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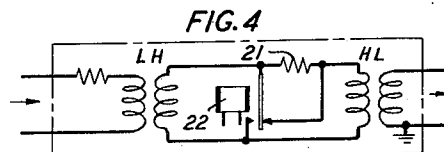
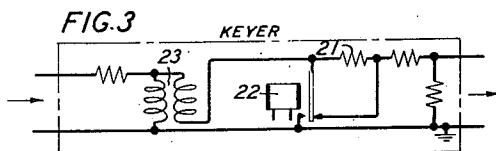
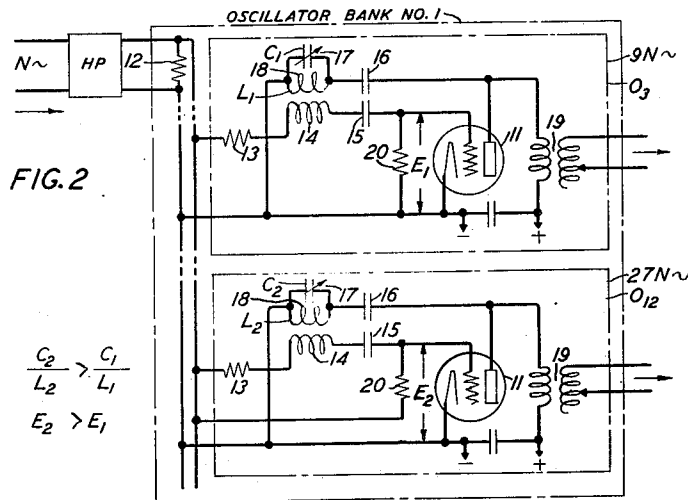
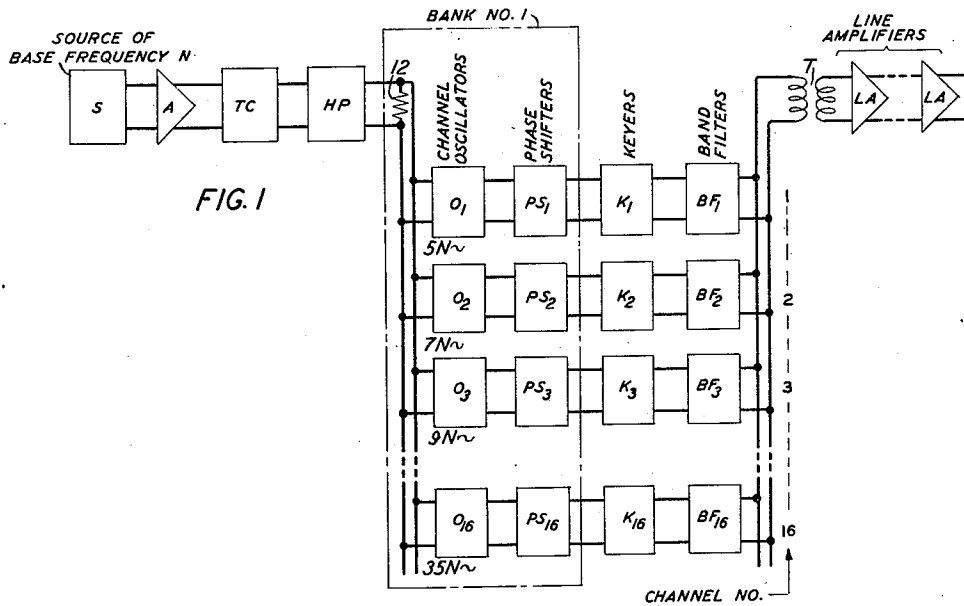
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2,314,422

CARRIER WAVE PRODUCTION AND CONTROL

Filed Sept. 10, 1940

3 Sheets-Sheet 1



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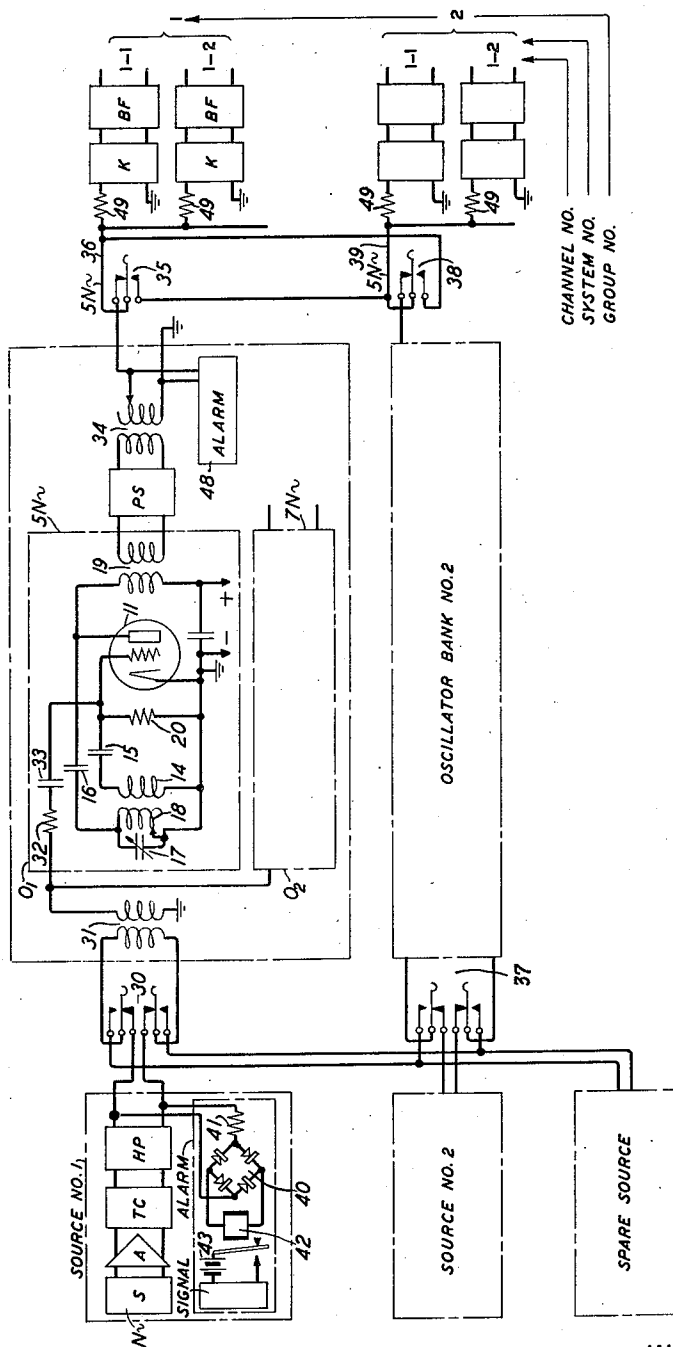
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FIG. 5



