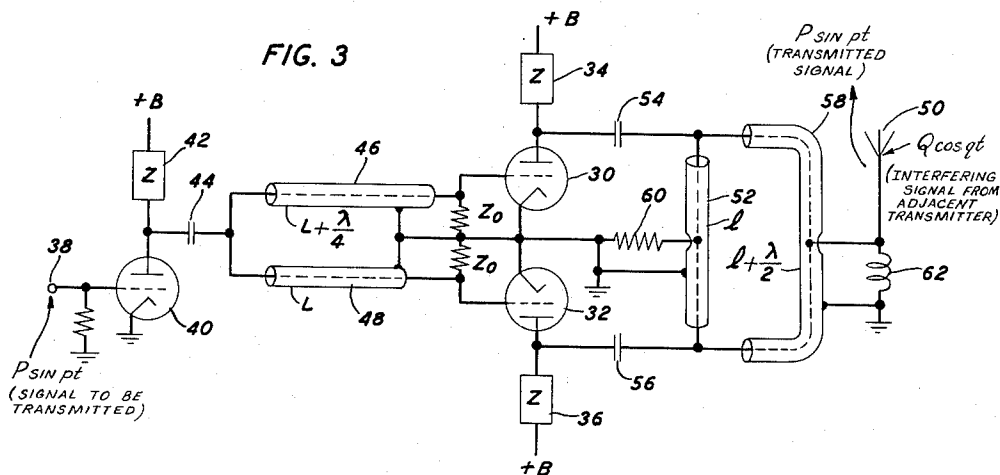
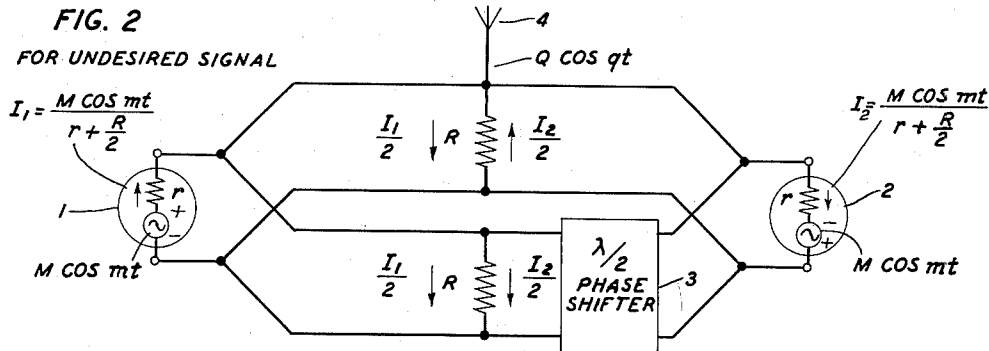
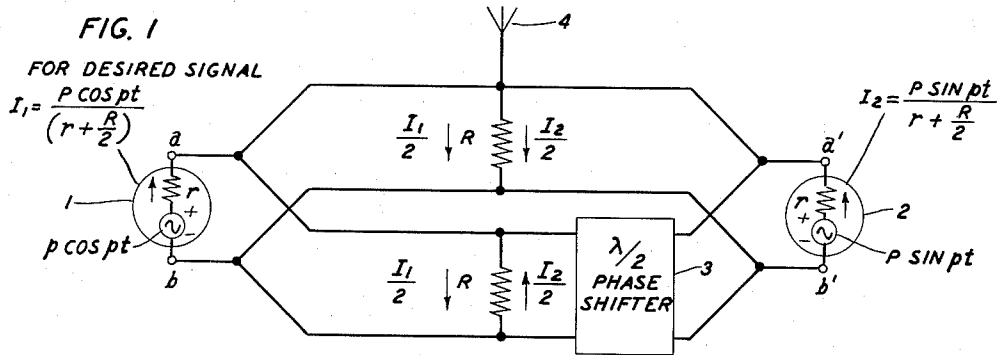


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OUTPUT STAGES OF ADJACENT TRANSMITTERS
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REDUCTION OF CROSS-MODULATION BETWEEN THE OUTPUT STAGES OF ADJACENT TRANSMITTERS

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This invention relates to radio transmitters and, more particularly, to improvements in such transmitters to permit their operation in close proximity to other transmitters without undesirable intermodulation distortions.

