

Circuit arrangement for the reduction of the distortions in an FM quadrature demodulator.

The invention relates to an FM quadrature demodulator in accordance with the pre-characterizing part of Claim 1. Such a demodulator is known from IEEE TRANSACTIONS ON CONSUMER ELECTRONICS, Vol. CE-28, No. 3, August 1982, pp. 383-392, New York, US; D. Wile: "Advanced FM-IF". The FM quadrature demodulator here comprises a multiplier stage to which the two input signals are applied with a frequency-dependent phase shift and the direct current of which is increased slightly by means of a d.c. feedback as a function of the deviation from the centre frequency.

The object of the present invention is to provide a circuit arrangement for reducing the distortions in an FM quadrature demodulator, which does not require such a feedback. According to the invention, this object is achieved by means of the measures described in the characterizing part of Claim 1.

The distortion, which is caused by the non-linear phase characteristic of the resonant circuit, and which the output signal experiences during the demodulation in the FM quadrature demodulator is compensated in the invention by an inverse distortion of the quadrature demodulator signal. As a result, the differential voltage at the two diode branches varies linearly as a function of the frequency deviation from a nominal value of the input signal to be demodulated. For a further linear amplification of this output signal, a linear amplifier is of course arranged subsequent to the diode branches.

The invention will be explained below in greater detail with reference to the drawings in which

Fig. 1 shows the block circuit diagram of an FM receiver according to the invention,

Fig. 2a shows the characteristic of the quadrature demodulator,

Fig. 2b shows the characteristic of the non-linear circuit for compensating the distortions,

Fig. 3 shows a preferred embodiment of the invention and Fig. 4 shows the waveform of the distortion factor with and without compensation of the distortions.

According to Fig. 1, the signal supplied from an antenna 1 is applied to a

high-frequency mixer stage 2 in which it is converted into an intermediate frequency of, for example, 10.7 MHz by means of a tunable oscillator 3. The output signal of the mixer stage 2 is amplified in an intermediate-frequency amplifier 4 and applied to an FM quadrature demodulator, preferably via a limiting amplifier which is not shown.

- 5 The FM quadrature demodulator comprises a multiplier stage 5, which at its high-impedance output generates a push-pull signal (i.e. the sum of the output currents is constant) which is proportional to the product of the voltages at the inputs of multiplier stage 5, and a phase shifter which generates a frequency-dependent phase shift between the voltages applied to the two inputs of multiplier stage 5. The phase shifter comprises
- 10 a parallel resonant circuit 6 with a Q factor $Q = 20$, the terminals of which are connected to the outputs of the IF amplifier 4 via two capacitors 7 and 8 the capacitance of which is approximately 15 times smaller than the capacitance of the capacitor in the parallel resonant circuit. The voltage in the parallel resonant circuit 6 is multiplied in multiplier stage 5 by the voltage at the output of IF amplifier 4. The parallel resonant
- 15 circuit is balanced in such a way that a minimum distortion factor of the second order occurs at the intermediate frequency (10.7 MHz). Such an FM quadrature demodulator is known from the VALVO Datenbuch 1983 "Integrated analog circuits for radio and AF applications" page 340.

- The two push-pull output terminals of the FM demodulator are connected
- 20 to earth via two forward-biased diodes 9 and 10 and to the input terminals of a linear amplifier 11, to the output of which a loudspeaker 12 is connected and between the input terminals of which a capacitor 13 is connected which short-circuits the demodulation products with twice the intermediate frequency. The currents delivered by multiplier stage 5, which comprise a direct and a smaller AF component, flow
- 25 completely through diodes 9 and 10, because the input impedance of linear amplifier 11 is high, and produce in these diodes a differential voltage which is amplified by amplifier 11 comprising various linear stages and is applied to loudspeaker 12.

- The operation of the invention can be explained with reference to Figs. 2a and 2b. Fig. 2a represents the demodulator characteristic, i.e. it shows the dependence
- 30 of the phase shift $\Delta\varphi$ produced by the phase shifter and of the output current difference ΔI on the deviation Δf of the frequency of the demodulated signal from the centre value (10.7 MHz). For the purpose of clarification, broken lines are used to show the characteristic which the quadrature demodulator should have if it were to operate

distortion-free. It can be seen that with greater frequency increments the amount of the slope decreases.

