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SIGNALING SYSTEM

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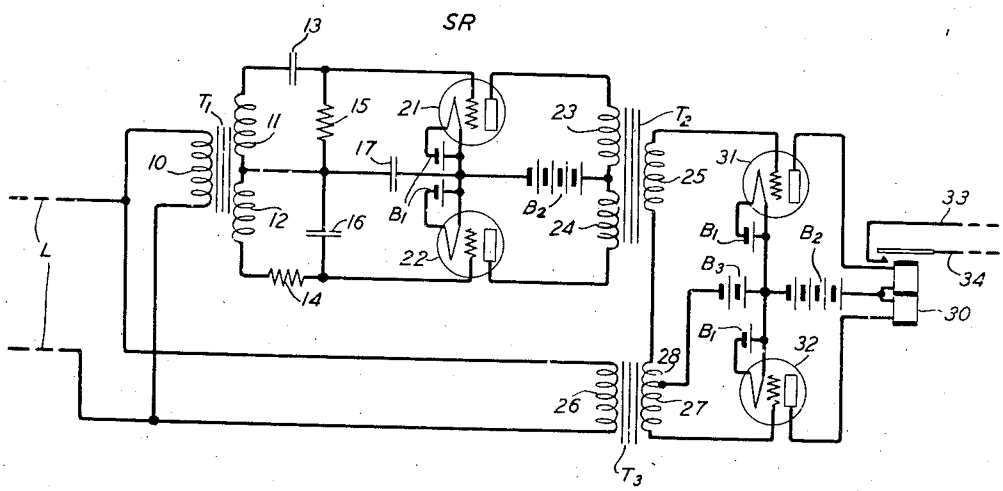

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SIGNALING SYSTEM

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This invention relates to signaling systems and particularly to systems employing voice frequency currents for transmitting signals.

Objects of the invention are an increase in the reliability of alternating current signaling and the prevention of false operation in response to interference currents.

In signaling systems in which current of one or more voice frequencies is used for signaling, the signal receiver must respond to signaling current without being responsive to voice currents or interference currents of signaling frequency. It is known in such systems to employ frequency selective or time delay arrangements for preventing false signal operations.

According to this invention, false signal operation is prevented in an alternating current signaling system by distinguishing between signaling currents which are of sine wave form and other currents due to the fact that a sine wave is the only wave form the mathematical derivative and integral of which are exactly alike. Representing the signal wave by $E \sin \omega t$, the first derivative is $E\omega \cos \omega t$ and the integral is

$$-\frac{E}{\omega}\cos \omega t$$

By applying the signal wave to differentiating and integrating channels, the outputs if adjusted to be equal in magnitude will cancel each other when combined. For any other wave, however, the derivative and integral will be different and the sum of the output of the two channels will not be zero. Therefore, the differentiating and integrating channels in combination may be used as a guard channel to prevent a signal response to any other than a sine wave.

A feature of the invention is a signal receiver for connection to a line through which voice currents and signals consisting of voice frequency currents are transmitted, operation of the signal relay being effected by the energization of one of its windings responsive to the transmission of signal current through the line, the operation of the relay while voice currents are being transmitted through the line being prevented by the energization of another winding connected to the combined output of an integrating channel and a differentiating channel.

A signal receiver arranged in accordance with the invention is shown in the drawing which consists of a single figure. The invention is not limited, however, in its application to the specific arrangement shown but may be applied generally to any device which it is desired to make responsive to sinusoidal waves and unresponsive to waves of other shape.

