

Sept. 3, 1940.

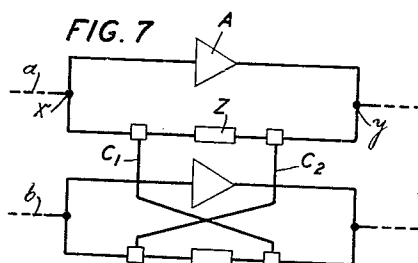
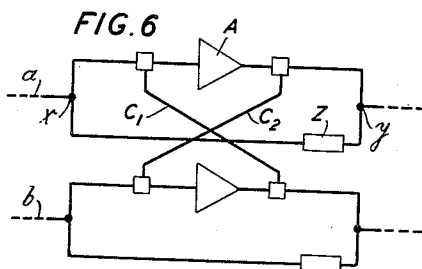
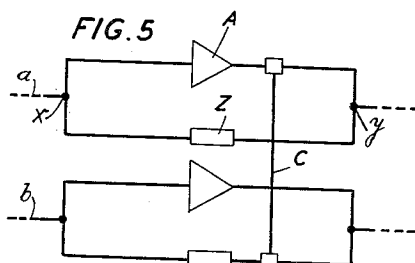
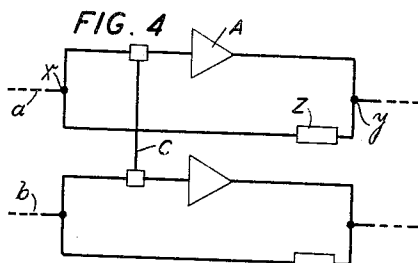
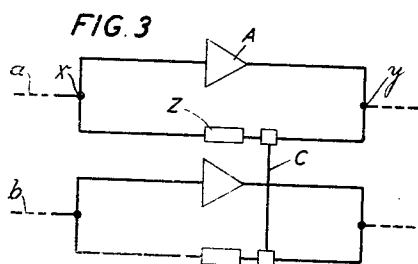
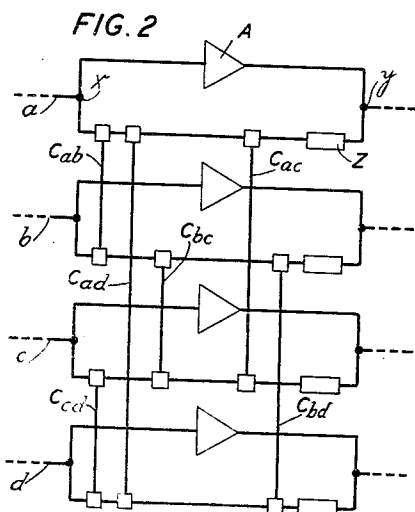
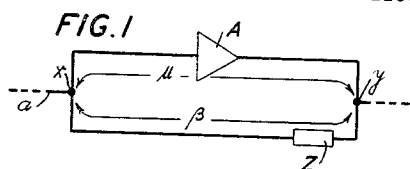
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2,213,564

