

UHF Remote Control System: Receiver Front End and Complete Receiver Design Hints

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1. Introduction

This report is a description of how to develop a cost-saving superhet receiver for radio frequency based remote control systems in the UHF range. It should be seen as a completion of the application report no.12, titled "Components for Radio Frequency based Remote Control Systems" [1].

The complete receiver consists of the front end, the IF part and the microcontroller. It is based on the IF receiver ICs of the U 431x B family of TELEFUNKEN Semiconductors. Circuit configurations for either a low standby current of 1 mA or a low supply voltage of 3.3 V are possible. The main goal of the front end development was to design an assembly that meets practical requirements with a reduced number of components and alignments, while achieving excellent sensitivity and a wide dynamic range. In a production line, only low-cost measurement equipment is necessary for testing and tuning.

First, the principle circuit arrangement is illustrated with different configurations to make either a low-voltage or a low-current receiver. Next, a circuit proposal for the front end is shown, using high performance transistors S 852 T of TELEFUNKEN Semiconductors.

Finally, a complete remote control receiver is introduced, optionally including the signal decoder that is designed with a low-current microcontroller (μC) of the M 43 C 200 family. The suggested circuits have been tested in practice and demoboards for SMD components were developed. These boards are not ready for series production but only for demonstration of the system features. They are suited for different operation frequencies, either for amplitude or frequency modulation and for a wide range of supply voltages. Four different versions have been completely specified and the part lists for them are included in the appendix. All measurement results in this paper were taken on these demoboards. In the UHF range, the printed circuit board must be regarded as a RF component. The layout co-determines the performance.

As a development is always done under different guidelines, the circuits introduced here may only be used as a basis for the customer's own developments. It will be necessary to adapt the circuits to the requirements of series production.

2. Circuit arrangement of a complete receiver

The receiver is based on a modular concept, such that there are different options for the interconnection of the subcircuits front end, IF part and signal decoder (e.g. μC). The choice of one of these circuit arrangements will be determined by the requirements for supply voltage, supply current and sensitivity. Circuit configurations and their features using different integrated circuits are given in table 1.

Figure 1 represents the low-current version with a standby current of 1 mA and an active

mode current of 3.5 mA, excluding the current consumption of the microcontroller. The Zener diode is used to limit the front end supply voltage with increasing receiver supply voltage. The optional resistor might be necessary, if the receiver IC will be switched between active and passive mode and the front end is designed exactly for 1 mA of current consumption. In the passive mode the supply current of the IF part is also 1 mA, so without an additional resistor no current would be left for the Zener diode. An exception is the U 4314 B with a

total current consumption of 1 mA. As the current is constant, the diode and the resistor can be left out. The supply voltage range of this setup is 7 V to 16 V. For low-voltage applications, the setup shown in figure 2 is useful. In order to limit the current

consumption, the supply voltage should be stabilized - otherwise it is restricted to values between 3.3 V and 4.7 V. If for stabilization a 4.7-V Zener diode is used in series with a 1-k Ω resistor, a supply voltage range of 4.5 V to 9 V can be achieved.

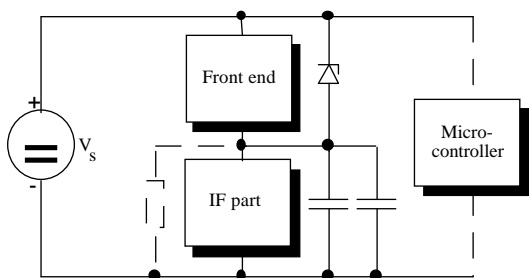


Figure 1 DC stacking of the front end and IF part

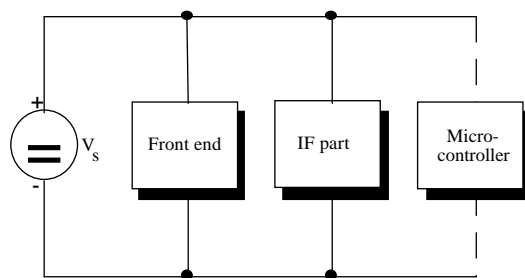


Figure 2 Front end and IF part in parallel

IC-TYPE	U 4311 B / U 4313 B		U 4314 B	
	Wake up or polling concept		Continuously active, without data filter	
	According to fig. 2	According to fig. 1	According to fig. 2	According to fig. 1
Minimum supply voltage	3.3 V	7 V	3.3 V	7 V
Supply current standby (incl. regulation, excl. DPU)	2 mA	1 mA		
Supply current permanent active (incl. regulation, excl. DPU)	4.5 mA	3.5 mA	2 mA	1 mA
Sensitivity (m = 80 %, resp. FM deviation 22.5 kHz), Wake up threshold	- 80 dBm	- 80 dBm		
Permanent or controller activated	- 105 dBm	- 105 dBm		
Modulation system	FM AM	FM AM	AM	AM
Relative system transmission rate with single stage transmitter	High low	High low	Low	Low

Table 1 Characteristics of remote control receivers with different ICs and different circuit arrangements

3. Front end for UHF remote control system

For the front end, two PCBs have been designed. The circuit diagram shown in figure 3 is identical for both versions. The layout shown in figure 4 and figure 5 is suited for combination with the IF/ μ C part according to figure 15 and figure 16 or the IF part as presented in [1]. The second PCB given in figure 17 and figure 18 already includes the IF part.

The tuner is suited for either a parallel circuit with the IF part or for DC stacking with it, as shown in figure 2 and figure 1. In the latter configuration the ground planes of the front end and the IF part are not on the same voltage level, C 100 must be used for the antenna connector to avoid a DC short circuit if the shielding of the antenna cable is grounded. Its value is not critical, 1 nF is proposed.

3.1 Circuit and alignment description

The front end consists of the prestage designed with a T 101 and T 102 in a cascode circuit - the local oscillator with T 103 and the mixer with T 104. A complete characterization for 433.92-MHz and 303.85-MHz operation frequency has been done. The PCB layout and the component placement are shown in figure 4 and figure 5. The cascode circuit was chosen to decouple the local oscillator of the antenna input in order to suppress radiation of the local oscillator. Measurements on several modules - based on a 50- Ω system - showed that the level of the local oscillator at the antenna input is approximately -65 to -70 dBm.

The low supply current of 300 μ A to 600 μ A effects a low-noise figure of the preamplifier. The input filter (C 101 to 103, L 101 and L 102) provides the far-off selectivity. As the 3-dB bandwidth of the input filter is approximately 30 MHz, no tuning of the coils should be necessary. Due to the high transit frequency

The front end is designed for a supply voltage of 3.3 V and a current consumption of approximately 1 mA. The supply voltage may be increased to 4.7 V so that a Zener diode D 101 of this voltage can be used for stabilization if the supply voltage is not stabilized by other means. With increasing supply voltage, the supply current also increases. Therefore at least the emitter resistors (R 104 and R 109) have to be changed if the front end is to work with a different supply voltage and a 1 mA supply current. Circuit variations for 5-V- and 3-V supply voltage have been tested, achieving the same sensitivity. To characterize the front end, it was combined with an IF part according to [1, fig. 40]. Test results and measurement conditions are discussed at the end of this paper.

of the transistors, it may be necessary to connect C 104 to the ground plane at the opposite side of the PCB in order to avoid oscillations (see arrow in figure 5). For the same purpose, R 110 may be inserted, but the PCB shown in figure 5 is not prepared for these modifications. The position where the printed conductor has to be cut up for the insertion of R 110 is marked with an asterisk in figure 5. The PCB of the front end combined with the IF part (figure 18) already includes all modifications. The amplified RF signal is fed to the base of the mixer transistor, T 104. If no wide transmission range is required, the value of C 107 may be increased while decreasing C 106. This will improve the strong signal behaviour while decreasing the receiver's sensitivity.

The developed front end requires only one or two alignments. The prestage gain has to be maximized by the tuning of L 103. A maximum of the AM output voltage of the receiver IC indicates the correct adjustment. For the

alignment of the prestage, the local oscillator, of course, must be locked on its operation frequency.

