

March 6, 1945.

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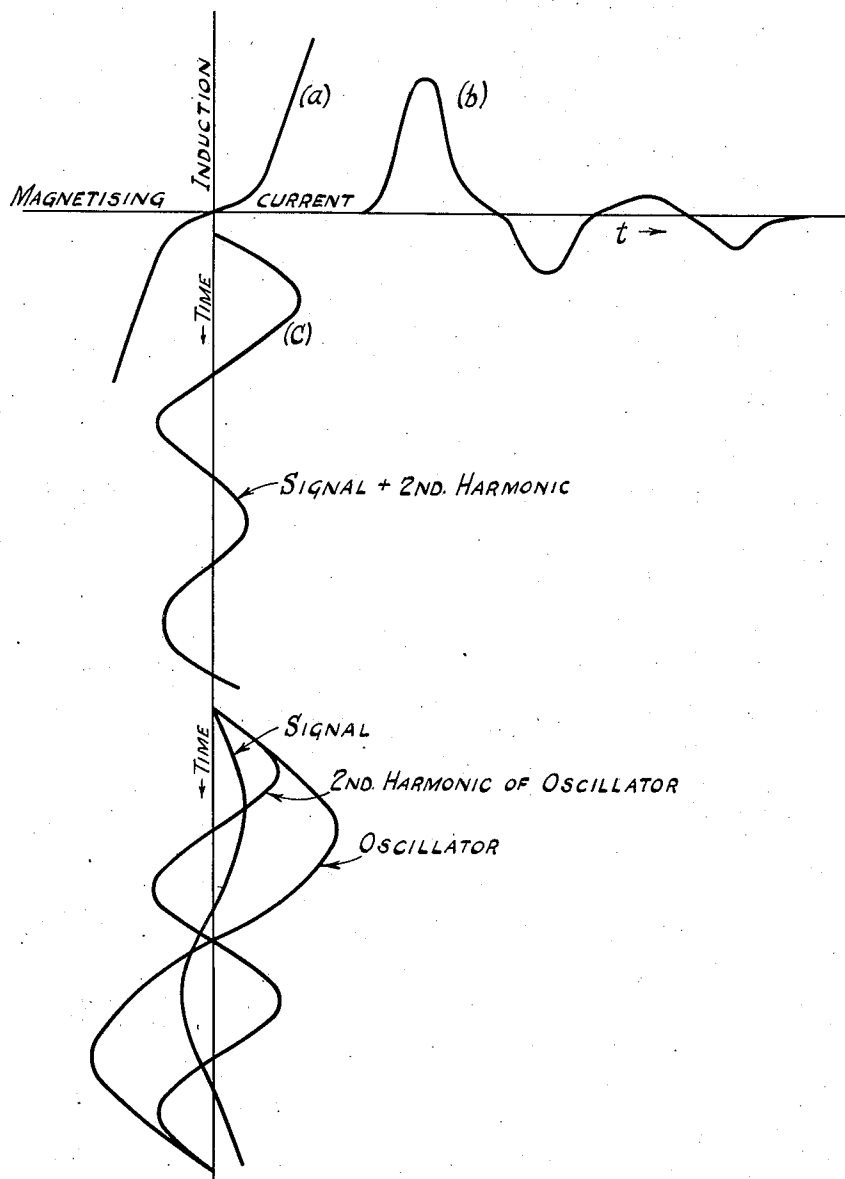
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MAGNETIC FREQUENCY CONVERTER

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Fig. 1.



