Jan. 31, 1967 H. SCHOEN 3,302,118

MULTIPLICATIVE MIXING WITH TRANSISTORS

Filed Nov. 3, 1964 2 Sheets-Sheet 1

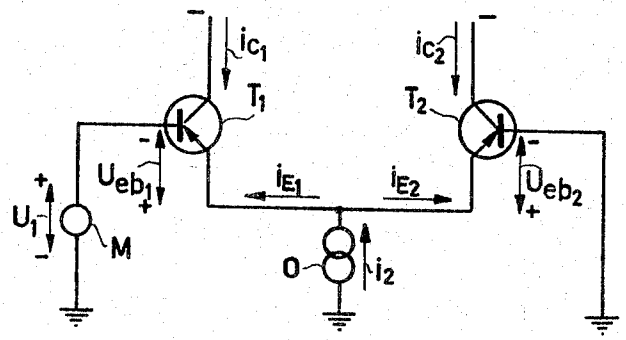


FIG.1

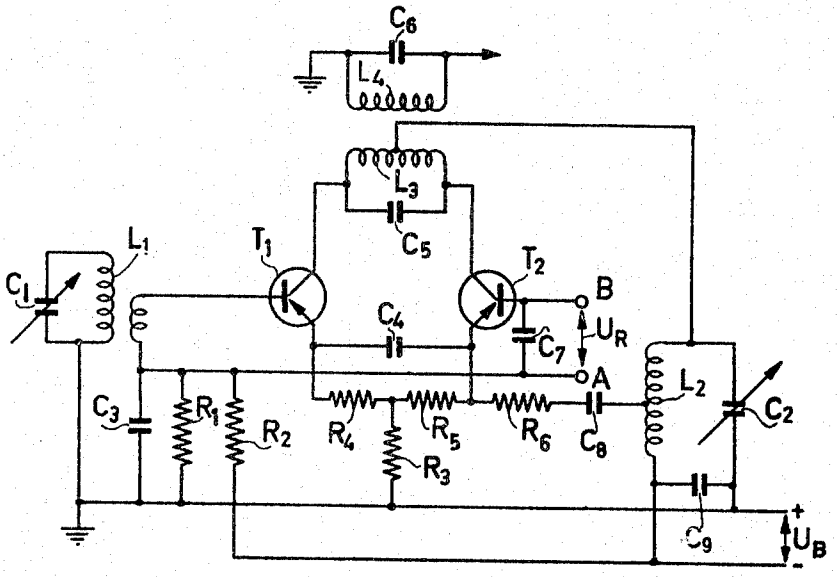


FIG.2

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MULTIPLICATIVE MIXING WITH TRANSISTORS

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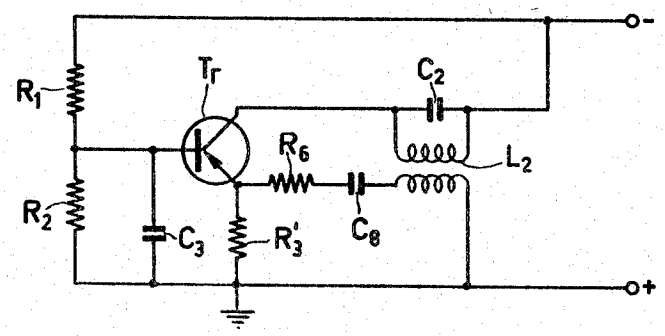


FIG.3

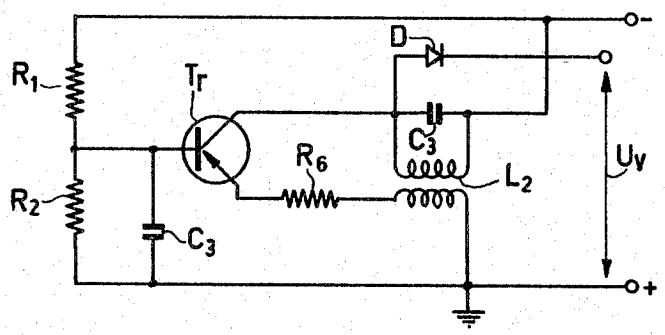


FIG.4

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MULTIPLICATIVE MIXING WITH TRANSISTORS

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The invention relates to a circuit for the multiplicative mixing of two signals.