The local oscillator is a Colpitts type in a common base circuit. Normally, the coil (L 104) must be tuned so that the oscillator locks on its operation frequency, which is determined by the SAW resonator. For this adjustment, the AM output of the receiver IC can also be used. If the oscillator is not locked in, no signal will be detected at the AM output. If components with small manufacturing tolerances - 2% to 5% - are used for C 108, C 109 and C 111, a fixed SMD inductance might be used for L 104, as shown on the second layout proposal in figure 17 and figure 18. The PCB shown in figure 4 and figure 5 is not prepared for the use of a chip inductor. The frequency of the SAW resonator must be 10.7 MHz above or below the transmission frequency. The local oscillator works both with one- and with two-port resonators. To ensure stable oscillation of the 423.22-MHz version with a one-port type and a 3.3-V supply voltage, it may be necessary to increase C 108 to 6.8 pF. Eventually C 109 also has to be enlarged. Tests on several SAW resonators and oscillator circuits revealed that one-port resonators work on an operation frequency which is approximately 50 kHz to 100 kHz higher than two-port resonators. Also the oscillator design has an influence on the operation frequency. Therefore, it is important to use the same type of resonator and oscillator circuit for the transmitter as well as for the receiver's local oscillator. To achieve maximum operation range for the complete remote control system, SAW resonators with small manufacturing tolerance should be used in order to limit the required IF bandwidth. A reduction of the IF bandwidth from 450 kHz to 180 kHz, for example, will lead to an

improvement of 2 dB in the receiver's total sensitivity. This is an experimental result, the theoretical reduction of noise would be 4 dB. The output signal of the local oscillator is fed via C 111 to the emitter of the mixer transistor (T 104). At the collector of this transistor, the intermediate frequency of 10.7 MHz can be picked up. C 112 and L 105 work as a notch filter on 10.7 MHz to avoid IF feedback and to improve the mixer gain. The parallel resonant circuit C 113 / L 106 is also matched to 10.7 MHz. Its impedance is approximately 300 Ω , so the subsequent ceramic IF-filter of the IF part can be connected directly to the collector of T 104. C 113 also suppresses the oscillator signal to reduce back-mixing effects on the collector.

The PCB layout given in figure 4 is single-sided but with a ground plane on one side. It is designed for the use of SMD resistors of 1206 or 0805 size. In figure 5 and figure 18 the placement of a two-port SAW is shown with the two inputs connected to each other. If a one-port resonator is used, it has to be turned with an angle of 90 degrees in a clockwise direction (looking at the PCB from the SMD side). The SAW and C 116 are mounted on the other side, which is covered by the ground plane. On the PCB shown in figure 5, C 116 should be soldered on both the SMD and the ground side. One further connection between the two ground areas should be done with a short wire close to C 107 / C 114 as it is prepared on the PCB. If the antenna connector is not mounted, two of the pads should also be used for the ground interconnection. It is advantageous to insert a short wire to the ground plane close to C 104. All these positions are marked with arrows in figure 5. The PCB shown in figure 18 includes connections to the ground plane and does not require any modifications.

3.2 Circuit diagram, PCB layout and component placement

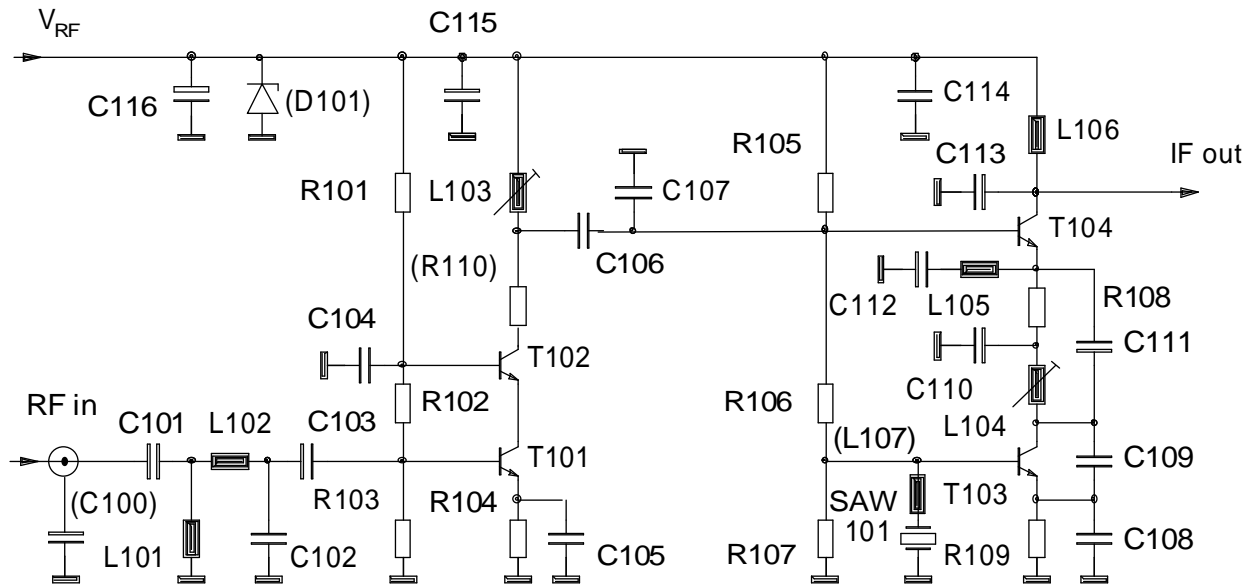


Figure 3 Front end for UHF remote control system

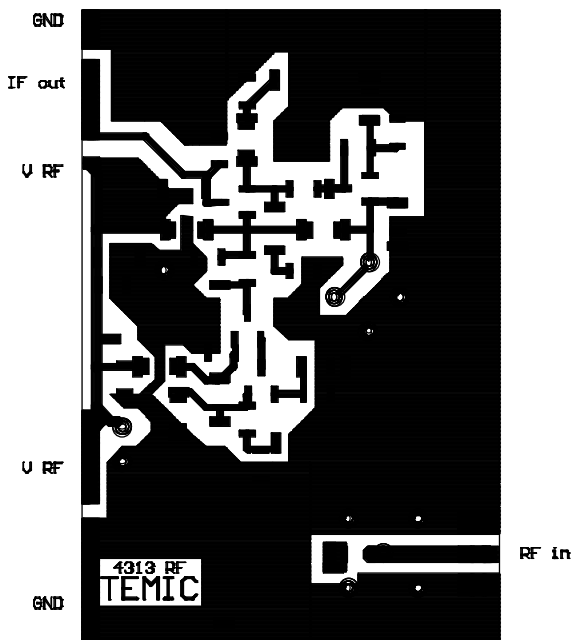


Figure 4 PCB layout, view: side of SMD components (original size: 47 x 30 mm²)

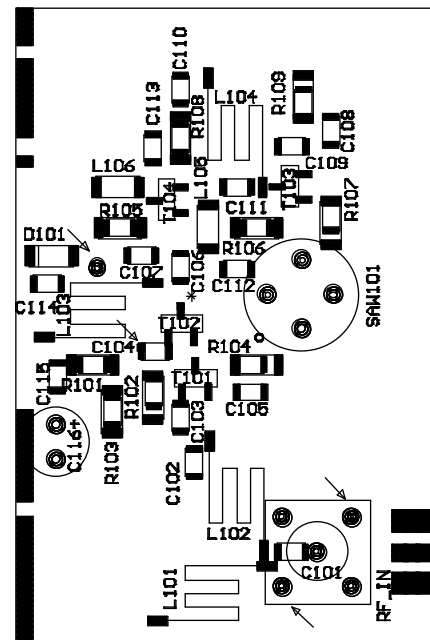


Figure 5 Component placement, view: side of SMD components

3.3 Components for operation on 433.92 MHz

All resistors have a manufacturing tolerance of 5% and are size 0805 or alternatively 1206.
All capacitors not otherwise specified have a 20% tolerance and are size 0805.

