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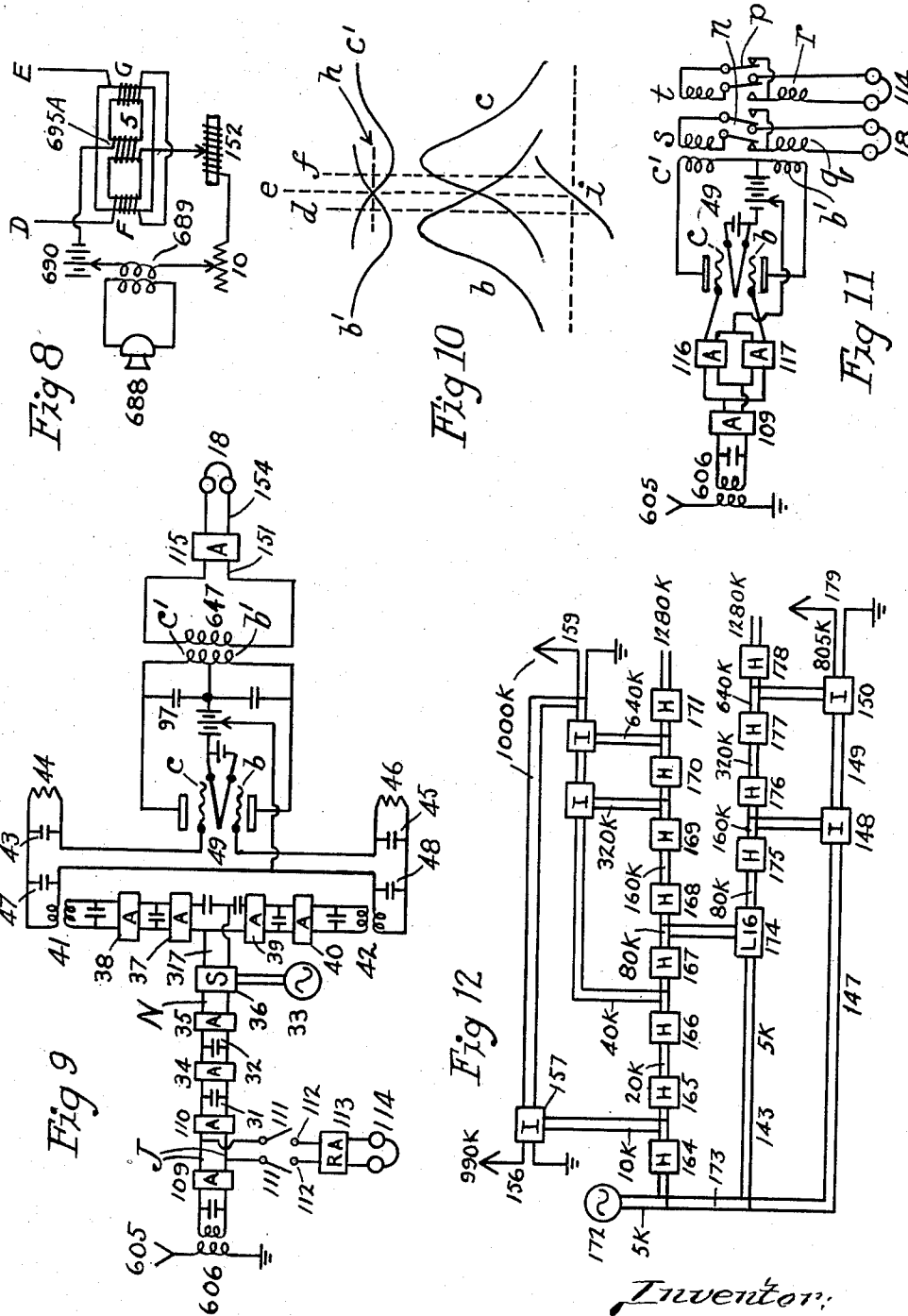
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2,164,032

CARRIER WAVE SIGNALING

Filed Feb. 14, 1930

4 Sheets-Sheet 2



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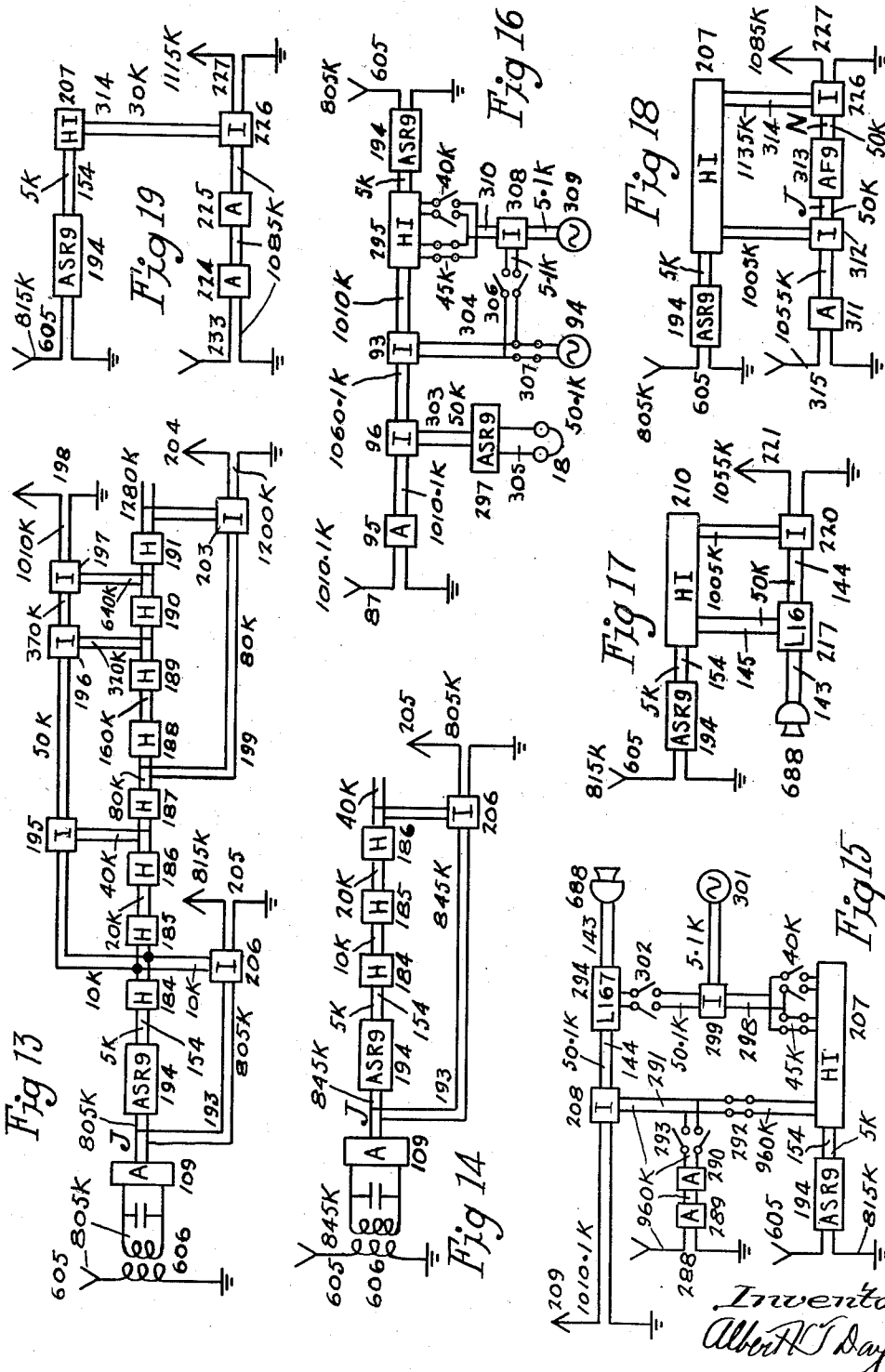
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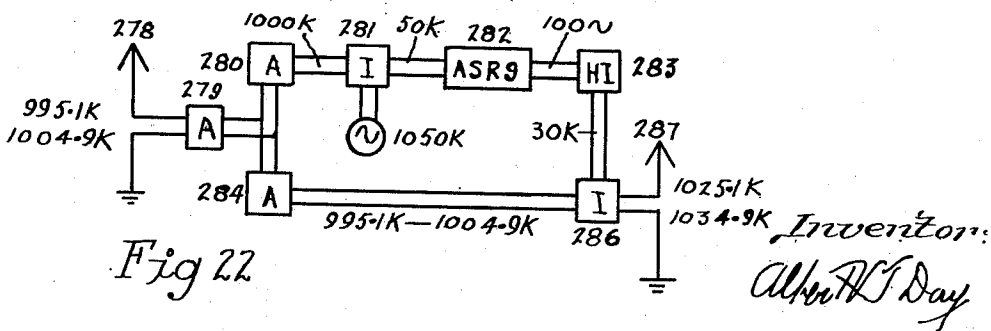
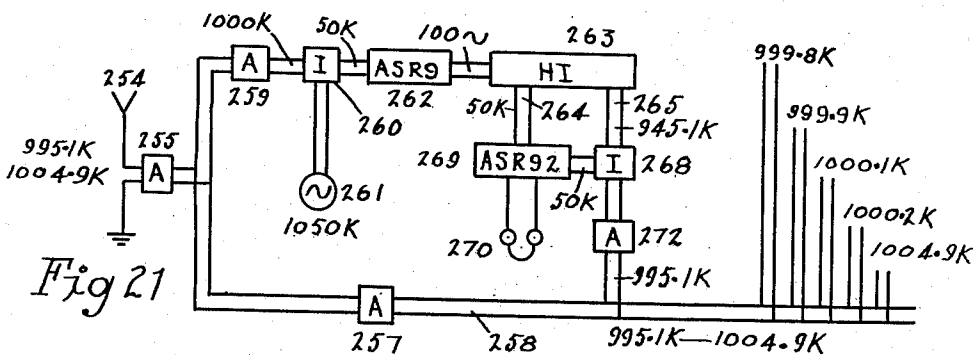
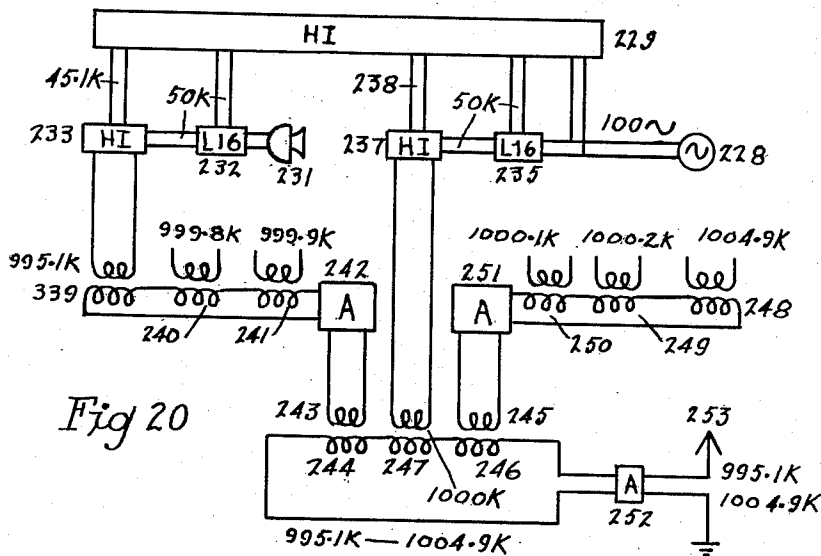
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CARRIER WAVE SIGNALING

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18 Claims. (Cl. 250—6)

GENERAL OBJECTS

The objects of this invention are to increase efficiency, reduce interference, provide more signaling channels within a given range or band of carrier frequencies, and to improve the signaling in such other ways as will appear from the following description and accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

Figures 1 and 2 respectively show the sending and receiving stations of a radio telegraph and telephone system.

