Aug. 19, 1941. R. LEE 2,253,381

HARMONIC REDUCTION CIRCUITS

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Fig. 1.

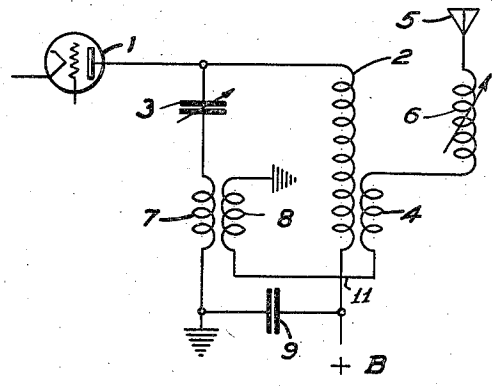


Fig. 2.

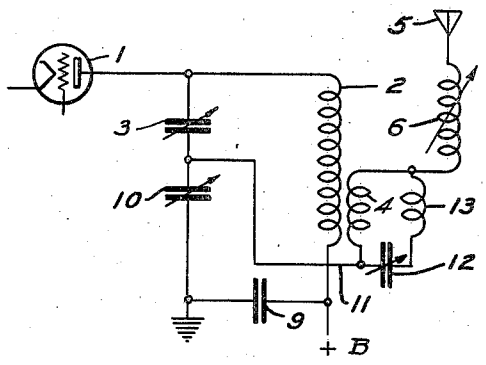
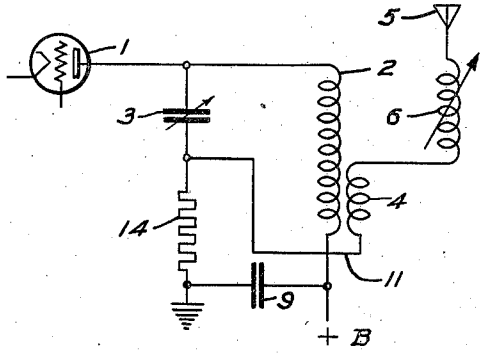


Fig. 3.



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HARMONIC REDUCTION CIRCUITS

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5 Claims. (Cl. 250—17)

This invention relates to radio transmission systems and more particularly radio frequency coupling circuits generally employed between a transmitter and its associated energy radiator.

In radio transmission systems, it is particularly important to maintain maximum effective energy transmission, and radiation at one predetermined fundamental frequency and care must be taken to prevent radiation at other frequencies, especially at such frequencies which are the multiple of the fundamental, generally referred to as harmonics.

Radiation of harmonics of the fundamental may be due to several causes, traceable either to the oscillator and associated power amplifier stage or to the coupling circuit between the final stage and the antenna, where it most frequently occurs. Harmonic generation in the tube circuit is due to the distortion of the wave shapes. These may be reduced to a considerable extent by the proper use of tubes and the critical adjustments of the circuits into which they function. However, the fulfillment of these conditions does not prevent the radiation of harmonics due to the antenna and characteristics of the coupling circuits. A transmission line or an antenna system has a distribution of inductance and capacity, and some of the harmonics generated in the tube circuits, although of very low percentage, may correspond with some of the harmonic frequencies of the transmission line or the radiation system and produce excessive harmonic radiation.

The particular feature of the present invention is the elimination of harmonics which may be present in the coupling circuit and the prevention of their radiation by the antenna.

Another feature of importance characterizing this invention is the provision of a coupling circuit in which energy transfer is accomplished at the fundamental frequency at maximum efficiency whereas currents of the harmonic frequencies are substantially counteracted by similar currents in phase opposition derived from a portion of the circuit rich in harmonic content.

In accordance with the invention, the capacity current in the tank circuit is utilized to obtain a voltage at a harmonic frequency, of such magnitude and polarity as to cancel the harmonic voltage in the antenna circuit. The antenna system is coupled to the tank circuit of the final radio frequency output stage by an arrangement of compound coupling to the inductive as well as the capacitive branch of the tank circuit, the two couplings being in opposite phase relation with respect to the undesired harmonic frequency components.

Other features and advantages will be apparent from the following description of this invention, pointed out in particularity by the appended claims, and taken in connection with the accompanying drawing, in which:

Figure 1 shows one embodiment of this invention wherein both couplings are inductive;

Fig. 2 shows a preferred embodiment in which the second coupling is taken directly from the capacitive branch; and

Fig. 3 illustrates a modification in which the capacitive branch has a resistance in series for deriving the harmonic voltage.