In many applications involving radio systems, it has been found necessary to operate a plurality of radio transmitters at different frequencies, but in close physical proximity. As an example, the mobile radiotelephone system employed for voice communication requires the use of a number of transmitters, the antennas for which necessarily are mounted on the roof of a single building. It has been found in such instances that intermodulation occurs amongst the transmitters, with the intermodulation products of the form $2p-q$ being particularly objectionable. By its nature, each transmitter involves nonlinear elements wherein intermodulation between components of different frequencies can occur. If it be assumed that a first transmitter operates at an angular frequency p and a second at an angular frequency q , the third-order intermodulation products of the form $2p-q$ occurring in the first transmitter are of substantial magnitude and tend undesirably to impair its performance by causing radiation of unwanted signals.

One solution used in the past involves the provision of relatively complicated balancing networks by means of which a number of transmitters, operating under such conditions that the undesirable intermodulation would otherwise occur, may be interconnected. These networks, which involve a large number of filter elements, are based on the proposition that any undesired signal component, which may be introduced into one transmitter from another, may be balanced out by introducing a similar component over an independent path wherein a phase shift may be introduced sufficient to cause cancellation. This expedient is costly and complicated.

It is the object of the present invention to provide an improved radio transmitter which may be operated in close proximity to others without the need of complicated interconnecting balancing networks and without the degradation of performance which would otherwise be caused by third-order intermodulation distortion.

In accordance with the present invention, third-order cross modulation distortion of the form $2p-q$ between radio transmitters, operated in close proximity at angular frequencies p and q , respectively, is substantially reduced or eliminated by modification of the individual transmitters. To this end, a transmitter may include an output stage having two tubes, each of which includes at least an anode, a cathode, and control grid elements; an antenna hybrid means interconnecting the antenna and the anodes of the two tubes; and driving means for applying the signal voltage to the control grids of the two tubes in phase quadrature.

The above and other features of the invention will be considered in greater detail in the following detailed specification taken in connection with the drawings in which:

Figs. 1 and 2 are generalized schematic circuit diagrams which will be found useful in analyzing the circuit

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connections of a transmitter arranged in accordance with the invention; and

Fig. 3 is a schematic circuit diagram of a transmitter in accordance with the invention arranged for operation at frequencies of the order of a few hundred megacycles per second.

In accordance with the invention, the third-order intermodulation distortion of the form $2p-q$ between two transmitters operating at angular frequencies p and q , respectively, may be minimized by driving the two tubes of the output stage of the transmitter in phase quadrature. Let it be assumed that the output tubes are identical and that either can be represented by a single nonlinear element. The response of this element may now be considered for two sinusoidal signals such as $P \cos pt$ and $Q \cos qt$. The total applied signal is then

$$e = P \cos pt + Q \cos qt \quad (1)$$

The current response may then be determined by expansion in power series. The unwanted third-order intermodulation product of angular frequency $2p-q$ depends upon the term

$$P^2 Q \cos^2 pt \cos qt \quad (2)$$

This may be written

$$\frac{1}{2} P^2 Q (1 + \cos 2pt) \cos qt \quad (3)$$

The component of angular frequency $(2p-q)$ is then given by

$$\frac{1}{4} P^2 Q \cos (2p-q)t \quad (4)$$

The above expression defines the intermodulation distortion products produced by a single tube when excited by two sinusoidal signals. In practice, one of these signals ($P \cos pt$) is, of course, the information signal applied to the tube in its function as part of the output stage of a radio transmitter; and the other is the weaker signal picked up either by the antenna or the transmitter output circuitry itself from an adjacent source of radio frequency energy.

If a second tube or nonlinear element having characteristics identical to those of the tube employed in the preceding development receives excitation such that the signal component is 90 degrees out of phase with that applied to the first tube, the input signal made up of the wanted signal and an interfering component is of the form

$$e = P \sin pt + Q \cos qt \quad (5)$$

The unwanted third-order intermodulation product now depends upon the term

$$P^2 Q \sin^2 pt \cos qt \quad (6)$$

This may be written

$$\frac{1}{2} P^2 Q (1 - \cos 2pt) \cos qt \quad (7)$$

The component of angular frequency $(2p-q)$ is then given by

$$-\frac{1}{4} P^2 Q \cos (2p-q)t \quad (8)$$

Comparison of (4) and (8) shows that the unwanted component of $(2p-q)$ frequency appears with a plus sign in the first tube and a minus sign in the second. Push-pull operation will therefore cause this component to tend to cancel out.

Such cancellation would be complete were it not for the fact that, in the push-pull circuit, the signal $P \cos pt$ from the first tube will be impressed on the second tube and alter the net phase of the combined signal appearing across that tube from the desired quadrature relation, $P \sin pt$. Similarly, the second tube will react on the first tube in the same undesired manner. As a result, the undesired $2p-q$ component will not be eliminated completely.

