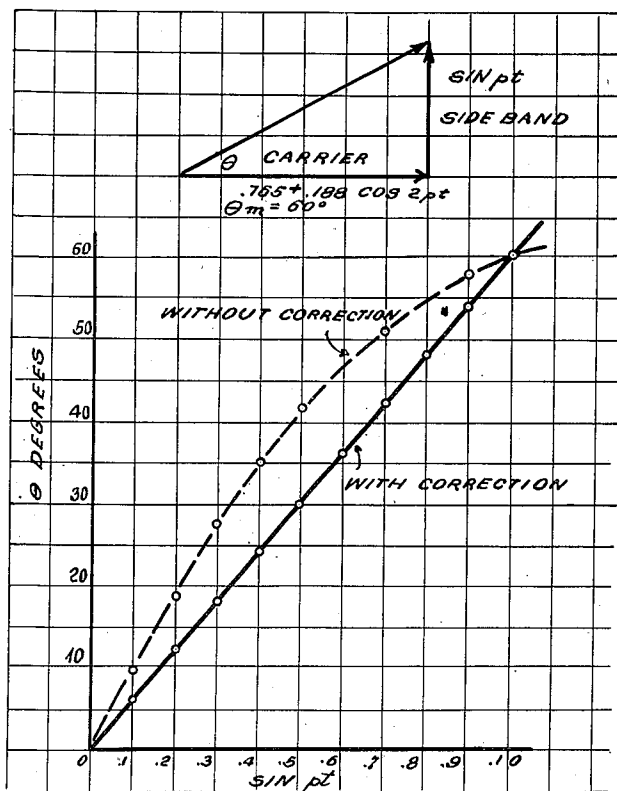
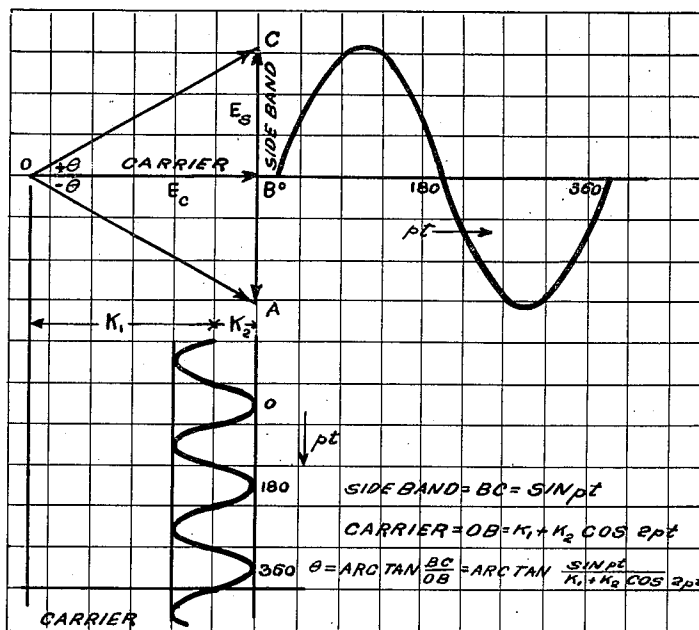
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2,301,907