Referring to the drawing, in Fig. 1, the vacuum tube 1 has in its plate circuit the parallel resonant tank comprising the inductance 2 tuned by the capacity 3. A coupling coil 4 transfers the output power to the antenna 5 in conventional manner through an antenna loading coil 6. An additional coil 7 is placed in the capacitive branch of the tank circuit in series with the condenser 3. Another coil 8 is coupled with the coil 7 and is so connected in the circuit in series with the antenna coil that at harmonic frequencies its induced voltage is in phase opposition with the voltage induced therein by the tank coil 2. Since both coils 4 and 8 are in series and since in a tank circuit the capacitive branch will contain predominantly harmonic currents in comparison with the inductive branch, the harmonic component can readily be cancelled out in coil 4. The harmonic component usually is only a fraction of the fundamental, hence both coils 7 and 8 may be made very small to produce the required magnitude of harmonic voltage to counteract the voltage in the coupling coil 4.

In the circuit of Fig. 1 as well as in the others, only the essential portion of a radio transmitter is shown in order to simplify the drawing and the description, and to more clearly point out the invention which resides in the particular portion of a radio transmission system.

The tube 1 is the source of radio frequency energy which in practical application is generally a power amplifier stage, although it may be any suitable source for producing high frequency currents. The various connections which are necessary in the grid and filament circuits of the tube 1 and preceding stages have been omitted. To those skilled in the art, the necessary connections for the various electrodes of the tube as well as the other components of a radio transmitting system will be self-evident. The capacity 9 shown

in all figures is the usual by-pass condenser furnishing a low-impedance path to radio frequency currents. Similar elements in the various figures are indicated by identical reference characters.

Referring to Fig. 2, the output circuit of tube 1 includes the tank circuit comprising the inductance 2 and the main tuning capacity 3. In series with the latter there is an additional capacity 10, the junction point of the two capacities being connected by lead 11 to the antenna coupling coil 4, the other terminal of which connects through the loading coil 6 to the antenna 4. In parallel with the antenna coupling coil 4 is a series resonant circuit comprising the condenser 12 and the inductance 13. It is seen that by means of the connection 11 the second capacity 10 in the capacitive branch of the tank circuit is effectively in series with the antenna coupling coil 4. The capacity current flowing in the capacitive branch produces a voltage drop across the condenser 10 which is applied to the antenna coupling coil 4. This voltage will be predominantly at a harmonic frequency, and being in phase opposition with any induced voltage in coil 4 from the tank inductance 2, it will effectively cancel out the harmonic voltage. The series resonant circuit shunting the antenna coupling coil 4 is tuned to the fundamental frequency in order to provide a low impedance path for currents at the fundamental frequency. which may be transferred from the capacitive branch in order to prevent cancellation thereof due to the inverse connection of coil 4.

The operation of the circuit of Fig. 2 in cancelling out all harmonic voltages from the antenna may be shown mathematically as follows: Let

E=harmonic voltage generated by tube 1
X_L=the reactance of the tank coil 2 at fundamental frequency
X_C=the reactance of the main turning capacity 3 at fundamental frequency
X'_C=the reactance of the series capacity 10 at fundamental frequency
ωM=the mutual inductance between coils 2 and 4 at fundamental frequency
n=the order of harmonic (n=2 for second, 3 for third harmonic, etc.)
I_C=harmonic current through main tuning capacity 3.
I_L=harmonic current through tank coil 2.

Now at any harmonic frequency

$$\frac{n\omega}{2\pi}$$

$$I_C=\frac{E}{-j\frac{X_C}{n}-j\frac{X'_C}{n}}=j\frac{nE}{X_C+X'_C}$$

$$I_L=\frac{E}{jnX_L}$$

Harmonic voltage induced in antenna circuit by mutual induction between coils 2 and 4=$jnI_L\omega M=E_L$.

Harmonic voltage across condenser 10=

$$-\frac{jI_CX'C}{n}=E_C$$

$$\frac{E_L}{E_C}=\frac{-n^2I_L\omega M}{I_CX'_C}=\frac{-n^2E\omega M(X_C+X'_C)}{n^2EX_LX'_C}$$

Hence by making $X_LX'_C=-\omega M(X_C+X'_C)$, $E_L=E_C$, or $E_L-E_C=0$ with proper polarity there will be no harmonic voltage in the antenna. Since n is perfectly general, this holds for all harmonics simultaneously. This would indicate that the fundamental is also cancelled out. However, the analysis neglects the antenna component of current in the condenser 10; this is practically true of all harmonics, but not of the fundamental. However, $I_L\omega M$ does introduce a voltage of such relation that the voltage across condenser 10 may not compensate for it and at the same time produce full output in the antenna. For this reason, it is desirable to short out the antenna coil 4 for the fundamental only by means of the series tuned circuit shown.

