

"FM-RECEIVER USING A RATIO DETECTOR WITH SILICON DIODES"

The invention relates to a method of receiving and demodulating a frequency modulated signal comprising the steps of

- 5 (i) applying the frequency modulated signal to an aerial input of an FM-channel,
- (ii) selecting the frequency modulated signal in an RF input stage in said FM-channel which stage is coupled to said aerial input,
- (iii) converting said frequency modulated signal to a frequency modulated IF signal in a mixer stage in said FM-channel which mixer
10 stage is connected to said RF input stage,
- (iv) amplifying the frequency modulated IF signal in an IF-circuit in said FM-channel which circuit is connected to said mixer stage, and
- (v) demodulating the frequency modulated IF signal in a ratio
15 detector present in said FM-channel which detector is connected to said IF-circuit, said ratio detector being of a type incorporating silicon diodes as the detection diodes and having a smoothing capacitor conductively connected to said diodes for the dynamic amplitude limitation of the ratio detector output signal in
20 dependence on the amplitude of the frequency modulated IF signal applied to said ratio detector. The invention also relates to an FM-receiver using such a method.

Such a method is used in an FM-receiver employed in the Philips television receiver type R 17B 720 and is published in printed form in the manual thereof.

- 25 In practice, an unwanted amplitude modulation of the FM-signal to be processed in an FM-receiver may be produced due to inter alia transmission noise, multi-path reception, a disadvantageous transmitter location, frequencies of unwanted transmitters close to the carrier frequency of the desired signal then occurring, edge detection on the side edges of the
30 IF-bandpass response, etc. In the known FM-receiver this unwanted amplitude modulation is predominantly suppressed at large input signals by amplitude limitation of the output signal of the FM-circuit and at small input signals by integration via the smoothing capacitor of the ratio detector.

- 35 The amplitude of the input signal at which the limiting action in the amplifier/limiter stages of the IF-circuit starts determines the input sensitivity of the FM-receiver. If this amplitude is small then the input

sensitivity is high and vice versa. The ratio detector of the prior art FM-receiver provides a low input sensitivity while maintaining a suppression of amplitude variations at also those input signals at which the amplifier/limiter stages of the IF-circuit are not limiting.

5 Consequently, the prior art FM-receiver is rather insensitive to interference, owing to, for example, noise and/or rapid field strength fluctuations, also when small signals are received, which is of particular importance in mobile FM-reception. It also shows a non-aggressive tuning behaviour without the need for additional circuits, such as, for example,
10 a muting circuit.

In the present state of the art it is, however, costly and complicated to realise adequately small signal processing in a ratio detector. In the ratio detector of the known FM-receiver use is made of silicon diodes as detection diodes. As is well known, silicon diodes have
15 a threshold voltage which, depending on inter alia the configuration and the diode surface area, may be between approximately 450 and 700mV. In order to obtain a correct detection of FM-signals having an amplitude smaller than this threshold voltage the silicon diodes of the ratio detector must remain in the conductive state also at such small signal
20 amplitudes. In the known FM-receiver this is realized by means of a bias circuit which applies a diode biasing current to the said silicon diodes. Such a biasing circuit is, however costly and complicated. In addition, the diode bias currents introduce in the tuned state an unwanted d.c. voltage component in the output voltage of the ratio detector, as a result
25 of which this output voltage is not suitable for AFC.

It is also known to use germanium diodes as detection diodes. Since germanium diodes exhibit a much lower threshold voltage than silicon diodes the use of a biasing circuit is not necessary. However, germanium diodes are much more expensive than silicon diodes. In addition, in
30 contrast with silicon diodes, they are not integratable.

It is an object of the invention to provide an FM-receiver which compared with the prior art FM-receiver can be realised in a simpler and cheaper manner and has at least the same advantageous properties.

According to the invention, a method as described in the opening
35 paragraph is characterised in that the noise generated in the part of the FM-channel preceding the silicon diodes of the ratio detector applies to the diodes an average noise voltage

which is at least equal to the threshold voltage of the silicon diodes and an average noise current which is equal to the diode forward current, this average noise current producing a d.c. voltage deviating from zero across the smoothing capacitor.