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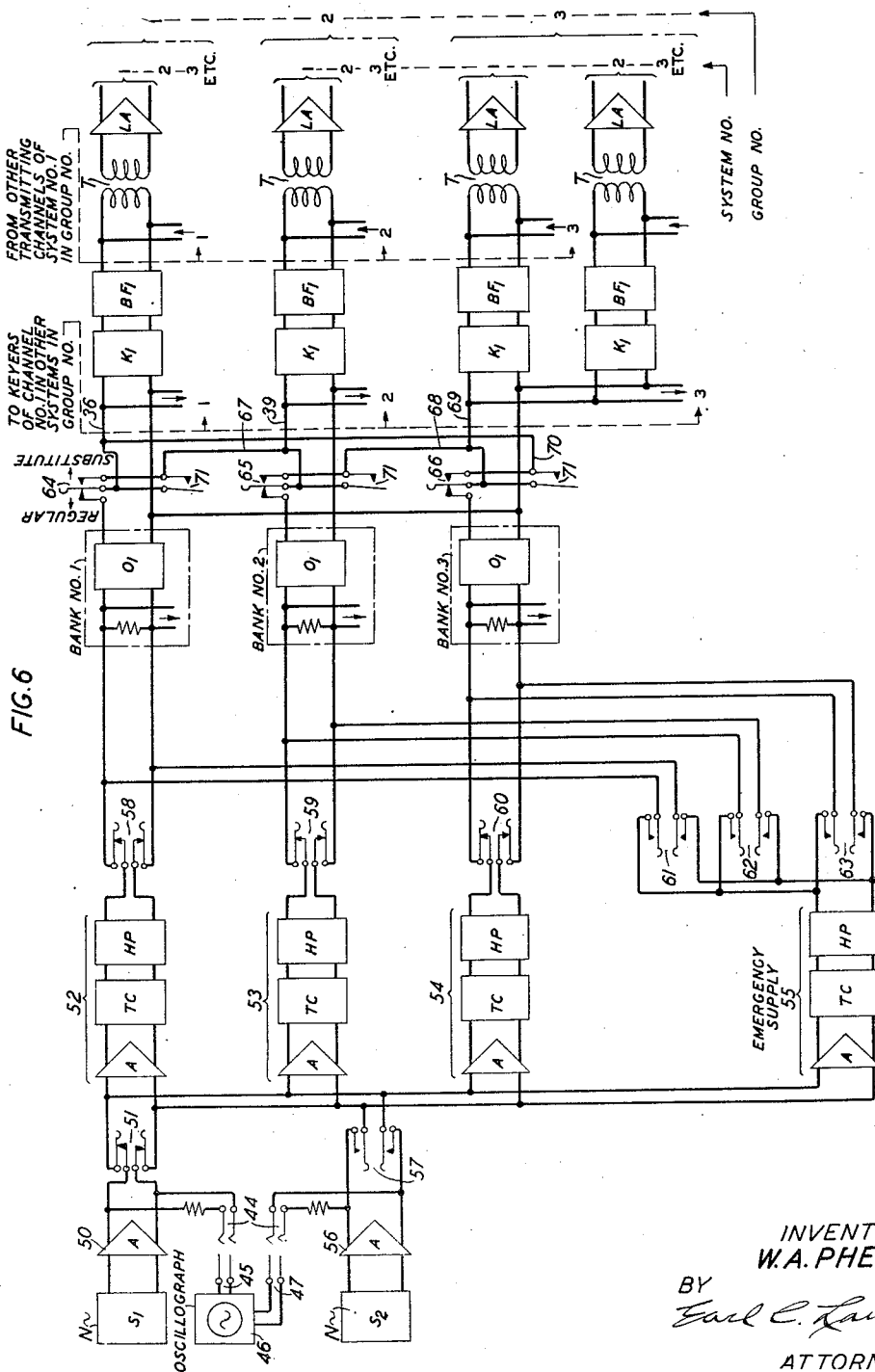
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CARRIER WAVE PRODUCTION AND CONTROL

Filed Sept. 10, 1940

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UNITED STATES PATENT OFFICE

2,314,422

CARRIER WAVE PRODUCTION AND CONTROL

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15 Claims. (Cl. 178—51)

This invention relates to the production and control of waves, and more particularly relates to methods of and means for efficiently supplying carrier waves to multiplex carrier wave systems in such a manner as to reduce interference between the channels and to reduce interruptions in the carrier wave service.

Multiplex carrier wave telegraph systems have heretofore been known in which each channel has a different carrier wave frequency equal respectively to a different odd harmonic frequency of a given base frequency wave, a separate vacuum tube oscillator being provided for supplying each different carrier wave frequency. In such a system even when great precaution is taken to maintain a supply of highly constant frequency for each channel, the gradual change in the relative phases of the currents in the several channels at times causes the maximum values of the different carriers in the common or main line circuit to approach coincidence and thus produce excessive peak amplitudes in the main line current. The line amplifiers and other equipment are thus subjected to corresponding peak loads. These peak loads tend to overload the circuit from the standpoint of distortion in transmission, to require equipment of much greater power capacity for the aggregate peaks than at other times, to increase the cost of equipment, and to produce undesirable distortion products, such as harmonics and products of intermodulation between the several currents of different frequency, thereby increasing the interchannel interference.

The difficulties resulting from the coincidence or piling up of the maximum values of the different carriers, have in some cases been reduced by avoiding the use of separate sources of carrier waves, and using in place thereof a harmonic producer or generator fed by the source of base frequency waves, the phase between the odd harmonics in such a harmonic producer system being adjusted by means of suitable phase shifters, so that the peaks of the carriers depart from coincidence and do not add up to excessive amplitudes in the line amplifiers. A similar result has also been attained by the use for the carrier source of a motor-driven inductor alternator, a separate rotor producing each frequency but with all rotors rigidly attached to the same shaft and phased in a random manner with respect to each other.

However, the remedy of using the harmonic producer or inductor alternator system for avoiding the pile-up of peaks, brings about other very serious difficulties. If either the base frequency

source or the harmonic producer of the first system, or the driving motor of the alternator of the latter system, for any reason falls to function, the whole carrier wave system is thrown out of service with serious consequences to the users who depend upon the system for the transmission of signals or messages, particularly in the case of large systems and groups of systems of the kind being used today.

Furthermore, in the harmonic producer system, the large amounts of amplification required to obtain carrier waves of adequate operating power for each channel from the relatively weak waves selected by the selective circuits in the output of the harmonic producer in such systems, require in turn powerful and expensive amplifying facilities. Any saving that could be made by avoiding the use of such powerful equipment would therefore be an important and desirable economy.

