

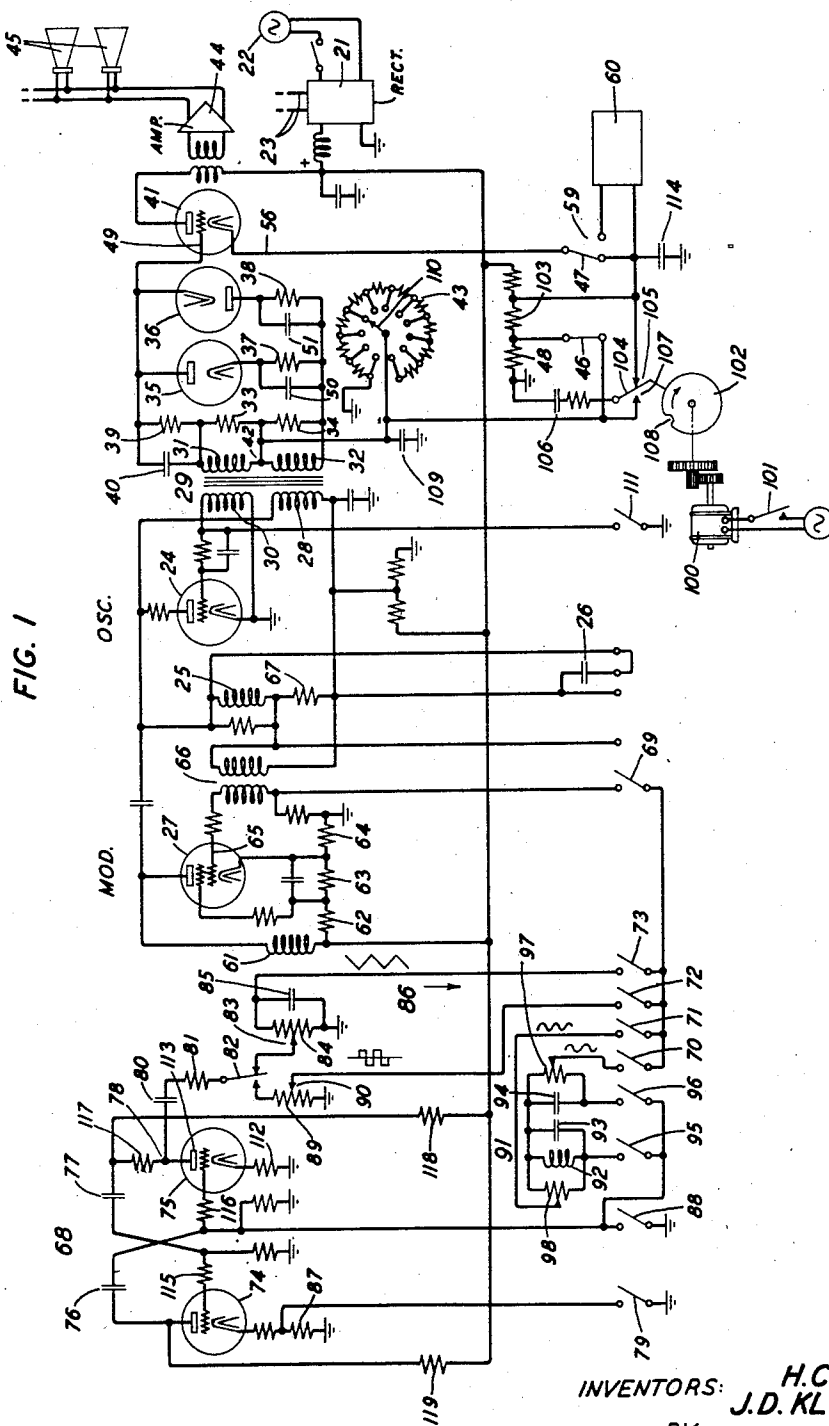
Dec. 7, 1948.