Known mixer stages employing transistors generally operate according to the principle of additive mixing. The received signal and the oscillator signal are additively supplied to the base-emitter junction of the mixing transistor and control the collector current of the transistor. Since the input characteristic is non-linear, the mixing products of the two input signals and also mixing products of the harmonics of the input signals occur in the collector current. The harmonic mixing products are disturbing, for example, in the case of super-heterodyne reception, because, as a result of intermediate frequency formation they cause the simultaneous reception of various frequencies. As a result, the reception of the desired signal may be considerably adversely influenced. Furthermore, the mixing efficiency of such circuit arrangements is affected by the content of higher harmonics of the oscillator-signal. The circuit may be connected to decrease the production of interfering signals, but the latter cannot be avoided entirely without simultaneously decreasing considerably the mixing efficiency for the useful signal.

These disadvantages may be prevented in principle by multiplicative mixing. Mixer stages which operate according to this principle must be constructed so that the output current can be controlled by at least two electrodes which are independent of each other. A relationship which is as linear as possible must exist between each input signal and the output signal.

In tube technology this principle is successfully realized by the use of multiple-electrode tubes, for example, mixing hexodes, built in a suitable manner. In such mixer stages all interferences can be substantially removed, with the exception of the so-called image-frequency at a distance of the double intermediate frequency of the desired receiving signal. This interference is in principle unavoidable, since the multiplication of this frequency by the oscillator frequency gives the same difference frequency as the multiplication of the desired frequency by the oscillator frequency. The commonly used transistors are in general comparable with triodes and controllable only at one electrode. So mixing with a single transistor can only be performed according to the additive principle resulting in the above disadvantage.

On the contrary, with the circuit arrangement according to the invention a multiplicative mixing of two signals is obtained. In the circuit, the emitters of two transistors, having base emitter junctions with substantially exponential current-voltage characteristics, are interconnected for alternating currents. A first signal source is connected between the bases in the sense of a voltage control of the base-emitter junctions of the two transistors. A second signal source is connected to the interconnected emitter electrodes in the sense of a current control of the base-emitter junctions of the two transistors. The mixed product is derived from at least one of the collector circuits.

It is noted that the invention is not limited to circuit arrangements for the formation of an intermediate frequency from two signals. The multiplicative mixer stage according to the invention is also suitable for other types of multiplicative mixing processes, for example, for amplitude modulation or for multiplicative measuring processes.

The invention will now be described in greater detail with reference to the drawing, in which—

FIG. 1 is a principal circuit diagram of the circuit arrangement according to the invention;

FIG. 2 is an example of a circuit according to the invention;

FIG. 3 shows the circuit arrangement shown in FIG. 2 in as far as the oscillator action is concerned; and

FIG. 4 shows a second circuit arrangement according to the invention in as far as the oscillator action is concerned.

The operation of the circuit arrangement is based on the fact that in transistors, wherein the base emitter junctions have substantially exponential current-voltage characteristics, the slope of this characteristic is proportional to the emitter current over a wide range. In certain conditions a conversion transconductance of 25% of the normal transconductance of the single transistor can be obtained without difficulty without mixing products of the higher harmonics with corresponding interferences occurring. This is a decisive advantage as compared with the commonly used additive mixer stage. The new mixer stage can be controlled without influencing the self-produced oscillator signal, if any. This is a further advantage as compared with an additive mixer stage.