Direct currents which differ by ΔI are applied to diodes 9 and 10. This produces in the diodes a differential voltage ΔU , whose dependence on the output
5 current of the FM demodulator ΔI is shown in Fig. 2b. It can be seen that with larger output current differences the amount of the slope increases. The characteristic shown in Fig. 2b is therefore the inverse of the characteristic in Fig. 2a so that the voltage difference ΔU at the input of the linear amplifier 11 is proportional to the deviation Δf from the centre frequency. The distortions produced by the FM quadrature demodulator
10 5 ... 8 are thus compensated by the oppositely directed distortions of the output signal at diodes 9, 10.

The extent to which the compensation is achieved is determined by the quality of the parallel resonant circuit 6, the efficiency of the multiplier stage and by the diode characteristics. Generally these parameters do not have the values to provide the
15 best possible compensation. It is therefore necessary to adapt the characteristic in Fig. 2b to the requirements of the characteristic in Fig. 2a. For instance, a reduction of the non-linearity of the diodes can be brought about by applying an additional direct current of a certain magnitude to each of the two diode branches; the distortions are, in fact, so
20 much the smaller, the smaller the current difference ΔI compared to the direct current through these diodes. Instead of this, it is also possible to connect a resistor in series with each of the diodes and to utilise the difference of the voltages in the series circuits of resistor and diode. This solution has the advantage that the d.c. voltage drop in the series circuit is greater than the d.c. voltage drop in one diode alone, which facilitates the further processing by linear amplifier 11.

25 On the other hand, the non-linearity may be increased by lowering the invariable d.c. component through the diodes, e.g. by connecting a resistor or a suitably biased d.c. source in parallel with the diodes. In this case the ratio between the signal-dependent current component ΔI and the constant direct current through the two diodes is increased, resulting in a more marked non-linearity.

30 Fig. 3 presents the detailed circuit diagram of an embodiment which can be connected between the output of the intermediate amplifier 4 and the input of the linear amplifier 11 in place of the components 5 ... 10 and 13. The input terminals 15 of the circuit, connected to the output of the IF amplifier 4, are connected directly to

the first input 17 of multiplier stage 5 and via capacitors 8 and 9 to the second input 16 of multiplier stage 5, to which the parallel circuit 6 with a Q-factor of approximately 20 is connected in parallel. The multiplier stage comprises a d.c. source in the form of an npn-transistor 18, whose emitter is connected to earth via a resistor 19, the base is
5 connected to a constant d.c. voltage U_0 and the collector is connected to the emitters of two further npn-transistors 20 and 21, whose bases are connected via equal-valued resistors 23 and 24 to the terminals of the first input 17. A resistor 22, which ensures that the alternating component of the signal between the bases of transistors 21 and 22 is always only a fraction of the input signal at the terminals 17, is connected between
10 the bases. The collector of transistor 20 is connected to the emitters of two transistors 25 and 26, while the collector of transistor 21 is connected to the emitters of two transistors 27 and 28. Transistors 25 to 28 are also of the npn-type. The interconnected base electrodes of transistors 25 and 27 are connected to the output of an emitter follower stage 29, while the bases of transistors 26 and 28 are connected to the output
15 of an emitter follower stage 30.

The interconnected collectors of transistors 26 and 27 on the one hand, and 25 and 28 on the other hand, form the output 45 of multiplier stage 5 connected to the input of the high-impedance linear amplifier 11. The series circuit of two forward-biased diodes 9 and 33 and 10 and 34 is also connected to these outputs via resistors 31
20 and 32, respectively, in each case. The other terminal of this series circuit is connected each time to a positive power supply terminal 37. Furthermore, a resistor 35 or 36 is connected in parallel to each of the two series circuits.

The voltage difference between the two aforementioned series circuits is connected to the bases of two pnp-transistors 38 and 39, whose common emitter lead
25 incorporates a d.c. source 40. The collector of transistor 38 is connected to the same output terminal of multiplier stage 5 to which its base is also connected via resistor 31; likewise the collector of transistor 39 is connected to the (other) output terminal of the multiplier stage to which its base is connected via resistor 32.

There are two reasons why the circuit has two diodes 9 and 33 or 10 and
30 34, respectively, in each case instead of one diode 9 or 10:

On the one hand, they produce the bias voltages for transistor 38 or 39 and the transistor forming the current source 40 and, on the other hand, the second diode (e.g. 33 or 34, respectively) eliminates precisely those non-linear distortions

which would otherwise be caused by the non-linear relationship between the base-emitter voltage of transistors 38, 39 and their collector current.

The network formed from components 9, 10 and 31 ... 40 is non-linear two-pole network the differential resistance of which increases, as shown by Fig. 2b with increasing signal level so that the distortions caused by the FM quadrature demodulator 5 ... 9 are largely compensated.