FREQUENCY MODULATION DISTORTION CORRECTION SYSTEM

Filed July 24, 1941

2 Sheets-Sheet 1



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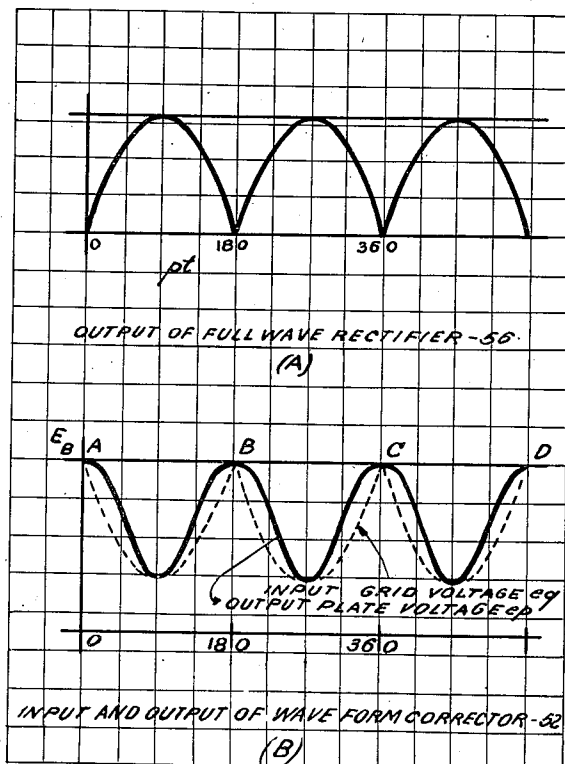
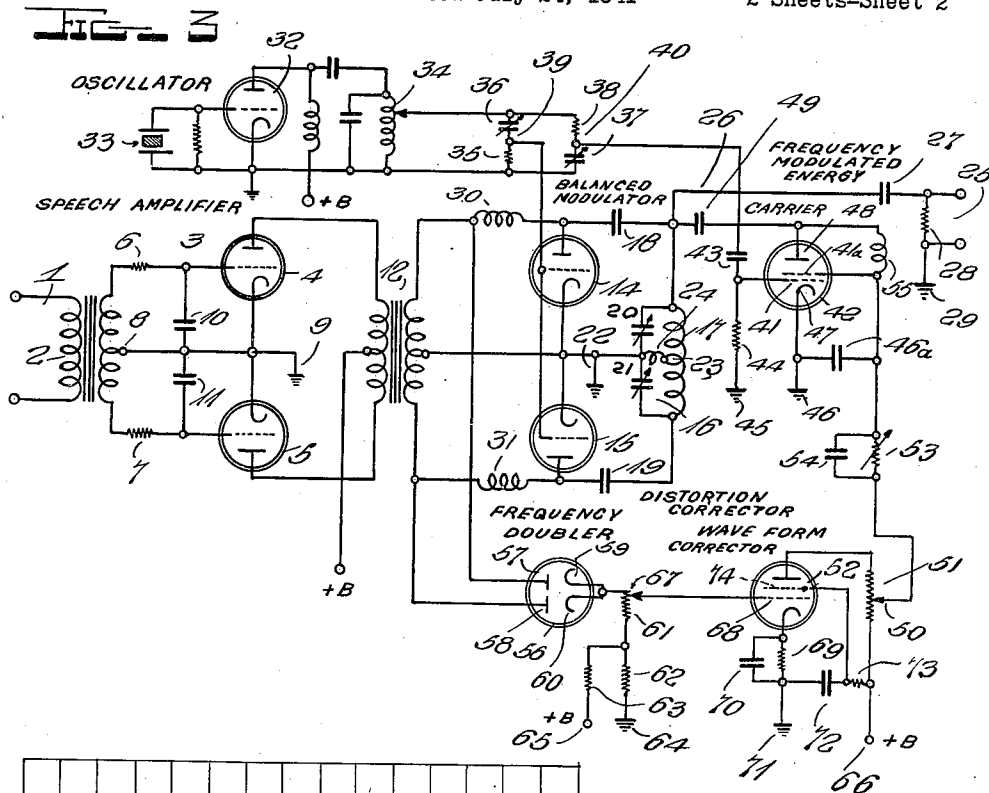
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FREQUENCY MODULATION DISTORTION CORRECTION SYSTEM

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2 Sheets-Sheet 2



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FREQUENCY MODULATION DISTORTION
CORRECTION SYSTEM

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Application July 24, 1941, Serial No. 403,910

8 Claims. (Cl. 179—171.5)

My invention relates broadly to modulation systems and more particularly to a frequency modulation distortion correction system.

One of the objects of my invention is to provide a system of frequency modulation in which the distortion at wide phase angle deviations is mini-
mized. The system of my invention applies particularly to phase modulators in which the side bands are added to the carrier in phase quadrature. The operation of phase modulators in the production of frequency modulated signals is well known to the art. Present systems use a maximum phase shift of the order of 30 degrees at low audio frequencies.

In systems using 30 degrees phase shift, analysis of the demodulated frequency modulation signal shows that distortions of the order of 7-8 percent are present. At 60 degrees phase shift the distortion is of the order of 28 to 30 percent. This is due to the non-linear relation of the phase shift angle and the amplitude of the side band voltage. It is the object of the system of my invention to provide an approximately linear relation between phase shift angle and side band amplitude for maximum phase shifts as high as 60 degrees or more.