5 The invention is based on the recognition that the minimum noise required at the silicon diodes for an adequate diode bias does not necessarily noticeably reduce the signal-to-noise ratio of the overall FM-receiver.

10 When the measure in accordance with the invention is used, the noise voltage applied to the silicon diodes of the ratio detector causes by means of peak detection across the detection circuits subsequent to the silicon diodes a d.c. voltage which is at least equal to the threshold voltage of these silicon diodes. As a result thereof these silicon diodes remain conductive, without an additional
15 biasing current even at very small signal amplitudes. This ensures specifically for those signals, which are not limited in the IF-portion, on the one hand a proper detection and on the other hand an effectual and continuously operating dynamic amplitude limitation. In addition as there is no additional biasing current, the output voltage of
20 the ratio detector is suitable for AFC and the FM-receiver in accordance with the invention can be realized in a simple and cheap manner.

 The use of silicon diodes in a ratio detector without biasing circuit is known per se from the article "Super high quality FM-detector
25 and its development process", by S.Inoue and Y. Isa, published in "IEEE Transactions on Consumer Electronics", Volume CE-24, No. 3, August 1978, pages 226-234. The sensitivity of the FM-receiver in which this prior art ration detector is employed is, however, very high so that amplitude variations are only suppressed by a
30 limitation of the IF-output signal. The IF-FM-signals applied to the ratio detector therefore reach the maximum limiting value already at a very small input amplitude and, during normal usage, always exceeds the threshold voltage of the silicon diodes. The problems as regards the detection and the limitation of small signals such as they occur
35 in the first-mentioned state of the art, do not occur here. The article

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does not contain any indication that these problems can be solved by dimensioning the portion of the FM-channel preceding the silicon diodes of the ratio detector as regards noise in accordance with the measure according to the invention.

5 The method of the invention may be further characterised in that the input sensitivity of the FM-channel, expressed as the voltage required at the aerial input to achieve a ratio detector output signal of half the value which would occur if the IF-circuit were limiting, is not lower than $40\mu\text{V}/3\text{dB}$, that the noise factor at aerial RF-input is at
10 least 4dB and the 3dB-bandwidth of the IF-circuit is at least 100kHz.

When this measure is used the noise generated in the RF-input stage within the IF-passband is adequately amplified to produce at the silicon diodes of the ratio detector a d.c. voltage which is at least of the same value as the threshold voltage of these silicon diodes.

15 With a preferred embodiment of the invention the noise factor of the RF-input stage may be 5dB, the 3dB-bandwidth of the IF-circuit 150kHz and the input sensitivity of the FM channel is $10\mu\text{V}/3\text{dB}$. When this measure is used, it is particularly suitable for use in a car radio.

20 The invention also provides an FM-receiver for use with the above described method.

The invention will now be further described with reference to the Figures shown by way of example in the accompanying drawings.

Herein:

25 Figure 1 shows the circuit diagram of an IF-circuit and a ratio detector for use in an FM-receiver in accordance with the invention.

Figure 2 shows some curves in which the variation of the amplitude of the output signal of the ratio detector is plotted as a function of an IF-FM-signal applied to the IF-input, on the one hand when germanium
30 diodes and on the other hand when silicon diodes are used,

Figure 3 shows the circuit diagram of an FM-receiver in accordance with the invention,

Figure 4 shows some curves in which the behaviour of the FM-receiver in accordance with the invention is shown as regards the
35 signal-to-noise ratio, the noise and the limitation of amplitude variations, as a

function of a test signal at the aerial input, and

Figure 5 is the same as Figure 4 but where germanium diodes are used in the ratio detector.