With an increase in the circuit quality the distortions of the FM quadrature demodulator would increase; in this case, too, a distortion minimum would also be achieved by replacing resistors 35, 36 and/or resistors 31 and 32 by lower resistance values. Instead of this, the current of current source 40 could also be increased. With a reduction in the circuit quality, resistors 31, 32 and/or 35, 36 would have to be increased or the current through current source 40 would have to be reduced.

If an additional phase shift were introduced by the multiplier stage 5, this would have the result that at the centre frequency ($\Delta f = 0$) there would be a phase difference distinct from zero or a current difference distinct from zero. This offset can be eliminated by means of a circuit which comprises two npn-transistors 41 and 42, whose emitters are connected to earth by way of a current source and whose collectors are each connected to one of the diode branches 9 and 33 or 10 and 34. The base of one transistor, for example 42, is connected to a fixed d.c. voltage and the base of transistor 41 is connected to the wiper of a d.c. voltage connected potentiometer. By varying the position of the potentiometer wiper it is possible to alter the ratio of the direct currents applied to diode branches 9, 33 or 10, 34 in such a way that at the centre frequency the output voltage ΔU becomes exactly zero.

The operation of the circuit according to the invention is illustrated in the diagram of Fig. 4. In this diagram, K_1 represents the curve of the distortion factor as a function of the frequency increment Δf which would occur in the case of a frequency deviation of 75 kHz and an audio-frequency signal of 1 kHz if a linear resistance network were connected to the output of the multiplier stage. It can be seen that even with an exact tuning the distortion factor is still greater than 0.5 % (for a Q-factor of 20). The larger the frequency increment, i.e. the greater the difference between the IF centre frequency and the difference from transmitter and oscillator frequency, the more the distortion factor will increase.

Curve K_2 shows the behaviour of the distortion factor for the circuit

arrangement of Fig. 3. It can be seen that up to a frequency increment of +40 kHz the distortion factor (for a Q-factor of 20, a frequency deviation of 75 kHz and an audio-frequency of 1 kHz) still remains below 0.1 %.

CLAIMS:

1. An FM quadrature demodulator, in which a resonant circuit (6) is used to generate a frequency-dependent phase shift between the signals applied to the two inputs of a multiplier stage (5), in which the sum of the output currents of the multiplier stage is at least substantially constant, and the output signal is derived from the difference
5 (ΔU) between the output voltages of the multiplier stage, provided with means for reducing the distortions caused by the nonlinear phase characteristic of the resonant circuit, characterized in that the means provided for reducing the distortions caused by the non-linear phase characteristic of the resonant circuit is a circuit which is fed with the output currents (ΔI) of the multiplier stage (5) and whose output voltage (ΔU) as a
10 function of the input current (ΔI) has at least substantially a waveform which is inverse to that of the amplitude of the output currents (ΔI) of the multiplier stage as a function of the frequency deviation (Δf) from a nominal value of the input signal to be demodulated, and which circuit comprises two correspondingly dimensioned diode branches (9, 10), one of the output currents of the multiplier stage being each time
15 applied to one of the two diode branches and the differential voltage (ΔU) being tapped from the diode branches.
2. An FM quadrature demodulator as claimed in Claim 1, characterized in that each diode branch has a diode (9 or 10) whose current depends exponentially on the applied voltage.
- 20 3. An FM quadrature demodulator as claimed in Claim 2, characterized in that each diode (9, 10) is connected via a resistor (31, 32) to one of the outputs of the FM quadrature demodulator and in that the voltage difference at the output of the FM demodulator (5 ... 8) serves as the output signal.
4. An FM quadrature demodulator as claimed in any one of Claim 2 or 3,
25 characterized in that a resistor (35, 36) is connected in parallel with each of the diodes (9, 10).
5. An FM quadrature demodulator as claimed in any one of Claims 2 to 4 characterized in that a further diode (33, 34) is connected in series with each diode (9,



10), in that two transistors (38, 39) are provided, whose interconnected emitters receive a direct voltage, in that the bases of the two transistors (38, 39) are each connected to one of the diode branches (9, 33; 10, 34), in that the collectors of the transistors are connected to the two outputs of the FM quadrature demodulator, and in that the output
5 signal of the circuit is the differential voltage (ΔU) which can be taken off from the collectors of the two transistors.

6. An FM quadrature demodulator as claimed in any one of Claims 1 to 5, characterized in that an additional auxiliary direct current can be applied to the two diode branches (9, 33; 10, 34) and in that the size of the auxiliary direct currents and/or
10 the ratio of the auxiliary direct currents is variable.





Signed at Eindhoven, The Netherlands
this 26th day of January 1993



Mr. H.A.C.M. van Jersel.