An essential condition for the multiplicative mixing with transistors is proportionality between the slope S and the emitter current. For frequencies below the limit frequency $f\alpha$ and emitter currents up to a few ma.:

$$S=\alpha\frac{i_E}{U_T} \tag{1}$$

where $\alpha\approx 1$ is the small signal current amplification in base arrangement,

$$U_T=\frac{KT}{q}$$

(=26 mv. at room temperature) is the so-called temperature voltage, and i_E is the instantaneous value of the emitter current. The small letter indicates that this relationship is also true for temporarily variable emitter currents.

Between the collector alternating current i_C and a signal u_{eb}, which is small with respect to U_T, at the input of the transistor the linear relationship:

$$-i_c=Su_{eb} \tag{2}$$

exists. From the combination of Equation 1 and Equation 2 it can be seen that it is possible in principle to mix with transistors according to the multiplicative principle since the collector alternating current is proportional to both u_{eb} and to the alternating current part i_e of the emitter current. However, it is not possible to control the low-ohmic base emitter junction of a single transistor and to vary the emitter current with a second signal when the frequencies do not differ by orders of magnitude. This condition usually is not fulfilled in mixer stages.

The problem is solved, however, when two transistors T_1 and T_2 are interconnected as shown in FIG. 1. The voltage u_1 of a signal source M is connected between the base supply lines of the two transistors. The emitters of the two transistors are interconnected and the current i_2 of a second signal source O, for example of an oscillator signal source, is applied to the interconnected emitters. Assuming that both transistors behave entirely equally, half the input voltage:

$$-u_{eb1}=u_{eb2}=\frac{u_1}{2}$$

appears at each transistor. Then the current i_2 of the

oscillator signal source O is also divided equally between the two transistors so that

$$i_{E1}=i_{E2}=\frac{i_2}{2}$$

The base emitter junctions of the two transistors are thus controlled simultaneously by a voltage ($u_1/2$) and a current ($i_2/2$). Both control operations are independent of each other as long as the internal resistance of the voltage source M is small as compared with the sum of the input resistances of the two transistors in common emitter arrangement and that of the current generator has a high resistance with respect to the parallel arrangement of the two input resistances in common base arrangement. Both conditions can easily be realized in practical circuit arrangements.

The collector currents are now equal to:

$$-i_{c1}=\alpha 1\frac{i_2}{2}-\alpha 1\frac{u_1 i_2}{4U_T}$$

$$-i_{c2}=\alpha 2\frac{i_2}{2}+\alpha 2\frac{u_1 i_2}{4U_T}$$

When u_1 is a pure alternating voltage of a frequency ω_1 (of the form $u_1=\hat{u}_1 \cos \omega_1 t$) and i_2 is a direct current (I_2) on which an alternating current of a frequency $\omega_2(i_2 \cos \omega_2 t)$ is superimposed, it can be demonstrated that the collector currents are composed of four parts, namely the average direct current $I_2/2$, alternating currents of the frequencies ω_1 and ω_2 and the mixing product of the two sine signals.

The two parts of the mixing product in both collector currents are different only in their sign. The mixing transconductance is approximately 25% of the normal transconductance since it can be calculated that the mixing transconductance S_c is determined by the expression:

$$S_c=\frac{m}{4}So$$

So indicates the normal transconductance of a transistor at the operating point in question and m indicates the modulation depth of the emitter current. This relationship holds in the range of the linear driving of the emitter current ($m\leq 1$). The relationship between the current i_E and base-emitter voltage U_{eb} is expressed by the following relationship when the frequencies are sufficiently low:

$$\left[i_E=I_{Eo}\exp\frac{u_{eb}}{u_T}\right]$$

where I_{Eo} is a transistor constant.

In the circuit arangement shown in FIG. 1 the base emitter voltages for $u_1=0$ are equal so that the emitter currents divide into the following relationship:

$$\frac{i_{E1}}{i_{E2}}=\frac{I_{Eo1}}{I_{Eo2}}=x$$

(current distribution factor).