Figure 1 shows an integrated IF-circuit A of the type TEA 5560 having terminals a_1 to a_9 , inclusive. The indices at the terminal reference numerals correspond to the terminal reference numerals as given in the manual associated with this integrated IF-circuit A. For a proper operation of the IF-circuit A the terminal a_9 is connected to ground and a supply voltage of between 10.2 to 16 V is applied to the terminal a_6 via a supply terminal 4. The supply terminal 4 is A.C.-connected to ground via a grounded capacitor C_{16} . The terminal a_5 is connected to a +8 V stabilised supply voltage produced by the IF-circuit A and to a grounded decoupling capacitor C_{10} . The terminal a_1 which is connected to an IF-input 1 via a coupling capacitor C_1 is coupled via a resistor R_1 to the terminal a_3 which itself is connected to the terminal a_2 via a decoupling capacitor C_2 . The terminal a_2 is connected to a grounded capacitor C_3 . The terminal a_4 is connected to ground via a resistor R_3 and a.c.-connected through a grounded capacitor C_7 . The terminal a_7 which forms the output terminal of the IF-circuit A applies an IF-output signal to an input 7 of the ratio detector R. The ratio detector R comprises two detector coil arrangements L_1 and L_2 which are connected to the input 7 and are interconnected in the manner shown and which is known per se from "Philips Data Handbook - Electronic Components and Materials", Part 5B, March 1977, using capacitors C_5 , C_8 and C_9 . The detector coil arrangement L_2 has two outputs which are conductively coupled in known manner via respective silicon diodes D_1 and D_2 , which are arranged in anti-phase, to on the one hand a smoothing capacitor C_{11} arranged between the two silicon diodes D_1 and D_2 for a dynamic amplitude limitation and on the other hand to detection circuits R_5 , C_{12} and R_6 , C_{13} , respectively for the FM-signal detection.

The resistors R_5 and R_6 are connected to ground and the capacitors C_{12} and C_{13} are connected on the one hand to an output 2 of the ratio detector R via an RC- π network formed by a series resistor R_7 , two capacitors C_{14} and C_{15} arranged on both sides of the series

resistor R_7 as well as a load resistor R_8 which for an adequate measurement is arranged in parallel with the capacitor C_{15} and on the other hand to an AFC-output 3.

In a practical embodiment the silicon diodes D_1 and D_2 are of the type BA 316 and have a threshold voltage of approximately 450 mV. The detector coil arrangements L_1 and L_2 are of the type 3122 138.20211 and 3122 138.20212, respectively. The resistors and capacitors employed have the following values:

	<u>Resistors</u>	<u>Value (Ω)</u>	<u>Capacitors</u>	<u>Value (F)</u>
10	R_1	330	C_1	2.2 n
	R_3	2.2 K	C_2	22 n
	R_5	5.6 K	C_3	22 n
	R_6	5.6 K	C_5	82 p
15	R_7	1 K	C_7	4.7 /u
	R_8	47 K	C_8	33 p
			C_9	82 p
			C_{10}	2.2 /u
			C_{11}	1 /u
20			C_{12}	4.7 n
			C_{13}	4.7 n
			C_{14}	2.2 n
			C_{15}	220 p

Considered by itself, the operation of the IF-circuit A and the ratio detector R as regards the limiting of amplitude variations and the FM-detection predominantly corresponds to the operation of the corresponding circuits of the first-mentioned prior art FM-receiver, without the use of a biasing circuit. This operation may therefore be assumed as being known.

The input sensitivity of the IF-circuit A is adjusted to 150 μ V/3dB. This means that for an IF-input signal of 150 μ V the amplitude of the IF-output signal at the output terminal a_7 is less by half, i.e. 3 dB, than the amplitude at full limitation.

Figure 2 shows by means of curve I when germanium diodes of the type AA119 are used as the diodes D_1 and D_2 , and by means of a dotted curve II when silicon diodes of the said type BA316 are used as the diodes D_1 and D_2 , the variation of the amplitudes of the output signal (V_o) of the ratio detector R at the output 2 as a function of the amplitude of an IF-FM-input test (V_i) signal applied to the input terminal a_1 of the IF-circuit A via the coupling capacitor C_1 , this input test signal having a centre frequency of 10.7 MHz, a frequency swing of 22.5 kHz and a modulation frequency of 1 kHz. In addition to the modulation signal, this output signal also comprises the noise produced in the IF-circuit A and in the ratio detector R owing to, for example, thermal or diode emission.