Other and further objects of my invention reside in the provision of an improved circuit arrangement for frequency modulation systems, as set forth in the following specification by reference to the accompanying drawings in which:

Figure 1 shows vectorily the relation of the carrier and side bands in the frequency modulation distortion correction system of my invention; Fig. 2 shows graphically the completed relation of phase shift angle and side band amplitude in the frequency modulation distortion correction system of my invention; Fig. 3 diagrammatically shows the frequency modulation distortion correction circuit of my invention; and Fig. 4 shows curve diagrams representing the voltage relations in the frequency modulation distortion correction circuit of my invention.

Fig. 1 illustrates the mechanics of the system of my invention by vector representation of the carrier and side bands. The side bands are added at an angle of 90 degrees as shown in the figure and their amplitude varied in accordance with the audio frequency. However, the carrier is also amplitude modulated simultaneously at twice the audio frequency in such a manner that approximately a linear relation obtains between side band amplitude and angle of phase shift.

In Fig. 1, the side band amplitude BC is given by:

$$BC = \sin \rho t \quad (1)$$

where

$$\frac{\rho}{2\pi}$$

is the audio modulating frequency

The carrier amplitude OB by

$$OB = K_1 + K_2 \cos 2 \rho t \quad (2)$$

where K_1 and K_2 are arbitrary constants of operation.

The angle of phase shift θ is expressed by

$$\theta = \arctan \frac{BC}{OB} \quad (3)$$

from (1) and (2)

$$\theta = \arctan \frac{\sin \rho t}{K_1 + K_2 \cos 2 \rho t} \quad (4)$$

If K_1 and K_2 are properly chosen, it can be shown that an approximate linear relation between the phase shift angle θ and side band amplitude $\sin \rho t$ exists. Since (4) is a transcendental equation, the solution is not a simple matter. In this case, point-by-point solution is the best means of establishing operating conditions. In an actual case, the maximum value of θ (the limiting value approaches 90 degrees) is selected and $K_1 + K_2 \cos 2 \rho t$ considered as a function of time $K_f(t)$. θ is then assumed to be linear with $\sin \rho t$ and $K_f(t)$ computed at intervals of the audio frequency cycle, so that this linearity obtains. From the resultant plotting of $K_f(t)$, the constants K_1 and K_2 may be evaluated. Actual plots show that the modulation of the carrier very closely approximates a double audio frequency cosine wave and is the reason for the selection of the expression $K_1 + K_2 \cos 2 \rho t$ to represent the carrier.

Fig. 2 shows the computed relation of phase shift angle θ and side band amplitude $\sin \rho t$ for the case where maximum was chosen as 60 degrees and the constants K_1 and K_2 0.765 and .198 respectively. The points approximate a straight line very closely and negligible distortion should result. The dotted curve shows the relation between θ and $\sin \rho t$ when the carrier is unmodulated. The solid line shows the relationship of the phase shift angle θ and the side band amplitude $\sin \rho t$ when corrected for distortion.

Fig. 3 shows the circuit arrangement of the system of my invention. The speech input circuit is indicated at 1 connected through audio frequency transformer 2 to the speech amplifier 3. The speech amplifier 3 comprises a balanced triode system constituted by tubes 4 and 5, as shown with their grid circuits connected to the secondary winding of speech input transformer 2, through the audio correction network comprising resistors 6 and 7, and condensers 10 and 11. The secondary winding of speech input transformer 2 has its mid-tap 8 connected to the cathode circuits of the triodes 4-5 and to ground 9. The output of the speech amplifier 3 is coupled through transformer 12 with the balanced modulator comprising tubes 14-15. The

tubes 14 and 15 are operated without a direct current anode supply and receive energy solely from the audio power delivered by transformer 12.