MITIGATION OF INTERCIRCUIT INTERFERENCE

Filed Feb. 4, 1939

3 Sheets-Sheet 1



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MITIGATION OF INTERCIRCUIT INTERFERENCE

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FIG. 8

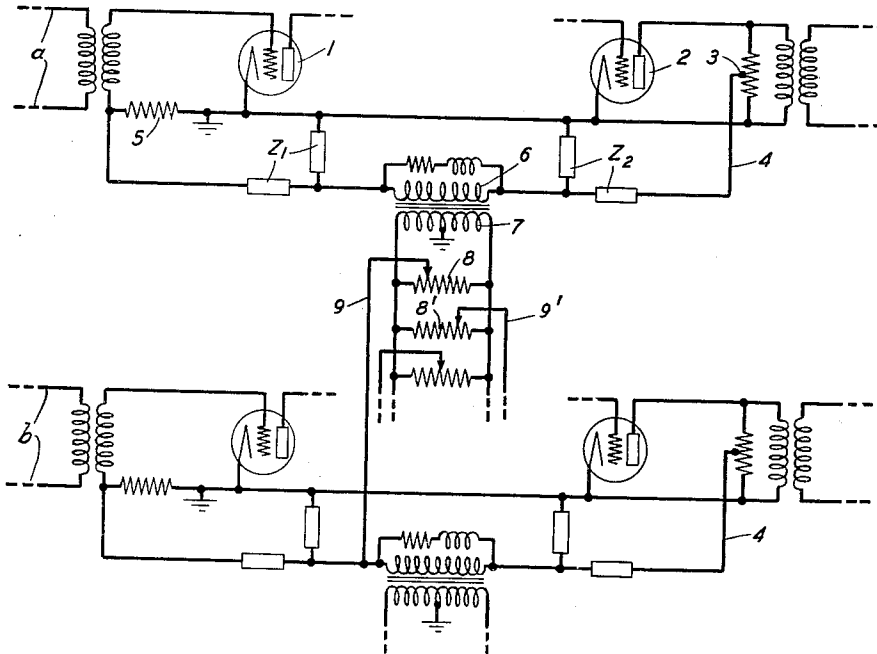
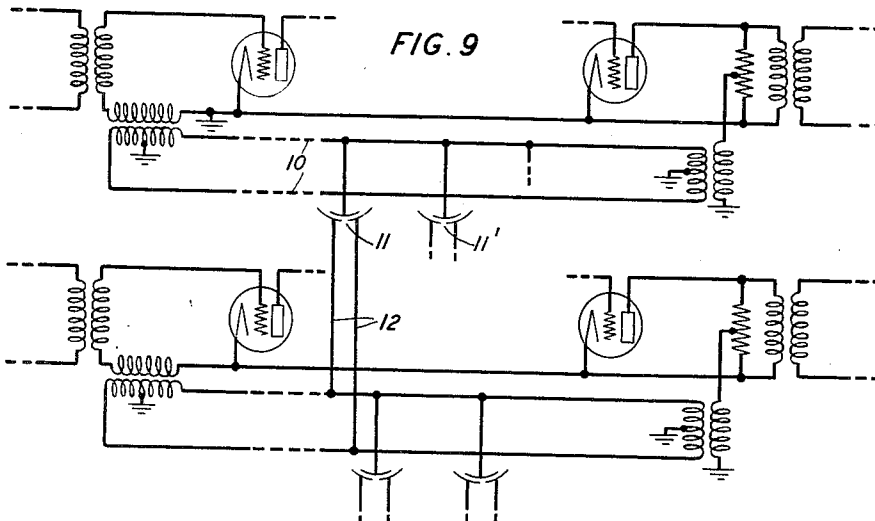


FIG. 9



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MITIGATION OF INTERCIRCUIT INTERFERENCE

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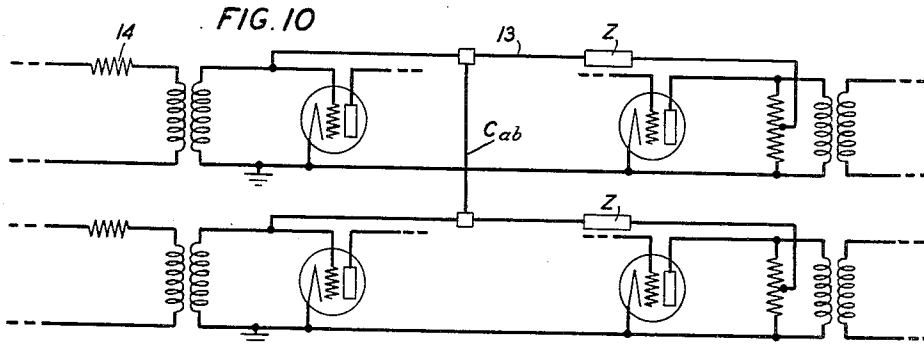