Figures 3-5 are vector diagrams of wave interactions which occur in the receiver of Figure 2.

Figure 6 is a radio sending station.

Figure 6A shows a modification of apparatus shown in Figure 6.

Figure 7 is a radio sending station.

Figure 8 shows a modification of the variable inductance which may be substituted in the apparatus of Figures 1, 6, 6A and 7.

Figure 9 shows a radio receiving station.

Figure 10 is a graph illustrating the operation of the receivers of Figures 9 and 11.

Figure 11 shows a radio receiving station.

Figure 12 shows a radio transmitting station for broadcasting controlling waves to control waves transmitted from other stations or otherwise employed at other stations.

Figure 13 shows a relay station which receives a controlling wave from the station of Figure 12 and employs the same to control other controlling waves broadcast from the station of Figure 13.

Figure 14 shows a relay station which duplicates a portion of Figure 13 both in structure and operation, but carries different wave-frequencies in its homologous circuits, to illustrate a sequence of stations for relaying the controlling waves.

Figure 15 shows a station which receives a controlling wave from a station such as Figure 13, and broadcasts a signal-modulated wave controlled by said controlling wave.

Figure 16 shows a station which receives a controlling wave from a station such as Figure 13 or 14, and receives a signal-modulated wave from a station such as Figure 15, and utilizes both said waves to render the signal.

Figure 17 shows a station which receives a controlling wave from another station such as Figure 13, and radiates a signal-modulated wave under control of said controlling wave.

Figure 18 shows a relay station which receives

the signal-modulated wave from the station of Figure 17, and receives a controlling wave from a station such as Figure 12, 13 or 14, and radiates a signal-modulated wave under control of both said received waves.

Figure 19 shows a relay station which receives the signal-modulated wave from the station of Figure 18, and receives a controlling wave from a station such as Figure 12, 13 or 14, and radiates a signal-modulated wave under control of both said received waves.

Figure 20 shows a communications station for radiating 98 signal-modulated waves within a signaling band allocation 10 kilocycles wide.

Figure 21 shows a station for receiving the 98 signals radiated from the station of Figure 20.

Figure 22 shows a relay station which may receive the 98 signals from a station such as Figure 20 and retransmit them to a receiving station such as Figure 21, or to another relay station such as Figure 22.

Throughout all the diagrams, a reference character including a number followed by K, will mean that the indicated wave-source, circuit or other element, generates, conducts or selects the wave frequency expressed by said number in kilocycles.

Figure 1

In the transmitting apparatus of Figure 1, four coils are connected to form a quadrilateral inductance 695. Each coil has a core 5 of properly laminated soft iron or permalloy or other magnetic material having a permeability which varies with the magnetizing force or flux density developed by the coil. Across two opposite corners of the quadrilateral inductance, the battery 690 and secondary of the transformer 689 are connected in series. Across the other two corners are connected a source of carrier waves 693 and condenser 694 and primary of the coupling 714, all in series. The wave source 693 may be of any suitable character. For instance it may consist in an ordinary oscillating audion located at 121 and delivering its output wave through the primary transformer coil 118. And in some instances the said wave may be transmitted through a suitable modulator 713 adapted to vary its amplitude in response to any suitable modulating wave, for instance from a telephone 691.

The strength of magnetizing current in the battery circuit 690 determines the permeability of the four cores 5, and thus determines the joint inductance of their four coils 695 in the carrier

wave circuit 693. By adjusting the mean battery current, the mean value of the inductance 695 is adjusted together with the variable capacity 694 to produce resonance in the circuit of the wave source 693 at the normal frequency of said source.

The microphone 688 produces voice undulations in the current from the battery 2 flowing in the primary coil of the audio transformer 689, or the telegraphic key 4 transmits through said primary coil the waves of a signaling generator 731 of audible frequency. Such audio waves are repeated in the secondary coil of the transformer 689 so as to modulate the current from the battery 690 and thus modulate the inductance 695, and the resonance of the circuit 693. As said inductance is increased above exact resonance value the carrier wave in said circuit 693 is subjected to a lag in phase, or a retardation in period. As said inductance is decreased below critical resonance the carrier wave phase or period is advanced or accelerated.

The coupling 714 transmits the modulated carrier wave from the circuit 693 to the transmitting aerial 3, and thus is radiated a wave whose phase or period is accelerated and decelerated in accord with the rise and fall of magnetizing current in the circuit 690, as modulated by a voice wave from the microphone 688, or a telegraphic wave from the generator 731. Relatively large accelerations and retardations of the wave phase or period may thus be accomplished with negligible variations in total impedance of the circuit 693, and consequently negligible modulations in the strength or amplitude of the radiated wave.

When a modulating wave from 691 varies the amplitude of the carrier wave delivered by the source 693, such strength modulations will be transmitted from the aerial 3 together with the modulations of phase or period effected by the telephone 688.

Figures 2-5

Figure 2 shows one form of apparatus for receiving the signals radiated from the transmitting station shown in Figure 1.

In Figure 2, the receiving aerial 605 delivers the received wave through a coupling 606 to the input terminals of two amplifiers 6 and 7. The amplifier 6 may consist in an audion cascade having so many stages that several of its last stages will be completely or practically saturated (or loaded to utmost amplitude capacity) by the weakest or most faded signal that is desired to be received. When only the phase-modulated signal is to be received, the amplifier 7 may be likewise constituted. Such amplifier saturation is intended to avoid aberrations due to fading.

The amplifier 6 delivers its output wave through the secondary coil of a coupling 644 to the input terminals of an ordinary rectifier 634. The primary of said coupling is energized by the wave from a source 22 which is thus superposed upon the carrier wave supplied to the rectifier 634. These superposed waves will have a frequency difference to produce a heterodyne beat. The consequent wave of the beat frequency or differential frequency will be delivered by the rectifier to an amplifier 636 whose output circuit will impel a small synchronous motor 637. The shaft of this motor rotates a simple inductor coil 639 inside a rotary field produced by the phase-splitting coils 640, 641 in circuit with the wave source 22. Thus the coil 639 derives from the rotary field a wave whose frequency is the fre-

quency of the source 22 plus or minus the mechanical rotations of the coil, according as the coil rotates against the rotary field or with it.

The motor 637 revolves uniformly with a velocity which is the difference between the mean frequency of the received carrier wave and the constant frequency of the source 22. Its mechanical inertia effectually resists acceleration and deceleration in response to the phase modulations of the carrier wave. Thus it rotates the inductor 639 uniformly at the rate of said mean frequency difference. When the frequency of the source 22 is less than the received carrier frequency, the rotation of the inductor 639 will be counter to the rotary field, so as to add the differential frequency to the rotary field frequency and thus derive the exact mean frequency of the received carrier wave. When the source 22 delivers a frequency greater than the carrier frequency, the inductor will revolve in the rotary field direction so as to subtract the differential frequency from the rotary field frequency in the wave derived by the inductor.

Thus the inductor 639 delivers a wave having the exact mean phase or mean frequency of the received carrier wave without its phase modulations. The constant wave thus derived is delivered through a collector 638 to the primary coil of a transformer 645 whose secondary coil has its terminals connected to the grids B and C of a rectifier 646. Thus the grids B and C receive potential waves of mean carrier frequency and opposite instantaneous signs, or 180 degrees phase difference. The phase of the mean carrier frequency thus impressed on the grids may be adjusted in many obvious ways, for instance by mounting the rotary field coils 640, 641 on trunnions to shift their angular position either against or with the rotative direction of the inductor 639.

The amplifier cascade 7 delivers the modulated carrier wave through a transformer 100 to the neutral point in the secondary of transformer 645 so as to impress said wave upon both grids with the same instantaneous sign. The modulated wave is thus superposed on the constant wave in the grids, and for most efficient rectification of the phase-modulated signal, these waves will be brought into quadrature phase relation by any suitable adjustment, for instance by regulating the phase of the constant wave as before mentioned. The relative amplitudes of these superposed waves is not of critical importance. They might be equal, or they might have the relative strengths indicated in the vector diagrams of Figures 3-5.

Figures 3-5 will first be discussed as showing the rectification of the phase-modulated signal. For this purpose the vectors $b-Y$ and $c-X$ of Figure 3 may be disregarded. The vectors $O-b$ and $O-c$ are the constant waves impressed on the grids B and C respectively; the vectors $b-B$ and $c-C$ are the modulated waves impressed on said grids B and C respectively; and the vectors $O-B$ and $O-C$ are the resultant waves impressed on said grids B and C respectively.

Figure 3 shows the grid waves when the carrier wave is not being subjected to a phase modulation. Figure 4 shows a counter-clockwise phase retardation of the carrier wave in the grids. Figure 5 shows a clockwise phase acceleration of the carrier wave in the grids. From these vector diagrams it is apparent that a retardation of carrier-wave phase increases the wave strength in the grid C and decreases it in the grid B; and

an advance of the carrier phase has the opposite effects. The grid battery 101 may be set to bias the grid potential at the negative bend in the familiar audion characteristic curve, so that the plate currents in the opposed transformer sections B' and C' will vary in correspondence with the wave amplitudes in their respective grids B and C. Thus a carrier phase retardation will magnetize the transformer secondary 647 in one direction, while a carrier phase advance will produce an opposite flux therein, so that the original modulating wave will be reproduced in the coil 647 to actuate the receiver 18 through an amplifier 648. Said original modulating wave has been particularly described as having audible frequency, but it might have ultra-audible or carrier frequency when the main carrier frequency is sufficiently higher.