The same procedure as in the preceding paragraph is effected with a non-modulated 10.7 MHz IF-input test signal. Curve III shows as a function of the amplitude of the non-modulated 10.7 MHz IF-input test signal the variation of the noise amplitude at the output 2 of the ratio detector R when germanium diodes are used as the detection diodes D_1 and D_2 and a dotted-curve IV shows the same variation when silicon diodes are used in the ratio detector R.

Below input values of $40 \mu\text{V}$ the effect of the low threshold voltage of germanium diodes (approximately 200 mV) and the effect of the high threshold voltage of silicon diodes (approximately 450 mV) can be clearly observed. When germanium diodes are used, an adequate FM-detection is ensured at a decreasing amplitude until the signal disappears in the noise, at approximately $1 \mu\text{V}$. When silicon diodes are used the amplitude of the ratio detector output signal decreases rather quickly below input signal amplitudes of $40 \mu\text{V}$, owing to the fact that the silicon diodes are cut-off. In response thereto, at a further increasing input amplitude the noise level first increases somewhat and, thereafter, below an input amplitude of approximately $15 \mu\text{V}$, it rapidly decreases. The absence of a measure to keep the silicon diodes D_1 and D_2 in the conducting state, also for small signals, consequently renders a proper small signal detection impossible.

Figure 3 shows an FM-receiver in accordance with the invention in which the IF-circuit A and the ratio detector R with silicon diodes D_1 and D_2 are incorporated. The elements corresponding to the

elements of Figure 1 are given the same reference numerals. The FM-receiver comprises an RF-input and mixer stage B of the type MMK 11E11, mark ALPS, which has an aerial input b_1 , a supply terminal b_2 , an output terminal b_3 , a ground terminal b_4 and an AFC-input terminal b_5 .

5 Via a first ceramic IF-filter F_1 the output terminal b_3 is connected to the base of a transistor T_1 . This transistor T_1 is used to adjust the input sensitivity of the FM-receiver and to compensate for the losses in the IF-filter F_1 and a second ceramic IF-filter F_2 . The collector of the transistor T_1 is connected to
10 the input terminal a_1 of the IF-circuit A via the second IF-filter F_2 . The output 2 of the ratio detector R is connected to a stereo decoder SD which applies left and right stereophonic signals to the left and right loudspeakers L and R via left and right audio amplifiers A_L and A_R .

15 The further elements shown are used for an adequate adjustment of the said circuits. So, the supply terminal b_2 is connected to a supply input 6 via an LC smoothing filter and the AFC input terminal b_5 is connected in the manner shown to the AFC-output 3 of the ratio detector R via resistors R_{12} , R_{13} and R_{14} , an amplitude diode
20 limiter D_3 , D_4 and grounded capacitors C_{20} and C_{21} . Via resistors R_{10} and R_9 the base of the transistor T_1 is connected to the collector, this collector being connected to the supply input 6 via collector resistors R_4 and R_2 . Via a variable emitter resistor R_{11} the emitter of the transistor T_1 is connected to ground, which
25 emitter resistor is used to adjust the gain of the transistor T_1 and consequently the input sensitivity of the FM-receiver. The resistors R_9 and R_{10} are connected to ground via a grounded capacitor C_{19} and the resistors R_2 and R_4 are connected to ground via a grounded capacitor C_{18} .

30 In a practical embodiment the noise factor of the RF-input and mixer stage B was 5 dB; the 3 dB-IF bandwidth of the ceramic filters F_1 and F_2 was 150 kHz; and the input sensitivity of the FM-receiver
10 $\mu\text{V}/3$ dB. Consequently, the FM-receiver shown is particularly suitable for use as a mobile FM-receiver,

35 The two ceramic filters F_1 and F_2 were of the type Murata SFE;

the transistor T_1 of the type BF 240 and the diodes D_3 and D_4 of the amplitude diode limiter were of the type BA315. As mentioned in the foregoing, the silicon detection diodes D_1 , D_2 of the ratio detector were of the type BA316.