FIG. 11

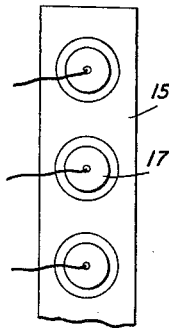


FIG. 12

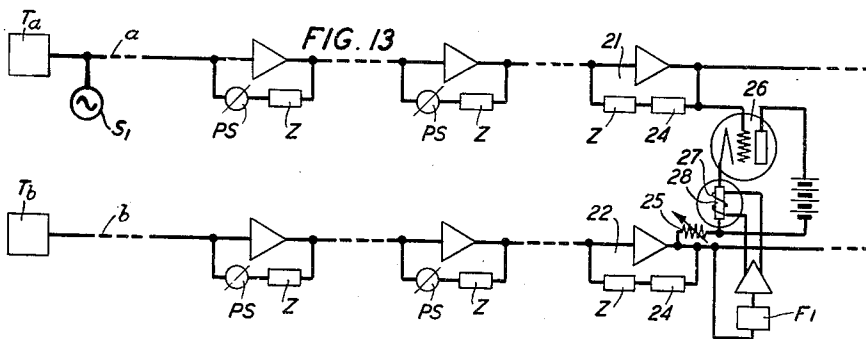
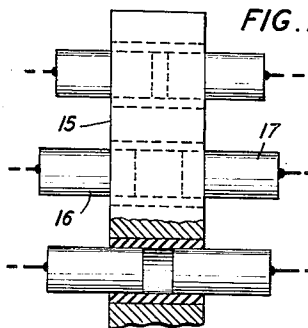
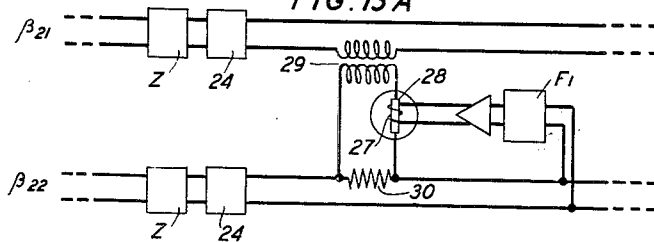


FIG. 13 A



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MITIGATION OF INTERCIRCUIT INTER-
FERENCE

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15 Claims. (Cl. 179-79)

The present invention relates to the reduction of interference in communication systems and more particularly to the mitigation of cross-talk and like effects in multicircuit signal transmission systems.

Interference effects of the kind mentioned are especially troublesome when two signaling circuits closely parallel each other for any considerable distance, as they may in open-wire systems where conductors are carried on the same pole line and as they do where conductor pairs are disposed together within a cable. Between adjacent circuits there is a practically unavoidable distributed mutual impedance or coupling which permits currents in each line to give rise to disturbing currents in the other line. The effect is greater the higher the frequency so an especially serious problem is presented in the design of multiplex carrier telephone circuits where today the frequencies employed range upward from 50,000 cycles per second.

It has been the practice to provide at intervals along a transmission line comprising a plurality of circuits between which there is an excessive residual amount of cross-talk, cross-talk balancing units which couple the circuits together in pairs in such manner that in each disturbed circuit there is introduced from each disturbing circuit a fractional part of the disturbing signal energy of such amplitude and phase as to neutralize the cross-talk currents or to balance them out as nearly as possible. As representative of the present practice, U. S. Patent to M. A. Weaver 2,080,217, May 11, 1937, is noted. Bearing in mind that the number of such cross-talk balancing couplings is equal to the number of pair combinations of circuits in cross-talk producing relation, it will be appreciated that to balance a cable comprising say 20 to 100 circuits a great number of units are required, 4950 units, in fact, for 100 circuits.

Since one of the principal objects of the present invention is to overcome various disadvantages and limitations inherent in the present practice, a few remarks relative to the design and operation of the cross-talk balancing systems exemplified by the Weaver patent will now be given by way of introduction. In the first place, it is evident that inasmuch as each balancing unit is interposed in the signaling circuit, it introduces a certain amount of signal attenuation, small to be sure, but quite substantial when multiplied by the number of units required for each circuit where a large number of circuits are to be balanced for cross-talk. Secondly, the

terminal impedances of the balancing units must accurately match, over the entire operating frequency range, the impedance of the circuits in which they are connected, else at least two undesirable consequences follow. The one consequence is that a mismatch of impedance results in reflection losses and further attenuation of the signals. The other consequence is that a portion of the signal energy is reflected at the point of impedance mismatch and the reflected portion itself gives rise to cross-talk of a kind that is extremely difficult and practically impossible to neutralize, as explained fully in H. Nyquist Patent 1,928,735, October 3, 1933. Thirdly, the designer has no option as to whether the terminal impedances of the balancing unit shall be high or low for these impedances are definitely determined by the impedance of the signaling circuit, which is of the order of 135 ohms for twisted-pair cable circuits and of the order of 600 ohms for open-wire lines; whereas, it is or may be more economical and simpler to provide units having other than these specified terminal impedances. Fourthly, if the signaling circuits are electrically balanced, as they usually are, the cross-talk balancing units must also be designed to preserve the balance, whereas if it were permissible to have units electrically unbalanced a simpler design might be possible.