Apparently, this relationship is independent of the value of the impressed total current. Since in general the transistors will not have exactly the same I_{Eo}, it is interesting to test the influence of the unequal distribution of the emitter currents on the mixing properties. From FIG. 1 it follows that

$$i_2=i_{E1}+i_{E2}$$

Using these two equations, the emitter currents may be written:

$$i_{E1}=i_2\frac{x}{1+x}$$

$$i_{E2}=i_2\frac{1}{1+x} \qquad (9)$$

The distribution u_1 between the two transistors is also dependent on the distribution of the emitter current.

The volages at the two transistors are proportional to the input resistance in base arangement which are proportional to the reciprocal value of the associated emitter currents

$$\frac{-u_{eb1}}{u_{eb2}}=\frac{i_{E2}}{i_{E1}}=\frac{1}{x}$$

and with $u_1=u_{eb2}-u_{eb1}$, the two voltage drops caused by u_1 are

$$u_{eb1}=-u_1\frac{1}{1+x} \quad u_{eb2}=u_1\frac{x}{1+x}$$

From these relationships for the distribution of the input voltage and the above relationships for the emitter current distribution it follows that the mixing products in the colletor currents are proportional to:

$$\frac{1}{\left(\sqrt{x}+\frac{1}{\sqrt{x}}\right)^2}$$

The two mixed current portions are equally large and oppositely directed indenpendently of the unequal distribution of the emitter currents. This also follows from FIG. 1. Since only the oscillator signal i_2 is supplied to the junction of the two emitters, the currents of the mixing products must compensate each other at this point.

From the above calculation it further follows that the mixing products of the collector current, and consequently also the mixing transconductance highly depend on the current distribution factor x. It becomes largest for equal distribution ($x=1$). It is thus necessary to compensate for differences of the input characteristics by suitable measures, for example by a direct voltage which is added to u_1, or by a strong direct current negative feedback. This strong dependence of the mixing transconductance on the current distribution renders a control of the mixing amplification possible by coupling a variable direct voltage in a base line.

Now the behavior remains to be explained in case of overdriving of the emitter current. This is of particular importance with respect to the oscillator circuit.

As soon as the amplitude of the oscillator signal exceeds the emitter current ($m>1$) distortions occur. A half wave is sharply limited in amplitude. An oscillogram of the common emitter current (and consequently substantially also of the sum of the two collector currents) would show the variation of a sine curve flattened on one side.

Up to a modulation degree $m=1$, the fundamental wave part increases proportionally to the modulation degree. Higher harmonics do not occur. In case of overdriving the fundamental wave part even further increases, it is true, but simultaneously also the average direct current and the content of higher harmonics constantly increases.

In case of overdriving, harmonics of the oscillator frequency occur which result in interferring mixing products. In order to obtain the above demonstrated advantage of the multiplicative mixing, the oscillator signal must be limited so that the driving range is avoided or at any rate just reached.

Naturally, the above described mixer stage can be controlled with a separately produced oscillator signal. By using a suitable circuit the amplitude of this signal can be kept constant and adjusted so that the driving limit of the mixer stage is not reached. Such a circuit is free of interferences, but it is expensive.

The oscillator signal may also be produce in the mixer stage. FIG. 2 shows such a device. In this figure the operating point of the two transistors T_1, T_2 is set by means of a potentiometer R_1, R_2 at the base of T_1 and resistors R_3, R_4 and R_5 in the emitter supply lines of T_1 and T_2. In addition, a control voltage U_R may be applied between the points A and B. As long as this control voltage is zero (for example A and B are interconnected) the emitter currents of the two transistors,

in the absence of an input signal, would have to be equal in order that the mixing transconductance reaches its highest value. This may be accomplished by providing a direct current negative feed back in the connection line of the two emitters. For that purpose, the equally large resistors R_3 and R_4 are provided. The resistances of these resistors should be as high as possible so that the current is more equally distributed between the transistors. On the other hand, the control voltage necessary for a certain decrease in amplification increases, when the negative feed back increases so that a compromise in the value of the resistors must be reached between the two requirements.