An object of the present invention is to reduce difficulties of the kind referred to above and to obtain one or more of the desirable results mentioned above.

A further object is to reduce the load on line amplifiers, loading coils, and other equipment in multiplex carrier wave systems, to reduce interference between channels and to reduce the noise level due to undesired intermodulation products in multiplex carrier wave systems.

Another object is to maintain a carrier wave system in working operation when there is a failure of the base frequency waves or of the harmonic waves controlling the frequency of the carrier waves, and to reduce the effects of the interruption by facilitating a substitution of a spare carrier supply, if there should be a failure of a channel oscillator.

Further objects are to simplify the supply of carrier waves of controlled frequency in a carrier wave system or in a combination of several groups of systems, and to provide simple and efficient arrangements for making substitutions of one or more parts of the wave supply circuits, and for maintaining a predetermined peak-reducing phase relation between the carriers in different channels when substitutions are made for the regular carrier wave supply.

In accordance with one aspect of the present invention, a carrier wave system is provided in which a different odd harmonic of a constant base frequency wave is employed as a carrier for each different channel of the system. The base frequency wave is transmitted to an odd harmonic producer to provide a complex wave adapted to serve as a control wave and consisting of

odd harmonics of the base frequency wave. Each of a plurality of channel oscillation generators supplies its waves to a different channel of the system, and has its frequency determining circuit tuned to the respective channel carrier frequency. The complex control wave from the harmonic producer is applied directly to the grid circuit of each channel oscillator without the intervention of a selective circuit and with such an amplitude as to pull the oscillator into synchronism with the nearest odd harmonic of the base frequency wave and to maintain synchronism throughout the ordinary range of frequency changes which would be likely to occur if the oscillator were not synchronized. The phases of the output waves of the different channel oscillators for any one system or a group of systems, are so related that coincidence and pile-up of peaks in the main line circuit is minimized to reduce the power requirements of line amplifiers and other line equipment, to reduce interference between channels, and to reduce the noise level. Also, a peak-reducing phase relationship which is satisfactory for most purposes may be obtained by reversing the phase of a number of the channels, the number being one-half, or approximately one-half of the total number of channels, the reversed half consisting of particular channels. In case of failure of either the base frequency source or of the harmonic producer, each channel oscillator continues to operate, so that there is no corresponding failure of the carrier wave channels, and the slight deviation of the output of the channel oscillator, in frequency and phase from its controlled value may be tolerated for the brief period required to restore or replace the supply.

A plurality of groups of carrier wave systems are so arranged that the regular carrier wave supply for any channel in the systems in one group, may be readily replaced by substituting therefor the supply for a corresponding channel in another group, or an emergency supply may be substituted for the regular supply of base frequency waves or of harmonic control waves, all without interruption of the carrier wave service, and without disturbing the peak-reducing phase relationship. The wave supply is thus arranged to operate a system or a number of groups of multi-channel carrier wave systems under unified control with a minimum of interchannel interference and intermodulation noise level, and with a minimum loss of service due to replacement or interruption of the carrier wave supply.

These and other objects and features of the invention will be understood more clearly from the detailed description which follows, in view of the accompanying drawings, in which:

Fig. 1 is a block diagram of the circuit of a multi-channel carrier wave telegraph system, showing certain features of the invention;

Fig. 2 shows in detail specific channel oscillator circuits, adapted for use in the Fig. 1 arrangement;

Fig. 3 shows a detailed circuit of a keyer, adapted for use in the Fig. 1 arrangement;

Fig. 4 shows a circuit of an alternative keyer which may be substituted for that of Fig. 3; and

Figs. 5 and 6 show in part diagrammatically and in part schematically different forms of carrier wave supply arrangements in accordance with the invention for supplying a plurality of groups of systems.

Referring to Fig. 1, the source S of base frequency N, is preferably an oscillation generator

of the space current type, for example like that shown in Meacham Patent No. 2,163,403 adapted to produce a highly constant output frequency and amplitude. The output of the source S is coupled with the amplifier A which transmits amplified waves to the tuned circuit or filter TC and prevents reaction of the succeeding circuits on the source S. The circuit TC is designed in accordance with well-known principles to pass only the wave of base frequency N to the producer of odd harmonics HP, and to suppress any harmonic or other components above or below the base frequency and accompanying the base frequency wave N, since any such components would tend to combine in the producer HP and produce even harmonics or other undesired components in the output thereof. The harmonic producer HP may be of the type disclosed in Wrathall Patent No. 2,117,752, issued May 17, 1938.

The grid circuits of the No. 1 bank of channel oscillators O₁, O₂ to O₁₆, are connected in parallel with the output of the harmonic producer HP, each oscillator generating a different odd harmonic frequency 5N, 7N, 9N, and so on up to 35N, or higher, and each oscillator supplying carrier waves to a different channel; the 5N oscillator supplying waves to channel 1; 7N to channel 2; 9N to channel 3; and so on. Connected in cascade with the output of each channel oscillator, there are in the order named, a phase shifter PS, a keyer K, and a band filter BF; the outputs of all the filters BF being connected in parallel and coupled by the transformer T with the multichannel main line, including the line amplifiers LA in cascade. The subscripts of the devices O, PS, K and BF indicate the channel numbers.

Fig. 2 shows two forms of a channel oscillator circuit of a type preferred for use in the Fig. 1 arrangement, one form serving better for use in a part of the bank of oscillators, for a plurality of carrier channels, and the other serving better for the remaining part of the bank, as will be explained further hereinafter. Each oscillator O₃, O₁₂, etc., includes a space current device 11 of the grid-controlled electron discharge type. An input circuit may be traced from the cathode of device 11, through the resistance coupling 12 in shunt with the output of the harmonic producer HP, through the resistance 13, the inductance coil 14 and the low impedance direct current blocking condenser 15 in series, to the grid of device 11. An output circuit acting as a feedback path may be traced from the anode of device 11 through the direct current blocking condenser 16 in series with the adjustable tuned frequency determining circuit 17, 18 to the cathode of device 11. Circuit 17, 18 includes the variable tuning condenser 17 of capacity C₁, in parallel with the coil 18 of inductance L₁, which is coupled by mutual inductance with the grid circuit inductance coil 14. Another output circuit includes the primary coil of transformer 19 between the anode of device 11 and the positive terminal of the space current source, the adjustable tapped secondary coil of transformer 19 permitting of adjustment of the carrier amplitude to the proper standard value for the following keyer K₃ or K₁₂ (Fig. 1). The transformer 19 may be utilized as a 180-degree phase shifter corresponding to the phase shifter PS₃, etc. (Fig. 1), since if desired, the external connections of one of its coils may be readily reversed with respect to the other coil. In oscillator O₃ the grid leak resistance 20 shunts the grid-cathode circuit of tube 11, while