For each of the foregoing disadvantages and limitations, applicant's invention permits a corresponding advantage to be obtained. Other advantages will be pointed out hereinafter.

In accordance with a principal feature of the present invention, interference currents in a signaling circuit are neutralized by introducing a balancing current (or voltage) in the mu-beta path of a stabilized feedback signal amplifier connected in that circuit. Similarly, in accordance with another feature, signaling currents to be used for balancing interference are derived from the mu-beta path of a stabilized feedback signal amplifier. Where these two features are combined, as in the preferred embodiments, it may be said that the invention is featured in an important aspect by the interconnection of the mu-beta paths of stabilized feedback amplifiers for the neutralization of cross-interference between the circuits in which the respective amplifiers are connected. Another feature of the invention readily permits neutralization of cross-talk from one circuit to another and separate neutralization of the cross-talk in the opposite direction, which is desirable where the cross-talk between the two circuits is not the same for the

two directions of cross-talk transmission. Stabilized negative feedback amplifiers are generally specified hereinafter but more by way of illustration of preferred embodiments than of limitation, as will appear more clearly from a consideration of the specific characteristics of such amplifiers that adapt them for use in accordance with the invention. For this reason and others, the claims are to be looked to for a more accurate statement of the true scope of the invention.

A fuller understanding of the nature of the present invention and of its various objects, features and advantages may be had from a consideration of the several typical embodiments now to be described with reference to the accompanying drawings. In the drawings:

Fig. 1 is a diagrammatic representation of a feedback amplifier;

Fig. 2 shows schematically an illustrative system in accordance with the invention in which cross-talk balancing connections are made between the beta circuits of a multiplicity of negative feedback amplifiers disposed in respective signaling circuits;

Figs. 3 to 7 show alternative manners of interconnecting the mu-beta circuits of negative feedback amplifiers for neutralizing cross-talk;

Figs. 8 to 10 show in greater detail illustrative systems in accordance with Figs. 2 and 3;

Figs. 11 and 12 show a preferred form of capacitive balancing element; and

Figs. 13 and 13A show cross-talk balancing systems in accordance with the invention in which compensation is made automatically for variations in the coefficient of cross-talk coupling.

Hereinafter a stabilized feedback amplifier will be represented diagrammatically in the conventional manner shown in Fig. 1. The mu circuit comprising the amplifying element A of one or more stages extends from the point x where the incoming signals to be amplified are received, to point y where the amplified signals are applied to the outgoing circuit. The beta circuit comprising the impedance element Z extends from point y to point x and provides for the transfer of a portion of the amplified signal to the input of the amplifier. The loop formed by the mu circuit and the beta circuit is called the mu-beta circuit or mu-beta loop.

In Fig. 2 there is shown diagrammatically a simple illustrative system in accordance with the invention in which provision is made for balancing out the cross-talk between four circuits comprising conductor pairs a , b , c and d which have been in cross-talk producing relation as by reason of having been carried within the same cable from a distant terminal station or repeater to the left. In each pair is interposed an amplifier of the stabilized negative feedback type, now well known in the art and described, for example, in H. S. Black Patent 2,012,671, issued December 21, 1937, comprising in the mu path x — y an amplifier element A of one or more stages and in the beta or feedback path y — x an impedance Z representative of the usual phase shifting and gain controlling networks, for example. The feedback amplifier may very conveniently be the signal amplifier at a repeater station along the cable, x and y embracing at least so much of the repeater as is bounded by a feedback path.

The beta circuits of all of the amplifiers in Fig. 1 are interconnected by cross-talk balancing units individual to each pair of amplifiers, as shown. Thus C_{ab} represents the cross-talk balancing coupling between the amplifier in circuit

a and the amplifier in circuit b , C_{bc} represents the coupling for reducing mutual interference between pairs b and c , etc. The circuit sequence of the coupling elements, that is, their relative positions in the beta circuits, is not necessarily the same in each amplifier, although it is so shown in Fig. 2. Considering coupling C_{bd} , for example, it will be noted that in the two beta circuits which it connects coupling C_{bd} is preceded by an equal number of couplings, namely two. This arrangement obviates any unnecessary difficulty that might conceivably be encountered in some cases if the couplings were made between electrically non-identical points in the beta circuits thereby connected. The nature of the coupling devices is not important at the moment, but illustrative examples are set forth hereinafter. It will be sufficient to state here that each coupling is intended and designed to transfer from each beta circuit to another a fractional part of the signal of such amplitude and phase as to neutralize the cross-talk appearing in the other beta circuit. On thus neutralizing the cross-talk appearing in the beta circuits it will be found that no cross-talk appears in the output circuits of the corresponding amplifiers, which indeed is one of the primary objects of the invention.