H. C. CURL ET AL
METHOD AND SYSTEM FOR ELECTRONICALLY
GENERATING COMPLEX SIGNALS

2,455,472

Filed April 10, 1945

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

FIG. 2A

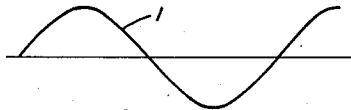


FIG. 2B

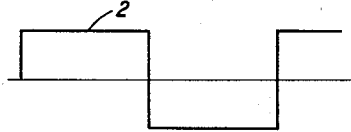


FIG. 2C

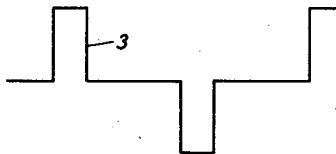


FIG. 2D

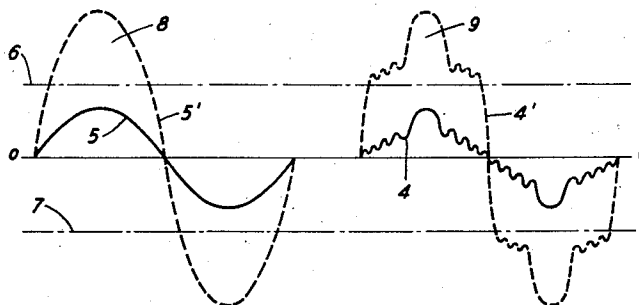


FIG. 2E

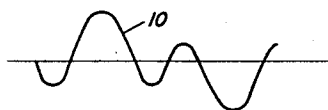


FIG. 2F

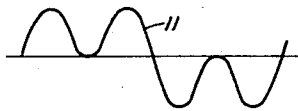
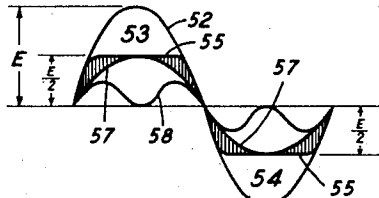


FIG. 3



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UNITED STATES PATENT OFFICE

2,455,472

METHOD AND SYSTEM FOR ELECTRONICALLY GENERATING COMPLEX SIGNALS

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6 Claims. (Cl. 179—171.5)

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This invention relates to signal generators and the object of the invention is to produce in an efficient and convenient manner a plurality of signals which may be easily heard and distinguished from each other.

In certain types of announcing systems such as those used on naval ships, it is necessary that the system be capable of transmitting information very quickly and accurately to various parts of the ship. In the case of alarms and other urgent messages, it has become the practice to transmit over the system at high acoustic level various distinctive signals each of which has a well-known meaning to those for whom it is intended. With the increasing complexity of naval ships, more and more types of signal are required and since the number of distinctive signals which can be obtained from a signal generator of any of the types heretofore available is quite limited, it has been necessary to provide a number of separate signal sources of widely different characteristics thereby increasing the space requirements for the apparatus and complicating the necessary interconnecting and control wiring.

According to this invention, the number of different signals obtainable from a single source is greatly increased by providing an electronic circuit which may be readily conditioned to generate any one of a large number of widely different sounds. These sounds may include single frequency, "jump" frequency or variable frequency tones of constant or varying amplitude and complex sounds of various kinds including those which simulate sirens, horns and bells.

All of these various signals are derived from a wave of primary or carrier frequency generated by a conventional vacuum tube oscillator, the tuning of which is controlled to hold the output frequency constant, or to vary it either in steps or continuously over any desired frequency range and at any desired rate. The output of this oscillator may be used as the signal source without further modification in the essential nature of the signal, if desired, or it may be changed radically in character by the addition of harmonics or by amplitude modulation effects.

An important feature of the invention is the generation of complex tones by frequency modulation to produce signals having a large number of frequency components. By proper choice of the carrier frequency, the frequency deviation and the modulating rate it is possible to control the frequencies and amplitudes of the various side frequencies so generated and in this way

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to produce a large number of signals of widely different tonal characteristics.

