

UHF Wireless Data Transceiver

Table of Contents

Introduction	1
Basics.....	2
Legal Regulations.....	2
Germany	2
Europe	2
RS232 Interface.....	2
Circuit Description	4
Interface Section.....	4
Transmitter	5
Receiver.....	6
Front End.....	6
IF and Baseband Section	7
PCB Layout of Transceiver	8
Measurement Results	9
Receiver Section.....	9
Transmitter Section	10
Conclusion	12
Appendix.....	13
Comparison between Loop and $\lambda/4$ Antenna.....	13
Complete Circuit Diagram	15
Circuit and Alignment Description	16
Component Placement.....	16
Component List.....	17
References.....	18

Introduction

Wireless communication is the challenge for the present and the next century. It promises a new kind of mobility, convenience, flexibility and versatility. In addition to that, wireless communication helps to save costs in many applications.

To ensure data integrity and to improve safety, duplex radio links are becoming more and more indispensable. Numerous applications can take advantage of TEMIC's technology, which has proven successful in the field of remote control and keyless entry systems:

- Wireless data transfer systems
(e.g., peer to peer and small networks, terminal, printer, keyboard, mouse, bar code reader and other peripheral links)
- Alarm and security systems
(for home and office to warn of burglary, fire and flood)
- Domestic installation
(e.g., lighting, heating, air-conditioning and telemetering)
- Home intercommunication systems
(exchanging data such as consumption, temperature, humidity, brightness etc.)

This application note is a guide for designing a low-cost half-duplex radio link in the UHF range, as it was already announced in ANT012 "Components for radio frequency based remote control systems" [1]. It can be characterized as a continuation of ANT013 "UHF remote control systems: receiver front end and complete receiver design hints" [2].

The transceiver described here was developed for direct

connection to a standard RS232C serial interface but may be easily adapted to other interfaces. If connected to the RS232C interface, no additional power supply is needed because the low-power concept of the transceiver allows the use of signal line voltages for its supply.

The SAW-based FM transceiver provides high-speed performance up to 38.4 kbps. The maximum operating range is 100 m. In practice, the operation range depends on the environment. In a typical office with walls and ceilings, distances up to 30 m can usually be reached.

The described transceiver fulfills the ETSI and even the German FTZ regulation, which is the toughest in the world. In tests through a temperature range from -25°C to +55°C, the transceiver has performed well.

The transceiver was designed for low-cost high-volume applications. To simplify production, the number of alignments has been reduced. Now, only two alignment points remain – one in the receiver and one in the transmitter section.

This application note begins with some basic information on legal regulations and the RS232 serial interface. Next, the transceiver concept is introduced, followed by a closer look at each section. Finally, a PCB layout and some measurement results are presented.

This application note is a guide which can be used as a basis for the customer's own development. The customer must adapt the circuits to his production requirements. Please note that our examples have not been tested for reliability and no worst case scenarios have been done. Customers who adapt any of our proposals must carry out their own testing and be convinced that no negative consequences will arise from the proposals.

ANT015

Basics

Legal Regulations

The following information on the regulations refers to the situation in spring 1995. It is expected that in Germany the national 17TR2100 standard will be replaced by the I-ETS 300 220 within the next few months.

Germany

At the present time, the regulations of Federal German Post Ministry (BMPT) Ordinance 17TR2100 must be considered in Germany. The guideline is called "Technische Richtlinie für Fernwirkfunkanlagen kleiner Leistung des nichtöffentlichen mobilen Landfunks (nömL)" [3]. Type approval must be done at the BZT (Bundesamt für Zulassungen in der Telekommunikation). After type approval, the transceivers can be used by the customers without paying license fees or needing any further approval. The ISM frequency band (i.e., industrial-, scientific- and medical applications) within the UHF range is between 433.05 MHz and 434.79 MHz (center frequency 433.92 MHz $\pm 0.2\%$). The maximum radiated power of the transmitter is limited to 25 mW. Harmonics and spurious radiation of the transceiver must be less than 1 nW up to 1 GHz and 30 nW between 1 GHz and 40 GHz. These power limits are valid during normal operation and during receiver and transmitter set up. Tests have to be done in a temperature range from -10°C to $+55^{\circ}\text{C}$. The antenna of the transmitter must be fixed.