When a strength-modulated signal is also impressed on the carrier wave, the vectors b—B and c—C will be simultaneously elongated and shortened. When this occurs in Figure 3 it will effect exactly equal strength changes in the resultant grid waves O—B and O—C, and consequently equal changes of counter-inductive plate currents in the coil sections B' and C', so as to have nil effect in the coil 647 and receiver 18. When the same strength modulation occurs in Figures 4 and 5, its effects will be nearly nil and silent because the phase relations in these diagrams are so near to the silent phase relations shown in Figure 3.

When it is desired to receive the strength-modulated signal and silence the phase-modulated signal, then the phase of the constant waves O—b and O—c will be shifted 90 degrees. For instance if these constant waves are retarded 90 degrees, they will still appear at O—b and O—c in Figure 3 after the phase of the modulated waves has advanced 90 degrees from b—B to b—Y and from c—C to c—X. Now obviously, simultaneous strength modulations in the waves b—Y and c—X will produce opposite amplitude variations in the resultant waves O—Y and O—X in the opposite rectifier grids B and C, so as to induce rectified waves in the coil 647 and receiving telephone 18. Obviously also, the phase modulations of the waves b—Y and c—X will produce relatively negligible amplitude variations in the resultant grid waves, so that their noise in the telephone 18 will be inaudible or very low.

The rectifier 646 will operate with only one grid and plate circuit, for instance when the grid C and plate circuit C' are omitted. Then for rectifying the phase-modulated signal, the constant and the modulated grid waves may have a mean phase relation corresponding with the vectors O—b and b—B in Figure 4. Now a phase modulation of the wave b—B will effectually modulate the strength of the resultant wave O—B in the grid B so as to actuate the telephone 18. But strength modulations of the wave b—B will produce only negligible strength modulations of the resultant grid wave O—b, and negligible noises in the telephone 18.

For rectifying a strength-modulated signal with the single grid B and coil B', the phase of the constant grid wave O—b of Figure 4 will be retarded slightly more than 90 degrees, so it will still appear in the position O—b of Figure 3 when the modulated wave has advanced slightly more than 90 degrees from b—B in Figure 4 to b—Y in Figure 3. Now the strength modulations of the wave b—Y will produce effectual

strength modulations in the resultant wave O—Y in the grid B to actuate the receiver 18, while phase modulations of the wave b—Y will produce relatively negligible strength variations in the said resultant grid wave, so that the resulting noise in the said receiver will be negligible.

The rectifier 646 may include carrier-frequency by-pass condensers such as 97. The battery 101 may be set to bias the grids for any kind of rectification, for instance the rectifying effect due to asymmetric amplification when the grid potential is adjusted at either bend in the audion characteristic. Or the familiar grid condenser and grid leak may be employed with the proper bias of grid potential.

GENERAL REMARKS

The strength-modulated signal from the telephone 691 of Figure 1 may be dispensed with, and the apparatus of Figures 1 and 2 may be employed solely for the phase-modulated signal. Certain advantages of the phase modulation may now be set forth.

In the specific apparatus above described the phase modulation or libration can never attain a phase displacement of 180 degrees between its greatest lead and its greatest lag. Therefore it necessarily consists in a phase acceleration which increases the carrier-wave frequency by less than a half cycle during one half cycle of the modulating wave, and a phase recession which decelerates the carrier-wave frequency by less than a half cycle during the ensuing half cycle of the modulating wave. Hence the numeric frequency-variation of the carrier wave is less than the actual frequency of the modulation which produces it, and the required frequency range or width of allocated signaling channel is correspondingly small. Thus the said frequency relation presents an advantage over ordinary strength-modulation which entails side-band frequency variations equal to the modulating frequency, and hence requiring a channel allocation of correspondingly wide range.

For instance, the usual strength-modulation of a 100 kilocycle carrier wave by a modulating wave of 1 kilocycle, entails two modulation waves or side-band waves of 99 and 101 kilocycles. Even if one of these side-bands is suppressed, the other still ranges 1 kilocycle, or 1 per cent., either above or below the basic carrier frequency, so as to require a wave channel at least 1 kilocycle wide, or 1 per cent. of the basic frequency. In comparison therewith, a 100 kilocycle carrier wave from the source 693 of Figure 1 may have its phase alternately accelerated and retarded 36 degrees, or 0.1 cycle, by a modulating wave of 1 kilocycle frequency from the generator 731 or microphone 688. Thus, the carrier wave is accelerated 0.1 cycle during 0.5 cycle of the modulating wave. That is, during the time lapse which would normally entail a carrier wave train of 50 cycles, each of said 50 waves is shortened only enough to cumulatively increase their total number from 50 cycles to 50.1 cycles. This modulation of the wave-length would constitute a frequency modulation entailing a frequency increase of only 0.2 per cent. if the rate of carrier phase acceleration were uniform during said time lapse or half cycle of the modulating wave. But said rate of phase acceleration varies with the rate of change in the instantaneous ordinates of the sinusoidal modulating wave. Therefore, said 0.2 per cent. frequency increase must be multiplied by the ratio (3.1416:2) of maximum sinu-

soidal change to mean sinusoidal change in the modulating wave. This correction results in an actual carrier-frequency increase of about 0.3 per cent. at the instant of zero modulating current when the carrier waves are being most rapidly shortened and accelerated.

The said 0.3 per cent. increase of carrier frequency during one-half cycle of the modulating wave, is followed by a corresponding 0.3 per cent. decrease during the ensuing half cycle of modulating wave, so that the total carrier-frequency modulation, and the required width of wave channel, is the sum of these opposite variations which aggregate only 0.6 per cent. of the basic carrier frequency, as compared with the 1.0 per cent. frequency range entailed in the side-band modulation above set forth. Moreover, the said 1.0 per cent. side-band range is irreducibly inherent in the ratio of modulating and carrier frequencies, whereas the said 0.6 per cent. carrier-frequency range entailed in the wave-length modulation of Figure 1 is proportionate to the maximum allowed phase displacement, which can be reduced at will much below the said 36 degrees assumed for convenient exposition.

Since the foregoing phase modulation and frequency modulation are concurrent aspects of a modulation of the wave-length, they will both be included in the generic term length modulation. In this connection, the wave length means the length of time of a wave cycle, so that the wave length is the mathematic reciprocal of the wave frequency.

The optimum latitude of phase libration or frequency modulation in the practice of the aforescribed modulating method, will depend on various considerations ascertainable by experiment or the application of known principles. Obviously a phase displacement, or frequency change, of 0.1 cycle in unit time, will vary the carrier frequency by a greater percentage when the mean carrier frequency is low, and by a lesser percentage when the mean carrier frequency is high. Therefore the employment of a very high carrier frequency may require a latitude of phase displacement and frequency variation exceeding the distortionless working limits of a modulator such as shown in Figure 1. To meet this requirement the transmitting apparatus of Figures 6, 6A, 7, may be employed.

Figure 6

In Figure 6, the coupling coil 8, modulating inductance 695, and condenser 694, constitute a circuit normally resonant to the carrier wave from the source 693. This resonance is modulated, as before described, by a modulating wave from 688 through the transformer 689. A rheostat 10 may be used to accomplish a fine critical adjustment of the mean magnetizing current from the battery 690.

As before explained the modulating wave in the circuit 143 modulates the phase and frequency of the carrier wave in the primary coupling coil 8, to constitute what may be generically called wave-length modulation. This modulated carrier wave is repeated in the secondary coil 9, and delivered to the input terminals of the apparatus 12. The unmodulated or constant carrier wave is also transmitted directly from the source 693 to the input terminals of the apparatus 11.

The apparatus 12 may be conveniently called a harmonator because its function is to deliver to the transformer 15 a wave which is a harmonic

or frequency multiple of its input wave. It is not illustrated in detail because many means of performing its said function are known to technicians. It may consist in a single audion adapted to deliver the desired harmonic, and an amplifier for boosting the output power of said harmonic. Or the box 12 may contain a cascade of frequency-multiplying audions with a sufficient amplifier for the output wave of each frequency-multiplier. For instance, an initial frequency-doubling audion may deliver its double frequency wave through an amplifier to a second frequency-doubling audion which will deliver the quadrupled frequency through an amplifier to the coupling 15. Or by a more extended cascade, a very high frequency multiple may be derived in said coupling 15. The amplifiers in the box 12 may be saturated or overloaded to deliver an output wave of practically constant amplitude under all conditions, and this wave will have its phase or frequency modulations truly multiplied in exact proportion to the multiplication of its mean frequency.

The apparatus 11 is required to deliver to the coupling 14 an unmodulated carrier wave whose frequency differs from the mean output frequency of the harmonator 12, preferably by an amount equal to the frequency of the source 693. In the simplest embodiment of this relation, the box 11 would merely contain circuit wires connecting the source 693 with the coupling 14, and the harmonator 12 would merely double the frequency supplied to it from the coil 9. But when the harmonator 12 delivers a higher multiple of the modulated frequency, the box 11 may also contain a harmonator to deliver an unmodulated frequency multiple differing from the said modulated multiple by an amount which is the unit frequency of the source 693.

For convenient discussion it may be assumed that the boxes 11 and 12 deliver respectively the 3rd and 4th multiples of the unmodulated and the modulated carrier waves. Such multiple waves are thus induced in the secondaries of the transformers 14 and 15 connected in series across the grids 51, 52 of an audion which may be called a combiner. Through a high resistance 16 these grids are biased at the negative bend in the audion characteristic. The resulting interaction of the two wave frequencies superposed on the grids, produces in each plate 19 and 20, a number of frequency-differentiated superposed waves including:

- (1) The lower input frequency from 14,
- (2) The higher input frequency from 15,
- (3) The difference of said input frequencies,
- (4) The sum of said input frequencies,
- (5) Harmonics of said input frequencies.

Since each input wave has opposite signs in the opposite grids, its consequent waves must have opposite signs in the plates 19 and 20, so that both input waves are neutralized in the joint plate circuit 102 and transformer coil 50. Those remaining waves which are undesired in the circuit 102 can be readily suppressed by proper tuning of the output transformer coils 50, 50A, and the output amplifier 23. In this specific instance, such resonance and filters as may be employed, will be adjusted to pass and amplify only that wave which has the differential frequency.