When the primary frequency is cyclically varied over a frequency range at a low rate, ordinarily once per second or less, a reproduction of this signal is characteristic of a siren. As the modulating rate is increased to about twenty times per second or more, a distinct change occurs in the character of the sound. The signal then consists of a group of non-harmonically related tones which give the sound a rather harsh quality simulating the sound of the well-known motor driven type of horn. With a carrier of suitable frequency and an appropriate modulating rate, the oscillator output also may be made to simulate a bell by means of a striking circuit of the type disclosed in Patent 2,254,699 to Owens.

In the preferred embodiment of the invention, the frequency of the primary oscillator is varied by a modulator of the variable reactance tube type in which the reactance depends upon the gain of the modulator and the gain is in turn controlled by varying the grid bias in accordance with the output of a variable frequency source such as a multivibrator or other control oscillator.

In this system the frequency of the signal is therefore determined by the magnitude of the bias voltage and the frequency varies with time in accordance with the time variations of the output voltage of the multivibrator or other control source producing the bias. When a multivibrator is used the output voltage, frequency and wave form are all readily variable, and such a combination therefore provides a very convenient and compact means for producing the wide variety of signals required.

Other frequency components, aside from those obtained by frequency modulation, are added to the signal by transmitting these components through one or more harmonic generating circuits thereby increasing the effective loudness of the signal as explained in more detail below.

According to a further important feature of the invention, it is shown that for maximum signal loudness and effectiveness, the frequency range, the harmonic content and the phase relationship of the various frequency components should be chosen with due regard to the characteristics of the amplifiers and loudspeakers of the system with which the signal generator is to be used.

These and other features of the invention will be more clearly understood from the following detail description and the accompanying drawing in which:

Fig. 1 is a signal generator according to the invention;

Figs. 2A and 2F show a series of signals of different wave forms considered in connection with the invention; and

Fig. 3 is a diagram illustrating a method of generating a signal of the wave form in Fig. 2F.

Before proceeding to describe the circuit of this generator certain general factors affecting the design should be considered. The frequency range transmitted by the amplifiers and loudspeakers usually used in announcing systems is limited to about 500 to 5000 cycles per second, or even less if only the range of maximum efficiency is considered. Within this band, if the possibility of confusion is to be avoided, only about two signals of the pure steady-tone frequency type can be used. To these may be added possibly two interrupted tones and one or two others in which the frequency alternates or "jumps" between two frequencies within the band.

To obtain a larger number of distinctive signals, it is therefore necessary to use some form of more complex sound. It is generally believed that certain complex sounds have greater attention value than a pure tone of the same energy content and it is well known that a complex tone comprising a number of components well separated from each other in the frequency scale so as to stimulate completely separate sets of auditory nerves, sounds louder than a pure tone of the same energy content. For example an article by Fletcher and Munson in the Bell System Technical Journal, October, 1933, shows that two tones each alone having a loudness of the order of 80 decibels, together will have a loudness level of about 89 decibels. The power level of this complex tone is only 3 decibels greater than either of its components, but its loudness is 9 decibels greater than either of its components. Thus a net increase in loudness of 6 decibels is achieved by separating the available power into two components of equal amplitudes but different frequencies. Since each 3 decibels increase in power level involves a doubling of the rated capacity of the power amplifier and loudspeakers, the substantial economy in high level systems of increasing the loudness of the signal by proper choice of wave form is readily apparent.

If signals are compared on the basis of relative loudness for the same electrical power input to the loudspeaker, it is found that greater loudness is obtained with a wave form of high peak factor, as shown in Fig. 2C, than with a sine wave form as shown in Fig. 2A. In systems where heating is the limiting factor, it therefore follows that for maximum loudness, wave forms with high peak factors should be used. However, in most signaling systems operation is intermittent and heating therefore is usually not the limiting factor. On the other hand electronic amplifiers are essentially peak limiting devices and in any case loudspeakers must be protected against excessive overloads. Hence with an electrical sine wave input, an increase in level beyond a certain point cannot produce any further increase in peak sound output and the output wave tends to approach the square wave form shown in Fig. 2B. In systems of this latter type, the relative merits of various wave forms should therefore be compared on the basis of relative loudness for the same peak amplitude.