in oscillator O_{12} the leak resistance 20 shunts the impedance elements 13, 14, 15. The other oscillators in bank 1 (Fig. 1) may have the same circuit as the oscillator O_3 or O_{12} (Fig. 2). The frequency determining circuit 17, 18 of each oscillator is tuned so that when there is no control wave supplied from harmonic producer HP, the frequency of each oscillator is approximately equal to or as close as practicable to the odd harmonic frequency to be supplied thereby, being preferably not more than a few cycles at most from the desired frequency. It will be seen that no frequency selective circuit is provided between the harmonic producer HP, and the grid or frequency determining circuit of each oscillator. When suitably adjusted, as explained in more detail hereinafter, the operation of the circuits is such that substantially the same complex odd harmonic control wave from harmonic producer HP is applied to each of the channel oscillator grids or frequency determining circuits, and pulls each oscillator into a fixed phase relation with respect to the base frequency wave and maintains this synchronous relation throughout the ordinary range of changes of circuit constants of each oscillator, even though such changes might cause the oscillator when unsynchronized to depart several cycles from the desired frequency.

The control wave applied across coupling resistance 12 produces the grid-cathode voltage E_1 in oscillator O_3 and voltage E_2 in oscillator O_{12} .

A part of the voltage produced by the output of the harmonic producer across resistance 12 is in turn impressed between the grid and the cathode of vacuum tube 11. The resistance 12 is connected into the network consisting of resistance 13, coil winding 14, condenser 15, resistance 20 and the grid-cathode circuit of the vacuum tube 11 in a different manner in the two oscillators O_3 and O_{12} and in such a manner that the voltage E_2 produced in oscillator O_{12} is greater than the voltage E_1 produced in oscillator O_3 . This is necessary in order to apply sufficient synchronizing force to the oscillator O_{12} since oscillator O_{12} is harder to synchronize than oscillator O_3 because in oscillator O_{12} the ratio of capacity C_2 of condenser 17 to the inductance L_2 of coil 18 is greater than the ratio of C_1 to L_1 of oscillator O_3 . When the ratio of C to L of the frequency determining circuit is relatively high, the stability and resistance to being controlled by the harmonic control wave has been found to be so large as to oppose maintenance of the desired synchronous relation between the oscillator output wave and the base frequency wave, whereas if the ratio of C to L be made too small the resulting lack in stability of the oscillator will cause it to drift excessively from its proper value in case of failure of the control waves. For satisfactory synchronization, it is therefore necessary to compromise by operating within a range of C to L ratios, having limits considerably short of those within which the oscillators would show greatest frequency stability when operating without the control wave. Because of practical considerations in making and operating a bank of oscillators, each generating a different frequency, it has been found expedient for purposes of simplification; that is, reduction in the number of different values of elements to be used, to construct the oscillators in such a way that as an incident thereto, the ratio of the capacity to the inductance in the frequency determining circuit differs considerably in the different oscil-

lators of the bank. The amplitudes of the synchronizing voltages E_1 and E_2 have therefore been made different to make up for the difference in controllability of the oscillators by the control wave, resulting from the different ratios of C to L. In practice it has been found possible to control all the oscillators in the bank by one or the other position of the grid leak 20 in Fig. 2, depending as a general rule upon the ratio of C to L, as explained above. By minimizing the number of oscillators in a bank connected like oscillator O_{12} , the power required to be delivered to resistance 12 by the synchronizing equipment can be reduced.

Fig. 3 shows one form of keyer device adapted for transmitting telegraph or other signals. Marking signals are transmitted over the channel line when the contacts of the relay 22 are in position shown with the high impedance element 21 in the line short-circuited by the back contacts of the relay 22. Spacing signals are produced by introducing impedance 21 in the line when the relay 22 operates to open its back contacts, and to short-circuit the line upon closure of the front contacts of the relay.

The auto-transformer coupling 23 in Fig. 3 may be replaced by the transformer arrangement shown in Fig. 4, which shows another typical keyer circuit in which H indicates the high impedance side of the high ratio transformer and L indicates the low impedance side, in each case. In the latter keyer, the relay contacts operate in a very high impedance circuit which tend to minimize the undesirable effect of any contact resistance which may develop in the relay. This circuit has another advantage over that of Fig. 3. It has been pointed out above that the phases of the currents from the oscillators O_1 , O_2 , O_3 , etc. must be so arranged by use of phase shifters PS or, more approximately, by reversing the output leads of certain oscillators, that the currents, when they reach the line amplifiers LA, will not have a tendency to peak up and overload the amplifiers. Now this assumes that all the keyers K and band filters BF of Fig. 1 have similar circuits. If, having found the best phase arrangement for a large number of telegraph channel equipments of one kind, some new channel equipments having different keyers or different types of band filters are added, they may need a different phasing arrangement for least load on their corresponding line amplifiers. Keyers of the type of Fig. 4 provide possibilities of easy turn-over of the phase by reversing leads at any convenient transformer winding without grounding the normally ungrounded side of any paralleling circuits which have not had their phases reversed. In this connection it should be noted that in practice all carrier telegraph circuits are normally unbalanced circuits up to transformer T of Fig. 1. The reason for this is that circuit elements designed to have one side grounded are usually cheaper to build.

The band filters BF in each channel of the system of Fig. 1 may be of well-known design, adapted to restrict the waves transmitted from that channel to the main line to only those components needed for conveying the signal consisting of the carrier wave with its essential side frequency components on one or both sides of the carrier, and to prevent waves of different frequency in the main line from entering that channel from other channels.

The phase shifter PS, shown in each channel, is preferably adjustable and may be of well-

known form, being preferably located at some point in the circuit between the oscillator O and the filter BF. The phase shifters are preferably adjusted so that the peaks of the carriers in the different channels depart to the desired extent from coincidence, in order to avoid overloading the main line amplifiers, or any loading coils (not shown) or other devices tending to intermodulate the several main line currents and cause inter-channel interference or increased noise level as a result of large aggregations of peaks in the main line current. By adjusting the relative phases of the carriers by means of the phase shifters PS, so that the peaks are distributed in a definite random relation, wherein the peaks are out of phase with each other to the greatest degree on the average, the difficulty of overloading by aggregation of peaks may be reduced or avoided, and since the load demand on the line amplifiers and other line equipment is less than would be the case with large aggregations of peaks, main line amplifiers and other main line equipment of more moderate and economical size and power capacity, and more economical operation, may be employed. In practice, it has been found possible to obtain a satisfactory random distribution of peaks for most purposes, causing the aggregate magnitude of the peaks to remain at all times much less than the sum of their individual peak magnitudes, by reversing one-half, or approximately one-half of the carriers of a system relatively to the other half or approximate half, the particular carriers to be reversed being determined by actual trial while observing the main line current representing all the carriers by a suitable indicator, such as an oscillograph, until peaks of undesired amplitude are suitably reduced in magnitude or made to disappear.