Referring to the drawing, a signal receiver SR is connected to a line L over which signals and voice currents are transmitted. The receiver SR comprises transformers T1, T2 and T3, amplifiers 21 and 22, detectors 31 and 32 and a polarized signal relay 30. Three batteries are shown, a battery B1 for energizing the cathodes of the amplifier and detector tubes, a battery B2 in the anode-cathode circuits of these tubes, and a battery B3 for biasing the grids of the detector tubes. Voice currents and signal currents in line L are applied through windings 10, 11 and 12 of transformer T1 to amplifiers 21 and 22 in parallel and through windings 26 and 27 of transformer T3 to the detector 32. The outputs of amplifiers 21 and 22 are differentially combined by windings 23 and 24, and applied through winding 25 of transformer T2 to the detector 31. The transformer T3 and detector 32 constitute a signal channel for operatively energizing the lower winding of relay 30; and the transformer T1, detectors 21 and 22, transformer T2 and detector 31 constitute a guard channel for energizing the upper winding of relay 30 to prevent its response to voice currents or response while voice currents are being transmitted over line L. The guard channel effect is obtained by connecting transformer windings 11 and 12 to the amplifiers 21 and 22 in such a manner that the output of amplifier 21 is proportional to the derivative of the line voltage across winding 10 of transformer T1 and the output of amplifier 22 is proportional to the integral of the line voltage. It is known that the current through a capacity is the derivative of the potential across it, and that the potential across a capacity is the integral of the current through it. Accordingly, the winding 11 of transformer T1 is connected through a condenser 13 to the grid of tube 21; and a resistor 15, having a very small impedance at the signaling frequency as compared with that of condenser 13, is connected in series with condenser 13 and winding 11 so that the current through resistor 15, and therefore the potential impressed on the grid of tube 21, are substantially the derivative of the voltage across winding 11. And the winding 12 of transformer T1 is connected through a resistor 14 to the grid of tube 22; and a condenser 16, having a reactance which is very small at the signaling frequency compared to the impedance of the resistor 14, is connected in series with winding 12 and resistor 14, so that the voltage across the condenser, and therefore the potential impressed on the grid of tube 22, are substantially proportional to the integral of the voltage across winding 12.

Representing the voltage applied by signaling current by $E \sin \omega t$, the first derivative is $E\omega \cos \omega t$ and the integral is

$$-\frac{E}{\omega}\cos \omega t$$

If then the outputs of detectors 21 and 22 are adjusted to be equal in magnitude and are differentially combined, the resultant will be zero; and there will be no current in the output circuit of detector 31, so that the energization of the lower winding of relay 30 in the output circuit of detector 32 will cause the operation of relay 30. The operation of relay 30 closes a circuit through conductors 33 and 34 for effecting any desired result. In response to the application of a voltage of any wave form other than that of a sine wave, the derivative and integral will be unlike in form and consequently the output of amplifier 21 will not be canceled by the output of amplifier 22; and the resultant energization of the winding 25 of transformer T3 effects a current in the output circuit of detector 31 which energizes the upper winding of relay 30 to prevent the operation of the relay by energization of its lower winding by current in the output circuit of detector 32.

Since the processes of integration and differentiation are somewhat imperfect due to the finite ratio of the shunt to series impedances, a winding 28 of transformer T3 adds a small part of the energy from the signal channel to the input to tube 31 to correct for secondary effects as hereinafter explained.

If the relative sensitivities of the amplifiers and detectors are properly chosen, relay 30 will be operated in response to signal currents alone but will be prevented from operating when voice or other non-sinusoidal currents are being transmitted in line L. The performance of the arrangement, both to steady-state and to transient conditions occurring at the start of a signal will be analyzed to show that the arrangement will provide the satisfactory operating margins. It is shown that the transient at the start of a signal is of the nature of two superposed condenser discharge curves, one large but of short duration and the other small but of longer duration. The transient contains no oscillations of the signal or any other frequency.

If a signal, E sin ωt, is applied to a differentiating network, the resultant is proportional to $E\omega\cos\omega t$; and if it is applied to an integrating network, the resultant is proportional to

$$-\frac{E}{\omega}\cos\omega t$$

These cosine waves are opposite in phase so that if they are multiplied by suitable constants to make them equal, and are then added, the result will be complete cancelation or zero. This is true for the steady-state condition, but the signal must begin and end, and it is of interest to investigate the nature of the starting and stopping transients.

Assume that at time $t=0$, a potential E $\sin(\omega t+\alpha)$ is suddenly applied to a capacity C and a resistance R in series. Then

$$E\sin(\omega t+\alpha)=iR+e_c$$

where e_c is the potential across the condenser. From this

$$i=\frac{E\sin(\omega t+\alpha)-e_c}{R}$$

but

$$q=Ce_c \text{ and } i=\frac{dq}{dt}=C\frac{de_c}{dt}$$

Equating these values of i and rearranging

$$\frac{de_c}{dt}+\frac{e_c}{RC}=\frac{E}{RC}\sin(\omega t+\alpha) \qquad (1)$$

This may be compared with

$$\frac{dy}{dx}+Py=Q$$

whose solution may be shown to be

$$y=\epsilon^{-\int Pdx}\left[\int\epsilon^{\int Pdx}Qdx+k\right]$$

By comparison

$$e_c=\epsilon^{-\frac{t}{RC}}\left[\frac{E}{RC}\int\epsilon^{\frac{t}{RC}}\sin(\omega t+\alpha)dt+k\right]$$