Since, as stated above, complex waves in general have greater attention value than pure tones, it would appear that a complex peaked wave such

as 4 of Fig. 2D should give much better results than the simple sine wave 5. In the absence of amplitude limitations in the system, the sine wave after amplification to the required high loudness level, takes the form of curve 5' and the complex wave with the same amplification takes the form of curve 4'. However, if the system is subject to amplitude limiting at the level indicated by the lines 6 and 7, the peaks 8 and 9 above and below the limiting lines are suppressed and the wave forms of the two signals as impressed on the loudspeakers are both essentially simple square waves as curve 2 of Fig. 2B. Such a square top wave while appreciably louder than a sine wave of the same peak value is not sufficiently distinctive and in any case if required, it can be produced from the simple sine wave form which is more easily generated than the wave of curve 4.

From the above single illustration, it will be clear that many complex waves, which might otherwise be useful in producing distinctive signals are not well suited to high level reproduction since they must be reproduced at relatively low levels to avoid loss of their distinctive characteristics.

By way of further example, it should be noted that when a signal wave form consists of a number of frequency components, care must be taken to avoid combining them in such relation as to produce a wave of high peak factor. Since the loudness and tonal character of a complex sound are in general nearly independent of the phase relation of its components, the phase may be adjusted as required by peak factor considerations. When, for example, the wave takes the form of $\sin wt - \sin 3wt$ as indicated by curve 10 of Fig. 2E, the peak factor is much higher than when the frequencies are combined as $\sin wt + \sin 3wt$ as shown by curve 11 of Fig. 2F. For the same peak power curve 11 is found to be about 2 decibels louder than curve 10. Hence for best results the wave form should be generated in such a manner as to control the phase of the harmonics to produce the desired complex sound without unnecessarily increasing the peak factor of its wave form.

In choosing the frequency components of the signal wave form, it obviously is desirable to select frequencies within the most efficient range of the particular loudspeakers to be used. It is well known, that in a frequency modulation system having a modulation rate fm and a carrier frequency f_0 , the modulation products will be f_0 , $f_0 \pm fm$, $f_0 \pm 2fm$, $f_0 \pm 3fm$, etc. As explained in detail by Shea, MacNair and Subrizi in an article, "Flutter in sound records" in the Journal of the Society of Motion Picture Engineers for November, 1935, the relative amplitudes of the carrier and the side frequencies in such a system vary with the ratio between the deviation in carrier frequency and the modulation rate, so that, by proper choice of the value of this ratio, the frequency components best suited for any given installation can be obtained.

In the circuit of Fig. 1, the necessary plate potential and filament current for all the tubes is derived from a conventional rectifier unit 21 which is energized from an alternating current source 22. The filament circuits (not shown) are connected to a suitable low potential supply associated with the leads 23 of the rectifier unit.

The primary or carrier signal frequency is generated by a conventional oscillator 24 which may be of the well-known tuned plate type, the

tuning being effected by the coil 25 and condenser 26 alone or by these elements in combination with the reactance tube 27 as described below. The output of the oscillator is applied to the winding 28 of the transformer 29 and the necessary feedback to the grid circuit is obtained through the other primary coil 30. When not in use the oscillator is disabled by closing the switch 111 to short-circuit the winding 30 and oscillation is started when desired by opening this switch.

The secondary windings 31 and 32 are shunted by suitable impedance stabilizing resistors 33 and 34 and by the rectifiers 35 and 36 connected to be conductive for signal pulses of opposite polarities above the biasing voltages appearing across the resistors 37 and 38. The rectifiers are connected across both secondary windings through the parallel combination of a high resistor 39 and a condenser 40 but it will be noted that the input of the following amplifier tube 41 is connected across only the winding 31 since the mid-point 42 of the secondary is by-passed to ground through the condenser 109. The circuit of tube 41 is conventional and its output may be amplified further as required, by a power amplifier 44 before being supplied to the loudspeakers 45 of the system.

Under most operating conditions the switches 46 and 47 are closed as shown and the positive potential across the resistor 48 is applied to both electrodes of the diodes and to grid 49 of the tube 41 but the grid is negatively biased with respect to the cathode as required since the positive potential across both resistors 48 and 103 is applied to the cathode.