The receiving signal is supplied to the base of T_1 through an input circuit (L_1, C_1). The emitters of the transistors T_1 and T_2 are interconnected for alternating current by a large capacitor C_4. The coupling of the oscillator circuit (L_2, C_2, C_9) to the interconnected emitters is effected through a capacitor C_8 and a resistor R_6.

The intermediate frequency is coupled out by means of an oscillatory circuit L_3, C_5 which, together with a circuit L_4, C_6 tuned also to the intermediate frequency, forms a band filter to which the following intermediate frequency stages are connected.

The primary circuit coil L_3 has a center tap. The oscillator circuit is connected to this tap. The direct current components of the two collector currents flow through coil L_2 to the tap. In principle, one of the two collectors could be connected directly to the oscillator circuit. The advantage of the center tap chosen in this case is that the intermediate frequency circuit is attenuated by the series arrangement of the output resistors of the two transistors and that no oscillator voltage occurs across the intermediate frequency output, as a result of difference formation of the two collector currents.

The capacitors C_3, C_4, C_7, C_8 and C_9 must have low impedances at the frequencies of all signals and oscillations present in the circuit.

The production of oscillator oscillations takes place as a result of the feed back coupling of the collector circuit to the emitter circuit through the oscillatory circuit L_2, C_2, C_9. The possibility of using the mixer stage as a self-oscillatory mixer stage and at the same time controlling the mixing amplification (by means of U_r) without influencing the oscillator action is based on the fact that the circuit arrangement for the oscillator signal appears as a single transistor with fixed operating point and having an emitter current equal to the sum of the two emitter currents. Variation of the current distribution does not vary the total emitter current.

FIG. 3 shows the device according to FIG. 2 in as far as it relates to the oscillator action. The two transistors T_1 and T_2 of FIG. 2, which are connected in parallel for the oscillator signal, are replaced by a single transistor T_r in FIG. 3. The resistor R'_3 replaces the resistors R_3, R_4 and R_5. The resistor R_6 is connected in the emitter supply line in order to obtain an effective current control of the emitter electrode.

The mixer stage in this type of oscillation production is operated in the overdriving range. The result hereof is that the content of higher harmonics of the oscillator signal can assume very great values in circumstances. This is undesired. It has appeared that an improvement can be obtained when a capacitor C_8 is connected in series with the resistor R_6, as a result of which the direct current part of the emitter current automatically flows entirely through R'_3.

A further decrease of the content of higher harmonics may be obtained, as shown in FIG. 4, by means of a limiting diode D. The diode is connected at the one end to the oscillator circuit L_2, C_2 and at the other end to a bias voltage U_v. By suitable proportioning of this bias voltage the distortions can be kept very small. When no diode is provided, the transistors act as limiting devices, so that distortion products resulting from the limiting action are produced directly in the transistors. The diode D, however, limits the oscillations, and hence produces distortion products externally of the transistors. The harmonics produced by the diode are filtered by the resonant circuit L_2, C_2, so that the presence of distortion products at the transistor is reduced.

What is claimed is:

1. A transistor mixing circuit comprising first and second transistors each having a base, emitter and collector electrode, alternating current conductive means connected between the emitter electrodes of said first and second transistors, a source of a signal voltage, means applying said signal voltage between the base electrodes of said first and second transistors, a source of a signal current, means for applying said current to the base-emitter junctions of said first and second transistors whereby a part of said current flows through the base-emitter junction of said first transistor and another part of said current flows through the base-emitter junction of said second transistor, and output circuit means connected to the collector electrode of at least one of said transistors.