Referring to Fig. 3, the circuit components are the same as in the previous figures, except that in series with the main tuning capacity 3, there is a resistor 14. The junction point of the latter and the condenser 3 is connected to the antenna coupling coil 4 by means of lead 11 in the same manner as shown in Fig. 2. The operation of the circuit is similar to Fig. 2, the capacity current flowing through the resistor 14 producing the necessary harmonic voltage which is applied to the antenna circuit. Since the harmonic voltages are always small, the resistor need not be so large as to seriously interfere with the tank circuit operation and consequently will consume little power.

I claim as my invention:

1. In a coupling circuit for radio frequency energy transfer, an input circuit comprising inductive and capacitive branches substantially in parallel and having undesired harmonic components of a frequency to be transferred to a substantially greater extent in one of said branches than in the other, a primary output work circuit capable of transmitting undesired harmonic components of said frequency, means for coupling said output work circuit to said inductive branch circuit, a separate secondary output circuit coupled to said capacitive branch circuit and a current conductive connection only coupling said means for coupling and said secondary output circuit whereby said undesired harmonic components are mutually counteracted.

2. In a system for radiating electro-magnetic waves, a source of radio-frequency energy including a tank circuit tuned to the frequency desired to be radiated comprising impedances branches and, having undesired current components of a multiple of said desired frequency to a substantially greater extent in one of said impedance branches than in another, an energy radiator, capable of transmitting undesired current components of a multiple of said desired frequency, means for coupling said radiator to said other branch of said tank circuit for energy transfer at said desired frequency and separate means for simultaneously only coupling said radiator to said one branch of said tank circuit carrying predominantly said undesired components, said couplings being in opposite phase relation with respect to said undesired components whereby said undesired components in said tank circuit and in said energy radiator are mutually counteracted.

3. In a system for radiating electro-magnetic waves, a source of radio-frequency energy including a tank circuit comprising an inductive branch and a capacitive branch, including a main tuning capacity substantially in parallel and tuned to a desired frequency to be radiated, said tank circuit carrying undesired harmonic current components of a multiple of said desired frequency, a second capacity in series with said capacitive branch, an energy radiator comprising

an antenna circuit having inductive reactances in series, one of said reactances being coupled to said inductive branch for energy transfer at the desired frequency, a current conductive connection between one terminal of said last mentioned reactance and the junction point of said second capacity and said main tuning capacity whereby said second capacity is serially included in said antenna circuit, the harmonic components currents therein tending to cancel similar components in said antenna circuit.

4. In a system for radiating electro-magnetic waves, a source of radio-frequency energy including a tank circuit comprising an inductive branch and a capacitive branch, including a main tuning capacity substantially in parallel and tuned to a desired frequency to be radiated, said tank circuit carrying undesired harmonic current components of a multiple of said desired frequency, a second capacity in series with said capacitive branch, an energy radiator comprising an antenna circuit having inductive reactances in series, one of said reactances being coupled to said inductive branch for energy transfer at the desired frequency, a current conductive connection between one terminal of said last mentioned reactance and the junction point of said second capacity and said main tuning capacity, whereby said second capacity is serially included in said antenna circuit, the harmonic components currents therein tending to cancel similar components in said antenna circuit, and a series resonant circuit tuned to said desired frequency paralleling said reactance.

5. In a system for radiating electro-magnetic waves, a source of radio-frequency energy including a tank circuit comprising an inductive branch and a capacitive branch, including a main tuning capacity substantially in parallel and tuned to a desired frequency to be radiated, said tank circuit carrying undesired harmonic current components of a multiple of said desired frequency, a resistance in series with said capacitive branch, an energy radiator comprising an antenna circuit having inductive reactances in series, one of said reactances being coupled to said inductive branch for energy transfer at the desired frequency, a current conductive connection between one terminal of said last mentioned reactance and the junction point of said resistance and said main tuning capacity, whereby said resistance is serially included in said antenna circuit, the harmonic components currents therein tending to cancel similar components in said antenna circuit.

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