Any signal potentials in the windings 31 and 32 will cause the diodes 35 and 36 to conduct on alternate half cycles of the signal wave and the diode currents charge the condensers 50 and 51 to potentials which vary with the amplitude of the signal. By proper choice of the values of the condensers and the associated resistors 37 and 38, these networks may be given time constants such that the biases on the diodes due to current in the resistors remain substantially constant throughout the cycle of the signal wave at the value required to cause the diodes to pass only the upper halves of the signal pulses. Moreover, since the biases are produced by the signal potential, they vary with changes in the signal amplitude so that the diodes tend to conduct only the upper half of the pulses at any signal amplitude.

If the curve 52 of Fig. 3 is taken as representing a signal potential of maximum value E appearing across the windings 31 and 32, the bias on the diodes assumes the value

$$\frac{E}{2}$$

and when the signal potential exceeds the bias voltage, the diodes conduct and become low impedance shunts for the peak portions 53 and 54 of the signal wave. The potential between the grid 49 of tube 41 and the lower point of winding 32 therefore varies substantially in accordance with the flat topped curve 55. Since the cathode 56 of the tube 41 is connected through ground and condensers 114 and 109 of the mid-point 42 of the transformer winding and one-half of the signal potential wave 52 is developed across the winding 32, the cathode potential, with respect to the lower end of winding 32, will vary with the signal wave in accordance with the curve 57 which is of one-half the amplitude of curve 52. The signal input potential to the tube 41 therefore varies in accordance with the difference

in amplitudes of the curves 55 and 57 as indicated by the curve 58.

It is therefore seen that by means of the circuit just described each sine wave component in the output of the oscillator 24 is converted to a complex wave according to Fig. 2F which has been shown to be desirable in systems of this type.

In the above description, the effect of the potential drop in the windings 31 and 32 due to diode current has been neglected but in practice this drop will produce some flattening of the peaks of the wave 52. However, if the value of resistor 39 is high, the effect of the diode current on the wave form is greatly reduced. Even though the peaks of wave 52 may be somewhat flattened, if the values of the resistors 37 and 38 and the condensers 50 and 51 are selected so as to make the bias voltage on the diodes equal to one-half the peak value of curve 52 of Fig. 3, the input to tube 41 will be a double peaked wave as required for greater effective loudness of the signal.

The action of this peak doubling circuit on a frequency modulated signal will be made clear by considering the following typical cases. If the output of tube 24 is 850 cycles modulated ± 150 cycles at a rate of two hundred times per second, the resulting output may be considered to consist of predominant frequency components of 450, 650, 850, 1050, 1250, etc. cycles per second having relative amplitudes and phases determined by the basic considerations involved in the analysis of frequency modulated waves. The effect of the peak doubling circuit on this complex tone may be considered the same as that of adding to the system a second frequency modulated oscillator which has a carrier of 2550 cycles (3 times 850 cycles), a frequency deviation of ± 450 cycles (3 times 150 cycles), but the same modulation rate. In other words the peak doubling circuit adds to the original complex tone other predominant components of 2150, 2350, 2550, 2750, 2950, etc., cycles per second. It is to be noted that all of these numerous components of the final complex signal so produced automatically have amplitude and phase relationships such that the peak factor is kept low, the resultant wave form at any instant being that of Fig. 2F.

It will also be understood that, if desired, other peak doubling circuits, similar to the one just described, may be added in tandem to increase further the number of frequency components in the signal finally delivered to the loudspeakers.

If amplitude modulation of the signal is desired, this may be introduced in various known ways as for example by closing the switch 47 on contact 59 to connect the cathode 56 to ground through any suitable variable biasing means 60 such as a motor driven potentiometer or oscillator.