2. A transistor mixer circuit comprising first and second transistors of the same conductivity type, each having a base, emitter and collector electrode, the emitter-base junctions of said transistors having exponential current voltage characteristics, alternating current conductive means connected between the emitters of said transistors, a source of a first signal, means applying said first signal between the base electrodes of said transistors, a source of a second signal, means applying said second signal to the emitter electrodes of said first and second transistors, whereby a part of the current from said source of a second signal flows through the base-emitter junction of said first transistor and another part of said current flows through the base-emitter junction of said second transistor, and the base-emitter junctions are controlled simultaneously by a voltage proportional to said first signal and a current proportional to said second signal, and output circuit means connected to the collector electrode of at least one of said transistors.

3. A transistor mixer circuit comprising first and second transistors of the same conductivity type each having a base, emitter and collector electrode, the emitter-base junctions of said transistors having exponential current-voltage characteristics, alternating current conductive means connected between the emitters of said transistors, a source of a signal voltage, means applying said signal voltage between the base electrodes of said transistors, oscillatory circuit means, means for coupling said oscillatory circuit means between said emitter electrodes and the collector electrode of at least one of said transistors whereby oscillations are produced at said emitter-electrodes, and part of the current of said oscillatory circuit means flows in the base-emitter junction of said first transistor and another part of said current flows in the base-emitter junction of said second transistor, and output circuit means connected to at least one of said collector electrodes.

4. A transistor mixer circuit comprising first and second transistors of the same conductivity type each having a base-emitter and collector electrode, the emitter-base junctions of said transistors having exponential current-voltage characteristics, alternating current conductive means connected between the emitters of said transistors, a source of operating potential having first and second terminals, first resistor means connected between said base electrodes and said first and second terminals for providing a base bias for said transistors, second resistor means connected between said emitter electrodes and said first terminal, a source of a signal voltage, means applying said signal voltage between the base electrodes of said first and second transistors, means providing oscillations, means applying said oscillations between said emitter electrodes and said first terminal, whereby a part of the cur-

rent from said means providing oscillations flows in the base-emitter junction of said first transistor and another part of said current flows in the base-emitter junction of said second transistor, and the emitter-base junctions of said transistors are controlled simultaneously by a voltage proportional to said signal voltage and a current proportional to said oscillations, output circuit means, and means connecting said output circuit means between at least one of said collector electrodes and said second terminal.

5. The mixer circuit of claim 4 wherein said means providing oscillations comprises an oscillatory circuit, means coupling said oscillatory circuit to said emitter electrodes, and means connecting said oscillatory circuit between said output circuit and second terminal, whereby said mixer circuit generates said oscillations.

6. A transistor mixer circuit comprising first and second transistors of the same conductivity type each having a base emitter and collector electrode, the emitter-base junctions of said transistors having exponential current-voltage characteristics, alternating current conductive means connected between the emitters of said transistors, a source of operating potential having first and second terminals, first resistor means connected between said base electrodes and said first and second terminals for providing a base bias for said transistors, second resistor means connected between said emitter electrodes and said first terminal, a source of a signal voltage, means applying said signal voltage between the base electrodes of said first and second transistors, means providing oscillations, means applying said oscillations between said emitter electrodes and said first terminal, whereby the emitter-base junctions

of said transistors are controlled simultaneously by a voltage proportional to said signal voltage and a current proportional to said oscillations, output circuit means, means connecting said output circuit means between at least one of said collector electrodes and said second terminal, a source of control voltage, and means for connecting said source of control voltage between the bases of said transistors for controlling the mixing amplification of said mixer circuit.

7. The mixer circuit of claim 6 wherein said output circuit comprises a tapped resonant circuit connected between the collectors of said first and second transistors and said oscillatory circuit is connected between the tap on said oscillatory circuit and said second terminal.

8. The mixer circuit of claim 6 comprising a non-linear device, and means connecting said non-linear device to said oscillatory circuit to limit amplitude of oscillating thereacross.

References Cited by the Examiner

UNITED STATES PATENTS

3,042,870	7/1962	Minner et al.	325—451
3,127,562	3/1964	Harvey et al.	325—440 X
3,184,682	5/1965	Healey	325—435

FOREIGN PATENTS

885,014	12/1961	Great Britain.

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