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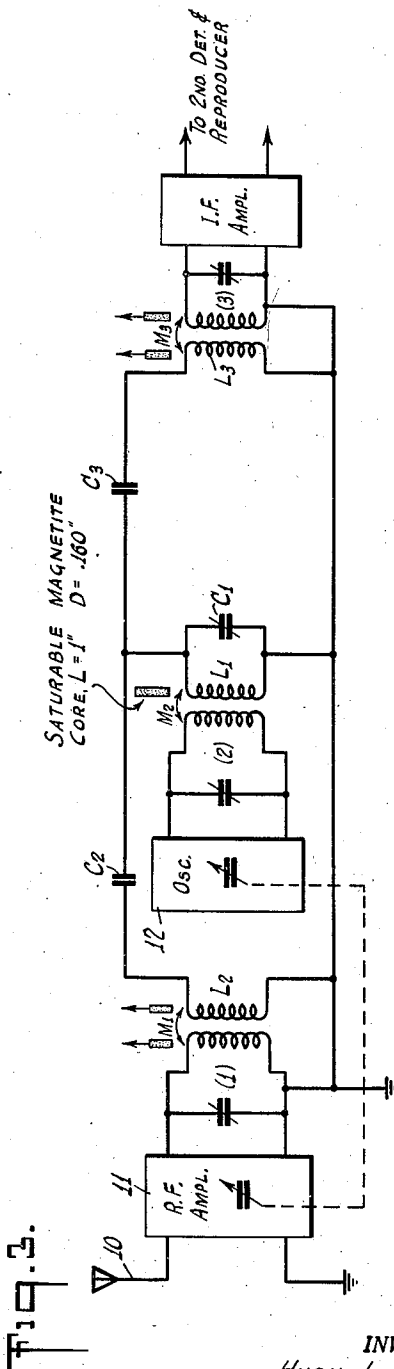
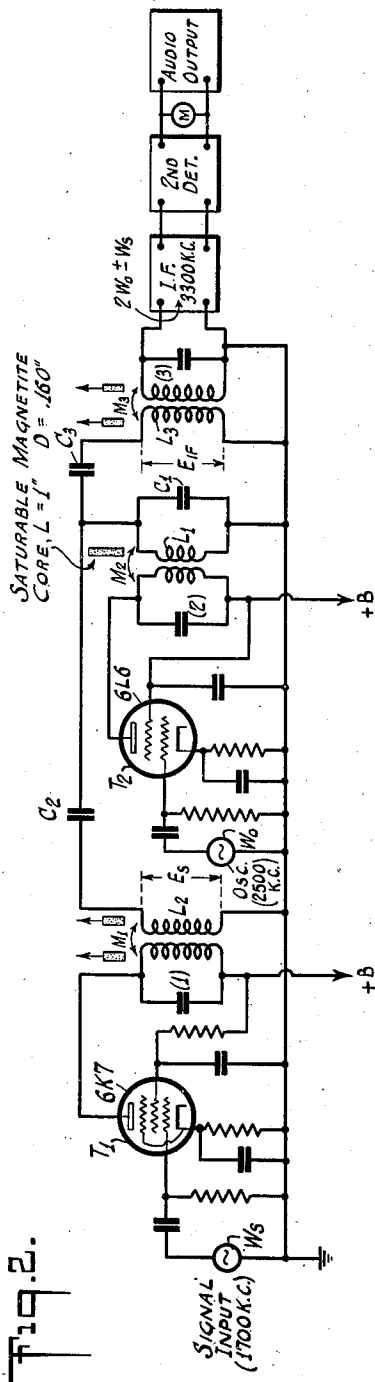
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MAGNETIC FREQUENCY CONVERTER

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9 Claims. (Cl. 250-20)

The present invention relates to a method of and a circuit arrangement for obtaining frequency conversion by magnetic means.

In radio receivers of the heterodyne or superheterodyne types it is customary to employ a vacuum tube mixer or heterodyne converter. In some applications where it is desired to avoid the use of a vacuum tube converter, the method and means of frequency conversion constituting the present invention can be employed with substantially the same efficiency. It is therefore an object of the invention to provide an alternative method and means of frequency conversion.

Since according to the invention the frequency conversion by magnetic means is accomplished without the use of a vacuum tube as the detecting means, the elimination of tube noises and consequent increased signal to noise ratio over the conventional vacuum tube heterodyne converter are of decided advantage at high and ultra-high frequencies.

Other objects are to improve generally the simplicity and efficiency of receivers of the heterodyne or superheterodyne types and to more particularly provide a receiver which is not only reliable in operation but capable of economical manufacture and assembly.