Frequency modulation of the output of the oscillator 24 may be effected in various known ways but in the circuit shown the tube 27 is used as a variable reactance in shunt to the oscillator coil 25 in the well-known manner as described for example in an article "Automatic frequency control" by Travis in the Proceedings of the I. R. E., vol. 23, October 1935, pages 1125 to 1141. Plate potential is applied to the tube through a suitable coil 61 and screen potential and cathode bias are derived from the voltage dividing resistors 62, 63 and 64. The grid 65 is excited from the oscillator 24 through the transformer 66 by the signal potential drop in resistor 67 so that the plate-to-ground circuit of the tube 27 becomes

effectively a shunt reactance which may be varied by varying the bias of the grid 65 in the manner explained in the article referred to above.

In this case the effective reactance of tube 27 is varied in various ways, as required for the particular type of frequency modulation desired, by means of bias potentials derived from the multivibrator 68 and applied to the grid 65 through switch 69 and a selected one of the switches 70 to 73.

The multivibrator 68 is basically of the conventional type in which the grids and plates of the tubes 74 and 75 are cross-connected through blocking condensers 76 and 77 to produce at the output terminal 78 a potential wave of the alternate positive and negative pulses characteristic of this type of circuit. However, for the purposes of this invention it is desirable to modify the usual wave form of these pulses so that they approach as nearly as possible to the ideal square wave of Fig. 2B. A very good approximation to this ideal wave is obtained in this circuit by the use of high resistors 115 and 116 to limit the grid currents and by connecting the grid of tube 74 to the plate of tube 75 through a resistor 117. The resistors 117 and 118 together should be approximately equal to resistor 119 but in this case best results were obtained by making resistor 117 of the order of three times resistor 118.

Siren signal

To produce a siren signal switches 69, 73 and 79 are closed to start the oscillator 68 and connect its output from terminal 78 to the grid 65 of the tube 27 over a circuit including condenser 80, resistor 81, switch 82, contact 83, resistor 84, condenser 85, conductor 86 and the switches 73 and 69.

For correct simulation of a siren it is of course desirable that the signal begin at its lowest frequency. For the circuit shown, this means that the potential of terminal 78 must always be increased positively by the initial pulse of the multivibrator.

When the switch 79 is open the oscillator 68 is blocked since the high resistor 87 produces such a large bias on the grid of tube 74 that the plate current is nearly cut off and the gain is so low that the circuit cannot oscillate. If necessary in any case to prevent undesired high frequency oscillations, the circuit may be further disabled when not in use by grounding the grid of tube 75 through switch 83 which would be opened when switch 79 is closed. When the switch 79 is closed to short-circuit resistor 87 the plate current of tube 74 suddenly increases and its plate potential decreases thereby driving the grid of tube 75 negative, decreasing its plate current and increasing its plate potential so that the initial output pulse is always in the positive direction as required. The cathode resistor 112 of the tube 75 is preferably so chosen that in the inactive condition the plate 113 is at about the same potential as its average potential when the circuit 68 is oscillating. Under this condition the condenser 80 is normally charged to its average operating potential and the transient drift in carrier frequency during the first few cycles of oscillation is reduced to a minimum.

The constants of the circuit of the oscillator 68 are such that it normally oscillates at some very low frequency preferably one cycle per second or less depending on the time of cycle of frequency modulation desired. In any case the frequency should be not more than a few cycles per second

since, as noted above, a higher modulating rate results in the loss of the siren effect. With these alternate positive and negative pulses applied to the resistor 84, the potential across the condenser 85 will vary with time, as the condenser charges and discharges, as a substantially symmetrical triangular wave of the oscillator frequency and of an amplitude depending on the setting of the contact 83. In one case a satisfactory triangular wave as indicated adjacent to conductor 86 was obtained with a resistor 84 of 250,000 ohms and a condenser 85 of 4 microfarads capacity.

Since this triangular wave is applied as a variable bias on the grid of tube 27, the impedance of this tube and consequently the frequency of the oscillator 24 will vary cyclically at the frequency of multivibrator 68 over a frequency range determined by the setting of contact 83. The frequency modulated output of tube 24 is then further augmented by the addition of frequency modulated components produced by the peak doubling circuit transmitted to the tube 41 in the manner already described and supplied to the loudspeakers to produce the siren tone.