Whereas Fig. 2 shows one particular manner of interconnecting the mu-beta paths of signal amplifiers for the neutralization of cross-talk, Figs. 3 to 7 show several possible alternatives in accordance with the invention. First, however, for purposes of comparison it may be noted that in Fig. 2 the interconnection is made between a point in the beta circuit of one amplifier and the corresponding point in the beta circuit of another amplifier, and more particularly between points that are electrically close to the junction x , that is, the "input" end of the beta circuit. In this part of the beta circuit the signal power is at a comparatively low level due to the attenuation introduced in the beta circuit by the elements represented by impedance Z. On the other side of impedance Z, that is, near junction y , the beta circuit signal power is at its maximum level. Power level is of interest to the designer inasmuch as it determines the power rating of the balancing units, and for other reasons which need not be mentioned.

The impedance level at the point in the beta circuit where a cross-talk balancing connection is made also is of interest. Thus, if the impedance be high, balancing units consisting of condensers will be found especially effective, whereas if the impedance level be low, inductive couplings will ordinarily be the more efficient. In a given case, the optimum impedance level for the particular type of balancing unit contemplated may be found at either end of the beta circuit or between or within impedance elements that are inserted in the beta circuit for particular purposes. Alternatively, resistance pads or other impedance changing elements may be inserted in the beta circuit for the primary purpose of providing the desired impedance level. Attenuation due to mismatching of impedances within the beta circuit is not necessarily disadvantageous, for the over-all gain of the amplifier, if the vectorial product $\mu\beta$ be large compared with unity, is substantially equal to the beta circuit attenuation, and any additional attenuation results in greater gain which can be offset if desired. Although it is evident that the beta circuit impedance may be varied over its

length in any desired manner, it will be assumed for purposes of specific example that near junction x the beta circuit impedance is high and near junction y comparatively low, corresponding to the relative impedances of the input circuit and the output circuit of the amplifier.

Referring now to Figs. 3 to 7, there are shown alternative embodiments of the invention differing from the embodiments shown in Fig. 2 in that the cross-talk balancing connections are made between different points in the respective mu-beta loops. In each case only two conductor pairs, a and b , are shown but it will be obvious from Fig. 2 how each system can be extended to accommodate any number of pairs that may be in cross-talk producing relation.

In Fig. 3 the cross-talk balancing connection C is established between like points in the two beta circuits, both of which points are near the junction y where the signal power level is maximum and the impedance relatively low.

In Fig. 4 the mu circuits of the two amplifiers are interconnected by the cross-talk balancing unit C , the point of connection being in each case near the junction x where the signal power level is low and the impedance level ordinarily is high.

In Fig. 5 unlike points in the mu-beta circuits of the two amplifiers are interconnected by the balancing unit C , one point being in the mu circuit of one amplifier and the other in the beta circuit of the other amplifier, both points being near the high signal level junction y .

In Figs. 6 and 7 the cross-talk balancing connections are so disposed that the transfer of balancing currents, is in substantially only one direction, that is, from one amplifier to the other and not in the reverse direction. In each case a separate balancing connection is provided for transferring balancing currents in the reverse direction. In Fig. 6 a point of high signal power level in each mu circuit is coupled to a respective point of low signal power level in the other mu circuit. In Fig. 7 the two beta circuits are interconnected, a point of high signal level in each beta circuit being coupled with a respective point of low signal level in the other circuit. In each of Figs. 6 and 7, cross-talk from pair a to pair b may be balanced independently of the adjustment for balancing cross-talk in the opposite direction of cross-talk transmission. Thus balancing connection C_1 is effective in transferring balancing power from pair b to pair a , but there is no substantial transfer of balancing power in the opposite direction through C_1 because of the great disparity in power levels between the points connected by the balancing unit. Similarly, balancing connection C_2 is effective in transferring power from pair a to pair b to neutralize cross-talk appearing in the latter.