However, this interaction between the two tubes may be avoided by a balancing hybrid arrangement. The resulting circuit configuration is shown in generalized form in Figs. 1 and 2 of the drawings. Attention is first directed to Fig. 1 wherein the applied voltages and currents are indicated for the desired signal; that is, the signal to be radiated by the transmitter in question. The generator and resistor r contained in the circle represent the driving E.M.F. and internal plate resistance of one tube while similar elements in circle 2 represents the other tube. In accordance with the invention, the signal voltages are applied in phase quadrature, that applied to tube 1 being $P \cos pt$, and that to tube 2, $P \sin pt$. Terminals a and b of tube 1 and the corresponding terminals a' and b' of tube 2 are interconnected by a network having two branches. In the upper branch, terminal a is directly connected to terminal a' and terminal b is likewise connected to terminal b' . The lower branch is similar with the exception that it includes a phase shifter 3 arranged to introduce a phase reversal or shift of $\lambda/2$ at the operating frequency. A load resistor R is connected between the conductors of the upper branch at its electrical midpoint and a second resistor R is connected between the conductors of the lower branch. An antenna 4 may be connected as part of the load resistor R in the upper branch while the lower branch includes no provision for the radiation of energy.

Analysis of this circuit indicates that the currents produced by the two tubes may be written

$$I_1 = \frac{P \cos pt}{r + R/2} \quad (9)$$

and

$$I_2 = \frac{P \sin pt}{r + R/2} \quad (10)$$

for tubes 1 and 2, respectively. These currents flow upwardly through resistors r , as indicated by the arrows in Fig. 1. In the upper branch of the network, currents, equal to $I_1/2$ and $I_2/2$, respectively, flow in the same direction through resistor R and therefore add vectorially. This is the desired signal and the drop across resistor R in the upper branch of the network serves to excite antenna 4. By virtue of the action of phase shifter 3, currents equal to $I_1/2$ and $I_2/2$ flow in opposite directions in the resistor R in the lower branch.

A similar analysis may now be made with reference to Fig. 2 for the undesired intermodulating signal. This is the signal picked up from an external source by the transmitter in question. The undesired third-order terms for tubes 1 and 2 may be obtained by considering each tube as a mixer to which is applied the local oscillator voltage in the form of the desired signal, either $P \cos pt$ or $P \sin pt$, as the case may be, and the weaker interfering signal, $Q \cos qt$, picked up from another transmitter. The modulation product of the form $2p-q$ may then be derived for tubes 1 and 2, respectively, as follows:

$$\begin{aligned} Q \cos qt \cdot (P \cos pt)^2 \\ = \frac{1}{2} Q P^2 \cos qt + \frac{1}{4} Q P^2 \cos (2p-q)t + \frac{1}{4} Q P^2 \cos (2p+q)t \end{aligned} \quad (11)$$

$$\begin{aligned} Q \cos qt \cdot (P \sin pt)^2 \\ = \frac{1}{2} Q P^2 \cos qt - \frac{1}{4} Q P^2 \cos (2p-q)t - \frac{1}{4} Q P^2 \cos (2p+q)t \end{aligned} \quad (12)$$

It will be noted that the undesired product of the form $2p-q$ appears with a positive sign for tube 1 and a negative sign for tube 2. This driving E.M.F. of the undesired form may be written as $M \cos mt$ and will therefore appear in opposite phase in the two tubes, as indicated in Fig. 2.

An analysis of the circuit arrangement of Fig. 2 with

such applied potentials may be undertaken in the same manner as outlined above for Fig. 1. In this instance, the output currents of tubes 1 and 2 are identical and each may be written as

$$I_1 = I_2 = \frac{M \cos mt}{r + R/2} \quad (13)$$

Because of the differences in phase of the two driving signals, however, this current flows upward through resistor r of tube 1 and downward through resistor r of tube 2. It follows then that in the upper branch of the network interconnecting the two tubes equal currents, but of opposite phase, flow in resistor R while in the lower branch, by virtue of the action of phase shifter 3, currents flow in the same direction. These are currents of the unwanted form $2p-q$. It will be noted that cancellation occurs in the upper branch from which the antenna 4 is fed while addition occurs in the lower branch where no radiating element is present.

This analysis shows that the interconnecting network of Figs. 1 and 2 is effective to cause radiation of the desired signal and suppression of the undesired third-order component.