5 The values of the further elements were:

	Resistors	Value (Ω)	Capacitors	Value (F)	Coils	Value (H)
	R_2	4.7 K	C_{17}	22 n	L_3	100 μ
10	R_4	330	C_{18}	10 n		
	R_9	270 K	C_{19}	10 n		
	R_{10}	330	C_{20}	4.7 n		
	R_{11}	470 (maximum)	C_{21}	0.33 μ		
	R_{12}	47 K				
15	R_{13}	1 K				
	R_{14}	330 K				

An aerial signal applied to the input terminal b_1 of the RF-input and mixer stage B is filtered, amplified and mixed in known manner to
 20 a centre frequency of 10.7 MHz. The IF-FM-signal thus obtained is thereafter filtered in the IF-filter F_1 and adjusted to a predetermined amplitude level by means of the transistor T_1 for the adjustment of a desired input sensitivity. Thereafter a further IF-selection is effected in the IF-filter F_2 and the IF-signal is processed in the
 25 manner described in the foregoing to form audio-frequency left and right stereo signals.

In the embodiment shown the noise factor of the RF-input terminal was, as mentioned already, 5 dB. The RF-input noise was then 0.66 μ V and a voltage of 2 mV was measured across the smoothing
 30 capacitor C_{11} . From this it may be concluded that in these circumstances the silicon diodes D_1 and D_2 were conducting and that consequently there was a diode bias across each of the detection circuits R_5 , C_{12} and R_6 , C_{13} of at least 450 mV threshold voltage. Starting therefrom, the total gain of the aerial input b_1 to the silicon detection diodes
 35 D_1 , D_2 was gradually reduced until the voltage across the smoothing

capacitor C_{11} had decreased to zero. With this gain an input sensitivity of the whole FM-receiver of approximately $30 \mu\text{V}/3 \text{ dB}$ was measured.

Generally, at an input sensitivity less than $40 \mu\text{V}/3 \text{ dB}$, that is to say an overall noise gain from aerial input b_1 to the diodes D_1 , D_2 of less than 105 dB, a noise factor of the RF-input stage of less than 4 dB and an IF-passband less than 100 KHz insufficient noise is produced to keep the silicon diodes D_1 and D_2 in the conducting stage. Within the range which is defined by these limit values an adequate operation of the measures in accordance with the invention can be obtained.

The amount of noise applied to the diodes D_1 and D_2 of the ratio detector R is predominantly determined by the RF-input noise occurring at the RF-input stage and which, after mixing, is within the IF-passband of the IF-filters F_1 and F_2 and is thereafter amplified in the transistor T_1 and the IF-circuit A. The noise voltage required for sufficient diode biasing can therefore be obtained with different combinations of amounts of input noise, IF-bandwidth and IF-amplification. It is alternatively possible to insert additional noise into the portion of the FM-channel preceding the diodes D_1 and D_2 , so as to realize the required noise voltage. For a person skilled in the art it will not be difficult to conceive different receiver constructions within the limitations of the main claim, the noise applied to the silicon diodes D_1 and D_2 producing a diode bias which is sufficiently large to keep these diodes in the conducting state, even at small signals.

In Figure 4 the behaviour of the FM-receiver shown in Figure 3 is measured as regards detection, noise and amplitude limitations. The measuring curve V is obtained by measuring the amplitude of the signal at the output 2 of the ratio detector R as a function of an amplitude variation of an FM-test signal applied to the RF-input terminal b_1 with a frequency swing of $22\frac{1}{2} \text{ kHz}$ and a modulation frequency of 1 kHz. The input sensitivity of the FM-receiver was adjusted to $15 \mu\text{V}/3 \text{ dB}$. The same was measured in Figure 5 but then using germanium diodes of the type AA119 as the detection diodes D_1

and D_2 and represented by means of measuring curve VIII. In spite of the difference in threshold voltage between germanium and silicon diodes no noticeable difference was found in the detection behaviour.