If it be assumed for convenience that the wave source 693 delivers a unit frequency of 100 kilocycles, then its unmodulated 3rd multiple will be 300 kilocycles in transformer 14, its modulated 4th multiple will have 400 kilocycles mean

frequency in transformer 15, and the mean differential of these multiple frequencies will be 100 kilocycles in the output transformer 50, 50A. Obviously while modulation is not occurring, the said differential output frequency will remain exactly constant at 100 kilocycles. When the 100 kilocycles wave at 9 is accelerated to gain 0.1 cycle in a given time, its 4th multiple in the transformer 15 is accelerated to gain 0.4 cycle in that same time, and the said differential output frequency will be simultaneously accelerated to gain the same 0.4 cycle. Likewise, when the wave at 9 is decelerated, the said output differential wave is decelerated four times as much.

Thus the phase displacement or frequency modulation of the carrier wave supplied to the harmonator 12 is multiplied in the output wave at 50A by an exact factor which is the frequency-multiplying factor of the said harmonator. There are practical limits to the said harmonator factor, but after the frequency modulation of the carrier wave has been thus multiplied it can be amplified, as at 23, and supplied to another harmonator like 12 coacting with another apparatus like 11 to operate another combiner like I, so as to magnify the frequency modulation again. And this procedure may be further repeated ad libitum.

To thus magnify the frequency-modulation of a carrier wave correspondingly magnifies or widens the range or band of frequencies included in its variations, wherefore the apparatus I together with the apparatus 11 and 12 may be designated as a band spreader when employed for this purpose. When the frequency modulation covers a considerable range the various successive tuning or resonance or wave-filtering elements employed in the band spreader may be adjusted for a flat-crest selectivity characteristic having the desired band width, so as to transmit all the modulation frequencies with substantially equal power, in accord with known principles. For instance, the successive tunings at 21 and 103 and throughout the amplifier cascade 23 may be staggered alternately above and below the mean carrier frequency. The amplifier cascade 23 may also be saturated or overloaded to assist in maintaining a constant power output. Band spreaders may be employed at receiving stations in lieu of the sending stations, or at both sending and receiving stations, when a suitable source of unmodulated waves is available to supply the apparatus 11.

When the carrier wave is to be transmitted by radio, the source 693 may supply any desired frequency higher than the 100 kilocycles above assumed for convenience of discussion, and such higher frequency may be transmitted direct from the amplifier 23 to the radiating aerial 3. Or a relatively low frequency may be employed in the modulating process and delivered by the amplifier 23 to an apparatus 13 which will convert it to a higher frequency to be radiated at 3. For this purpose the box 13 may contain harmonators like the apparatus 12, and may also contain one or more combiners like the apparatus I which will combine the output waves of said harmonators to produce any desired frequency. Such an apparatus hereinafter called a harmonator-combiner is more fully exemplified in Figures 12 and 13.

Figure 6A

A modification of the modulator of Figure 6 is shown in Figure 6A. A modulating wave from

the telephone 688 is applied through the transformer 124 to reinforce current from the battery 690 in one pair of magnetizing coils 127, 128, while simultaneously reducing such battery current in the opposed pair 129, 130, and vice versa. Thus the opposite pairs oppositely vary the permeability of their respective cores and the consequent inductance of their associated pairs of coils 131, 132 and 133, 134 in parallel circuits of the wave source 693 and normally in resonance with respective condensers 135, 136. Thus the carrier-wave phase is advanced in the transformer 114 while it is retarded in the transformer 115, and vice versa.

The harmonators 11 and 12 and the band-spreading process correspond to the description of Figure 6, excepting that the ultimate phase libration will be the sum of the opposed phase displacements in the harmonator output circuits 122, 123. Consequently the initial phase libration will be multiplied by a factor which is the sum of the two frequency-multiplying factors of said two harmonators.

The inductance 152 and resistance 153 of the modulating circuit may be adjusted to produce any desired strength-ratio of high and low frequency modulating waves. Such an adjustment may be desirable when the ultimate rectification is the type hereinafter described in Figures 9 and 10.

Figure 7

In Fig. 7 the inductance 695 between the terminals D—E is modulated by a signaling wave from 688, and is included in a resonant circuit with the condenser 28 and feed-back coil 24 of an oscillating audion. Said inductance modulation correspondingly varies the natural oscillation frequency of the audion, and thus produces the required frequency modulation in its output wave in the coupling 25, 26. This frequency-modulated wave is transmitted through the amplifier cascade 27, switches 104, and sending aerial 3. This amplifier cascade may be saturated or overloaded and will deliver the frequency-modulated wave with a constant amplitude.

When it is desirable, the switches 104 may be closed upon the points 105 so as to transmit the frequency-modulated wave through the ordinary strength-modulator 106, amplifier 107, and sending aerial 3A. The voice wave or other modulating wave from 108 will then produce an ordinary strength-modulation in the carrier wave whose frequency has been modulated by a signaling wave from 688. When this is done, the saturated amplifier 27 prevents transmission of strength-modulation effects from the frequency-modulated circuit 25 to the strength-modulated circuit 106, and thus prevents the signal 688 from interfering with the signal 108. The amplifier 27 also prevents any transmission of strength-modulating effects from the modulator 106 to the oscillating plate circuit 25, such as might produce modulation of the oscillator frequency and thus make the signal 108 interfere with the signal 688. Thus the wave radiated at 3A may carry two modulations and two signals.

Figure 8

Figure 8 shows a modified form of variable inductance which may be substituted for the variable inductance 695 in Figs. 1, 6, and 7. In Fig. 8 the core 5 is subjected to the modulated magnetizing force of the coil 695A, and the effective

modulated inductance inheres in the coils F and G whose terminals D—E correspond to the terminals D—E in Figs. 1, 6, and 7. The resistance 10 and inductance 152 may adjust the strength ratio of modulating waves of different frequencies.

GENERAL REMARKS

It will be understood that the broad principle of wave-length modulation (specifically expounded upon Figures 1, 6, 6A, 7 and 8) is not limited to audible frequencies of the modulating wave, but may also be applied with higher modulating frequencies when the carrier frequency is sufficiently high. In the ensuing schematic diagrams, modulating apparatus embodying the general principles of said specific figures will be symbolized in a box such as 174 of Figure 12 and 294 of Figure 15. In these boxes the symbol L indicates that the length of the wave is modulated, as distinguished from the ordinary modulation of its amplitude; and the digits 1, 6, 7 connote respectively Figures 1, 6 and 7 as examples of the modulating method involved.

Figures 9-11

Figure 9 shows another form of receiving apparatus which may be employed in lieu of that shown in Figure 2.

In Figure 9, the frequency-modulated, or phase-modulated, carrier wave is received in the aerial 605 and transmitted through the coupling 606 and initial amplifier 109 to the wires J. When the received wave is both frequency-modulated and strength-modulated, the said coupling and first amplifier are tuned for a flat selectivity characteristic wide enough to receive uniformly all the side bands involved in the strength modulation, as well as the frequency limits of the frequency modulation. To rectify the strength-modulated signal the switches 111—112 will be closed to actuate the apparatus 113 including an ordinary rectifier and audio amplifier operating the receiver 114. The selectivity characteristic of transmission from the aerial through the said rectifier will be so flat that the frequency modulation of the carrier wave will not entail amplitude changes in the rectifier input grids, and hence will not produce audible effects in the receiver 114.

The wires J lead into a cascade of amplifiers 110, 34, 35 comprising staggered tuning circuits or other filtering means providing a flat selectivity characteristic for the wave band including the frequency limits of the wave-length modulation which carries the signal for the receiver 18. As before explained, such a wave band or signaling channel may be much narrower than that required for strength-modulated signals, and the ether may carry many other signals transmitted by wave-length modulation in adjacent narrow channels. The said amplifier cascade may be extended until the desired signal is fully amplified and the said adjacent signals are effectually suppressed, and may then be further extended until the final stages are saturated or overloaded, for instance in the box 35.

The output wave from the amplifier box 35 may be transmitted directly through the box 36 to the input terminals of the two amplifier cascades 37, 38 and 39, 40. Or the box 36 may contain a suitable band spreader (such as constituted in the apparatus 11, 12 and I of Figure 6) if a suitable source of unmodulated waves is provided at 33. The output circuit of such a band spreader will supply the expanded wave band to the said

amplifier cascades. The circuits of the spreader will be tuned to provide a flat or uniform transmission characteristic for all frequencies entailed in the wave-length modulation of the desired signal, so that all such frequencies will be equally impressed on the input grids of the said amplifier cascades. The said cascades respectively excite the rectifier grids c and b through condensers 43, 45 with grid-leaks 44, 46. Said grids respectively control the plate currents flowing counter-inductively through the opposed sections c', b', of the transformer which actuates the receiver 18 through an amplifier 115. Any simultaneous equal increase or decrease of battery current in said coil sections c' and b' will have nil effect in their secondary coil 647.

Figure 10 is a graph showing the effects of waves of different frequencies applied to the rectifier grids b and c of Figures 9 and 11. Successive ordinates such as d, e, f, show wave amplitudes for successive frequencies. The mean carrier frequency taken at e may be assumed as 1000 kilocycles. If no band spreader is employed, the minimum and maximum carrier frequencies due to modulation, and taken at d and f respectively, may be assumed as .05 kilocycle (50 cycles) below and above the said mean frequency. This assumes a signaling channel between d and f which is only 100 cycles wide, or one hundredth of one per cent of the mean frequency.

The curves b and c respectively show the frequency-selectivity of transmission through the amplifiers 39, 40 and 37, 38, to the grids b and c. The peak frequencies of these amplifier cascades are staggered or offset respectively below and above the limits of the signaling modulation. The curves b' and c' show the battery currents in the transformer sections b' and c' controlled by the grids b and c respectively. The curve i shows the difference between the currents b' and c', which is inductively effective on the transformer secondary coil 647. This output characteristic i may be nearly straight within the limits of the modulation band, so that the shifting of the carrier frequency back and forth between the limits d—f, as effected by wave-length modulation, will produce practically distortionless rectified waves in the said coil 647.