The circuit of the balanced modulator includes the balanced tank circuit 16 comprising inductance 17 connected at opposite ends with the anodes of tubes 14 and 15 through coupling condensers 18 and 19. The inductance 17 is tuned by tank circuit condensers 20 and 21 which are connected in balanced relation with their adjacent capacity areas connected to the cathode circuits of tubes 14 and 15 and to ground indicated at 22. The inductance 17 has its midpoint 23 connected through the audio shunting choke coil 24 with the cathode circuit of tubes 14 and 15. The radio frequency side band energy developed in tank circuit 16 is supplied to the output system 25 leading to additional stages of frequency multiplication and amplification through conductor 26, condenser 27 and resistor 28 connected to ground 29. Radio frequency energy is excluded from the speed frequency amplifier circuit coupled through transformer 12 with the balanced modulator tubes 14—15 by the inclusion of the choke coils 30 and 31 between the anodes of tubes 14 and 15 and the secondary winding of the speech frequency input transformer 12 as shown.

The oscillator for the transmitter is shown at 32 constituting a triode controlled by piezo-electric crystal 33 and having its output circuit 34 connected to a phase shifting network comprising resistance 35, variable condenser 36, variable condenser 37 and resistance 38. Connections are taken from taps 39 and 40 in the phase shifting network to the control grids of the balanced modulator tubes 14—15 and to the control grid 41 of the carrier wave amplifier tube 42, respectively. The phase shift of the between the grid voltages of the balanced modulator and carrier tubes are plus and minus forty-five degrees from oscillator voltage. Thus the total phase angle between carrier and side band voltages is ninety degrees. The connection taken to the control grid 41 of the carrier wave amplifier tube 42 includes coupling condenser 43. The input circuit to the carrier frequency amplifier tube 42 is completed through resistance 44 to ground 45 and from ground 46 to the cathode 47. The output circuit of the carrier wave amplifier tube 42 includes plate 48 which connects through coupling condenser 49 with the common load impedance 17 of the balanced modulator tank 16. The carrier is thus added to the side bands and carried through conductor 26 leading to the output system 25. The voltage for the plate 48 of the carrier wave amplifier tube 42 is obtained from the variable tap 50 on output resistor 51 in the output circuit of wave form corrector tube 52. This anode voltage is amplitude modulated in accordance with voltage appearing across resistor 51. The anode voltage is passed through the series connected variable resistor 53 shunted by condenser 54 through the choke coil 55 for impressing audio frequency voltage on plate 48 of tube 42. The auxiliary grid 41a in tube 42 connects to the lead from the wave form corrector tube 52 intermediate the resistance condenser combination 53—54 and choke coil 55. The value of resistance 53 controls the parameter K_1 in the formulas recited above while the position of the tap 50, on resistance 51 controls the parameter K_2 in the above formulas. The radio frequency output of the carrier wave amplifier tube

42 is modulated at double audio frequency in accordance with the plate voltage. A by-pass condenser 46a connects across the plate potential supply circuit for tube 42 as indicated.

The manner of obtaining amplitude modulation of the carrier wave amplifier tube 42 constitutes the novel and important feature of my invention. This amplitude modulation of the carrier at twice the audio modulation frequency is obtained by the coaction of a frequency doubler tube 56 with the wave form corrector tube 52; heretofore referred to. The frequency doubler tube 56 is a full wave rectifier including plate electrodes 57 and 58 and cathodes 59 and 60. The plate electrodes 57 and 58 are connected to the output of the speech amplifier at the secondary of transformer 12. The cathodes 59 and 60 are connected through load resistor 61 and biasing resistor 62 to ground at 64. Resistor 61 is connected across the potential +B at 63 through series resistor 62. The voltage developed across resistor 62 limits the operating angle of the diode rectifier 56 and aids in controlling the characteristic of the plate voltage curve as shown in B of Fig. 4. This source of potential +B which connects at 65 can be from a common source and supply all points in Fig. 3 marked +B. The cathode heating potential for all of the tubes may be obtained from a common source. The load resistor 61 is provided with an adjustable tap 67 which connects to the control grid 68 of the wave form corrector tube 52. Proper bias is obtained for the wave form corrector tube 52 through the series cathode resistor 69 shunted by condenser 70 and connected to ground indicated at 71. Potential for the screen 74 of tube 52 is supplied through resistor 73 from the source at 66. The screen potential is by-passed to ground by condenser 75.