Fig. 7 may be treated as illustrative also of another feature of applicant's invention whereby a single cross-talk balancing connection may serve to provide different cross-talk balancing effects for the two directions of cross-talk balancing current transmission. All that is required in any case is that the points connected by the balancing unit differ as to signal power level by an amount corresponding to the difference in cross-talk balancing effect desired. For specific example, if in the case of Fig. 7 it be assumed that the cross-talk coupling or transmission from pair a to pair b be a few decibels higher than the coupling or transmission from pair b to pair a , then coupling unit C_2 will suffice if it couples a

point in the a circuit amplifier that is at a signal power level a few decibels higher than the coupling point in the b circuit amplifier. The necessary difference in power level is provided by the beta circuit impedance Z , which may conveniently be an adjustable resistance pad.

It will be appreciated that where a single balancing unit is employed the transmission-frequency characteristic will be the same for the two directions of transmission through the unit, whereas with the arrangement using two units this limitation does not obtain.

It has been remarked hereinbefore that attenuation due to coupling units inserted in the beta circuit of a negative feedback amplifier is reflected in increased over-all repeater gain. On the other hand, a coupling unit inserted in the mu circuit, as in Fig. 4, for example, has the opposite effect, that is, it decreases the repeater mu circuit gain, but this decrease can be offset by increasing the amplification in the mu circuit. The transmission-frequency characteristic of a cross-talk balancing element in the mu circuit has no significant effect on the over-all transmission-frequency characteristic of the repeater, especially so when $\mu\beta$ is large compared with unity. Under the same circumstances, the impedance-frequency characteristics of a balancing unit, whether in the mu circuit or the beta circuit, has no significant effect on the input impedance or on the output impedance of the repeater, hence the difficulties due to reflection cross-talk effects are substantially eliminated. The characteristics of the negative feedback amplifier with large $\mu\beta$, further, are such that with a coupling element disposed in the beta circuit and near the input end thereof the cross-talk balance is practically independent of μ , β and $\mu\beta$, so that changes in the latter do not require compensating adjustment of the balancing units. On moving the coupling element to the output end of the beta circuit, the balance is made a function of β but not of μ , so that the balancing effect can be made a controlled function of the gain of the repeater. With the coupling element in the mu circuit, the balance is a function of $\mu\beta$.

Fig. 8 shows in somewhat greater detail an embodiment of the invention similar to the embodiments illustrated in Figs. 2 and 3 in which cross-talk between circuits a and b is balanced by interconnection of the beta circuits of the two amplifiers. Each amplifier comprises a plurality of stages of which only the first and last are shown. The beta circuit is electrically unbalanced with respect to ground and extends through conductor 4 from an impedance 3 comprising an output circuit bridge through intermediate impedance elements Z_1 and Z_2 and balancing units to an impedance 5 in the grid circuit of the first amplifier tube 1. Impedances Z_1 and Z_2 represent the various networks which may appear in the beta circuit, such as phase shifting, attenuation equalizing and automatic attenuation regulating networks. The cross-talk balancing equipment comprises a transformer having one winding 6 in series relation in conductor 4 of the beta circuit of the one amplifier and a second winding 7 shunted by a potential divider 8, the slider of which is connected through a conductor 9 to an appropriate point along conductor 4 of the beta circuit in the other amplifier. It is contemplated that the latter point be so chosen with regard to impedance and signal power levels that the cross-talk balancing connection is effective to

neutralize cross-talk in both directions of cross-talk transmission. The mid-point of transformer winding 7 is grounded so that potential divider 8 provides not only for adjustment of the amplitude but also for phase reversal of the cross-talk balancing current. The cross-talk balancing path may be given any desired transmission-frequency characteristic as by shunting one of the transformer windings by a reactive circuit such, for example, as the resistor-inductor combination shown connected across winding 6. The transformer winding 7 may be connected by other conductors 9' to any number of other signal amplifiers for cross-talk balancing purposes, and to this end the potential divider 8 may be provided with a corresponding number of additional contactors or individual potential dividers 8' may be connected as illustrated.