It will be observed that upon the foregoing assumptions of frequency range, the curves b and c represent a very acute tuning between the box 36 and the rectifier grids. There seems to be no theoretic limit to such compression of signaling channels employing wave-length modulation, but there is of course a practical limit to the sharpness of tuning which can be maintained with sufficient constancy to function as required. Therefore the graph of Figure 10 must be generically considered as representing any desired mean carrier frequency and any desired frequency range or width of signaling channel between the limits d and f. Obviously this wave band may be expanded either by effecting wider frequency variation in the initial modulator, or by introducing suitable band spreaders at the sending or receiving station or at both stations. It seems probable that the best general practice will be evolved in sending wave bands compressed to the practicable limit to attain the maximum number of signaling channels, and then employing band spreaders at the receiving stations to facilitate the rectifying process represented in Figure 10.

Figure 11 shows a receiving apparatus which does not employ saturated or overloaded amplifiers. It is designed to receive both a frequency-

modulated signal and a strength-modulated signal through a common rectifier. The wave carrying said two modulations is first sent through an amplifier at 109 tuned for a flat selectivity which amplifies all its components equally. It is then transmitted through the amplifiers 116 and 117 tuned in accordance with the curves *b* and *c* of Figure 10, so as to energize the grids *b* and *c* accordingly.

The primary transformer coil *b'* excites the secondary coils *q* and *r*, and the primary coil *c'* excites the secondaries *s* and *t*. The secondaries *q* and *s* connected in series may be considered as a single coil corresponding to the coil 647 of Figure 9, and in like manner responding to frequency modulations to actuate the receiver 18. But the strength modulations in coils *b'* and *c'* are simultaneous and so nearly equal as to be practically neutralized in their counterinductive effects in the coils *q* and *s*, so they do not effectually actuate the said receiver 18.

The secondary coils *r* and *t* are connected in coinductive relation to simultaneous increase or decrease of battery current in the coils *b'* and *c'*, so as to actuate the receiver 114 in response to strength modulations. The audio electro-motive force thus induced in the circuit *r-t* is proportionate to changes in the mean plate current in the coils *b'* and *c'*, and hence will be practically zero when the currents in these coils are varied oppositely and almost equally by the frequency modulation. The curve *h* in Figure 10 indicates the said mean plate current, and shows its practical constancy within the limits of frequency modulation between *d* and *f*.

When the pole changer *n* is operated to reverse the connections of the coils *q* and *s* they will actuate the receiver 18 in response to strength modulations. Likewise the reversal of the pole changer *p* will make the receiver 114 responsive to wave-length modulations. Thus either receiver may receive either signal, and one receiver may be dispensed with when the apparatus is only required to receive one signal at a time, for instance in the reception of a broadcast programme.

GENERAL REMARKS

The apparatus of Figure 9 included between the amplifier input circuit *J* and the amplifier output circuit 154 constitutes amplifying and rectifying means for translating the wave-length modulations of a carrier wave into waves of the modulation frequency, whether that modulation frequency be in the audio range or of higher order such as 50 kilocycles or more. Of course when the rectified output wave has definite frequency characteristics, the output amplifier in the box 115 may be tuned accordingly. In the ensuing schematic diagrams such apparatus will be collectively symbolized in a box like 194 of Figure 13 and designated as a demodulator without specific reference to its amplifying and band-spreading functions. The symbols ASR9 in the said box 194 respectively connote amplifiers, band-spreader, rectifier, and Figure 9 which details their arrangement, but these indications are casual and not binding. For instance, when the *S* is omitted, an engineering study of the case may nevertheless prescribe a band spreader, and vice versa.

Figure 12

Figure 12 shows a station for radiating controlling waves to control waves employed at other stations either for sending or receiving signals.

A wave source 172 is regulated to deliver a master wave of 5 kilocycles to the bus circuit 173. This master wave is converted into progressively doubled frequencies by a cascade of harmonators 164, 165, 166, etc., as far as desired. The resulting wave frequencies are added or subtracted according to convenience, to produce a resultant wave whose frequency may be any desired multiple of the 5 kilocycles master frequency.

For instance, the waves of 40 and 320 kilocycles from the harmonators 166 and 169 are supplied to the input circuits of a combiner 162 such as the apparatus I of Figure 6. In this case the circuits 21, 50 and 103, 50A and the circuits within the amplifier cascade 23, are tuned to pass and amplify that wave whose frequency is the sum of the input frequencies. Thus the combiner 162 delivers 360 kilocycles to a similar combiner 160, which also receives 640 kilocycles from the harmonator 170, and delivers the sum of these frequencies or 1000 kilocycles to a radiating aerial 159. The said 1000-kilocycle wave may also be led into a combiner 157 supplied with another frequency from the harmonator cascade, for instance 10 kilocycles from the harmonator 164, and these frequencies may be added or subtracted in the combiner, for instance to deliver their differential frequency of 990 kilocycles to the radiating aerial 156. Thus the aerials 156 and 159 radiate unmodulated waves of different frequencies in exact multiple synchronism with the master source at 172, and any number of such frequency-differentiated waves may be likewise derived and radiated.

The box 174 symbolizes wave-length modulating apparatus. In this instance the wave to be modulated is 80 kilocycles supplied to the circuit 145 from the harmonator 167, but it might be any other synchronous multiple of the master wave having sufficient frequency to be modulated by the master wave frequency.

The master wave of 5 kilocycles is fed into the modulating circuit 143 so as to impress wave-length modulations on the 80-kilocycle wave delivered by the modulator 174 to the harmonator cascade 175, 176, 177, 178, etc. The progressively doubled frequencies of this cascade all carry the wave-length or frequency modulation of the master wave, which may be conveniently called the standard modulation. These modulated waves may be added or subtracted in any combinations to produce a wave having a frequency which may be any multiple of the cascade input frequency. Any such resultant wave will carry the standard modulation, and its frequency may be further determined in stages of 5 kilocycles by adding or subtracting the master wave frequency or any multiple thereof derived from the cascade 164, 165, etc.

In the illustrated instance, the master wave of 5 kilocycles is added to the standard-modulated wave of 160 kilocycles in the combiner 148, and the resulting standard-modulated wave of 165 kilocycles is added to the standard-modulated wave of 640 kilocycles in the combiner 150, and the resulting standard-modulated wave of 805 kilocycles is radiated from the aerial 179. Obviously waves having any other multiple of the master wave frequency and likewise carrying the standard modulation, may be likewise derived and radiated at the station of Figure 12.

The station of Figure 12 may be regarded as a key station or master station in an extensive synchronized radio broadcasting and communications system such as will now be indicated.

For convenient discrimination the wave frequencies in such a system may be classified in three categories, as follows:

- (1) Even multiples of the 5 kilocycle master frequency, employed as unmodulated controlling waves to regulate transmitting and receiving operations;
- (2) Odd multiples of the 5 kilocycle master frequency, employed as controlling waves to carry the standard modulation, and also employed as carrier waves for voice signals which are to be received at a relay station and re-radiated;
- (3) Frequencies spaced at 100 cycles throughout the 5 kilocycle bands between said even and odd multiples of the master frequency, employed as carrier waves for voice signals to be directly transmitted without relaying.

Figure 13

Figure 13 shows a relay station which receives the standard-modulated wave from the aerial 179 of Figure 12, and employs it to control the radiation of another standard-modulated wave of odd-multiple frequency, and also to control the radiations of unmodulated controlling waves of even-multiple frequency.

The standard-modulated wave of 805 kilocycles from the station of Figure 12 is received in the aerial 605 of Figure 13, and transmitted through a suitably tuned coupling 606 and amplifier 109 to the demodulator 194 which delivers the standard master wave of 5 kilocycles to the harmonator cascade 184, 185, etc., to 191. Frequency multiples thus provided are added by the combiners 195, 196, 197 to produce the unmodulated controlling wave of 1010 kilocycles radiated at 198. Also the frequency multiple 80 kilocycles is subtracted from the frequency multiple 1280 kilocycles in the combiner 203 to produce the unmodulated controlling wave of 1200 kilocycles radiated at 204.

The standard-modulated wave of 805 kilocycles is delivered by the circuit J to a combiner 206 which receives also an unmodulated wave of the master frequency or any multiple thereof derived from the box 194 and the harmonator cascade 184, 185, etc. This combiner 206 may deliver either the sum or the difference of its said input frequencies, which resultant in either case will differ from the frequency received at 605 by an amount which is the frequency of the said unmodulated wave supplied to the combiner. The said resultant output wave from the combiner 206 is radiated at 205, and will be made to differ from the frequency received at 605 sufficiently to avoid interference therewith. In the illustrated instance, the combiner 206 adds 10 kilocycles to the said received frequency so as to radiate 815 kilocycles from the aerial 205. Obviously the resultant wave radiated from 205 will carry the standard wave-length modulation of 5 kilocycles.

Obviously any further number of unmodulated controlling waves, and standard-modulated controlling waves, may be derived and radiated at the station of Figure 13, in accord with the foregoing principles.

GENERAL REMARKS

In the ensuing schematic diagrams, any combination of harmonators and combiners such as shown in Figures 12 and 13 will be collectively symbolized in a box like 207 of Figure 15, and designated as a harmonator-combiner. In Figure 15 the harmonator-combiner 207 translates

a 5 kilocycle wave from the circuit 154 into 960 kilocycles in the circuit 292.

Figure 14

Obviously the standard-modulated wave of 815 kilocycles radiated from 205 in Figure 13, may be received by a second relay station constructed upon the principles of Figure 13 but having its receiving aerial 605 and associated apparatus properly tuned for the said 815 kilocycles. Said second relay station may again add 10 kilocycles to the standard-modulated wave so as to radiate a standard-modulated wave of 825 kilocycles from its aerial corresponding to 205 of Figure 13. Said 825 kilocycles may likewise control a third relay station to radiate a standard-modulated wave again increased 10 kilocycles to 835 kilocycles. A fourth station in the relay chain will accordingly receive the 835 kilocycles and radiate 845 kilocycles. A fifth station indicated in Figure 14 receives the 845 kilocycles and subtracts 40 kilocycles therefrom in its combiner 206 so as to radiate from its aerial 205 the frequency of 805 kilocycles originally radiated from 179 in Figure 12 and received at 605 in Figure 13.

The stations of Figures 13 and 14 will be so distantly separated that the 805 kilocycles radiated from Figure 14 will not interfere with the same wave received by Figure 13 from Figure 12. From the station of Figure 14, a second chain of relay stations may be extended to a remote station which will radiate 845 kilocycles, too far away to affect the station of Figure 14, but effective to control another station like Figure 14. Thus relay chains may be extended horizontal in all directions from a master station such as Figure 12. Any station in any chain may be used as a center from which lateral relay chains may extend, and every station may radiate as many unmodulated controlling waves as may be desired. Thus any desired area or the entire globe may be supplied with the standard-modulated waves and unmodulated controlling waves in multifrequency synchronism with a single master wave.