Integrating,

$$e_c=\epsilon^{-\frac{t}{RC}}\left[\frac{E}{RC}\epsilon^{\frac{t}{RC}}\left(\frac{\frac{1}{RC}}{\frac{1}{R^2C^2}+\omega^2}\sin(\omega t+\alpha)-\frac{\omega}{\frac{1}{R^2C^2}+\omega^2}\cos(\omega t+\alpha)\right)+k\right]$$

Let

$$\frac{1}{RC}=\omega_1 \quad e_c=E\left[\frac{\omega_1^2}{\omega_1^2+\omega^2}\sin(\omega t+\alpha)-\frac{\omega\omega_1}{\omega_1^2+\omega^2}\cos(\omega t+\alpha)\right]+k\epsilon^{-\omega_1 t} \qquad (2)$$

When $t=0$, $e_c=0$. Therefore,

$$k=E\left[\frac{\omega\omega_1}{\omega_1^2+\omega^2}\cos\alpha-\frac{\omega_1^2}{\omega_1^2+\omega^2}\sin\alpha\right]$$

Substituting in (2)

$$e_c=E\left[\frac{\omega_1^2}{\omega_1^2+\omega^2}\sin(\omega t+\alpha)-\frac{\omega\omega_1}{\omega_1^2+\omega^2}\cos(\omega t+\alpha)+\epsilon^{-\omega_1 t}\left(\frac{\omega\omega_1}{\omega_1^2+\omega^2}\cos\alpha-\frac{\omega_1^2}{\omega_1^2+\omega^2}\sin\alpha\right)\right] \qquad (3)$$

The drop across the resistance is

$$iR=E\sin(\omega t+\alpha)-e_c=E\left[\frac{\omega^2}{\omega_1^2+\omega^2}\sin(\omega t+\alpha)+\frac{\omega\omega_1}{\omega_1^2+\omega^2}\cos(\omega t+\alpha)+\epsilon^{-\omega_1 t}\left(\frac{\omega_1^2}{\omega_1^2+\omega^2}\sin\alpha-\frac{\omega\omega_1}{\omega_1^2+\omega^2}\cos\alpha\right)\right] \qquad (4)$$

Equations 3 and 4 may be taken to represent the potentials at the outputs of the integrating and differentiating networks in Fig. 3. Let the steady-state potentials in the output of each circuit at the signaling frequency, $\omega_0/2\pi$, bear a ratio of Δ to the applied potential (assumed to be the same for both circuits). Then in Equation 3 $\omega_1=\Delta\omega_0$ and in Equation 4 $\omega_1=\omega_0/\Delta$. Also let $\omega=S\omega_0$. Substituting these values in (3) and (4) and adding the two equations, we get,

$$\frac{e_c+iR}{E}=\left(\frac{\Delta^2}{S^2+\Delta^2}+\frac{S^2}{S^2+\frac{1}{\Delta^2}}\right)\sin(\omega t+\alpha) \qquad (5)$$

$$+\left(\frac{\frac{S}{\Delta}}{S^2+\frac{1}{\Delta^2}}-\frac{\Delta S}{S^2+\Delta^2}\right)\cos(\omega t+\alpha)$$

$$+\epsilon^{-\Delta\omega_0 t}\left(\frac{\Delta S}{S^2+\Delta^2}\cos\alpha-\frac{\Delta^2}{S^2+\Delta^2}\sin\alpha\right)$$

$$+\epsilon^{-\frac{\omega_0 t}{\Delta}}\left(\frac{\frac{1}{\Delta^2}}{S^2+\frac{1}{\Delta^2}}\sin\alpha-\frac{\frac{S}{\Delta}}{S^2+\frac{1}{\Delta^2}}\cos\alpha\right)$$

Since Δ is small compared with unity, this equation may be simplified by omitting the higher order infinitesimals.

$$\frac{e_c+iR}{E}=\Delta^2\left(S^2+\frac{1}{S^2}\right)\sin(\omega t+\alpha)-\Delta\left(\frac{1}{S}-S\right)\cos(\omega t+\alpha)$$
$$+\frac{\Delta}{S}\epsilon^{-\Delta\omega_0 t}\left(\cos\alpha-\frac{\Delta}{S}\sin\alpha\right)$$
$$+\epsilon^{-\frac{\omega_0 t}{\Delta}}(\sin\alpha-\Delta S\cos\alpha) \qquad (6)$$