The novel features characteristic of my invention are set forth with particularity in the appended claims. The invention itself, however, both as to its construction and mode of operation together with further objects and advantages thereof, will best be understood by reference to the following description taken in connection with the accompanying drawings in which Fig. 1 shows certain curves in order to explain the invention, Fig. 2 discloses a circuit arrangement embodying the invention and which will serve to demonstrate the conversion efficiency of this type of frequency mixer or converter, and Fig. 3 is a practical embodiment of the invention in a superheterodyne receiver.

The invention is based on the fact that a non-linear relationship exists between induction and magnetizing force of ferro-magnetic cores. By reason thereof the magnetic effects may be used for the purpose of shifting the frequency band of a signal to a new band of frequencies. However, in order to minimize radio frequency losses a powdered magnetic material with a suitable binder is utilized, an easily saturated material like magnetite being the most efficient.

Referring to Fig. 1 the non-linear relation between induction and magnetizing current of a ferro-magnetic core that may be used to carry

out the invention is shown by the curve *a*. Illustrated also are the oscillator current wave, its second harmonic and the signal current wave. The signal frequency when added to the oscillator second harmonic gives the curve *c*. Hence, when the wave of such a form as illustrated by *c* is impressed upon the characteristic shown by *a*, the resultant wave *b* with its obvious dissymmetry shows that detection has resulted.

The frequency terms present in a magnetic detector or converter, as an approximation, may also be determined by considering only the voltage drop across the coil containing the saturable magnetic core. This voltage drop is

$$e = -L di/dt \quad (1)$$

An approximate expression for the inductance *L* results from the fact that the change in permeability is independent of direction of the radio frequency flux, i. e., no linear term is present and the permeability is a function of current. Therefore assume that

$$L = L_0 + ki^2 \quad (2)$$

where *k* is a constant and *i* the instantaneous current. Substituting the above value of *L* in (1)

$$e = (L_0 + ki^2) di/dt \quad (3)$$

If the current *i* involves the two, i. e., signal and oscillator frequencies, for example,

$$i = a \cos \omega_0 t + b \cos \omega_s t$$

then the detection terms as obtained from Equation 3 are

$$\frac{abk}{4} [a \sin (2\omega_0 \pm \omega_s) t + b \sin (\omega_0 \pm 2\omega_s) t]$$

Since in general the oscillator amplitude *a* greatly exceeds the signal amplitude *b*, the frequency terms of interest are $2\omega_0 \pm \omega_s$.

The magnetic frequency converter according to the invention is shown in Fig. 2 to consist of three coupled circuits, tuned to the oscillator, signal and intermediate frequencies. As pointed out above, the intermediate frequency may be chosen as $2\omega_0 + \omega_s$ or $2\omega_0 - \omega_s$, where ω_0 , ω_s are the oscillator and signal frequencies, respectively. To obtain some idea as to the conversion efficiency to be expected with such a converter, the circuit arrangement which I have used will now be described. For convenience the signal, oscillator and intermediate frequencies were chosen as 1700, 2500, 3300 kc. respectively. The element values of the three coupled circuits were readily determined by means of Foster's reactance theorem such that the network was anti-

resonant at 1700, 2500, 3300 kc. with the series resonant points at 2100 and 2900 kc. The tube T_1 which was of the type 6K7 together with tuned circuit 1 provided a convenient means of introducing the signal frequency ω_s to the main network. Likewise, the amplifier tube T_2 (type 6L6) with tuned circuit 2 served to introduce the oscillator frequency ω_o . The tuned circuit 3 was sharply tuned to the intermediate frequency, the output of which was coupled to one or more intermediate frequency stages IF, followed by a second detector, audio output stage and reproducer in the usual way. Although iron core tuning was used for the tuned circuits, the coils and core were all of conventional design so that little or no saturation effects occurred in these circuits. On the other hand, coil L_1 was closely wound on a magnetite core having a length of 1 inch and a diameter of .160 inch. With this large ratio (approximately 6 to 1) of length to diameter, the core is capable of considerable flux concentration.