In one case, where a system included sixteen odd harmonic carrier wave channels, good results were obtained in reducing aggregate peak amplitudes when the lowest channel carrier frequency was 425 cycles per second, or $5N$ where N , the frequency of the base frequency waves, was 85 cycles per second, the other channel frequencies being respectively consecutively higher odd harmonics of N ; one-half of the carriers, having the following respective frequencies, being reversed in phase: 595, 1105, 1275, 1615, 1955, 2125, 2295, 2895. It will be understood, however, that in other practical cases employing the same number of channels but using other different types of circuit units, that is, different circuit designs of keyers or filters, or both, a different group of carriers might need to be reversed. At this point it should be borne in mind that the primary purpose of establishing a definite phase relation among the several carrier currents entering the line is to prevent the build-up of high peaks of current, or voltage, which will overload momentarily the vacuum tubes in the line repeaters or overload such other elements as the loading coils. The primary purpose of synchronizing the several oscillators, that is, of locking them in step with a base frequency master oscillator, is merely to ensure that the desirable phase relationship mentioned above, when one attained, will be continued. Merely locking the oscillators in step with the master oscillator is not by itself sufficient; the proper phase relation between the several currents must also be brought about.

It may be thought that this phasing operation will be of doubtful value when the currents pass over a cable circuit loaded in the usual manner with inductance coils, as such a circuit is known to produce large changes in phase and it might

seem that the phase relationship so established will soon be lost due to the different phase shifts produced by the cable in currents of different frequencies. Such a condition actually does occur after the currents have traversed a considerable length of cable but the proper phase relation is maintained approximately in passing through the first few repeaters. After such a distance has been traversed by the currents the effect of the cable has produced a random distribution of phase and the likelihood of high peaks piling up in any repeater is very small. So, with synchronized oscillators unless the proper phase relations between the currents have been established before the currents have entered the line the first few repeaters will be overloaded and will produce undesired products of modulation. In any case, with synchronized currents, those repeaters beyond the first few each contribute a small amount of modulation due to some non-linearity of their characteristics over the range of current voltage which passes through them but this modulation may be overshadowed by that produced in the first few repeaters. It should be noted that without any synchronization of currents there is a constantly changing pattern of currents on the line at all points and every repeater will be subjected now and again to the maximum current or voltage peak and it is likely that several repeaters may be subjected simultaneously to high peaks. When the currents have been synchronized the current pattern stays unchanged at any point in the line although this pattern will be different at every successive point in the line.

In Fig. 5, the elements S, A, TC and HP are the same as in Fig. 1. The harmonic producer HP in the source No. 1 transmits its odd harmonic control wave over the inner or normal contacts of the manual switch key 30, to the bank 1 of odd harmonic oscillators O_1 , O_2 , etc., each having a tuned frequency determining circuit 17, 18, as in Fig. 2, coupled with the grid circuit inductance 14. Control waves from the harmonic producer HP are fed to the primary of the transformer 31, the secondary providing a synchronizing control wave source for each oscillator in the bank, the secondary being connected between the grounded cathode of the space current device 11 and through the resistance 32 and direct current blocking condenser 33, directly with the grid of device 11. The inductance 18 in Fig. 5 is made adjustable to provide for adjustment of the ratio of the capacity 17 to the inductance 18 to a value permitting of suitable synchronizing control of the oscillator by the harmonic control wave without excessively reducing the stability of the oscillator when the oscillator is called upon to operate without the control wave. It will be understood that the circuit of oscillators O_2 and O_3 and the other oscillators (not shown) in the bank are similar to that of oscillator O_1 except that each oscillator is tuned to oscillate at a different odd harmonic of the base frequency wave.

The output transformer 19 of oscillator O_1 has its secondary connected with a phase shifter PS having an output coupling transformer 34 with a variable tapped secondary for adjustment of the channel carrier wave voltage. The phase shifter PS is adapted to adjust the phase of the carrier to any desired value where the desired degree of refinement of phase adjustment is not attainable by the mere use of the coil connections of the transformer 19 or 34 in

their normal or their reversed phase. For most practical purposes adjustment of the phase to one of the two positions 180 degrees apart at the terminals of one of the transformers 19 or 34, or elsewhere in the channel is sufficient, and the special phase shifter PS may be omitted. In any event, it will be understood that the Fig. 5 arrangement is preferably adjusted to have the peak-reducing phase relationship described above in connection with Figs. 1 and 2.

A circuit for the carrier wave of frequency 5N for channel 1, may be traced from the upper terminal of the secondary of transformer 34 through the upper normal contact of the manual transfer switch key 35, the main contact of key 35, over conductor 36 to the inputs of two or more keyers K, in parallel, the circuit returning by way of ground to transformer 34. Each of the keyers K in group 1 supply carrier waves to a No. 1 channel in a different system, numbered respectively 1, 2, etc., in group 1, as indicated in Fig. 5. The resistances 49 prevent impedance changes in each keyer from affecting greatly the currents in other channels connected to the same oscillator.

The source No. 2, constructed similarly to source No. 1, transmits its control waves over the inner contacts of the manual switch key 37 to the bank 2 of oscillators, constructed similarly to the bank 1, and including a series of oscillators O₁, O₂, etc., (not shown), as in bank 1. The output circuit from the bank 2 for the carrier wave of frequency 5N for channel 1 may be traced from the upper right terminal of bank 2 through the upper normal contact and the main contact of manual transfer switch key 38, over conductor 39 to the inputs of two or more keyers K in parallel, the circuit returning by way of ground as in group A. Each of the keyers K in group 2 transmits carrier waves to a No. 1 channel in a different system numbered respectively, 1, 2, etc., in the group 2.

The spare source of control waves so designated in Fig. 5 is constructed similarly to source No. 1, and has its output conductors connected with the outer contacts of both keys 30 and 37.

Each source is provided with an alarm across its output, as shown in connection with source No. 1, the alarm including a full-wave bridge type of rectifier 40 having one diagonal thereof connected across the output terminals of the harmonic producer HP, the current limiting resistance 41 being connected in series therewith. The relay coil 42, connected across the other diagonal of the bridge, remains energized as long as the control wave is maintained at its proper amplitude. If the control wave fails, coil 42 deenergizes and allows its back contacts to close, connecting the battery 43 across the alarm signal to give warning of the failure. Key 30 may then be operated to its off-normal position opening its inner contacts to disconnect bank 1 from source No. 1, and closing its outer contacts to connect bank 1 with the spare source as a substitute for source No. 1. The spare source may be similarly substituted for source No. 2, either at the same or at a different time from its connection with source No. 1 by operating key 37 to its off-normal position, thereby opening its inner contacts disconnecting bank 2 from source No. 2, and closing its outer contacts to connect bank 2 to the spare source. If either source No. 1 or No. 2 fails, keys 30 and 37 make it possible to quickly substitute the spare source with a minimum delay.