C 101	6.8 pF, 10%	R 107	47 k Ω
C 102	1.5 pF, 10%	R 108	220 Ω
C 103	100 pF	R 109	1 k Ω
C 104	1 nF	(R 110	\approx 470 Ω)
C 105	100 pF	T 101	S 852 T
C 106	6.8 pF	T 102	S 852 T
C 107	33 pF	T 103	S 852 T
C 108	4.7 pF, 5% (6.8 pF with one-port SAW resonator)	T 104	S 852 T
C 109	3.3 pF, 5%	SAW 101	R2531 (423.22 MHz), Siemens Matsushita
C 110	100 pF	L 101	air loop \varnothing 2.5 mm, wire \varnothing 0.4 mm
C 111	3.9 pF, 5%	L 102	air coil 3 turns \varnothing 2.5 mm, wire \varnothing 0.4 mm, length 2.5 mm
C 112	470 pF	L 103	air coil 3 turns \varnothing 2.5 mm, wire \varnothing 0.4 mm, to be tuned
C 113	470 pF	L 104	air coil 3 turns \varnothing 2.5 mm, wire \varnothing 0.4 mm or 22-nH inductance TOKO LL 2012-F 22 NK (PCB not prepared, see text)
C 114	100 pF	L 105	SMD fixed inductance 0.47 μ H
C 115	1 nF	L 106	SMD fixed inductance 0.47 μ H
C 116	10 μ F, 10 V		
R 101	22 k Ω		
R 102	33 k Ω		
R 103	33 k Ω		
R 104	1 k Ω		
R 105	10 k Ω		
R 106	22 k Ω		

3.4 Components for operation on 303.85 MHz

All resistors have manufacturing tolerance of 5% and are size 0805 or alternatively 1206.
All capacitors not otherwise specified have a 20% tolerance and are size 0805.

C 101	6.8 pF, 10%	R 108	220 Ω
C 102	3.3 pF, 10%	R 109	1 k Ω
C 103	100 pF	(R 110	\approx 470 Ω)
C 104	1 nF	T 101	S 852 T
C 105	100 pF	T 102	S 852 T
C 106	10 pF	T 103	S 852 T
C 107	33 pF	T 104	S 852 T
C 108	6.8 pF, 5%	SAW 101	R640 (314.5 MHz), Siemens Matsushita, 1-port resonator, different mounting to figure 5 and figure 18!
C 109	4.7 pF, 5%		
C 110	100 pF		
C 111	4.7 pF, 5%	L 101	air coil 2 turns \varnothing 2.5 mm, wire \varnothing 0.4 mm, length 1.5 mm
C 112	470 pF		
C 113	470 pF	L 102	air coil 4 turns \varnothing 2.5 mm, wire \varnothing 0.4 mm, length 2.5 mm
C 114	100 pF		
C 115	100 pF	L 103	air coil 5 turns \varnothing 2.5 mm, wire \varnothing 0.4 mm, to be tuned
C 116	10 μ F, 10 V	L 104	air coil 5 turns \varnothing 2.5 mm, wire \varnothing 0.4 mm, to be tuned
R 101	22 k Ω	L 105	SMD fixed inductance 0.47 μ H
R 102	33 k Ω	L 106	SMD fixed inductance 0.47 μ H
R 103	33 k Ω		
R 104	1 k Ω		
R 105	22 k Ω		
R 106	22 k Ω		
R 107	47 k Ω		

4. Front end measurement results

The following measurements provide basic characteristics of the front end. The measurements were taken on the tuner board shown in

figure 4 and figure 5, matched with an IF board according to [1, figure 40] or the IF part shown in figure 15 and figure 16 of this paper.

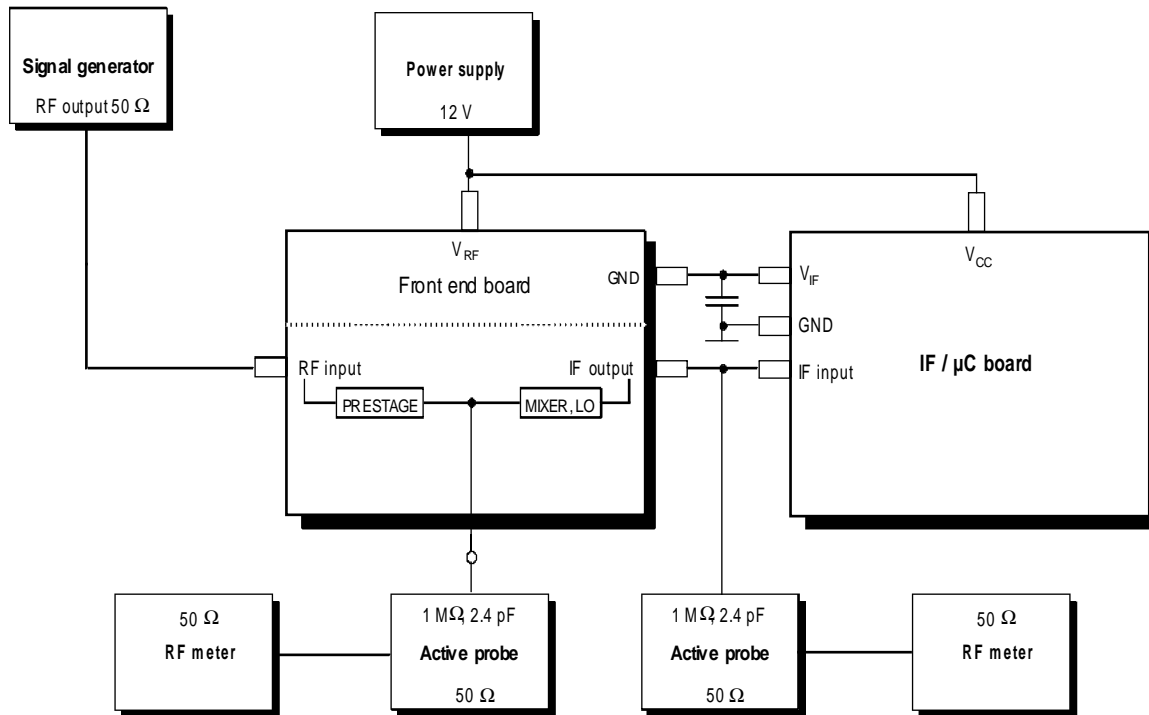


Figure 6 Setup for front end voltage / prestage power gain measurement

The voltage gain of the complete front end shown in figure 8 and the conversion gain of the mixer given in figure 9 are both measured with the IF part remaining in the active mode. This means that the quiescent current of the front end is in the range of 2.5 mA. The supply voltage is approximately 4.5 V. The IF-filter remains in the circuit in order to achieve a correct termination of the mixer. The measurement setup for the front end gain measurement is given in figure 6. Figure 7 shows the setup for the mixer conversion gain measurement. For the measurement of the voltage level the use of a high-resistive probe is absolutely necessary to minimize the influence of the measurement equipment on the circuit. The front end voltage gain is measured between the an-

tenna input and the input of the IF-filter. The mixer conversion gain is measured between the base and the collector of T 104.

A level of 0 dB μ V at the 50- Ω antenna input corresponds to -107 dBm, which is approximately the achievable sensitivity of the complete receiver.