Referring to Fig. 4 it will be understood that the wave form of the voltage delivered by the full wave rectifier tube 52 has high harmonic content and must be passed through the circuit of wave form corrector tube 52 which constitutes a wave form correction circuit that corrects the wave form to within five percent of the true double audio frequency. The tube 52 functions as a super-control remote cut-off tube which shapes the half wave pulses from full wave rectifier tube 56 to the desired form. The super-control wave form corrector tube 52 is biased cut-off and the grid voltage limited to the threshold of grid current on audio peaks by the cathode resistor 69 and shunted condenser 70 heretofore described. In Fig. 4 the curves shown A represent the voltage output of tube 56 which are applied to the control grid 68 of wave form corrector tube 52.

The characteristics of the super-control wave form corrector tube 52 when operated in the manner described are such that the wave form of the plate voltage and grid voltage are not altered but follow the general contour shown in B of Fig. 4. The plate voltage (solid curve) approximates a true double frequency cosine wave. Slight discontinuities at the points ABCD may be minimized by reducing the operating angle of the diode full wave rectifier. This is accomplished by means of resistors 62 and 63 operating from the plate supply voltage 65 of frequency doubler tube 56.

The system of distortion correction of my invention permits large angles of phase shift of the phase modulator with low distortion. It decreases the amount of phase multiplication

quired for wide band frequency modulation and results in simpler apparatus and a reduction of noise due to random disturbances in the phase modulator circuit. Present systems use 30 degrees phase shift and a multiplication of 4000 to 5000. The distortion at lowest audio frequency when the phase is modulated to the 30 degree maximum is 7-8%. Application of this system of correction to this circuit would reduce the distortion to 1-1.5 percent. The latter figure is based on experimental data.

If a system using 60 degree maximum phase shift is used, the phase multiplication can be reduced by half to 2000 to 2500. Thus the random noise should be reduced 6 db. The distortion without the correction system would be 28-30% and with correction 2 to 3 percent. These latter figures are also based on preliminary experimental data, and could probably be bettered by a more accurate synthesis of the double frequency audio voltage referred to above.

While I have described my invention in one of its preferred embodiments, I desire that it be understood that modifications may be made and I intend no limitations upon my invention other than may be imposed by the scope of the appended claims.

What I claim as new and desire to secure by Letters Patent of the United States is as follows:

1. In a frequency modulated signaling system a radio frequency oscillator, a carrier wave amplifier having a cathode, an anode, a control grid electrode and a screen grid electrode, means for impressing unmodulated radio frequency energy from the oscillator which is shifted in phase at a fixed value of 45 degrees leading the oscillator voltage upon the control grid electrode, means for impressing a doubled audio frequency modulation simultaneously upon said screen grid electrode and said anode, and means connected with the output of said carrier wave amplifier subject to the composite influence of a basic audio frequency modulated side band voltage and a carrier voltage modulated at twice the audio frequency.

2. In a frequency modulated signaling system an audio frequency modulation circuit, a balanced amplifier connected with said audio frequency modulation circuit, a balanced modulator having symmetrically arranged output circuits and a common input circuit, a tuned tank circuit connected with the output of said balanced modulator, a carrier wave amplifier having a pair of input circuits, means connected between said audio frequency modulation circuit and one of the input circuits of said carrier wave amplifier for impressing a doubled audio frequency modulation upon said carrier wave amplifier, an oscillator, means for applying energy from said oscillator to the input circuit of said balanced modulator at a fixed phase difference lagging the oscillator by 45 degrees, the input voltage at said carrier wave amplifier leading the oscillator voltage by 45 degrees whereby the net difference at the input circuits of the said balanced modulator and the said carrier wave amplifier is 90 degrees, and a connection between the output of said carrier wave amplifier and said tuned tank circuit, whereby said tank circuit is subjected to the composite effect of said balanced modulator output and said carrier wave amplifier output.

3. In a frequency modulated signaling system an audio frequency modulation circuit, a balanced amplifier connected with said audio frequency modulation circuit, a balanced modulator

having symmetrically arranged output circuits and a common input circuit, a tuned tank circuit connected with the output of said balanced modulator, a carrier wave amplifier having a pair of input circuits, means connected between said audio frequency modulation circuit and one of the input circuits of said carrier wave amplifier for impressing a doubled audio frequency modulation upon said carrier wave amplifier, means for correcting the wave form characteristic of said doubled audio frequency modulation, an oscillator, means for applying energy from said oscillator to the input circuit of said balanced modulator at a fixed phase difference lagging the oscillator by 45 degrees, the input voltage at said carrier wave amplifier leading the oscillator voltage by 45 degrees whereby the net difference at the input circuit of said balanced modulator and said carrier wave amplifier is 90 degrees, and a connection between the output of said carrier wave amplifier and said tuned tank circuit, whereby said tank circuit is subjected to the composite effect of said balanced modulator output and said carrier wave amplifier output.