In case of failure in one of the banks of oscil-

lators, say bank 1, causing failure of the supply of carrier waves for channel 1 in group 1, the alarm 48, similar to the alarm shown in more detail in source No. 1, connected across the secondary of transformer 34, gives warning. Key 35 may then be switched from its regular or normal upper position to its lower position, breaking the connection with bank 1 through its upper contacts and closing through its lower contacts a connection with the main supply conductor 39 for group 2, so that channels 1 of all systems in groups 1 and 2 are then supplied in parallel from bank 2. In case of failure of oscillator O₁ (not shown) of bank 2, key 38 may be switched from its regular upper position to its lower position, breaking its upper contacts and the connection with bank 2 and closing through its lower contacts a connection with the main supply conductor 36 for group 1, so that channels 1 of all systems in groups 1 and 2 are then supplied in parallel from bank 1.

It will be understood that the bank 1 of the type shown in Figs. 1 and 2, may be substituted in place of the bank 1 of the type shown in Fig. 2, and vice versa, and that the same type of arrangement as shown in detail for channel No. 1, in Fig. 5, is also provided, with proper frequency design, for each of the other channels of different carrier frequency in Fig. 5, although for the purpose of clearness and simplification of the drawing, unnecessary duplication of channel details has been avoided. It will thus be clear for example that channel No. 2 in each system in group 2 normally is supplied with carrier waves of a frequency 1N from channel oscillator O₂ (not shown) in bank 2, and for emergency purposes may be disconnected from bank 2 and connected with oscillator O₂ of bank 1 by means of a transfer key (not shown), associated with channel 2 of group 2.

Fig. 6 shows a preferred form of carrier wave supply arrangement, as applied to a plurality of groups of systems. In this figure, the carrier wave supply connections are shown in detail for channel No. 1 in a plurality of systems, in each of a plurality of groups, and it will be understood that the other channels (not shown in Fig. 6) are constructed for their respective frequencies similarly to channel No. 1, and are connected with the main line circuit as shown in Fig. 1, the phase of approximately one-half the carriers being preferably reversed to minimize peaks, as described above in connection with Figs. 1 and 2.

The source S₁ transmits base frequency waves to amplifier 50 from which amplified waves are transmitted over normal contacts of the manual switch key 51 to four harmonic control wave supply sets 52, 53, 54, 55, in parallel, each of the sets 52, 53, 54, providing a regular supply of carrier waves to a different one of three banks of channel oscillators, and the set 55 serving as an emergency or spare set. The amplifier 50, besides amplifying, serves to prevent the reaction on the source S₁ of circuit changes when switch 51 or its connected load circuits are changed. In each of the four control wave sets 52, 53, 54, 55, the amplifier A, the selective circuit TC and the odd harmonic producer HP are in cascade, as in Fig. 1.

In case it is desired to substitute another source for source No. 1, the emergency source S₂ with its output amplifier 56, may be connected with the control wave sets 52, 53, 54, 55 over the off-normal contacts of switch 57. Before such a substitution of S₂ for S₁ is made, source S₂ should preferably be brought into complete synchronism with source S₁ both as to frequency and phase. To accomplish

this, the pair of terminals 44 from amplifier 50 should be connected to terminals 45 which lead to one pair of plates of a cathode ray oscillograph 46. Similarly the pair of leads 44 from amplifier 56 should be connected to terminals 47 which lead to the other pair of plates of the cathode ray oscillograph 46. Sources S₁ and S₂ are provided with a fine adjustment of part of the frequency determining element and this adjustable element in S₂ is now adjusted until the pattern on the cathode ray oscillograph indicates that S₂ is emitting current of the same frequency as that from S₁ and in phase with it. Now, with switch 51 still closed, switch 57 is moved to its closed position to connect the output of amplifier 56 in parallel with that of amplifier 50, switch 51 being then opened to disconnect amplifier 50 and source S₁ from sets 52, 53, 54, 55, to substitute one source of base frequency waves for another without making any incidental interruption in the carrier wave supply.

In order to avoid undesirably complicating Fig. 6, the showing of alarm devices, such as shown in Fig. 5, has been omitted, but it will be understood that such alarms are preferably provided, as in Fig. 5, across the output of each harmonic producer HP, and across the output of each oscillator, as at 48, Fig. 5, an alarm being also preferably provided across the output of each of the amplifiers 50, 56 in Fig. 6.

The outputs of harmonic control wave sets, 52, 53, 54 connect respectively with banks 1, 2, 3 of channel oscillators by way of the normal contacts respectively of manual switch keys 58, 59, 60. Each of the banks 1, 2, 3 in Fig. 6, is an arrangement similar to bank 1 in Figs. 1, 2 or 5. The output of the emergency set 55 is provided with normally open switches 61, 62, 63, connectable by closure with oscillator banks 1, 2, 3, respectively, to supply control waves in place of the regular supplies 52, 53, 54, respectively.

When transferring one of the banks, say bank 1, from the regular to the emergency supply of control waves while both sets 52 and 55 are operating, key 61 is closed to connect the outputs of sets 52 and 55 in parallel, the key 58 then being opened to disconnect set 52 from bank 1 without having interrupted the supply of control waves or the carrier wave service. No transient disturbance of any size will have been produced by the transfer because all the sets 52, 53, 54, 55 are similar in design and all are fed from the same source S₁ or S₂ and so the outputs of all the sets 52, 53, 54, 55 are substantially in phase with each other at all times. Substitutions of the emergency supply 55 for sets 53 or 54, or for any two or all three regular sets may be similarly made.

Banks 1, 2, 3 of the channel oscillators regularly supply over the left-hand contacts of transfer keys 64, 65, 66, respectively, all the carrier waves for groups 1, 2, 3, respectively, the general arrangement of keyers K and filters BF, transformer T, and line amplifiers LA in each system, being similar to that described in connection with Fig. 1. The circuits of each bank are adjusted so that the carrier waves for supplying a given channel from one bank, are in synchronism with the carrier waves for supplying a channel of the same frequency from another bank, so that when an oscillator of one bank is substituted for an oscillator of another bank as a source of carrier waves for a given channel, the peak-reducing relation established by the regular supply will be provided also by the sub-

stitute supply. This phase angle adjustment may be made, if desired, by the phase shifter PS in the bank (see Figs. 1 and 5), or elsewhere in the circuit.