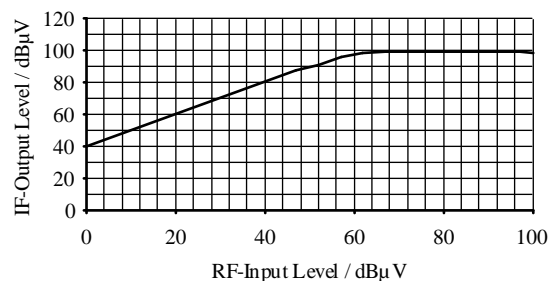


Figure 8 Front end voltage gain

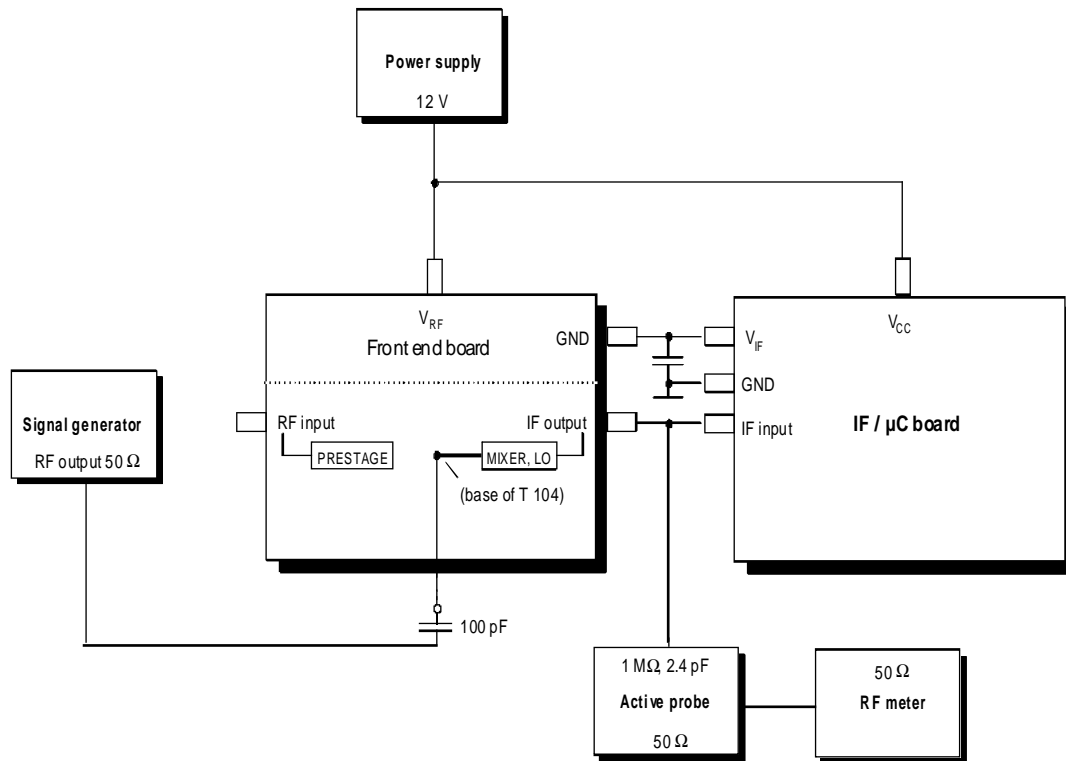


Figure 7 Measurement setup for mixer conversion gain

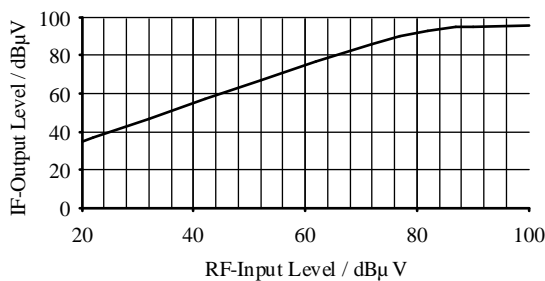


Figure 9 Conversion gain of the mixer

Thus according to figure 8, the usable linear operation range of the front end is 60 dB, which fits well to the linear range of the AM demodulator implemented in the receiver IC. If the receiver works outside of the linear operation range, amplitude errors will occur, leading to bit errors or even to inverted data if AM is used. Frequency modulation does not require a linear amplitude transfer, therefore the dynamic range of the FM receiver version is larger, reaching more than 100 dB. With the

actual characterization, RF input level may deviate between 0 dBm and -105 dBm for $V_S = 4.5$ V. On the contrary, the power gain measurement of the prestage shown in figure 10 is referred to 50Ω , as it is quite usual. The measurement setup is similar to figure 6, but the local oscillator and the mixer are not mounted, R 105 is replaced by 50Ω .

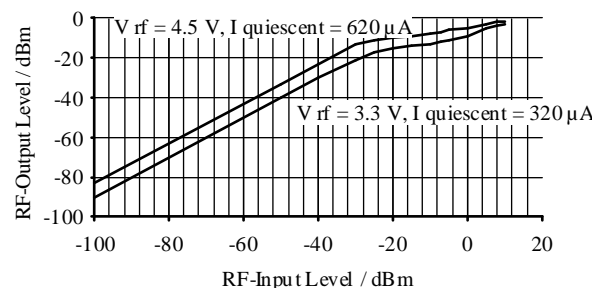


Figure 10 Power gain of the prestage in dependence of the quiescent current, referred to 50Ω

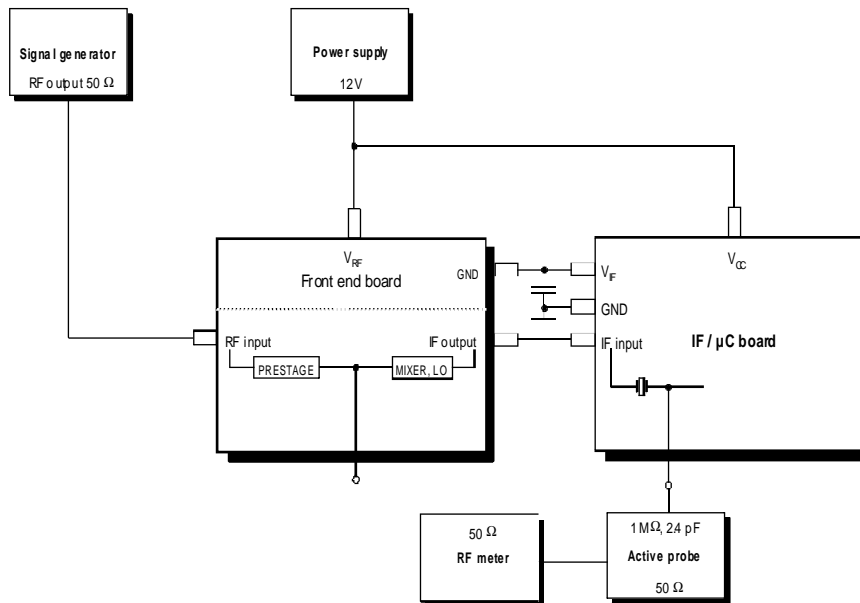


Figure 11 Measurement setup for the front end frequency response

Especially for this RF measurement, a very short connection between the front end ground and the shielding of the probe is essential. With the actual characterization the prestage power gain is approximately 10 dB with 3.3-V supply voltage and 15 dB with 4.5 V.

measurement. It can be seen from a comparison of figure 12 and figure 13, that the front end provides the far-off selectivity, while the main part of the much better total selectivity proceeds from the IF-filter. The measurement setup is shown in figure 11. Due to the toleran-

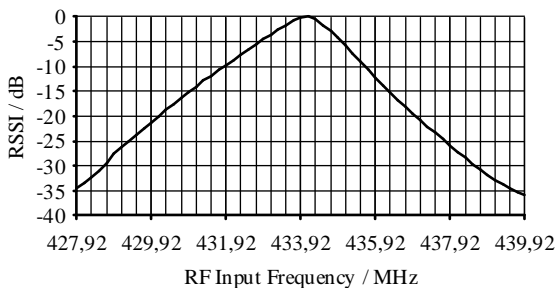


Figure 12 Overall frequency response with the IF-filter replaced by $C = 10 \text{ nF}$, RF input level -70 dBm

Figure 12 shows the selectivity of the front end with R 110 inserted. The y-axis represents the **Received Signal Strength on the Intermediate frequency (RSSI)**. The measurement setup is according to figure 11 but the IF filter is replaced by a capacitor ($C = 10 \text{ nF}$) for this

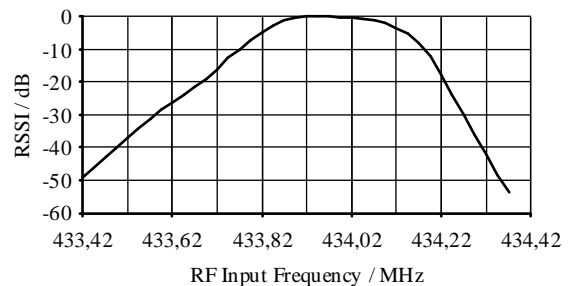


Figure 13 Overall frequency response including the IF-filter, RF input level -70 dBm

ce of the local oscillator's SAW resonator, the IF is not exactly 10.7 MHz. Therefore, the frequency response curve in figure 13 is asymmetric. In a production line, if the typical deviation from 10.7 MHz is known, the center frequency of the IF-filter should be matched.

5. SMD demoboard with IF part and microcontroller

For the purpose of demonstrating the performance and testing the receiver ICs in an actual remote control system, a small printed circuit board for SMD components, containing the IF part and the microcontroller, was developed. The size of this board is the same as that of the front end. The external connections are fitting together. The two PCBs are also suited for sandwich mounting, then the total size is $47 \times 30 \times 16 \text{ mm}^3$. If the circuit arrangement shown in figure 1 is used, the two different ground planes of the RF and IF parts have to be coupled by capacitors of approximately 100 pF and 100 nF (see figure 14). Remember that in this case, the shielding of the antenna and the negative pole of the supply voltage are not identical; therefore the antenna shielding and ground must be AC-coupled with a capacitor (C 100) of approximately 1 nF.