4. In a frequency modulated signaling system an audio frequency modulation circuit, a balanced amplifier connected with said audio frequency modulation circuit, a balanced modulator having symmetrically arranged output circuits and a common input circuit, a tuned tank circuit connected with the output of said balanced modulator, a carrier wave amplifier having a pair of input circuits, means connected between said audio frequency modulation circuit and one of the input circuits of said carrier wave amplifier for impressing a doubled audio frequency modulation upon said carrier wave amplifier, an oscillator, means for applying energy from said oscillator to the input circuit of said balanced modulator at a fixed phase difference lagging the oscillator by 45 degrees, the input voltage at said carrier wave amplifier leading the oscillator voltage by 45 degrees whereby the net difference at the input circuits of said balanced modulator and said carrier wave amplifier is 90 degrees, and a connection between the output of said carrier wave amplifier and said tuned tank circuit, whereby said tank circuit is subjected to the composite effect of said balanced modulator output and said carrier wave amplifier output, and a condenser and resistance connected in parallel with respect to each other and disposed in series between said means for correcting the wave form characteristic of said doubled audio frequency modulation and said carrier wave amplifier.

5. In a frequency modulated signaling system an audio frequency modulation circuit, a balanced amplifier connected with said audio frequency modulation circuit, a balanced modulator having symmetrically arranged output circuits and a common input circuit, a tuned tank circuit connected with the output of said balanced modulator, a carrier wave amplifier having a pair of input circuits, means connected between said audio frequency modulation circuit and one of the input circuits of said carrier wave amplifier for impressing an audio frequency modulation at twice the frequency of said first mentioned audio frequency upon said carrier wave amplifier, an oscillator, means for applying energy from said oscillator to the input circuit of said balanced modulator at a fixed phase difference lagging the oscillator by 45 degrees, the input voltage at said carrier wave amplifier leading

the oscillator voltage by 45 degrees whereby the net difference at the input circuit of said carrier wave amplifier is 90 degrees, and a connection between the output of said carrier wave amplifier and said tuned tank circuit, whereby said tank circuit is subjected to the composite effect of said balanced modulator output and said carrier wave amplifier output.

6. The method of maintaining a linear relation between phase shift angle and amplitude of side band voltage in frequency modulator systems which comprises compositely modulating a carrier wave amplifier by adding the voltages of the side band frequencies at an angle of approximately 90°, varying their amplitude in accordance with an audio modulating frequency deriving a second modulating signal from said audio modulating frequency at double the said audio modulating frequency and simultaneously subjecting the carrier wave amplifier to modulation by said second modulating signal in such manner that approximately a linear relation obtains between side band amplitude and angle of phase shift.

7. The method of minimizing distortion at wide phase deviations in frequency modulation

systems which comprises simultaneously modulating the output voltage of a carrier wave amplifier system and the side-band voltage of a balanced modulator system, the balanced modulator system being modulated by an audio frequency signal and the carrier wave amplifier system being modulated simultaneously by a second signal which is derived from the aforesaid audio frequency signal, the second signal being so derived that it is always twice the value of the signaling frequency.

8. The method of effecting an approximately linear relation between phase shift angle and side-band amplitude in frequency modulation systems which comprises compositely modulating the output voltage of a carrier wave amplifier system and the side-band voltage of a balanced modulator system, the balanced modulator system being modulated by an audio frequency signal and the carrier wave amplifier system being modulated simultaneously by a second signal which is derived from the aforesaid audio frequency signal, the second signal being so derived that it is always twice the value of the signaling frequency.

ROGER JOSEPH PIERACCI.

CERTIFICATE OF CORRECTION.

Patent No. 2,301,907.

November 10, 1942.

ROGER JOSEPH PIERACCI.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 1, first column, line 35, for "completed" read --computed--; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 12th day of January, A. D. 1943.

(Seal)

Henry Van Arsdale,
Acting Commissioner of Patents.