Figure 15

Figure 15 shows a station for radiating a signal-modulated wave under control of a controlling wave which may be derived from the synchronized system above described.

The aerial 605 receives a standard-modulated controlling wave, for instance 815 kilocycles from the station of Figure 13. This controlling wave is translated by the demodulator 194 to render the master wave frequency of 5 kilocycles in the circuit 154 which controls the harmonator-combiner 207 to deliver any desired unmodulated frequency multiple such as 960 kilocycles through the switch 292 and circuit 291 to the combiner 208. Or the same unmodulated controlling wave of 960 kilocycles may be directly transmitted from one of the controlling stations (such as Figures 12, 13, 14) and conveyed through a suitably tuned aerial and amplifiers 288, 289, 290 and the switch 293 to the circuit 291.

The box 294 contains a wave source and wave-length modulator controlled by a modulating wave from the telephone 688. Said wave source is adjusted or tuned to deliver to the combiner 208 a signal-modulated wave having a mean frequency of 50.1 kilocycles which is added to the unmodulated wave of 960 kilocycles to produce a signal-modulated wave of 1010.1 kilocycles which is radiated from the aerial 209.

A number of other transmitting stations like

Figure 15 may likewise be controlled by the same even multiple of the master wave, to wit, 960 kilocycles, in their circuits 291. Such stations may be collectively designated as the 960 kilocycle group, and other even multiples of the master wave may likewise control respective groups of transmitting stations. The several transmitting stations of any one group will deliver signal-modulated waves of different mean frequencies to the input circuits 144 of their respective combiners 208. Consequently their signal-modulated waves radiated at 209 will likewise differ.

The lowest frequency among the modulator output circuits 144 should be the minimum which will serve as a good carrier for the modulating wave from 688. From that minimum the said modulated frequencies will range upward throughout a band nearly equal to the separation or difference between the even multiples of the master wave. In the illustrated instance said band is 10 kilocycles wide, and it is assumed that the said modulated frequencies are separated by 100 cycles or 0.1 kilocycle. The lowest of them may be assumed at 45.1 kilocycles, and the highest at 54.9 kilocycles. Thus are omitted the waves of 45 and 50 kilocycles which would occur in serial order at the extremes of the 10 kilocycle band. The 50 kilocycle wave which would occur in the middle of this series is also omitted. This arrangement provides 98 of such frequencies, which is to say that each even-multiple of the master wave will allow the operation of 98 transmitting stations. The said 45 and 50 and 55 kilocycle waves are omitted because they would combine with the controlling wave from the circuit 291 to radiate from 209 three signal-modulated waves whose frequencies would constitute exact multiples of the master wave which are preferably reserved as channels for controlling and relaying as before mentioned. But any of said channels not thus employed may be included in the series of signaling waves radiated from the aeriels 209.

Now collectively regarding a group of transmitting stations like Figure 15 under one controlling frequency in their circuits 291, it is obvious that their combined radiations compose a wave band 9.8 kilocycles wide and averaging 50 kilocycles higher than said controlling frequency, e. g., averaging 1010 kilocycles when said controlling frequency is 960 kilocycles. And it is clear that this wave band is established upon the frequency level of the 960 kilocycles derived from the master wave, so that the frequencies of all signal-modulated carrier waves in said band must vary equally in response to accidental variations in said master frequency. Thus the chance of interference from overlapping of said carrier frequencies is reduced to the relatively small percentage of error entailed in the local tuning or regulating of the lower carrier frequencies averaging 50 kilocycles in the modulator output circuits 144. That is to say: while it might be impracticable to tune or otherwise regulate a wave of 1010 kilocycles for a differentiation of 0.1 kilocycle or about one hundredth of one percent; it may yet be practicable to regulate a 50 kilocycle wave for 0.1 kilocycle differentiation which is one-fifth of one percent. Figure 15 assumes that the wave source in the box 294 is thus locally regulated to deliver a mean frequency of 50.1 kilocycles, and the modulator in said box is constructed and regulated to modulate said mean frequency within its allocated band width of 0.1 kilocycle without approaching the actual limits

thereof so closely as to entail interference with signals in the adjacent bands.

The chance of accidental overlapping of adjacent signaling channels can be still further reduced by making their 0.1 kilocycle differentiation constitute a still greater percentage of those local frequencies whose local regulation maintains said differentiation. This can be done by reducing the said locally regulated frequencies. The frequencies modulated in the several boxes 294 cannot be reduced much below the 45 kilocycles minimum before mentioned, without impairing their carrier function. But said carrier waves can be maintained at their respective frequencies already prescribed and each of them can be derived partly from the master wave and partly from a locally regulated wave instead of being derived wholly from a local source in the box 294 as before explained. For instance, assume that said local source is disconnected in the modulator box 294 of Figure 15, and this modulator now derives its input carrier wave of 50.1 kilocycles through the switch 302 from the combiner 299. The modulator 294 still operates in accordance with the explanation of Figures 1, 6, 6A, 8, but its said input carrier frequency is the sum of the frequencies supplied to the combiner 299.

The combiner 299 receives a multiple of the master-wave frequency developed in the harmonator-combiner 207, to wit 45 kilocycles through the switch 45 K. The combiner also receives a wave of 5.1 kilocycles from the locally tuned source 301. These waves are added in the combiner to render the required carrier frequency of 50.1 kilocycles, but the tuned differentiation of 0.1 kilocycle which separates adjacent signaling channels is now about two percent of the frequency of the locally regulated wave, instead of only one-fifth percent as obtained when the locally regulated frequency was 50 kilocycles. The wave sources 301 of the different transmitting stations may be tuned for local frequencies ranging in steps of 0.1 kilocycle from 5.1 to 9.9 kilocycles. Half the stations of one group will add their said local frequencies to 40 kilocycles derived through their switches 40 K and the harmonator-combiner 207, and will thus produce in their circuits 302 a series of carrier frequencies ranging in steps of 0.1 kilocycle from 45.1 to 49.9 kilocycles. The remaining stations of said group will likewise add their said local frequencies to 45 kilocycles from their switches 45 K, to produce carrier waves ranging from 50.1 to 54.9 kilocycles in their circuits 302.

The box 299 of Figure 15 may contain a differential combiner in lieu of a summation combiner, if the switches 40 K, 45 K supply it with 55 and 60 kilocycles. Local waves from the source 301 ranging between 10 and 5 kilocycles, when subtracted from 55 kilocycles, will produce combiner output frequencies ranging from 45 to 50 kilocycles. The combiner will likewise deliver from 50 to 55 kilocycles when said local waves are subtracted from 60 kilocycles. Or the combiner 299 may be used alternatively to add or subtract its input frequencies according to the procedure which will employ the lower frequency from the local source 301. For instance, the combiner will produce summation output frequencies ranging from 45.1 to 47.5 kilocycles by adding 45 standard kilocycles and locally regulated waves ranging from 0.1 to 2.5 kilocycles. Instead of adding locally regulated frequencies above 2.5 kilocycles, the combiner will produce differential output frequencies ranging from 47.5

to 49.9 kilocycles by subtracting from a standard 50 kilocycle wave the locally regulated waves ranging from 2.5 to 0.1 kilocycles. When the locally regulated wave is only 0.1 kilocycle, the frequency differentiation between adjacent signaling channels is 100 percent of the locally regulated frequency. When employing 2.5 kilocycles as the highest locally regulated frequency in the above scheme, the 0.1 kilocycle channel separation is 4 percent of said locally regulated frequency.

Now collectively considering all groups of transmitting stations like Figure 15, it is clear that when the multiples of the master frequency are all reserved for controlling and relaying channels, each group will radiate a band of carrier waves 9.8 kilocycles wide including 98 frequencies spaced 0.1 kilocycle with an extra space of 0.2 kilocycle in the middle or mean frequency position. The mean frequency of each signaling band is 50 kilocycles above the frequency level of the even-multiple controlling wave on which it is established, so that said bands are ranged at intervals of 10 kilocycles corresponding to the intervals in such controlling waves. The extreme frequencies in adjacent signaling bands are separated by 0.2 kilocycle to provide intervening channels for the odd-multiple controlling waves, and the middle spaces of 0.2 kilocycle in all the signaling bands leave channels for all the even-multiple controlling waves.

Thus a system whose controlling waves cover a range of 1000 kilocycles will provide 9800 signaling channels.

Figure 16

Figure 16 shows a receiving station whose aerial 87 receives a signal-modulated wave, for instance the wave of 1010.1 kilocycles from the station of Figure 15. This wave is amplified at 95 and fed to the combiner 96.

A standard-modulated wave, for instance 805 kilocycles from Figure 12 or 14, may be received on a separate aerial 605 and translated by the demodulator 194 to supply the master frequency of 5 kilocycles to the harmonator-combiner 295 which delivers 1010 kilocycles to the combiner 93. This is exactly 50 kilocycles higher than the unmodulated wave of 960 kilocycles supplied to the combiner 208 of Figure 15.

A frequency-variable wave-source 94 is tuned or otherwise regulated to supply to the combiner 93, the same frequency adopted for the modulated wave supplied to said combiner 208 in Figure 15, to wit, 50.1 kilocycles. Thus the sum of the frequencies supplied to the combiner 93 is exactly 50 kilocycles higher than the sum of the frequencies supplied to the combiner 208 of Figure 15, which latter summation frequency of 1010.1 kilocycles is transmitted to the aerial 87 of Figure 16. Hence the summation output frequency of the combiner 93 supplied to the combiner 96, is exactly 50 kilocycles higher than the signal-modulated frequency which this combiner receives from the aerial 87. Therefore the differential frequency delivered by the combiner 96 to the demodulator 297 is a signal-modulated wave whose mean frequency is exactly 50 kilocycles.

Such reduction of the mean carrier frequency to 50 kilocycles gives it 0.2 percent frequency differentiation from the adjacent signaling channels spaced at 0.1 kilocycle, whereby said adjacent channels can be suppressed by the filtering or tuning function in the apparatus 297 which

selectively amplifies and rectifies the required signal for the telephone 18. When only voice signals are to be transmitted without high musical notes, a still lower frequency may be adopted for this ultimate carrier wave with the advantage of a reciprocal increase in the percentage of its frequency differentiation.