The IF part is designed either for FM or AM operation with a quasi DC-coupled data filter according to [1, figure 34 and figure 40]. R 9 and R 10 are left out, C 11 is replaced by the IF-filter. The circuit diagram of the FM version is given in figure 14. The PCB layout and component placement can be seen in figure 15 and figure 16. For AM operation, wire BR 1 and C 10a have to be mounted. For FM operation, BR 2 and C 10b are mounted. R 5a and R 5b are different versions of the data filter, only one of them is used. The use of R 5b provides a decreased rise time of the data filter for FM operation if the discriminator is not tuned exactly to the actual operation frequency, for example, if the transmission frequency deviates from the correct value. When using the R 5b, C 4 can be increased to 150 nF in order to obtain a low-end, cut-off frequency below 10 Hz. R8a/b and R 13a/b

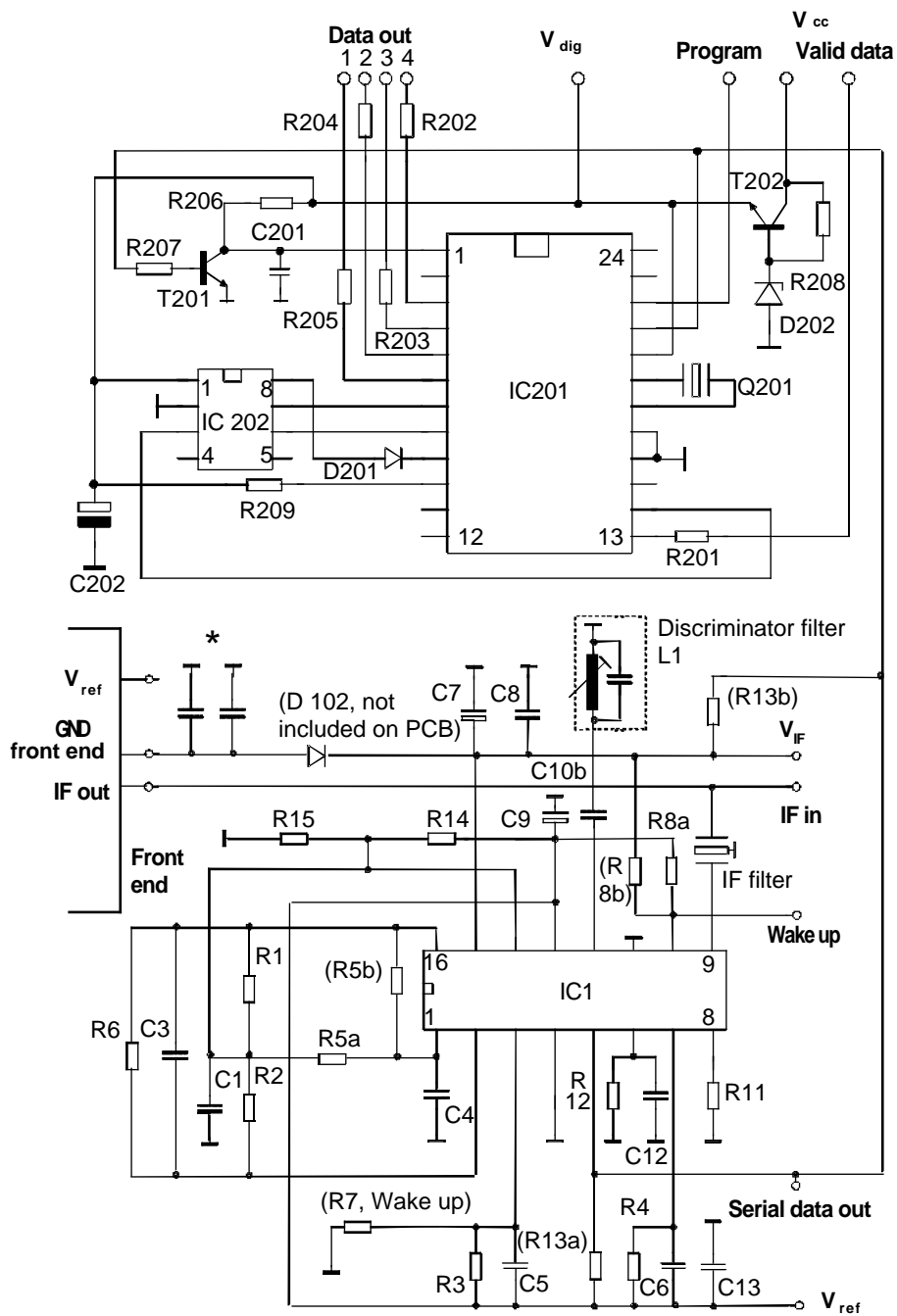
determine, whether the wake up output and the data output are referred to the reference voltage V_{ref} ('a'-resistors) or to the IF supply voltage V_{IF} ('b'-resistors). If the microcontroller on board is used, R 13 has to be left out. R 8 is only required if the wake up output is needed, R 3 and C 5 can be left out, if the internal wake up circuit of U 4311 B / U 4313 B is not used.

The only difference between U 4311 B-C and U 4313 B is the polarity of the data output. So all types of microcontrollers can be used without insertion of an inverter stage.

The signal decoder is equipped with a TELEFUNKEN Semiconductors low-current microcontroller C 2001 AM. This IC belongs to the M 43 C200 family and it was designed for demonstration of the RF remote control system. It provides 65536 different address codes and transmission or reception of 4 data bits. By setting the 'program' connector to ground for a short time, the microcontroller turns to the learn mode. If a correct data telegram is received, the address will be stored in the EEPROM, e 6210 (TEMIC EUROSIL). The supply voltage V_{dig} is stabilized to a value of 4.5 V to 5.5 V by D 202. A suitable type of diode must be tested - the value in the part lists is only a proposal. A transmitter, using the same microcontroller, is under development.

The microcontrollers of the M 43 C200 series can be custom designed to meet special requirements such as code hopping or a greater number of addresses, for example.

For further information concerning the microcontroller and the EEPROM, please consult the data sheets.



* = coupling capacitors between the ground planes

Figure 14 Circuit diagram of the IF part for FM with microcontroller, DC stacked with front end

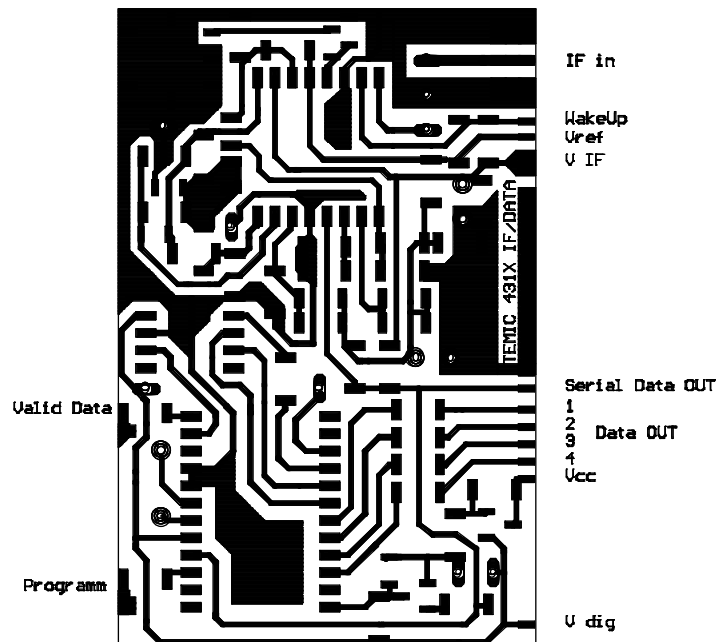


Figure 15 Layout of IF and digital part (original size: 47 x 30 mm²), view: SMD component side

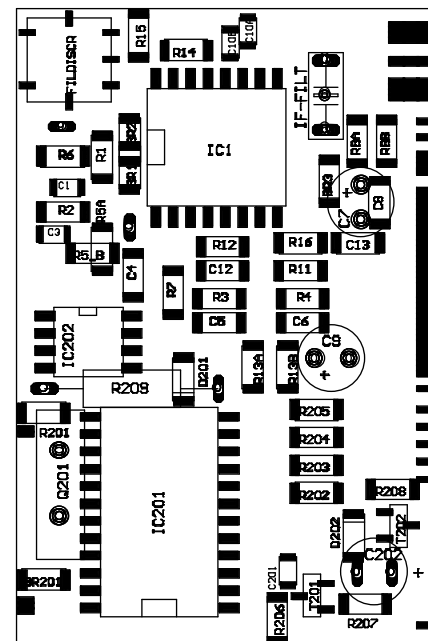


Figure 16 Component placement of IF / digital part, view: SMD component side

6. SMD demoboard of receiver, RF and IF part

Aiming at improved reproducibility and easier handling, an additional receiver demoboard was developed, using fixed chip inductors and containing RF and IF part on a single double-sided PCB. The circuit diagram is similar to the circuits that were described previously. The configuration, whether the RF and IF part are in parallel or series connected, can be chosen by different component assembling. The supply voltage range for the serial version is 7 V to 16 V, for the parallel version it is 4.5 V to 9 V.