In one particular design a carrier frequency of 850 cycles per second is frequency modulated ± 150 cycles per second at a rate of one cycle per second to produce a siren-like effect. This particular combination was chosen so that the frequency band corresponded to the most efficient part of the loudspeaker response characteristic. It should be noted that in this device as one component varies slowly from 700 to 1000 cycles another component varies at the same rate from 2100 to 3000 cycles, thus stimulating various sets of the hearing nerves to increase the loudness of the signal. The effect of this signal is therefore that of a tone slowly rising and falling in pitch as in the case of the conventional siren.

Jump frequency signal

If a jump frequency signal is required the operation of the circuit is the same as for the siren tone except that switch 73 is opened, switch 72 is closed and switch 82 is moved to its other position to connect the multivibrator to resistor 89. In this case the square wave output from the multivibrator is applied without modification to the grid of the tube 27 so that the bias is changed suddenly from one extreme value to the other instead of varying gradually as in the case of the siren tone. The tuning of the oscillator 24 is therefore changed at twice the multivibrator frequency to cause the signal to "jump" between two frequencies which will be respectively above and below the steady tone frequency by an amount proportional to the amplitude of the square wave as determined by the setting of contact 90 on resistor 89. This signal is best employed at low modulation rates of 1 to 3 times per second.

Horn signal

To reproduce a horn type signal the circuit is the same as for the siren signal except that the frequency supplied from the multivibrator is increased well above the siren range to a frequency of the order of 200 cycles per second. In accordance with known practice this may be effected conveniently by connecting across the output circuit of one of the tubes a network tuned to the desired frequency in which case the wave form of the potential across the network will be approximately a sine wave of the frequency to which the network is resonant. In this case the network

91 comprises a single coil 92 and two condensers 93, 94 which, when connected in parallel across the coil produce resonance at about 200 cycles per second.

For horn signals switches 95 and 96 are closed to connect the network across the output of tube 74, switches 72 and 73 are both open and the 200-cycle output is taken at a suitable level from the potentiometer 97 and impressed on the grid 65 of the tube 27 through switches 70 and 69. Under this condition the effective inductance in the tuned circuit of the oscillator 24 is cyclically varied at 200 cycles per second to frequency-modulate the output of this oscillator over a band corresponding to the setting of potentiometer 97. This gives a very complex tone of a harsh sounding character which simulates the sound of a motor driven type of horn. With a carrier frequency of 850 cycles and a frequency deviation of ± 150 cycles, the principal frequency components of appreciable magnitude are 450, 650, 850, 1050 and 1250 cycles per second. A similar set of frequency components are produced around 2550 cycles as a carrier by the harmonic generator circuit.

Bell tone

For bell tone effects, switches 96 and 70 are opened and switch 71 is closed thereby removing condenser 94 and potentiometer 97 from the circuit and connecting potentiometer 98 to the grid of tube 27. The condenser 93 is of such capacity that the network is now resonant to some suitable higher frequency such as 400 cycles per second and the output of oscillator 24 is frequency-modulated over a frequency band of a width determined by the setting of the potentiometer 98. With an 850-cycle carrier and a frequency deviation of ± 150 cycles as before, the principal components of this signal are 450, 850, 1250 and 1650 cycles, with another set of frequency components similarly spaced about 2550 cycles. To give this complex signal the percussion characteristic of a bell it is of course necessary that it be transmitted to the loudspeakers in pulses having a suitable logarithmic decrement as in the Owens patent referred to above.

For this purpose the switch 46 is opened and the motor 100 is energized by closing switch 101 so that the cam 102 is revolved at ninety revolutions per minute or any other suitable speed according to the striking rate desired. The opening of switch 46 removes the positive potential across resistor 48 from the grid of tube 41 which then goes to ground potential and the potential across resistors 48 and 103 bias the tube to cut-off.