It will be noted that when $S=1$, the only term left after a time long enough for the exponential terms to disappear is the first. It is this term which is compensated for by introducing in opposite phase through winding **28** a small amount ($2\Delta^2$) of the original signal in the input to the guard channel detector **31**. With this compensation, the sinusoidal components applied to the detector become

$$\Delta^2\left(S-\frac{1}{S}\right)^2\sin(\omega t+\alpha)+\Delta\left(S-\frac{1}{S}\right)\cos(\omega t+\alpha) \qquad (7)$$

and both disappear at the signaling frequencies $S=1$). In the neighborhood of the signaling frequency, the first term is small compared to the second and may be neglected.

The magnitude of the transient terms (the third and fourth terms) of Equation 6 evidently depends upon the phase, α, of the signal wave at the time $t=0$. Also, it will be noted that the second transient term is in general the largest, but has a very short time constant, Δ/α_0. Making use of approximations in which higher order infinitesimals are neglected, the sum of the transient terms is given in the following table for a variety of conditions assuming $S=1$.

Sum of transient terms

α	Formula	$t=0$	$t=\frac{\Delta}{\omega_0}$	$t=\frac{1}{\omega_0}$	$t=\frac{1}{\Delta\omega_0}$	$t=\frac{n}{\omega_0}$
$\frac{\pi}{2}$	$\epsilon^{-\frac{\omega_0 t}{\Delta}}-\Delta^2\epsilon^{-\omega_0 t}$	1	ϵ^{-1}	$-\Delta^2$	$-\Delta^2\epsilon^{-1}$	$-\Delta^2+\epsilon^{-\frac{n}{\Delta}}$
$\left(\frac{\pi}{2}-\frac{\Delta}{S}\right)$	$\epsilon^{-\frac{\omega_0 t}{\Delta}}(1-\Delta^2)$	1	ϵ^{-1}	$\epsilon^{-\frac{1}{\Delta}}$	$\epsilon^{-\frac{1}{\Delta^2}}$	$\epsilon^{-\frac{n}{\Delta}}$
$\frac{\pi}{4}$	$\frac{1-\Delta}{\sqrt{2}}\left(\Delta\epsilon^{-\Delta\omega_0 t}+\epsilon^{-\frac{\omega_0 t}{\Delta}}\right)$	$\sqrt{\frac{1}{2}}$	$\sqrt{\frac{1}{2}}\epsilon^{-1}$	$\sqrt{\frac{1}{2}}\Delta^{(1-\Delta)}$	$\sqrt{\frac{1}{2}}\Delta^{(1-\Delta)}\epsilon^{-1}$	$\sqrt{\frac{1}{2}}\Delta\epsilon^{-\Delta n}$
ΔS	$\Delta\epsilon^{-\Delta\omega_0 t}(1-\Delta^2)$	Δ	Δ	$\Delta(1-\Delta)$	$\Delta\epsilon^{-1}$	$\Delta\epsilon^{-n\Delta}$
0	$\Delta\left(\epsilon^{-\Delta\omega_0 t}-\epsilon^{-\frac{\omega_0 t}{\Delta}}\right)$	0	$\Delta(1-\epsilon^{-1})$	Δ	$\Delta\epsilon^{-1}$	$\Delta\epsilon^{-n\Delta}$

As noted above, the time constant of the second transient term is very short so that for values of t greater than $1/\omega_0$ (the time corresponding to one radian of the signal wave) it disappears in comparison with the first transient, (except when

$$\alpha=\frac{\pi}{2}-\frac{\Delta}{S}$$

which makes the first term zero for all values of t) and the latter only need be considered. The first transient is a maximum when $\alpha=0$, being

$$\frac{\Delta}{S}\epsilon^{-\Delta\omega_0 t}$$

At $t=\frac{1}{\omega_0}$ (one radian), the transient is $\frac{\Delta}{S}$

$t=\frac{1}{\Delta\omega_0}\left(\frac{1}{\Delta}\text{radians}\right)$, the transient is $.37\,\frac{\Delta}{S}$

$t=\frac{2\pi}{\Delta\omega_0}\left(\frac{1}{\Delta}\text{cycles}\right)$, the transient is $.002\,\frac{\Delta}{S}$.