In the embodiment of the invention shown in Fig. 9, the amplifier is of the series feedback type but the beta circuit 19 is electrically balanced and inductively coupled to both the output circuit bridge and the input circuit of the amplifier. Cross-talk balancing may be effected by a capacitive connection between one side of one beta circuit 19 and one side or the other of the other beta circuit. To facilitate adjustment, a three-plate differential condenser 11 may be employed for this purpose, the movable plate of which is connected to one side of the one beta circuit and the other two plates of which are connected by leads 12 to respective sides of the other beta circuit. Other differential condensers 11' may be connected to each beta circuit to provide for cross-talk balancing with other signal amplifiers in the system.

Fig. 10 shows signal amplifiers of the feedback type which, more specifically, are of the shunt feedback type, the feedback circuit comprising a conductor 13 extending from the output circuit to the grid of the vacuum tube in the first stage. A cross-talk balancing connection C_{ab} of any suitable type connects two beta circuit conductors 12. A resistor 14 is provided in the input circuit of each amplifier to maintain a predetermined impedance facing the line, inasmuch as the short-circuiting effect of the shunt feedback connection would otherwise cause an impedance mismatch into the amplifiers.

Figs. 11 and 12 show a variable condenser structure that may be used in a system of the kind shown in Fig. 9 where a differential capacitive effect is to be obtained between each beta circuit and a plurality of other beta circuits. The metallic base plate 15, constituting one plate of each condenser, is provided with a number of transverse cylindrical holes in each of which slide a pair of cylindrical metallic members 16 and 17. The latter are insulated from the base plate and form the other two plates of each condenser. By proper adjustment of the movable members 16 and 17, the total capacitance between the circuits thereby coupled and the differential capacitance may be easily adjusted to provide the required cross-talk balance.

The cross-talk balancing systems known heretofore are not adapted to compensate for variations in the coefficient of cross-talk coupling between adjacent signaling circuits, such as might occur because of shifting of the relative positions of open-wire lines. In Fig. 13 is shown schematically a system in accordance with the present invention in which such variations in couplings are automatically compensated under the control of a pilot wave. T_a and T_b represent the

terminal stations for two signal transmission lines a and b which are in cross-talk producing relation and which have a plurality of repeaters therein including at the right an automatic gain regulating repeater having a cross-talk balancing connection between the respective beta circuits of the repeater amplifiers 21, 22. For simplicity of illustration, it is supposed that the beta circuits are of such character that cross-talk balancing can be effected by a single condenser interconnecting them. The necessary capacitance in this case is afforded by the grid-cathode capacitance of a triode 26 which is automatically adjusted in a manner to be described.

Over line a there is transmitted a pilot wave generated by source S_1 which creates in line b an induced current of magnitude comparable with that of the signal cross-talk currents therein. The magnitude of the induced pilot wave arriving at repeater 22 in line b varies just as the coefficient of coupling between the two lines varies. At repeater 22 the induced pilot currents are selected by a filter F_1 and utilized to control the capacitance afforded by the triode 26. More specifically, the selected pilot currents are transmitted to the heater element 27 of a thermistor unit 28 which is disposed in the cathode lead of the triode, that is, in the common grid-anode return branch. Variations in the resistance of the thermistor unit 28 corresponding to variations of the coupling coefficient between the two transmission lines are translated into corresponding variations in grid-cathode capacitance. A manually adjustable resistance 25 in series with the balancing capacitance facilitates adjustment of the automatic compensator so as to make it effective over the range of variation of cross-talk coupling coefficient likely to be encountered.

Fig. 13A shows a modification of the control system for the system of Fig. 13 in which variations of the coefficient of cross-talk coupling are compensated by corresponding variations of attenuation in the cross-talk balancing path. Only the beta circuits, β_{21} and β_{22} , of the two repeater amplifiers are shown in addition to the cross-talk balancing circuit. The latter is illustrated as comprising a transformer 29 one winding of which is connected in series in the beta circuit of amplifier 21 and the other winding of which is connected through thermistor 28 across an impedance 39 arranged in series in the beta circuit of amplifier 22. The heater element 27 of the thermistor unit receives the output currents from pilot wave filter F_1 and controls the attenuation introduced in the balancing circuit by thermistor 28. As the coefficient of cross-talk coupling decreases, the intensity of the induced pilot wave currents arriving at amplifier 22 decreases whereupon the thermistor 28 is caused to vary in temperature in such sense as to increase its resistance and the attenuation it introduces into the balancing circuit. Thus the coupling afforded by the balancing circuit varies in the same sense as the coefficient of cross-talk coupling and the one effect can be made to compensate for the other.