Practical circuits utilizing the principles of the invention may take many forms. The exact nature will depend upon the frequency of operation and upon the manner in which the anode circuits of the transmitter output stage and the antenna itself are interconnected.

Fig. 3 shows a typical transmitter circuit embodying the invention and adapted for use at a frequency of the order of a few hundred megacycles. In the circuit of Fig. 3, tubes 30 and 32 constitute the output stage of a transmitter. Each includes anode, cathode, and control grid elements. The anodes of these tubes are connected in push-pull configuration and are supplied with direct current from a source indicated at $+B$ through filtering impedances 34 and 36, respectively. An input signal applied at terminal 38 is amplified by a driver stage comprising vacuum tube 40 and applied to the grids of tubes 30 and 32, respectively, by way of a network wherein the excitation for the grid of one of the two tubes is shifted relatively to that for the other by an angle of 90 degrees. The anode of tube 40 is connected to a source of positive potential $+B$ by way of impedance 42. The output is applied through a coupling capacitor 44 to a pair of transmission lines 46 and 48. As indicated in the drawing, transmission line 46 is electrically a quarter-wave longer than transmission line 48 at the operating frequency of the transmitter. The two lines are terminated in their characteristic impedances Z_0 . These impedances also form the grid return impedances for the two tubes 30 and 32 of the transmitter output stage. Although not shown, conventional impedance-transforming networks may be employed in this connection if desired to match the input impedances of output stage tubes 30 and 32. In any event, it will be noted that inputs proportional to the signal to be transmitted are applied to the grids of tubes 30 and 32 in phase quadrature.

The anodes of tubes 30 and 32 are interconnected and are connected to an antenna 50 by a balancing network corresponding to those described in connection with Figs. 1 and 2. To this end, the two anodes are interconnected by a transmission line 52 of length l , blocking capacitors 54 and 56 being provided to eliminate direct-current components from the output circuitry. The anodes are also interconnected by a second transmission line 58 of electrical length

$$l + \frac{\lambda}{2}$$

Line 52 is tapped at its electrical center, and the tap on the inner conductors is grounded by way of an impedance 60. Line 58 is similarly tapped and the inner conductor is grounded by way of an inductor 62, to which is also connected antenna 50. The combined impedance of

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the inductor 62 and the antenna 50 is equal to the impedance of the element 60. A consideration of this circuit will indicate that the anode circuits of the two tubes are interconnected by two paths differing in total length by one-half wavelength, thus preventing interaction between the tubes and at the same time coupling each of the tubes to the antenna, as required by the generalized circuits of Figs. 1 and 2.

What is claimed is:

1. In a radio transmitter for transmitting a given signal comprising a modulated carrier, means for reducing third-order cross modulation distortion caused by other transmitters operating at different carrier frequencies and in close proximity thereto comprising an output stage having two tubes each of which includes at least anode, cathode and control grid elements, an antenna, means comprising a hybrid circuit interconnecting the antenna and the anodes of said tubes, and means for applying the same modulated carrier signal to the control grids of the two tubes in phase quadrature.

2. In a radio transmitter for transmitting a signal comprising a modulated carrier operating at a carrier of angular frequency p , means for reducing cross modulation of the form $2p-q$ caused by other transmitters operating at a carrier of angular frequency q in close proximity thereto comprising an antenna, an output stage having two tubes connected to said antenna and each including an anode, cathode and control grid elements, means included in the circuit interconnecting the anodes of said tubes and the antenna to compensate for interaction between said tubes, and means for applying the same modulated carrier signal to the control grids of said tubes in phase quadrature.

3. In a radio transmitter for transmitting a signal comprising a modulated carrier, means for reducing third-

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order cross modulation distortion caused by other transmitters operating in close proximity thereto comprising an antenna, an output stage having two tubes each of which includes at least an anode, cathode and control grid elements, means connecting said anodes to said antenna in push-pull relationship, said means including a hybrid circuit, and means for applying the same modulated carrier signal to the control grids of the two tubes in phase quadrature.

4. In a radio transmitter for a signal comprising a modulated carrier, means for reducing third-order cross modulation distortion caused by other transmitters operating in close proximity thereto comprising an output stage having two tubes each of which includes at least anode, cathode and control grid elements, an antenna, an impedance member matching the antenna impedance, first means interconnecting the anodes of said tubes and connected at its electrical center to the said impedance member, second means interconnecting the anodes of said tubes and connected at its electrical center to said antenna, one of said interconnecting means being one-half wavelength longer in total electrical length than said first connecting means and means for applying the same modulated carrier signal to the control grids of the two tubes in phase quadrature.

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