From this, the relative sensitivity of the guard and signal channels is determined. For example, if it is desired that the circuit respond in a time

$$t=\frac{1}{\Delta\omega_0},$$

the signal channel must have a sensitivity of about $.37\Delta$. The steady-state sensitivity of the guard channel is then the same as that of the signal channel at a frequency determined by the relation

$$\Delta\left(S-\frac{1}{S}\right)=.37\Delta,$$

or

$$S=1.2 \text{ or } .83$$

At frequencies farther from the signal frequency the guard channel sensitivity exceeds that of the signal channel, and at frequencies closer to the signal frequency the guard channel is less sensitive than the signal channel.

From the above, it is apparent that satisfactory operating margins are obtained in the signal receiver SR.

The specific arrangement described above to illustrate the invention may be altered in detail without departing from the spirit of the invention. For example, amplifiers **21** and **22** may in practice be any form of amplifier, utilizing other types of tubes than triodes and consisting of more than one stage of amplification; **31** and **32** may be any form of detector; and any suitable responsive device may be used in place of the relay **30** and conductors **33** and **34**.

What is claimed is:

1. In a signaling system including a line subjected to voice currents and to signals consisting of voice frequency currents of sine wave form, a signal receiver for responding to incoming signals, said receiver comprising a differential signal relay, a signal channel for effecting the operative energization of a first winding of the relay responsive to signaling currents, and a guard channel consisting of two amplifiers in multiple and a detector controlling the energization of a second winding of said relay, the output circuits of said amplifiers being differentially connected to the input circuit of said detector, the input circuit of one of said amplifiers being arranged so that the current in its output circuit is proportional to the derivative of the current in the line and the input circuit of the other amplifier being arranged so that the current in its output circuit is proportional to the integral of the current in the line, the currents in the output circuits of said amplifiers being equal in response to signaling currents whereby the sec-

ond winding of said relay is ineffective to prevent the operation of said relay upon energization of its first winding, the current in the output circuit of said other amplifier in response to voice currents being larger than the output of said one amplifier to effect the energization of the second winding of the relay and thus prevent the operation of the relay.

2. In a signal device for connecting with a line through which voice currents and voice frequency signaling currents of sine wave form are transmitted, a polarized signal relay, a signal channel for energizing an operating winding of said relay responsive to current in a connected line, and a guard channel for energizing a biasing winding of said relay responsive to voice currents, said guard channel comprising two amplifiers, means differentially applying the outputs of said amplifiers to said biasing winding, and means controlling the level of energy applied to said amplifiers responsive to currents in said line so that the current in the output circuit of one of the amplifiers is proportional to the derivative of the current in the line and the current in the output circuit of the other amplifier is proportional to the integral of the current in the line, the current in the operating winding of said relay responsive to signaling current effecting the operation of the relay and the current in the biasing winding of the relay preventing the operation of said relay responsive to voice currents.

3. In a signal device for connection with a line through which voice currents and voice frequency signaling currents of sine wave form are transmitted, a polarized signal relay, a signal channel for energizing an operating winding of said relay responsive to current in a connected line, and a guard channel for energizing a biasing winding of said relay responsive to voice currents in a connected line, said guard channel comprising two amplifiers, means differentially applying the outputs of said amplifiers to said biasing winding, and means controlling the level of energy applied to said amplifiers responsive to currents in said line so that the current in the output circuit of one of the amplifiers is proportional to the derivative of the current in the line and the current in the output circuit of the other amplifier is proportional to the integral of the current in the line, the current in the operating winding of said relay responsive to signaling current effecting the operation of the relay and the current in the biasing winding of the relay preventing the operation of said relay responsive to voice currents and preventing the operation of said relay responsive to currents having a voice current component.

4. In a signal device, a signal relay, means comprising an input transformer for energizing an operating winding of said relay, another input transformer, a first amplifier, a second amplifier, means connecting said first amplifier to said other input transformer so that the current in the output circuit of said first amplifier is proportional to the derivative of the energy applied to said other input transformer, means connecting said second amplifier to said other input transformer so that the current in the output circuit of said second amplifier is proportional to the integral of the energy applied to said other input transformer, and means differentially combining and applying the outputs of said amplifiers to energize another winding of said relay to oppose the operation of the relay, the outputs of said amplifiers being equal and opposite responsive to sine wave signaling current applied to said input transformers, the energization of said operating winding being sufficient to operate the relay responsive signaling current alone, said other winding being operatively energized by the combined outputs of said amplifiers to prevent the operation of said relay when voice currents are applied to said input transformers.