In accordance with another feature of the invention as illustrated in Fig. 13, means are provided throughout the line for equalizing transmission phase shifts in the several circuits. For this purpose, phase shifters PS may conveniently be provided in the beta circuits of the repeater amplifiers. On adjusting the phase shifters so that the phase shift undergone by signals in their transmission from the terminal stations to any

given point along the line is the same in each signaling pair, the cross-talk currents will likewise be equalized with respect to phase shift. Cross-talk balancing may then be more readily effected or the distance between cross-talk balancing points substantially increased.

Although the present invention has been described with reference to signal amplifiers of the negative feedback type, in which in each case the vectorial product $\mu\beta$ is preferably large compared with unity, the invention is adaptable also to amplifiers of the stabilized positive feedback type, in which $\mu\beta$ may be comparable with unity. In other respects, too, the various embodiments herein disclosed are to be considered as illustrative, for the invention comprehends also such other embodiments as come within the spirit and scope of the appended claims.

What is claimed is:

1. In a system comprising several pairs of signaling circuits in cross-talk producing relation, a signal amplifier of the stabilized feedback type in each of said signaling circuits, each of said amplifiers having a mu-beta circuit, and means coupling said mu-beta circuits together in pairs in energy transfer relation for the neutralization of cross-talk.

2. In combination, a pair of signaling circuits in cross-interfering relation, a signal amplifier of the stabilized negative feedback type in each of said circuits, and means for reducing the cross-interference comprising an electrical coupling between the mu-beta circuits of said amplifiers.

3. A combination in accordance with claim 2 in which said coupling connects points in the beta paths of both amplifiers.

4. A combination in accordance with claim 2 in which said coupling connects points in the mu paths of both amplifiers.

5. A combination in accordance with claim 2 in which said coupling connects a point in the beta path of one amplifier and a point in the mu path of the other amplifier.

6. A combination in accordance with claim 2 in which said coupling connects points of different signal power levels.

7. In combination, a pair of circuits in cross-talk producing relation, a signal amplifier of the stabilized feedback type in one of said circuits, means for deriving cross-talking currents from the other of said circuits, and means for electrically introducing the derived currents into the mu-beta circuit of said amplifier.

8. In combination, a pair of circuits in cross-talk producing relation, a signal amplifier of the stabilized feedback type in one of said circuits, means for deriving cross-talking currents from the mu-beta circuit of said amplifier, and means

for introducing the derived currents into the other of said circuits.

9. In combination, two signal sources and respective signaling circuits connected thereto, a signal amplifier of the negative feedback type in one of said circuits, the other of said signaling circuits being electrically connected into the mu-beta circuit of said amplifier.

10. A combination in accordance with the claim next preceding in which said other circuit is electrically connected into the beta path of said mu-beta circuit.

11. In combination, a pair of signaling circuits in cross-talk producing relation, a signal amplifier of the stabilized feedback type in each of said circuits, automatic gain controlling means in the mu-beta circuit of each of said amplifiers, and cross-talk balancing means coupling points in said mu-beta circuits where the signal power level is maintained substantially constant under the control of said gain controlling means.

12. In combination, a pair of signaling circuits in a cross-talk producing relation that is variable with respect to time, an electrical coupling between said circuits for the neutralization of cross-talk, and means for automatically varying said coupling in response to variations in the said cross-talk producing relation.

13. In combination, a pair of signaling circuits in cross-talk producing relation, means coupling said circuits for the neutralization of cross-talk, means responsive to changes in the distributed cross-talk coupling between said circuits, and means operating under the control of said responsive means to effect a compensating change in said coupling means.

14. In combination, a pair of signaling circuits having substantial distributed mutual impedance, a cross-talk balancing coupling between said circuits, and means for automatically changing said coupling to compensate for fluctuations in said mutual impedance, said means comprising a control wave source connected to one of said circuits for transmission of control waves thereover along with the signals, means for selectively receiving the currents induced in the other of said circuits by said control waves, and means responsive to changes in the amplitude of the induced currents so selected.

15. A carrier current signaling system comprising a plurality of signal transmission lines that over at least a substantial portion of their lengths are in cross-talk producing relation, means in said lines for equalizing the transmission phase shifts in the respective lines throughout said portion, and cross-talk balancing means interconnecting said lines in the vicinity of said portions.

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