It should be pointed out that in this circuit arrangement maximum change in permeability is desired and not necessarily high Q for the coil and core to be saturated. For this reason coarse rather than fine magnetite should be used when possible because greater change in permeability is possible with larger particles. For high frequency use, in order to maintain a reasonable Q , finer magnetite particles are necessary, thereby resulting in less change in permeability, and necessitating greater local oscillator voltage than in lower frequency applications. The values M_1 , M_2 , M_3 in the drawing all corresponded to critical coupling values.

The conversion efficiency of the network is determined by the ratio of i - f voltage E_{if} appearing across coil L_3 to the signal voltage E_s across L_2 where the oscillator voltage is varied until maximum i - f output is obtained. In making the measurements, since considerable oscillator voltage also appeared across L_3 , the following method was used to determine the conversion efficiency. With a given signal, the oscillator voltage was varied until maximum output was obtained as denoted by the meter M in the output of the second detector circuit. Then, with the rest of the circuit, except for L_3 and output circuit disconnected, the i - f voltage was introduced across L_3 until the output meter read the same as previously. By this means the i - f voltage appearing across L_3 could readily be obtained, and the conversion efficiency determined. With a coarse magnetite (60-140 mesh) "saturating" core the measured conversion efficiency was about 20% for a variation of signal voltage from 1 to 10 volts. With micronized or fine magnetite the efficiency was but 2 or 3 per cent lower.

In order to demonstrate that some tube in the set-up rather than magnetic effects was not the cause of rectification, an air core coil of the same value as the "saturating" coil L_1 was substituted in place of L_1 . With the same coupling to the oscillator tuned circuit 2 as previously no output was observed when the circuit 3 was tuned to the intermediate frequency. When, however, very tight coupling to circuit 2 was provided, some output at intermediate frequency did appear.

Again, the coil L_1 was replaced by an air core coil of the same inductance and with the same coupling to the oscillator input coil, but the coil L_2 was replaced by a coil plus core of the same inductance value except that the ratio of length to diameter was made the same as in the first

experiment. With this arrangement saturation effects occurred in the signal branch of the circuit rather than in the oscillator branch. It was found that with this arrangement practically the same conversion efficiency resulted as in the case where the coil L_2 was the "saturating" coil.

The circuit of Fig. 3 is generally similar to that of Fig. 2 and shows a practical embodiment of the invention as applied to a superheterodyne receiver. Signals picked-up by the antenna 10 are amplified in RF amplifier stage 11, the amplified energy appearing in its tunable output circuit 1. An oscillator 12 of conventional design is connected to the tunable circuit 2. As explained above the sum or difference frequencies are developed in the L_1 - C_1 circuit which contains the saturable magnetite core. By way of the coupling condenser C_3 and the coil L_3 the resulting intermediate frequency is transmitted to the circuit 3 which may then be amplified, detected and reproduced in the usual manner.

As already pointed out, it is possible to detect on the sum frequencies as well as the difference frequencies. For example, if the oscillator frequency is 1250 kc. and the signal frequency 1700 kc., then the i. f. (sum frequencies) is 4200 kc. The approximate element values of the network used in the circuit of Fig. 3 which was parallel resonant at these above frequencies and series resonant at 1500 and 3000 kc. were as follows:

$L_1=4 \mu h.$	$C_1=1960 \mu \mu f.$
$L_2=290 \mu h.$	$C_2=40 \mu \mu f.$
$L_3=2 \mu h.$	$C_3=1400 \mu \mu f.$

With this arrangement the measured conversion efficiency was 12% approximately, a lower value than when the detection was based on the difference frequencies. Disregarding differences in L/C ratios for the two cases, the degree of coupling is less when the frequencies are rather widely separated and hence decreased efficiency results.

With optimum L/C ratios consistent with good circuit Q and a good design of the core and coil to be saturated, the efficiency values given above can be increased to compare more favorably with values obtainable with a tube converter.

It is to be understood that the values above chosen were only by way of example, and that in a particular case the values of the circuit elements L_2C_2 , L_1C_1 , L_3C_3 of Fig. 2 or 3 are determined such that the network is parallel resonant to the signal oscillator and intermediate frequencies where the oscillator is inductively coupled to the saturable core and coil combination (L_1).