5. In a signal device, a signal relay, means comprising an input transformer for energizing an operating winding of said relay, another input transformer, a first amplifier, a second amplifier, means connecting said first amplifier to said other input transformer so that the current in the output circuit of said first amplifier is proportional to the derivative of the energy applied to said other input transformer, means connecting said second amplifier to said other input transformer so that the current in the output circuit of said second amplifier is proportional to the integral of the energy applied to said other input transformer, and means differentially combining and applying the outputs of said amplifiers to energize another winding of said relay to oppose the operation of the relay, the outputs of said amplifiers being equal and opposite responsive to sine wave signaling current applied to said input transformers, the energization of said operating winding being sufficient to operate the relay responsive to signaling current alone, said other winding being operatively energized by the combined outputs of said amplifiers to prevent the operation of said relay when voice currents alone are applied to said input transformers and also when both voice and signaling currents are simultaneously applied to said input transformers.

6. A signal device comprising a polarized signal relay, an input transformer and a detector constituting a signal channel for energizing an operating winding of said relay, a second input transformer, the primary windings of said input transformers connected in parallel, a first amplifier, a second amplifier means comprising a secondary winding of said second transformer and a condenser and a resistor connected in series with said winding for impressing on the grid of the first amplifier a potential proportional to the derivative of the level of energization of the primary winding of the second transformer, means comprising another secondary winding of said second transformer and a condenser and a resistor in series with said other secondary winding for impressing on the grid of the second amplifier a potential proportional to the integral of the level of energization of the primary winding of the second transformer, means comprising a third transformer differentially combining the outputs of said amplifiers, and means comprising a detector applying the combined outputs of said amplifiers to a biasing winding of said relay.

7. A signal device comprising a polarized signal relay, an input transformer and a detector constituting a signal channel for energizing an operating winding of said relay, a second input transformer, the primary windings of said input transformers connected in parallel, a first amplifier, a second amplifier means comprising a secondary winding of said second transformer and a condenser and a resistor connected in series with said winding for impressing on the grid of the first amplifier a potential proportional

to the derivative of the level of energization of the primary winding of the second transformer, means comprising another secondary winding of said second transformer and a condenser and a resistor in series with said other secondary winding for impressing on the grid of the second amplifier a potential proportional to the integral of the level of energization of the primary winding of the second transformer, means comprising a third transformer differentially combining the outputs of said amplifiers, and means comprising a detector applying the combined outputs of said amplifiers to a biasing winding of said relay, the outputs of said amplifiers being equal and opposite responsive to sine wave signaling current applied to said input transformers and the energization of the operating winding of the relay being effective to operate the relay responsive to signaling current, the outputs of said amplifiers being unequally responsive to voice currents and the biasing winding of the relay being thereby energized sufficiently responsive to voice currents to prevent the operation of the relay when voice currents are applied to said transformers.

8. A signal device comprising a polarized signal relay, an input transformer and a detector constituting a signal channel for energizing an operating winding of said relay, a second input transformer, the primary windings of said input transformers connected in parallel, a first amplifier, a second amplifier means comprising a secondary winding of said second transformer and a condenser and a resistor connected in series with said winding for impressing on the grid of the first amplifier a potential proportional to the derivative of the level of energization of the primary winding of the second transformer, means comprising another secondary winding of said second transformer and a condenser and a resistor in series with said other secondary winding for impressing on the grid of the second amplifier a potential proportional to the integral of the level of energization of the primary winding of the second transformer, means comprising a third transformer differentially combining the outputs of said amplifiers, and means comprising a detector applying the combined outputs of said amplifiers to a biasing winding of said relay, the outputs of said amplifiers being equal and opposite responsive to sine wave signaling current applied to said input transformers and the energization of the operating winding of the relay being effective to operate the relay responsive to signaling current, the outputs of said amplifiers being unequally responsive to voice currents and the biasing winding of the relay being thereby energized sufficiently responsive to voice currents to prevent the operation of the relay when voice currents are applied to said transformers alone or in combination with signaling current.

9. In a signaling system, the method of selectively distinguishing between alternating signaling current of a sine wave form and current of other wave form, said method comprising rectification of the received alternating current for effecting a signal operation responsive to sine wave current, amplification of the received alternating current to obtain a current which is proportional to the derivative of the amplitude of the received current, amplification of the received alternating current to obtain a current which is proportional to the integral of the amplitude of the received current, and the differential combination of the two amplified currents for preventing a signal response to received alternating current of other than sine wave form.

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