5 Measuring curve VI in Figure 4 shows the variation of the amplitude of the output signal of the ratio detector R at an amplitude variation of an unmodulated RF-measuring signal, silicon diodes being used. The same is shown by means of measuring curve IX in Figure 5, when germanium diodes are used. Also for the noise behaviour the use
10 of germanium or silicon diodes does not produce a noticeable difference.

The same can be concluded as regards the limitation of amplitude variations. In Figure 4 measuring curve VII shows the variation of the magnitude of amplitude modulations in the output signal of the ratio detector R at an amplitude variation of an RF test signal
15 which is amplitude-modulated by a constant modulation index 0.3, silicon diodes being used, and Figure 5 shows the same by means of measuring curve X for the case that germanium diodes were used.

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CLAIMS:-

1. A method of receiving and demodulating a frequency modulated signal comprising the steps of:

- (i) applying the frequency modulated signal to an aerial input of an FM-channel,
- (ii) selecting the frequency modulated signal in an RF input stage in said FM-channel which stage is coupled to said aerial input,
- (iii) converting said frequency modulated signal to a frequency modulated IF signal in a mixer stage in said FM-channel which mixer stage is connected to said RF input stage,
- (iv) amplifying the frequency modulated IF signal in an IF-circuit in said FM-channel which circuit is connected to said mixer stage, and
- (v) demodulating the frequency modulated IF signal in a ratio detector present in said FM-channel which detector is connected to said IF-circuit, said ratio detector being of a type incorporating silicon diodes as the detection diodes and having a smoothing capacitor conductively connected to said diodes for the dynamic amplitude limitation of the ratio detector output signal in dependence on the amplitude of the frequency modulated IF signal applied to said ratio detector, characterised in that in order to provide a bias for the silicon diodes the noise generated in the part of the FM-channel preceding the silicon diodes of the ratio detector applies to the diodes an average noise voltage which is at least equal to the threshold voltage of the silicon diodes and an average noise current which is equal to the diode forward current, this average noise current producing a d.c. voltage deviating from zero across the smoothing capacitor.

2. A method as claimed in Claim 1, characterised in that the input sensitivity of the FM-channel, expressed as the voltage required at the aerial input to achieve a ratio detector output signal of half the value which would occur if the IF-circuit were limiting, is not lower than $40\mu\text{V}/3\text{dB}$, that the noise factor at the



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aerial input is at least 4dB and the bandwidth of the IF-circuit is at least 100kHz.

3. A method as claimed in Claim 2, characterised in that the noise factor of the IF-input stage is 5dB, the bandwidth of the IF-circuit is 150kHz and the input sensitivity of the FM-channel is 10 μ V/3dB.

4. An FM-receiver for use with the method as claimed in Claim 1, 2 or 3, said receiver comprising an FM-channel coupled to an aerial input, the FM-channel comprising in succession an RF-input stage, a mixer stage, an IF-circuit and a ratio detector, the ratio detector incorporating silicon diodes for the demodulation of a frequency modulated signal when present in said FM-channel and a smoothing capacitor conductively connected to said diodes for the dynamic amplitude limitation of the ratio detector output signal in dependence on the amplitude of the ratio detector input signal, characterised in that means are provided in said FM-channel whereby the noise generated in the part of the FM-channel preceding the silicon diodes of the ratio detector applies to the diodes as a bias an average noise voltage which is at least equal to the threshold voltage of the silicon diodes and an average noise current which is equal to the diode forward current, this average noise current producing a d.c. voltage deviating from zero across the smoothing capacitor.

5. An FM-receiver as claimed in Claim 4, characterised in that a transistor is connected between the mixer stage and the IF-circuit and means are provided for varying the gain of the transistor whereby the input sensitivity of the FM-receiver may be adjusted.

6. A method of receiving and demodulating a frequency modulated signal substantially as herein described with reference to Figures 1, 3 and 4 of the accompanying drawings.

7. An FM-receiver substantially as herein described with reference to Figures 1, 3 and 4 of the accompanying drawings.