The pins for supply voltage, ground, reference voltage, serial data out and wake up out are available at the border of the PCB. The RF input is fed to a SMB or SMC connector. If the circuit is configured according figure 1, the components with the extension 'P' must not be used. For the arrangement shown in figure 2, the components with 'S' must not be mounted.

Usually the components C 15S and C 16S are not required, their use depends on the external voltage supply circuitry. The printed circuit board and the component placement are shown in figure 17 and figure 18.

The 433.92-MHz version has been characterized and the component values are - apart from the following exceptions - identical with the part lists in the appendix, excluding the numbers 2xx of the microcontroller part. For the input filter and the oscillator coil, fixed chip inductors are used. For L 103, a tuneable, non-shielded molded coil was chosen. For more miniaturized layouts, the fixed inductors are available in 0603 size (TOKO LL 1608), for L 103 a type with reduced height like the TOKO MC 131 might be used. In this case, the quality factor Q is reduced. The following parts are different from the subsequent part lists:

BR 4P/S	0 Ω , size 1206	L 102	27 nH, TOKO LL 2012-F27NK
BR 5P/S	0 Ω , size 1206	L 103	TOKO MC 119 type, S1 ^{1/2} (space wound) Part No. E 525 HN 100039
R 17P	1 k Ω , tolerance 10%, size 1206	L 104	22 nH, TOKO LL 2012-F22NK
C 14S	100 pF, tolerance 50%, size 0805		
(C 15S	1 nF, tolerance 50%, size 1206) optional		
(C 16S	10 μ F, 10 V) optional		
C 101	10 pF, tolerance 10%, size 0805		
C 102	1.5 pF, tolerance 10%, size 0805		
C 106	4.7 pF, tolerance 10%, size 0805		
L 101	8.2 nH, TOKO LL 2012-F8N2K		

For R 110, a value between 100 Ω and 470 Ω can be used. If the oscillator does not work properly at low supply voltages, it can be improved by insertion of L 107 in series with the SAW resonator. The PCB is prepared for the use of a chip inductor of 0805 size - values between 10 nH and 47 nH are suitable. If no inductor is necessary, the pads must be shortened.

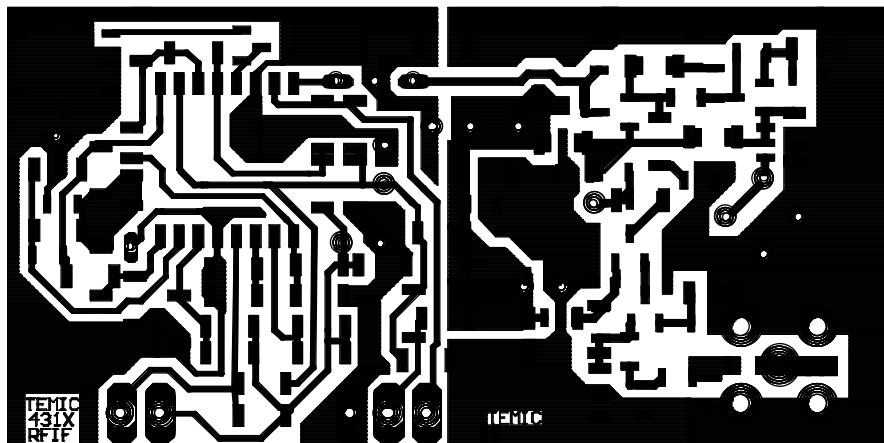


Figure 17 Layout of RF/IF demoboard (original size: 58 x 29 mm²), view: SMD component side

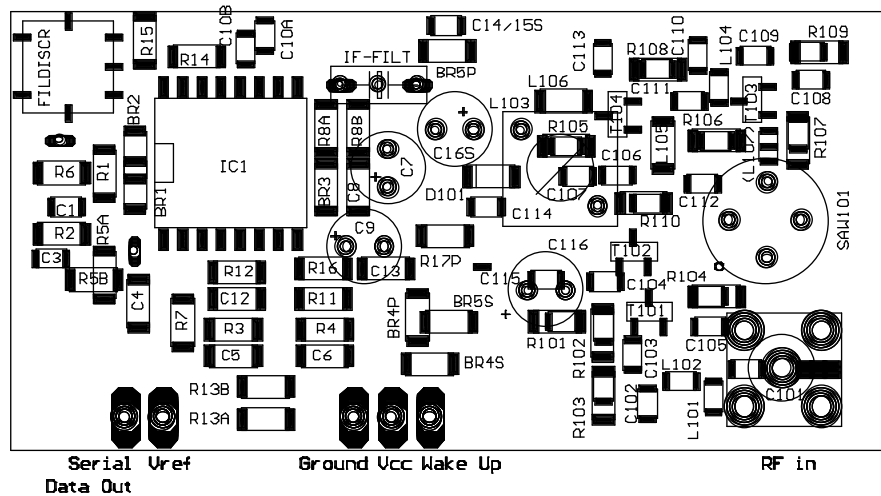


Figure 18 Component placement of RF/IF demoboard, view: SMD component side

7. Receiver measurement results

The following measurements give the achievable performance of a complete remote control receiver. They were taken on the front end matched with the FM IF/data board according to figure 15 and figure 16 of this paper. The board was operated in the permanent active mode. The measurement conditions correspond to those of the IF measurements presented in the application report (of course with exception of the operation frequency).

Figure 19 shows the characteristic of the logarithmic AM demodulator. The operation range of the demodulator covers 60 dB, which corresponds to the capability of the front end that was shown in figure 8.

If the front end is operated outside of the linear range, amplitude errors will decrease a modulation depth of even 100% to values below 50%. In this case, the operation range

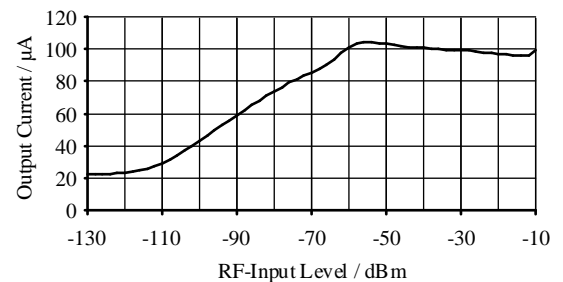


Figure 19 AM demodulator characteristic versus input level

of the demodulator is also exceeded and this behaviour may lead to incorrect pulse widths of the received data or even to inverted data. If an increased dynamic range of 100 dB is required, frequency modulation must be chosen. By principle this modulation type is insensitive to amplitude errors.

For the bit error measurements a **P**seudo **R**andom **S**equence (PRS) of 2^5-1 with a transmis-

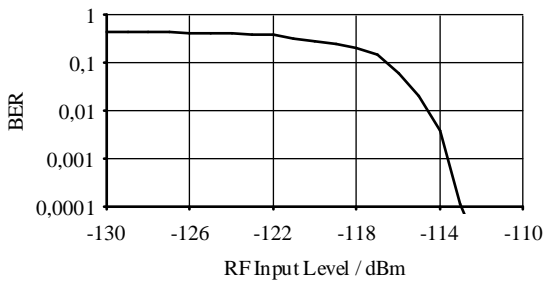


Figure 20 Bit error rate for a 2 kBit/s PRS of length 2^5-1 , FM, deviation 22.5 kHz

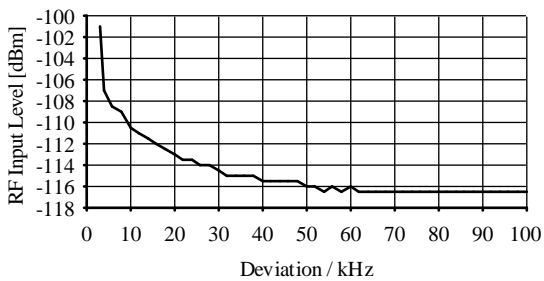


Figure 21 RF sensitivity for $BER < 10^{-3}$

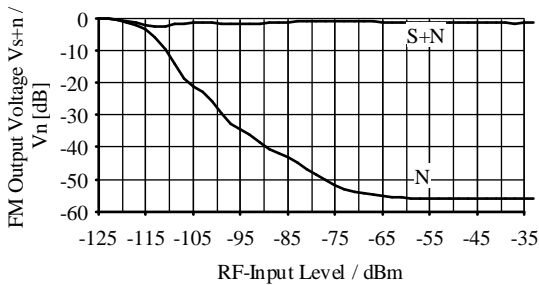


Figure 22 Signal to noise ratio for FM without data filter, deviation = 22.5 kHz

sion rate of 2 kBaud was used. The curve in figure 21 represents the required RF input level to achieve a bit error rate below 10^{-3} in dependence of the FM deviation. The data filter was quasi DC coupled according to version b) for both measurements.