When Figure 16 is a broadcast receiving station its local wave source 94 will be variable to produce frequencies ranging between 45 and 55 kilocycles in steps corresponding with the carrier frequencies in the circuits 144 of the transmitting stations like Figure 15. When the harmonator-combiner 295 of Figure 16 delivers a given master-frequency multiple to the combiner 93, the telephone 18 will derive the signal of that transmitting station whose controlling frequency level in circuit 291 is 50 kilocycles lower than said given multiple, and whose modulator output frequency in circuit 144 corresponds with the said local wave source 94 of the receiving station.

Obviously the same correspondence of transmitting and receiving stations will obtain if all the transmitting and receiving combiners (208 and 93 in Figs. 15 and 16) are made differential instead of summation combiners.

The liability of error in regulating the frequency in the circuit 1060.1 K of Figure 16 is based upon the percentage of error in tuning the relatively low frequency source 94. This percentage may be still further reduced by opening the switch 307, and supplying the required adjustable frequency to the combiner 93 through the switch 306 from the combiner 308. The combiner 308 receives 40 or 45 kilocycles through switches 40K or 45K from the harmonator-combiner 295. The combiner 308 also receives from the variable source 309 a wave of any desired frequency between 5 and 10 kilocycles, which is added to the said 40 or 45 kilocycles to produce in the circuit 306, 304, a summation wave of any desired frequency between 45 and 55 kilocycles. Thus the percentage of tuning error is based upon the still lower relative frequency of the source 309. The liability of tuning error can be still further reduced by limiting the locally regulated frequency range of the source 309 between 5.1 and 7.5 kilocycles, and employing the combiner 308 to add or subtract said frequencies to or from standard frequencies of 40 or 45 or 55 or 60 kilocycles derived from the harmonator-combiner 295.

Figure 17

Figure 17 shows a transmitting station for radiating a signal on one of the carrier frequencies reserved for relaying channels, i. e., one of the odd multiples of the master frequency.

The aerial 605 receives a standard modulated wave from a controlling station like Figures 12, 13, 14, for instance the wave of 815 kilocycles from the aerial 205 of Figure 13. This wave is translated by the demodulator 194 to supply the 5 kilocycles master frequency to the harmonator-combiner 210, which in turn supplies 50 and 1005 kilocycles respectively to the wave-length modulator 217 and combiner 220. Said 50 kilocycle wave is modulated by a signal in the circuit 143, and the resulting carrier wave is fed to the combiner 220 which adds it to the said 1005 kilocycles to produce a signal-modulated wave of 1055 kilocycles which is radiated from 221.

Figures 18-19

Figures 18 and 19 show stations for relaying

Figures 20-21

signal-modulated carrier waves. Their aerials 605 receive standard-modulated waves (from stations like Figures 12, 13, 14) which the demodulators 194 translate into the 5 kilocycles master wave supplied to the harmonator-combiners 207.

The aerial 315 of Figure 18 receives a signal-modulated wave, for instance 1055 kilocycles from the aerial 221 of Figure 17. This is amplified at 311 and fed to the combiner 312 which subtracts from said 1055 kilocycles a master-frequency multiple of 1005 kilocycles derived from 207. The resulting wave in the circuit J has the differential mean frequency of 50 kilocycles and carries the same wave-length modulation carried by the combiner input wave of 1055 kilocycles. The object of thus reducing the mean frequency of the carrier wave is to increase the ratio or percentage of its 0.1 kilocycle frequency-differentiation from adjacent signaling waves derived from the ether. Thus the desired signaling wave can be more selectively amplified in the box 313 containing filtering and saturated amplifying means, for instance like the apparatus between the circuits J and N of Figure 9.

The amplified 50 kilocycles signal-modulated wave from the box 313 is fed to the combiner 226 wherein it is subtracted from 1135 kilocycles supplied by the combiner-harmonator 207. The resulting wave having the differential frequency of 1085 kilocycles carries the signal modulation and is amplified by the amplifier contained in the box 226. This amplifier is shown at 23 in the corresponding box I of Figure 6. As before mentioned, this amplifier may be power-saturated. Its output wave is radiated from the aerial 227. The combiner 226 could also add its said input waves and deliver to the radiating aerial a signal-modulated wave of 1185 kilocycles. The chief requirement is to differentiate the radiated frequency from the frequencies received at 315 and 605, sufficiently to avoid interference.

In Figure 19 the aerial 233 receives a signal-modulated wave, for instance the 1085 kilocycles radiated from 227 in Figure 18. It is assumed that all other waves impressed on 233 are frequency-differentiated by sufficient percentages to permit selective amplification of said 1085 kilocycles in the amplifier cascade 224, 225, whose output stages will be saturated to insure practically constant strength of their output wave carrying the wave-length modulations. Said amplified signal-modulated wave, and an unmodulated wave of 30 kilocycles from the harmonator-combiner 207, are added and amplified in the combiner 226 as in Figure 18. Their summation wave is then radiated from 227 as a signal-modulated wave of 1115 kilocycles.

The sequence of relay stations like Figures 18 and 19 may be extended to any desired extent, and the last in the chain may radiate the signal on any desired frequency, which of course can be established in the final combiner 226 by supplying thereto any necessary frequency through the circuit 314. Said circuit 314 as shown would only render integral multiples of the master frequency fed to the harmonator-combiner 207, but obviously the intermediate frequency steps of 0.1 kilocycle can be introduced by a local tuned generator, in the manner of employing the generators 301 and 309 in Figures 15 and 16 respectively.

Where a communications enterprise has procured the use of a limited signaling channel, for instance the usual 10 kilocycles wide, the same may be employed for many frequency-differentiated signaling waves without dependence upon a general synchronizing system such as embodied in Figures 12-19. Figures 20 and 21 respectively show sending and receiving stations for utilizing such a channel allocation for the transmission of 98 signals.

In Figure 20 a wave source 228 supplies a master wave of 100 cycles or 0.1 kilocycle to the harmonator-combiner 229, and also to the wave-length modulator 235 wherein said master wave modulates a 50 kilocycle wave from said harmonator-combiner. The 50 kilocycle wave thus modulated is translated by the harmonator-combiner 237 into a wave of 1000 kilocycles carrying the same master-wave modulation in the circuit 1000 K. If the harmonator-combiner 237 receives only the said 50 kilocycle wave it can deliver only integral multiples thereof. When any intermediate frequency is desired it can be created by adding or subtracting the required number of cycles derived through a circuit 238 from the harmonator-combiner 229 which can supply any multiple of its input wave of 100 cycles. In this instance the 1000 kilocycles is taken as the middle of the allocated signaling band. It will serve as the controlling wave at the receiving station.

A 50 kilocycle wave from the harmonator-combiner 229 receives a wave-length modulation from the telephone 231 and is supplied to the harmonator-combiner 233 which produces the 19th multiple thereof (950 kilocycles) and adds to said multiple 45.1 kilocycles derived through the circuit 45.1 K. The resulting signal-modulated 995.1 kilocycle wave is fed to the primary transformer coil 995.1 K. Forty-nine of these coils symbolized at 995.1 K, 998.8 K, 999.9 K, likewise derive signal-modulated waves from the harmonator-combiner 229 and separate telephones like 231. Their 49 secondary coils such as 339, 240, 241 are connected in the input circuit of an amplifier 242, which delivers their amplified composite to the transformer 243, 244. The frequencies in this group range by steps of 0.1 kilocycle from 995.1 to 999.9 kilocycles inclusive.

The next wave in the same spacing order is the controlling wave delivered to the transformer 1000 K, 247.

Next in the same order are 49 signal-modulated waves ranging from 1000.1 to 1004.9 kilocycles derived through the transformer 245, 246 from the amplifier 251 and 49 coils such as 1000.1 K, 1000.2 K, 1004.9 K, all in the manner of deriving the group of 49 waves below the middle controlling frequency.

The controlling wave and the 98 signaling waves are superposed in the circuit 247, amplified at 252, radiated from 253, received at 254 in Figure 21, amplified at 255, and delivered to the circuit 256.

The amplifier 259 of Figure 21 is tuned for the 1000 kilocycle controlling wave carrying the master-wave modulation. Its output waves are supplied to the combiner 260 which receives 1050 kilocycles from a local wave source 261, and delivers the differential frequency of 50 kilocycles carrying the master-wave modulation. This low-frequency controlling wave is selectively amplified

and rectified in the demodulating box 262, which feeds the master wave of 100 cycles to the harmonator-combiner 263.

The amplifier 257 amplifies the entire wave band received from the transmitting station, and delivers it to the bus circuit 258.

The amplifier 272 is tuned for the particular signaling wave of 995.1 kilocycles. It delivers this wave and other unsuppressed waves to the combiner 268 which also receives from 263 a constant wave 50 kilocycles different from said particular signaling wave. The combiner delivers a wave having the differential frequency of 50 kilocycles which carries the signaling modulation and is selectively amplified and rectified in the apparatus 269 to render the audio signal at 270.

The apparatus 269 may include amplifying and band-spreading and rectifying means according with the principles of Figure 9. It may derive 50 kilocycles from the harmonator-combiner 263 through a circuit 264 to supply the non-modulated wave 33 of Figure 9 required by the band spreader 36 of that figure. Also, the rectifying means between the circuits 317 and 151 of Figure 9 may be replaced by the rectifying means between the circuits 316 and 318 of Figure 2, in which case the local wave required in circuit 319 of Figure 2 will be supplied by the said circuit 264 of Figure 21 with suitable phase adjustments.

All the signaling waves in the bus circuit 258 will be translated in the same manner as the signal rendered in the telephone 270. Each signal will employ apparatus such as 268 and 269, supplied with waves of proper frequency from the harmonator-combiner 263.

Figure 22

Figure 22 shows a station for relaying all the signals superposed in a 10 kilocycle wave channel in the manner of Figures 20 and 21.

The entire wave band radiated at 253 in Figure 20 is received at 278 in Figure 22 and amplified at 279.

The controlling wave is further amplified at 280 and translated by the differential combiner 281 to produce 50 kilocycles which is demodulated at 282 to reproduce the 100 cycle master wave which is then supplied to the harmonator-combiner 283.

The superposed controlling wave and 98 signaling waves are amplified at 284 and supplied to the combiner 286 which raises or lowers the frequency level of the entire band by the numeric frequency which said combiner receives from the harmonator-combiner 283, or from any sufficiently constant source. The diagram indicates a frequency addition of 30 kilocycles to the entire band which is radiated from 287. This frequency differentiation of the radiated wave band prevents its interference with the wave band received at 278. Of course any ensuing relay station or receiving station will provide frequencies of local tuning and local wave sources suitable for handling the translated frequency thus transmitted from Figure 22.