The networks consisting of L_1C_1 , L_2C_2 , L_3C_3 are equivalent to three parallel resonant circuits but these resonant circuits are not independent of one another but are coupled such that parallel resonance occurs at the oscillator, signal and intermediate frequencies chosen. It will be understood, of course, that other coupling methods and arrangements might be used.

While I have shown preferred embodiments of the invention, it will be understood that modifications and changes may be made without departing from the spirit and scope of the invention, as will be understood by those skilled in the art.

What I claim is:

1. A magnetic frequency converter for combining the frequencies of a pair of high frequency sources, comprising a pair of circuits each tunable to the frequency of one of said sources, and a third circuit provided with a saturable magnetic core coupled to each of the first mentioned circuits whereby there is produced in said third cir-

circuit an intermediate frequency due to the interaction in said third circuit of the frequencies of the first two circuits.

2. A magnetic frequency converter for use in a superheterodyne receiver comprising a pair of circuits tunable respectively to the frequency of the incoming signal and to the frequency of the local oscillator, and a third circuit provided with a saturable magnetic core coupled to each of the first mentioned circuits whereby there is produced in said third circuit an intermediate frequency due to the interaction in said third circuit of the frequencies of the first two circuits.

3. A system of frequency conversion comprising a first resonant circuit tunable to one radio frequency, a second resonant circuit tunable to a second radio frequency, and a third circuit effectively coupled to said first and second circuits and fixedly tuned to the intermediate frequency resulting from the interaction of the first and second frequencies, said latter circuit being provided with a saturable ferro-magnetic core which is instrumental in effecting the frequency conversion.

4. In a radio receiver of the superheterodyne type, a magnetic frequency converter for combining the frequencies from a signal source and a local oscillator source, comprising a first resonant circuit tunable to the signal frequency, a second resonant circuit tunable to the oscillator frequency, and a third circuit fixedly tuned to the difference frequency resulting from the interaction in said third circuit of the signal frequency and the second harmonic of the oscillator frequency, said latter circuit being provided with a saturable ferro-magnetic core.

5. A magnetic frequency converter for combining the frequencies from a single source and from a local oscillator source, comprising a first resonant circuit tunable to the signal frequency, a second resonant circuit tunable to the oscillator frequency, and a third circuit fixedly tuned to the sum or difference frequencies resulting from the interaction in said third circuit of the signal frequency and the second harmonic of the oscillator

frequency, said latter circuit being provided with a saturable magnetite core having a length and a diameter in the ratio of approximately 6 to 1.

6. In a receiver circuit of the superheterodyne type, a source of signal frequencies, a source of local oscillation frequencies, a network comprising a coil provided with a ferro-magnetic core and a condenser shunting the coil, means for coupling each of said sources to the network wherein the frequencies of said sources are combined, and means for deriving from said network a resultant intermediate frequency.

7. In a receiver circuit of the superheterodyne type, a source of signal frequencies, a source of local oscillation frequencies, a network comprising a coil provided with a saturable magnetite core and a condenser shunting the coil, means for coupling each of said sources to the network wherein the frequencies of said sources are combined, and means for deriving from said network a resultant intermediate frequency.

8. In a receiver circuit of the superheterodyne type, a source of signal frequencies, a first tuned circuit coupled to said source, a source of local oscillation frequencies, a second tuned circuit coupled to said latter source, a network comprising a coil provided with a ferro-magnetic core and a condenser shunting the coil, means for closely coupling the first and second tuned circuits to the network wherein the frequencies of said sources are combined, and circuit means closely coupled to said network for deriving therefrom a resultant intermediate frequency.

9. A system of frequency conversion comprising a network having an inductance provided with a saturable ferro-magnetic core in which a non-linear relation exists between the change in permeability of the core and the magnetizing current, means for impressing upon said network oscillations of a plurality of differing radio frequencies, and means for deriving from said network a combined frequency resulting from the interaction in said network of the plurality of differing frequencies.

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