With the cam follower spring 104 engaging contact 105, as shown, the condenser 106 is charged over a path extending from the high potential end of resistor 103 to contact 105, through the follower spring 104 and a current-limiting resistor to condenser 106. When the spring 104 drops into the notch 108 of the cam 102 so that the spring momentarily engages contact 107, a portion of the charge of condenser 106 is transferred to the much smaller condenser 109 and the latter is suddenly charged to a potential sufficient to reduce the negative bias on grid 49 to normal value and permit the frequency-modulated output of tube 24 to pass to the loudspeakers.

However, with further rotation of the cam the transfer circuit is opened at contact 107, the charging circuit for condenser 106 is reclosed at contact 105 and condenser 109 begins to discharge through the rheostat 43. As the voltage across

condenser 109 falls toward zero the negative bias on the grid 49 increases logarithmically toward cut-off and the signal is damped at a rate depending on the position of the arm 110, to produce the bell tone effect.

The output of a plurality of independent oscillators would vary in relative phase from time to time and usually would not give a wave form which permits of reproduction at maximum loudness. The use of frequency modulation in the manner described above to produce the complex signal required for generating a bell tone not only eliminates the plurality of special oscillators ordinarily required for this purpose but it also ensures that the various components of the signal shall be in the proper relative phase to keep the peak factor low.

A bell tone signal having the particular components given in the above illustration sounds rather harsh but this is an advantage where the attention value of the signal is the primary consideration. If a more musical signal is required it can be obtained by using harmonically related components, as, for example, by using a carrier of 800 cycles per second in which case the components would be 400, 800, 1200, etc. cycles per second.

While the invention has been described with reference to a particular circuit for purposes of illustration, it will be understood that the signal generating facilities described may be used in a number of different combinations according to the requirements of the particular case and that the circuits shown and the procedures described may be modified in various ways within the scope of the following claims. For example, in the above description of the siren, motor driven horn and bell tones only the modulation rate is changed. Many other distinctive tones can be obtained as required by also changing the carrier frequency or the frequency duration, or both.

What is claimed is:

1. In a signaling system, a source of oscillations of variable intensity, a balanced circuit connected to said source, a pair of oppositely poled diodes connected across the balanced circuit, means for variably biasing each diode to substantially one half the potential impressed on the diode from the source, a signal path having an unbalanced input circuit and an output circuit adapted to be connected to a loudspeaker, and means for impressing on the input circuit of the path the potential existing across only one side of the balanced circuit.

2. The method of generating a highly complex signal which consists in producing oscillations of a predetermined carrier frequency, frequency-modulating the oscillations at a constant modulation rate and range of frequency deviation to produce a wave having a plurality of side frequency components, operating on said wave to produce therein a predetermined component which is a multiple of the carrier frequency and other components of frequencies corresponding to those which would be obtained by frequency-modulating the multiple frequency component at said constant rate but with said multiple of said deviation range and controlling the amplitude and phase relationships of said components to increase the ratio of the loudness of said highly complex signal to the intensity of said highly complex signal.

3. In a signal generator, the combination with a variable frequency oscillator for generating signal frequencies and a harmonic generator com-

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prising means for generating and adding to the output of said oscillator a third harmonic component substantially equal in magnitude to the fundamental of each signal frequency generated by said oscillator, of means for controlling the relative phase of said fundamentals and harmonic components to produce a complex single wave without substantially increasing the peak factor of the signal.

4. In a signal generator, a signal oscillator, a variable reactance tube for controlling the frequency of said oscillator, a source of control oscillations for cyclically varying the gain of said reactance tube to frequency-modulate the output of the signal oscillator, means interposed between said source of control oscillations and said reactance tube for selectively adjusting the time rate of the change in gain of said reactance tube, means for generating and adding to the output of said signal oscillator a third harmonic component substantially equal in magnitude to the fundamental of each signal frequency generated by said signal oscillator, and means for controlling the relative phase of said fundamentals and harmonic components to produce a complex single wave without substantially increasing the peak factor of the signal.

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5. A signal generator according to claim 4 having means for providing a plurality of voltage values for the output of the source of control oscillations.

6. A signal generator according to claim 4 having means for providing a plurality of frequencies for the output of the source of control oscillations.

HERBERT C. CURL.
JAMES D. KLEINKAUF.

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