Transfer keys 64, 65, 66 operate somewhat similarly to keys 35, 38, Fig. 5, each having a regular position, when the main contact is to the left in Fig. 6, and a substitute position to the right. The right contact of key 64 connects by way of conductor 67 with the upper channel conductor 39 leading to keyers K₁ of channel 1, group 2, so that when key 64 moves to the right, the corresponding channel conductors 36, 39, respectively, for channel 1, of groups 1 and 2, are connected together. The right contact of key 65 in a similar manner connects by way of conductor 68 with the corresponding upper channel conductor 69 for channel 1, group 3. Similarly the right contact of key 66 connects by way of conductor 70 with the corresponding channel conductor of the next group in the combination of groups, which in this case is conductor 36 of group 1.

The other channel conductor which provides a return circuit for the upper channel conductor of each group, connects directly as shown in Fig. 6, or by ground as shown in Fig. 5, with the lower output terminals of all of the channel oscillators for that channel in all of the groups.

By throwing to the right, the transfer key for channel 1 of any given group, while the other transfer keys for channel 1 of the other groups remain in their regular positions, the upper channel conductor for channel 1 of the given group is thereby connected directly with the corresponding channel conductor of the next group in the combination of groups, thus substituting for the disconnected channel oscillator in the given group, the regular supply oscillator for that channel in the next group.

For example, in case it is desired to make a substitution for the regular supply of carrier waves for group 1, because of failure of the regular supply, or for any other reason, key 64 may be thrown to the right, causing its main contact to break from its left contact and disconnect the upper conductor 36 of channel, group 1, from oscillator O₁ in bank 1, thus disconnecting bank 1 as a supply for channel 1, the key 64 substituting through its right contact, the channel 1 oscillator which regularly supplies group 2, bank 2. Similarly, when key 65 is in its right position, while the other transfer keys remain in their regular positions, channel 1 of group 2 is disconnected from bank 2 and is connected with bank 3 as a substitute supply; and when key 66 alone is to the right, channel 1 of group 3 is disconnected from bank 3 and bank 1 is substituted for bank 3. When any two transfer keys, say 65, 66, are thrown to the right while the third key, 64, remains in its regular left position, all three groups are supplied from that oscillator which retains its regular connection, that is, from channel oscillator O₁ in bank 1, in the assumed case, the groups 2 and 3 being supplied over the right contacts of keys 65 and 66. The described arrangement of transfer keys 64, 65, 66, thus makes possible a wide range of quick substitutions, with relative simple equipment.

As the number of systems, or groups of systems, associated together in a network or combination as a whole, is increased, it becomes increasingly important to avoid as far as possible all interruptions in the carrier wave supply and to reduce the

duration of unavoidable interruptions. In order to prevent interruption and to insure continuity of carrier wave service during operation of transfer keys 64, 65, 66, while the regular channel oscillators are functioning, there is preferably provided a separate manually operable bridge key 71, associated with each transfer switch, each key 71 having a pair of preferably normally spring-apart contacts, adapted when closed to bridge the main and right contacts of the transfer key to permit of closing the circuit of these latter contacts while they are open and while the main and left contacts remain closed. This arrangement permits of conveniently connecting the substitute supply in parallel with the regular supply before disconnecting the regular supply from the channel 1, so that a continuous supply of carriers may be provided at all times for operating the channel 1.

If we assume that channel 1 of group 1 is to have bank 2 substituted for bank 1, as its supply of carrier waves, the key 71, associated with transfer key 64, is first closed, thereby placing the outputs of said oscillators in parallel. Transfer key 64 is next thrown to the right, and key 71 is then released, leaving only oscillator O₁ of bank 2 supplying waves to group 1. No disturbance to telegraph service results from this switching operation as the outputs of the oscillators of the same frequency in all banks are at all times approximately in phase with each other because all are locked in step with the same base frequency source S₁ or S₂.

It will be understood that the switching equipment and the operation thereof for the other channels of the Fig. 6 combination, are similar to those for channel 1. The arrangement in Fig. 6, is thus adapted for conveniently and efficiently making various substitutions and replacements in the channel oscillator carrier wave supply, the harmonic control wave supply, or the base frequency wave supply, while maintaining continuity of the operation of all systems in each of a plurality of groups, and while preserving the peak-reducing phase relationship in the main line of each system by employment of the single base frequency wave to maintain the phase of all the carriers in a predetermined relationship.

While Fig. 5 shows only two, and Fig. 6 only three groups of systems and their associated equipment, it will be seen that the method of arranging and operating the various parts of the combination shown, are applicable to a greater or smaller number of systems, groups of systems, banks of channel oscillators, sets of harmonic control wave supplies, base frequency sources, and their associated equipment.

While specific combinations and methods have been described as examples illustrating the invention, it will be understood that the invention is not limited to these details, but may be utilized in other different variations and forms, within the scope of the appended claims.

What is claimed is:

1. In combination in a carrier wave supply system, a source for supplying a complex wave consisting of a plurality of synchronized harmonics of a given base frequency wave, a group of individual carrier wave oscillators of the space current type, each having a frequency determining circuit tuned to a different harmonic of said base frequency wave, and means for transmitting the complex wave from said source to all of said oscillators for synchronizing them at their respective frequencies.

2. In combination in a carrier wave supply system, a group of individual carrier wave oscillators, each having a resonant frequency determining circuit and being capable of self-oscillation at a frequency which is a desired different harmonic of a given base frequency wave, and means for synchronizing said oscillators comprising a source of waves of said given base frequency, a harmonic generator supplied from said source for producing harmonics of said base frequency, and means for impressing the complex harmonic output of said harmonic generator directly on the frequency determining circuits of all of said oscillators to force them into oscillation at the desired harmonic frequencies.

3. The method of forcing a plurality of oscillators of the space current type each having a resonant frequency determining circuit, to oscillate in precise harmonic relation to a base frequency wave, each at a different harmonic frequency, which includes tuning them approximately to that relation, generating from said base frequency wave a complex wave including a plurality of harmonics of said base frequency wave, and transmitting said complex wave to each of said oscillators to synchronize them in the desired harmonic relation.

4. In combination, in a carrier wave supply system, a plurality of oscillators of the space current type, each of which has a resonant frequency determining circuit, the method of operation which includes tuning the frequency determining circuit of each of said oscillators to a different odd harmonic of a given base frequency wave, generating from said base frequency wave a complex wave including a plurality of exact odd harmonics of said base frequency wave, and synchronizing each of said oscillators at the exact harmonic frequency nearest the approximate harmonic frequency of the oscillator by transmitting said complex wave to the frequency determining circuit of each of said oscillators.