Figure 22 shows the (S+N)/N characteristic without use of the data filter. For the (S+N)/N

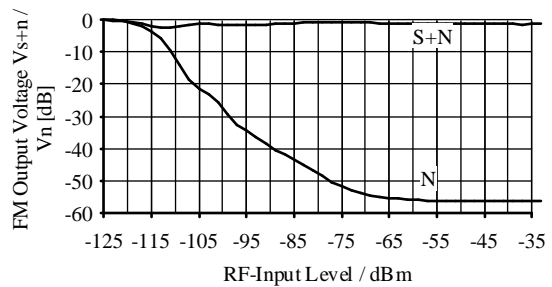


Figure 23 Signal to noise ratio for FM with data filter version b), $C_4 = 150$ nF, deviation 22.5 kHz

measurement shown in figure 23, version b) of the data filter was used as described previously. The 'edges' in the diagram at 0 dB and -80 dB result from the limited dynamic range of the quasi DC-coupled data filter. The value of C_4 was changed to 150 nF and the frequency response of this filter is shown in figure 24. The noise floor of the measurement setup is approximately at -60 dB; therefore the curve is flattened at the high end.

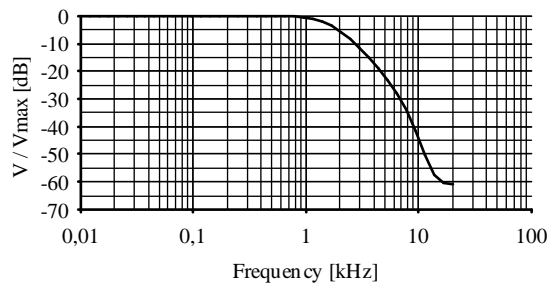


Figure 24 Frequency response of the data filter version b), $C_4 = 150$ nF

Important note:

These application examples have not been examined for series use or reliability, and no worst case scenarios have been developed. Customers who adapt any of these proposals must carry out their own testing and be convinced that no negative consequence arise from the proposals.

8. Appendix

8.1 Components for complete receiver on 433.92 MHz, FM

Circuit arrangement is according to figure 1, quasi DC-coupled data filter.

All resistors have a manufacturing tolerance of 5% and are size 1206 (No. 1xx also 0805 possible).

All capacitors not otherwise specified have a tolerance of 20% and are size 0805.

BR 2	0 Ω	R 206	470 k Ω
BR 3	0 Ω	R 207	220 k Ω
BR 201	0 Ω	R 208	10 k Ω
R 1	22 k Ω	R 209	10 k Ω wired
R 2	100 k Ω	C 1	15 nF
(R 3	220 k Ω) optional	C 3	330 pF
R 4	330 k Ω	C 4	47 nF, size 1206
R 5a	100 k Ω (see text)	(C 5	150 nF, size 1206) optional
R 5b	22 k Ω (see text)	C 6	150 nF, size 1206
R 6	1 M Ω	C 7	10 μ F, 16 V
R 7	22 k Ω	C 8	100 nF, size 1206
(R 8	100 k Ω) optional	C 9	10 μ F, 6 V
R 11	18 k Ω	C 10b	22 pF
R 12	330 k Ω	C 12	150 nF, size 1206
(R 13	22 k Ω) optional	C 13	100 nF, size 1206
R 14	22 k Ω	C 101	6.8 pF, 10%
R 15	22 k Ω	C 102	1.5 pF, 10%
R 101	22 k Ω	C 103	100 pF
R 102	33 k Ω	C 104	1 nF
R 103	33 k Ω	C 105	100 pF
R 104	1 k Ω	C 106	6.8 pF
R 105	10 k Ω	C 107	33 pF
R 106	22 k Ω	C 108	4.7 pF, 5%
R 107	47 k Ω	C 109	3.3 pF, 5%
R 108	220 Ω	C 110	100 pF
R 109	1 k Ω	C 111	3.9 pF, 5%
(R 110	100 Ω to 470 Ω)	C 112	470 pF
R 201	100 Ω	C 113	470 pF
R 202	100 Ω	C 114	100 pF
R 203	100 Ω	C 115	1 nF
R 204	100 Ω	C 116	10 μ F, 10 V
R 205	100 Ω	C 201	10 nF
		C 202	10 μ F, 10 V
		L 101	air loop \varnothing 2.5 mm, wire \varnothing 0.4 mm

L 102	air coil 3 turns \varnothing 2.5 mm, wire \varnothing 0.4 mm, length 2.5 mm	T 201	BC 848
L 103	air coil 3 turns \varnothing 2.5 mm, wire \varnothing 0.4 mm, to be tuned	T 202	BC 848
L 104	air coil 3 turns \varnothing 2.5 mm, wire \varnothing 0.4 mm, length 2.5 mm	Q 201	4 MHz
L 105	SMD fixed inductance 0.47 μ H	SAW 101	R 2531 (423.22 MHz), Siemens Matsushita
L 106	SMD fixed inductance 0.47 μ H	IC 1	U 4313 B-FL, U 4311 B-C-FL
D 101	Zener diode 4.7 V (e.g. TZM C 4V7)	IC 201	C 2001 AM
D 201	LL 4148	IC 202	EEPROM e 6210 (EUROSIL)
D 202	Zener diode 6.0 V	Discrimi- nator - filter	TOKO 614BG-0073GW (incl. 100 pF)
T 101	S 852 T	IF - filter	10.7 MHz with low insertion loss, e.g. TOKO SK 107 M1-A0-10X
T 102	S 852 T		
T 103	S 852 T		
T 104	S 852 T		

8.2 Components for complete receiver on 433.92 MHz, AM

Circuit arrangement is according to figure 1, quasi DC-coupled data filter.

All resistors have a manufacturing tolerance of 5% and are size 1206 (No. 1xx also 0805 possible).

All capacitors not otherwise specified have a tolerance of 20% and are size 0805.

BR 1	0 Ω	R 105	10 k Ω
BR 3	0 Ω	R 106	22 k Ω
BR 201	0 Ω	R 107	47 k Ω
R 1	22 k Ω	R 108	220 Ω
R 2	680 k Ω	R 109	1 k Ω
(R 3	220 k Ω) optional	(R 110	470 Ω)
R 4	330 k Ω	R 201	100 Ω
R 5a	100 k Ω (see text)	R 202	100 Ω
R 5b	22 k Ω (see text)	R 203	100 Ω
R 6	1 M Ω	R 204	100 Ω
R 7	22 k Ω	R 205	100 Ω
(R 8	100 k Ω) optional	R 206	470 k Ω
R 11	18 k Ω	R 207	220 k Ω
R 12	330 k Ω	R 208	10 k Ω
(R 13	22 k Ω) optional	R 209	10 k Ω wired
R 16	100 k Ω	C 1	4.7 nF
R 101	22 k Ω	C 3	82 pF
R 102	33 k Ω	C 4	150 nF, size 1206
R 103	33 k Ω	(C 5	150 nF, size 1206) optional
R 104	1 k Ω	C 6	150 nF, size 1206