GENERAL REMARKS

Wherever two input waves are combined to produce an output wave whose frequency must vary with the frequency of one or both input waves, this purpose can be accomplished by either a summation or differential combiner, providing all coacting combiners in the system are accordingly conditioned. When a combiner subtracts the frequency b of one wave from the fre-

quency c of another wave, the resulting frequency may be expressed as the algebraic sum of a plus c frequency and a minus b frequency. Hence, where the claims designate the algebraic summation of frequencies or waves, they are intended to include generically the algebraic summation of two positive component frequencies to produce a resultant frequency greater than either component frequency, and also to include the algebraic summation of positive and negative component frequencies to produce a resultant frequency less than the greater component frequency.

Various advantages inhere in the general scheme of modulating the wave-length of a carrier wave of relatively low frequency on the order of fifty kilocycles, and then translating that modulated carrier into a correspondingly modulated carrier of higher frequency suitable for radiation. For instance, that procedure can employ certain desirable types of modulators not so well adapted for modulating the higher frequencies. Also, the percentage or range of a phase modulation can be more accurately controlled when the lower frequencies are being modulated.

Broadly considered, the signal from any species of wave-length modulator according with the principles of Figures 1, 6, 6A, 7, 8, can be translated by a demodulator of either species exemplified in Figures 2, 3, 4, 5, 9, 10. For instance, wave-length modulation according to Figures 1, 6, 6A, 8, produces maximum frequency of the carrier wave at the instant of maximum phase acceleration, and vice versa; and these frequency variations are effective in a demodulator according to Figures 9 and 10. Also, wave-length modulation according to Figures 7, 8, produces maximum phase advance of the carrier wave at the instant of normal frequency following a frequency increase, and vice versa; and these phase librations are effective in a demodulator according to Figures 2, 3, 4, 5, providing they are held within proper limits by duly limiting said frequency variation in the modulator.

The wave-length modulation of a carrier wave can be effectually transmitted through an indefinitely extended amplifier cascade without obliteration by any degree of overloading or power saturation which the said carrier wave may develop in any number of amplifier stages. Apparently there would be no limit to the weakness or evanescence of signals thus receivable if the amplifiers could be absolutely isolated from foreign waves of external and inherent origin. Such foreign waves will mask or suppress the desired signaling wave when they saturate the amplifier cascade at one of its stages anterior to the stage where power saturation would be produced by the signaling wave alone. And the signaling wave will effectually preponderate when it produces saturation at an amplifier stage anterior to the stage where saturation would be developed by the foreign waves acting alone.

Despite its foregoing limitations, the amplifier cascade with saturated output stages is useful to maintain uniform output power of a signaling wave whose input power is widely fluctuating. It is also useful to accomplish transmission through any number of relaying stations when it is insured that each station shall always receive a wave strong enough to dominate the foreign waves in its input amplifier stages. This requirement can be satisfied by placing the relay stations close enough together, and when this is

done the signal may be radiated from each station with relatively small power. Such a chain of stations encircling the globe will be practicable and relatively inexpensive.

5 In general, amplifier cascades may be power-saturated to maintain constant output power when only required to transmit the wave-length modulations of a single carrier frequency. This procedure will have many incidental uses, such as suppressing objectionable strength modulations, for instance when it is found that the output wave of a harmonator or combiner carries strength modulations derived from one of the lower frequencies employed in generating it.

10 The broad principles above explained are not only applicable to telephone and telegraph signaling, but also to signaling in its broader sense including television and the control of radio beacons and direction finders and position finders, and the remote control of all manner of apparatus including air craft and other dirigible devices. Therefore this broad interpretation should be applied to those claims which are not otherwise limited.

25 I claim:

1. The method of employing a length-modulated carrier wave which consists in deriving therefrom a second carrier wave of lower mean frequency with corresponding length modulations covering a greater frequency range, deriving from the second carrier wave a third carrier wave having corresponding length modulations covering a greater frequency range, and deriving a signal from the length modulations of the third carrier wave.

2. The method of translating a length-modulated carrier wave which consists in deriving a second carrier wave therefrom as a frequency multiple with corresponding length modulations, deriving from the second carrier wave a third carrier wave having a lower mean frequency and corresponding length modulations, and deriving a fourth carrier wave as a frequency multiple of the third carrier wave.

3. The method of translating a length-modulated carrier wave which consists in deriving a second carrier wave therefrom as a frequency multiple with corresponding length modulations, deriving from the second carrier wave a third carrier wave having a lower mean frequency and corresponding length modulations, deriving a fourth carrier wave as a frequency multiple of the third carrier wave, and amplifying the wave energy to approximate power saturation at successive stages in the foregoing procedure.

4. Apparatus for receiving a carrier wave whose frequency and strength are modulated by different signals, comprising: a circuit whose impedance to the carrier wave increases as the carrier frequency increases, and vice versa; a circuit whose impedance to the carrier wave decreases as the carrier frequency increases, and vice versa; translating means responsive to simultaneous opposite strength modulations in said frequency-variable impedance circuits to render the frequency-modulated signal; and means for reversing the energy relation between said translating means and one of the frequency-variable impedance circuits to make said translating means responsive to simultaneous like strength modulations in said circuits to render the strength-modulated signal.

5. The method of producing a length-modulated carrier wave which consists in: providing two companion carrier waves; oppositely modulating their wave lengths so that one derives an increase of wave length while its companion derives a decrease of wave length, and vice versa; multiplying the frequency of one modulated wave to produce a mean frequency different from the unmultiplied mean frequency of its companion modulated wave; and beating said multiplied and unmultiplied carriers together to produce a resultant length-modulated carrier wave having their differential frequency.

6. The method of producing a length-modulated carrier wave which consists in: providing two companion carrier waves; oppositely modulating their wave lengths so that one derives an increase of wave length while its companion derives a decrease of wave length, and vice versa; multiplying the frequencies of both modulated companion waves to produce secondary modulated waves having different mean frequencies; and beating the secondary modulated waves together to produce a resultant length-modulated carrier wave having their differential frequency.

7. The method of signaling, which includes, producing carrier energy, shifting the phase of the carrier energy in accordance with intelligence to be transmitted, frequency multiplying the phase shifted carrier energy to increase the phase shift and transmitting the frequency multiplied phase shifted carrier energy.

8. The method of signaling by phase modulation, which includes producing carrier energy of substantially constant frequency, phase shifting the carrier energy in accordance with intelligence to be transmitted, eliminating amplitude variations in the phase shifted carrier energy, frequency multiplying the limited energy, and transmitting the frequency multiplied energy.

9. The combination of a source of oscillations, of means for impressing phase modulations thereon at signal frequency, and means for increasing the absolute shift in phase of said oscillations comprising a frequency multiplier connected with said source of oscillations.

10. The method of signaling by means of carrier wave energy and signal wave energy which comprises the steps of superimposing said signal wave energy on said carrier wave energy to vary the phase of the latter by the former, and multiply the frequency of the resultant energy of varying phase to increase the phase variation.

11. A signaling device comprising in combination a phase modulator in which a carrier wave has its phase varied at signal frequency, a utilization circuit, and a frequency increasing device connected on the one hand with said phase modulator and on the other hand with said utilization circuit, said frequency increasing device serving also to increase the phase variation in said wave.

12. The method of signaling by phase modulation which includes generating super-audible oscillations, phase modulating the super-audible oscillations in accordance with a signal, frequency multiplying the phase modulated oscillations, producing constant high frequency oscillations, heterodyning the phase modulated oscillations with the constant high frequency oscillations, and transmitting energy resulting from the heterodyning process.

13. Apparatus for transmitting phase modulated waves comprising a source of super-audible oscillations, means for phase modulating the super-audible oscillations in accordance with a signal, means for frequency multiplying the phase modulated oscillations, a source of high frequency oscillations of substantially constant frequency

quency, means for heterodyning the high frequency oscillations with the frequency multiplied phase modulated oscillations, and means for transmitting out-put energy derived from said heterodyning means.

14. Apparatus as claimed in the preceding claim characterized by the fact that means are provided for frequency multiplying the output of said heterodyning means and being characterized by the fact that means are provided for transmitting the output of said last mentioned frequency multiplying means.

15. In a signaling system, a source of super-audible oscillations, a source of signals, a phase modulator connected to both of said sources, a frequency multiplier connected to said phase modulator, a source of high frequency oscillations of constant frequency, a heterodyning modulator connected to said source of high frequency oscillations and to said frequency multiplier, a frequency multiplier connected to said heterodyning modulator, and a load circuit connected to said last named frequency multiplier.

16. The signaling method which consists in providing a master wave source (a), deriving therefrom a wave (b), providing a frequency-adjustable oscillating wave (c), combining said waves (b) and (c) to produce a wave (d) whose frequency is an algebraic summation of their respective frequencies while impressing a signaling modulation on said wave (d), transmitting that wave (d) to a receiving point, deriving another wave (e) from the master source (a), providing another frequency-adjustable oscillating wave (f), producing at said receiving point a wave (g) derived from the waves (d, e, f) and thus carry-

ing the signaling modulation of the wave (d), determining the frequency of said wave (g) by adjusting the oscillating frequencies of the waves (c) and (f), and deriving a signal from said modulation of the wave (g).

17. The signaling method which consists in producing a master wave, deriving therefrom a carrier wave, impressing a modulation on that carrier wave, transmitting that carrier wave to a receiving point, producing at that receiving point a supplemental wave whose frequency differs from the received carrier frequency by a fixed ratio maintained by continuously deriving each individual cycle of that supplemental wave from a definite one or more cycles of the master wave in a continuous definite relative count of the master wave cycles and supplemental wave cycles, heterodyning the received carrier wave and supplemental wave to produce a beat wave carrying the aforesaid modulation, and deriving a signal from that beat wave modulation.

18. The signaling method which consists in producing a master wave, deriving therefrom a carrier wave, impressing a modulation on that carrier wave, transmitting that carrier wave to a receiving point, producing a beat wave at that receiving point by heterodyning the received carrier wave with a supplemental wave whose frequency differs from the received carrier frequency by a fixed ratio maintained by continuously deriving the supplemental wave frequency from the master wave frequency independently of the beat wave frequency, and deriving a signal from the beat wave modulation ensuing from the said heterodyne coaction.

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