5. In a multichannel carrier wave system, a separately operable carrier wave oscillator having a resonant frequency determining circuit for each channel thereof, each said oscillator being capable of self oscillation at a desired different predetermined frequency which is harmonic to a given base frequency, and means including a source of waves of said base frequency and a harmonic generator responsive to said source, for producing and applying to the frequency determining circuit of all of said oscillators a complex wave comprising a plurality of exact harmonics of said base frequency to pull them into oscillation at the desired different harmonic frequencies.

6. In a multichannel carrier wave system, a separately operable carrier wave oscillator for each channel thereof, each said oscillator having a resonant frequency determining circuit tuned to a different frequency approximately equal to a respectively different odd harmonic of a given base frequency wave, a harmonic generator for generating from said base frequency wave, a complex wave including a plurality of exact harmonics of said base frequency wave, and means including a coupling for transmitting said complex wave from said harmonic generator to the frequency determining circuit of each of said oscillators for synchronizing each of said oscillators at the exact harmonic frequency nearest the approximate harmonic frequency of the oscillator.

7. In a carrier wave supply system having a group of individual oscillators of the space cur-

rent type, each said oscillator having a frequency determining circuit containing capacitance and inductance tuned to a different harmonic of a given base frequency wave, and certain of said frequency determining circuits having a higher ratio of capacity to inductance than other of said circuits, the method of operation which includes producing a complex wave including a plurality of synchronized harmonics of said base frequency wave, applying said complex wave to all of said oscillators, and making the voltage of the complex wave applied to certain of said oscillators having a higher ratio of capacity to inductance in their frequency determining circuits greater than that applied to other of said oscillators having relatively lower ratios of capacity to inductance in their frequency determining circuits.

8. In a carrier wave supply system, a group of individual oscillators of the space current type, each said oscillator having a frequency determining circuit containing capacitance and inductance tuned to a different harmonic of a given base frequency wave, certain of said frequency determining circuits having a higher ratio of capacity to inductance than other of said circuits, a source of said waves of said base frequency, a harmonic generator responsive to the base frequency wave from said source for producing a complex wave consisting of harmonics of said base frequency wave, means for transmitting said complex wave to all of said oscillators with a larger amplitude to certain of said oscillators having a higher ratio of capacity to inductance in their frequency determining circuits than in other of said oscillators.

9. In combination, a group of space current devices of the type having a cathode, an anode, and a control grid, a coupling impedance common to the grid-cathode circuits of all of said devices, a separate impedance individual to each of said grid-cathode circuits, said separate impedance including a direct current blocking condenser, a grid leak element for each of said grid-cathode circuits, and means for making the grid-cathode voltage derived from said coupling greater in certain of said space current devices than in other of said devices, said means including the connection of said leak element in shunt with said separate impedance and in series with said coupling impedance in those space current devices which are to have the greater grid-cathode voltage and including the connection of said grid leak in shunt with the series connection of said impedances in the other of said devices.

10. In combination, a group of carrier wave oscillators of the space current type having a cathode, an anode, and a control grid, each said oscillator being tuned to generate a different frequency harmonic to a given base frequency wave, a synchronizing coupling conductive to direct current and common to the grid-cathode circuits of all of said oscillators, a separate impedance individual to each said grid-cathode circuit and in series with said coupling, said separate impedance including a direct current blocking condenser, and means for making the grid-cathode synchronizing voltage derived from said coupling greater in certain of said oscillators than in other of said oscillators, said means including a grid leak element connected in shunt with said separate impedance and in series with said coupling in those oscillators which are to have the greater grid-cathode voltage and including a grid leak element connected in shunt with the series con-

nection of said impedance and said coupling in the other of said oscillators.

11. In combination, a plurality of groups of carrier wave telegraph systems, a plurality of channels in each of said systems, a separate carrier wave supply circuit for each of said groups and normally connected with one of the channels in each of the systems in said group for transmitting carrier waves of the same frequency thereto, means common to said supply circuits for said different groups for synchronizing the carrier waves transmitted to the channels connected therewith, each of said supply circuits having means associated therewith for transferring the channels normally connected therewith to a supply circuit of the same frequency for another of said groups.

12. In combination, a plurality of groups of carrier wave telegraph systems, a plurality of channels in each of said systems, a separate carrier wave supply circuit for each of said groups and normally connected with one of the channels in each of the systems in said group for transmitting carrier waves of the same frequency thereto, means common to said supply circuits for said different groups for synchronizing the carrier waves transmitted to the channels connected therewith, each of said supply circuits having means associated therewith for transferring the channels normally connected therewith to a supply circuit of the same frequency for another of said groups, and means for temporarily connecting said normal and substitute supply circuits in parallel while transferring said connections.

13. In combination, a plurality of groups of carrier wave telegraph systems, a plurality of channels in each of said systems, a separate carrier wave supply circuit for each of said groups and normally connected with one of the channels in each of the systems in said group for transmitting carrier waves of the same frequency thereto, each of said supply circuits having means associated therewith for transferring the channels normally connected therewith to a supply circuit of the same frequency for another of said groups.

14. In a carrier wave supply system, a source of base frequency waves, means for producing under the control of said base frequency waves a plurality of harmonics thereof, each harmonic to serve as a carrier for a different channel in a carrier wave system, a separate carrier wave supply unit for each different carrier wave frequency for transmitting said carrier from said harmonic producing means to the channel of corresponding frequency, each said supply unit having channel terminals normally connected therewith for connecting with a plurality of channels employing the same carrier frequency in different systems within a first group of systems, a corresponding set of supply units for a second group of carrier wave systems, means for equalizing the phase angles between the input of each said unit of the same carrier frequency in said different groups and said channel terminals therefor, and means for transferring said channel terminals from the unit normally connected therewith to another of said supply units normally connected with channel terminals for channels of the same frequency in another of said groups.

15. In a carrier wave supply system, a group of individual channel oscillators each having a frequency determining circuit including capacitance and inductance, each for producing a car-

rier wave which is a different harmonic of a given base frequency, and a master control for said group of oscillators comprising a master oscillator for generating a wave of said given base frequency, a harmonic generator controlled by the wave produced by said master oscillator, for generating a complex wave including a plurality of exact harmonics of said base frequency, corresponding to the different harmonics to be produced by said channel oscillators, and means for applying said complex wave directly to the frequency determining circuits of all of said channel oscillators to force them into oscillation, each at the desired harmonic frequency, the ratio of

5 capacitance to inductance in the frequency determining circuits of at least some of said channel oscillators being selected at a value which will insure that the latter channel oscillators will remain in synchronism for the normal range of operating conditions of said master oscillator and said latter channel oscillators, and at the same time will insure that each of said latter oscillators will be sufficiently stable to produce an approximately constant frequency while operating uncontrolled due to a failure of said master control.

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