C 7	10 μ F, 16 V	L 103	air coil 3 turns \varnothing 2.5 mm, wire \varnothing 0.4 mm, to be tuned
C 8	100 nF, size 1206	L 104	air coil 3 turns \varnothing 2.5 mm, wire \varnothing 0.4 mm, length 2.5 mm
C 9	10 μ F, 6 V	L 105	SMD fixed inductance 0.47 μ H
C 10a	10 nF	L 106	SMD fixed inductance 0.47 μ H
C 12	150 nF, size 1206	D 101	Zener diode 4.7 V (e.g. TZM C 4V7)
C 13	100 nF, size 1206	D 201	LL 4148
C 101	6.8 pF, 10%	D 202	Zener diode 6.0 V
C 102	1.5 pF, 10%	T 101	S 852 T
C 103	100 pF	T 102	S 852 T
C 104	1 nF	T 103	S 852 T
C 105	100 pF	T 104	S 852 T
C 106	6.8 pF	T 201	BC 848
C 107	33 pF	T 202	BC 848
C 108	4.7 pF, 5%	Q 201	4 MHz
C 109	3.3 pF, 5%	SAW 101	R 2531 (423.22 MHz), Siemens Matsushita
C 110	100 pF	IC 1	U 4313 B-FL, U 4311 B-C-FL
C 111	3.9 pF, 5%	IC 201	C 2001 AM
C 112	470 pF	IC 202	EEPROM e 6210 (EUROSIL)
C 113	470 pF	IF - filter	10.7 MHz with low insertion loss, e.g. TOKO SK 107 M1-A0-10X
C 114	100 pF		
C 115	1 nF		
C 116	10 μ F, 10 V		
C 201	10 nF		
C 202	10 μ F, 10 V		
L 101	air loop \varnothing 2.5 mm, wire \varnothing 0.4 mm		
L 102	air coil 3 turns \varnothing 2.5 mm, wire \varnothing 0.4 mm, length 2.5 mm		

8.3 Components for complete receiver on 303.85 MHz, FM

Circuit arrangement is according to figure 1, quasi DC-coupled data filter.

All resistors have a manufacturing tolerance of 5% and are size 1206 (No. 1xx also 0805 possible).

All capacitors not otherwise specified have a tolerance of 20% and are size 0805.

BR 2	0 Ω	R 209	10 k Ω wired
BR 3	0 Ω	C 1	15 nF
BR 201	0 Ω	C 3	330 pF
R 1	22 k Ω	C 4	47 nF, size 1206
R 2	100 k Ω	(C 5	150 nF, size 1206) optional
(R 3	220 k Ω) optional	C 6	150 nF, size 1206
R 4	330 k Ω	C 7	10 μ F, 16 V
R 5a	100 k Ω (see text)	C 8	100 nF, size 1206
R 5b	22 k Ω (see text)	C 9	10 μ F, 6 V
R 6	1 M Ω	C 10b	22 pF
R 7	22 k Ω	C 12	150 nF, size 1206
(R 8	100 k Ω) optional	C 13	100 nF, size 1206
R 11	18 k Ω	C 101	6.8 pF, 10%
R 12	330 k Ω	C 102	3.3 pF, 10%
(R 13	22 k Ω) optional	C 103	100 pF
R 14	22 k Ω	C 104	1 nF
R 15	22 k Ω	C 105	100 pF
R 101	22 k Ω	C 106	10 pF
R 102	33 k Ω	C 107	33 pF
R 103	33 k Ω	C 108	6.8 pF, 5%
R 104	1 k Ω	C 109	4.7 pF, 5%
R 105	10 k Ω	C 110	100 pF
R 106	22 k Ω	C 111	4.7 pF, 5%
R 107	47 k Ω	C 112	470 pF
R 108	220 Ω	C 113	470 pF
R 109	1 k Ω	C 114	100 pF
(R 110	470 Ω)	C 115	100 pF
R 201	100 Ω	C 116	10 μ F, 10 V
R 202	100 Ω	C 201	10 nF
R 203	100 Ω	C 202	10 μ F, 10 V
R 204	100 Ω	L 101	air coil 2 turns \varnothing 2.5 mm, wire \varnothing 0.4 mm, length 1.5 mm
R 205	100 Ω	L 102	air coil 4 turns \varnothing 2.5 mm, wire \varnothing 0.4 mm, length 2.5 mm
R 206	470 k Ω	L 103	air coil 4 turns \varnothing 2.5 mm, wire \varnothing 0.4 mm, to be tuned
R 207	220 k Ω	L 104	air coil 4 turns \varnothing 2.5 mm, wire \varnothing 0.4 mm, to be tuned
R 208	10 k Ω		

L 105	SMD fixed inductance 0.47 μ H	Q 201	4 MHz
L 106	SMD fixed inductance 0.47 μ H	SAW 101	R 640 (314.5 MHz), Siemens Matsushita
D 101	Zener diode 4.7 V (e.g. TZM C 4V7)	IC 1	U 4313 B-FL, U 4311 B-C-FL
D 201	LL 4148	IC 201	C 2001 AM
D 202	Zener diode 6.0 V	IC 202	EEPROM e 6210 (EUROSIL)
T 101	S 852 T	Discrimi- nator filter	TOKO 614BG-0073GW (incl. 100 pF)
T 102	S 852 T	IF - filter	10.7 MHz with low insertion loss, e.g. TOKO SK 107 M1-A0-10X
T 103	S 852 T		
T 104	S 852 T		
T 201	BC 848		
T 202	BC 848		

8.4 Components for complete receiver on 303.85 MHz, AM

Circuit arrangement is according to figure 1, quasi DC-coupled data filter.

All resistors have a manufacturing tolerance of 5% and are size 1206 (No. 1xx also 0805 possible).

All capacitors not otherwise specified have a tolerance of 20% and are size 0805.

BR 1	0 Ω	R 108	220 Ω
BR 3	0 Ω	R 109	1 k Ω
BR 201	0 Ω	(R 110	470 Ω)
R 1	22 k Ω	R 201	100 Ω
R 2	680 k Ω	R 202	100 Ω
(R 3	220 k Ω) optional	R 203	100 Ω
R 4	330 k Ω	R 204	100 Ω
R 5a	100 k Ω (see text)	R 205	100 Ω
R 5b	22 k Ω (see text)	R 206	470 k Ω
R 6	1 M Ω	R 207	220 k Ω
R 7	22 k Ω	R 208	10 k Ω
(R 8	100 k Ω) optional	R 209	10 k Ω wired
R 11	18 k Ω	C 1	4.7 nF
R 12	330 k Ω	C 3	82 pF
(R 13	22 k Ω) optional	C 4	150 nF, size 1206
R 16	100 k Ω	(C 5	150 nF, size 1206) optional
R 101	22 k Ω	C 6	150 nF, size 1206
R 102	33 k Ω	C 7	10 μ F, 16 V
R 103	33 k Ω	C 8	100 nF, size 1206
R 104	1 k Ω	C 9	10 μ F, 6 V
R 105	10 k Ω	C 10a	10 nF
R 106	22 k Ω	C 12	150 nF, size 1206
R 107	47 k Ω	C 13	100 nF, size 1206
		C 101	6.8 pF, 10%

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C 102	3.3 pF, 10%	L 104	air coil 4 turns Ø 2.5 mm, wire Ø 0.4 mm, to be tuned
C 103	100 pF	L 105	SMD fixed inductance 0.47 µH
C 104	1 nF	L 106	SMD fixed inductance 0.47 µH
C 105	100 pF	D 101	Zener diode 4.7 V (e.g. TZM C 4V7)
C 106	10 pF	D 201	LL 4148
C 107	33 pF	D 202	Zener diode 6.0 V
C 108	6.8 pF, 5%	T 101	S 852 T
C 109	4.7 pF, 5%	T 102	S 852 T
C 110	100 pF	T 103	S 852 T
C 111	4.7 pF, 5%	T 104	S 852 T
C 112	470 pF	T 201	BC 848
C 113	470 pF	T 202	BC 848
C 114	100 pF	Q 201	4 MHz
C 115	100 pF	SAW 101	R 640 (314.5 MHz), Siemens Matsushita
C 116	10 µF, 10 V	IC 1	U 4313 B-FL, U 4311 B-C-FL
C 201	10 nF	IC 201	C 2001 AM
C 202	10 µF, 10 V	IC 202	EEPROM e 6210 (EUROSIL)
L 101	air coil 2 turns Ø 2.5 mm, wire Ø 0.4 mm, length 1.5 mm	IF - Filter	10.7 MHz with low insertion loss, e.g. TOKO SK 107 M1-A0-10X
L 102	air coil 4 turns Ø 2.5 mm, wire Ø 0.4 mm, length 2.5 mm		
L 103	air coil 4 turns Ø 2.5 mm, wire Ø 0.4 mm, to be tuned		

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