Europe

In 1992, the ETSI (European Telecommunications Standard Institute) proposed the Interim European Telecommunication Standard I-ETS 300 220 [4].

Basically, this standard is similar to the FTZ standard but less stringent on several points. I-ETS 300 220 distinguishes between different classes of transceivers. The relevant class for our transceiver is 1a, which allows a maximum radiated power of 10 mW ERP. Harmonics and spurious radiation of the transceiver must be less than 4 nW up to 1 GHz and $1\ \mu\text{W}$ above 1 GHz. Between 230 MHz and 470 MHz as well as between 862 MHz and 1 GHz, the limit of maximum radiation is 250 nW. Tests have to be done in a temperature range from -25°C to $+55^{\circ}\text{C}$. The antenna of the

transmitter must be fixed. The standard gives a guideline for the use of a spectrum analyzer:

- Start frequency: 432.05 MHz
- Stop frequency: 435.79 MHz
- Resolution bandwidth: 100 Hz
- Scan speed: slowest

The following countries have accepted without restriction the I-ETS 300 220:

Denmark, Italy, Norway, Spain and Sweden. In the United Kingdom, 433.92 MHz is restricted for automotive use only. There is a similar situation in France, though several applicants received their certificates successfully for non-automotive related products. The other European countries are likely to adopt standards similar to I-ETS 300 220.

RS232 Interface

The RS232 interface was developed for serial data transmission between computers and modems. Today, it has been established as a standard serial port for all IBM compatible PCs. This port is used for all kinds of data transmission between computers, printers, modems and other peripheral equipment. Numerous signal lines are defined. With regards to simple port-to-port connection, however, a set of three signal lines is sufficient for bi-directional transmission:

- TxD: Transmit data line
- RxD: Receive data line
- GND: Ground

Usually the data is transmitted in a half-duplex mode by using a X_{on}/X_{off} protocol. The RTS (**R**quest to **S**end) and DTR (**D**ata **T**erminal **R**eady) handshake lines are not needed in this transfer mode. These lines can be used to control the data transceiver (transmit or receive mode) and to deliver the necessary power supply for it. Considering a handshake line, a logic '0' is represented by a driven voltage of between $-5\ \text{V}$ and $-15\ \text{V}$ and a logic '1' of between $+5\ \text{V}$ and $+15\ \text{V}$.

Some typical curves (handshake line output voltage versus current) are shown in figure 1 (logic '1'). Considering the worst case, it can be said that the voltage will not fall below 5 V when drawing 4 mA of current out of the handshake line.

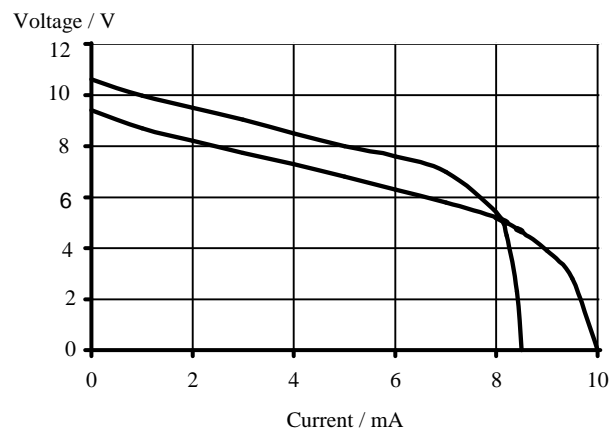


Figure 1. Handshake line output voltage versus current

At RxD (receiving), a voltage of between -3 V and -15 V represents '1', and a voltage of between +3 V and +15 V represents '0'. That means, that voltages of between -3 V and +3 V are undefined. In practice, most interfaces recognize voltages of between -3 V and +1~2 V as logic '1', while voltages higher than 2 V mostly represent '0'. These facts are important in order to understand the transceiver's concept within the interface section.

As an RF-based data link is more sensitive to RF interference than a wired link, correct transmission must be guaranteed by using a special protocol. The protocol must recognize and correct all errors that appear. The handling may be solved by software within the PC or with the help of a microcontroller. Be aware that microcontrollers can generate additional RF interference.

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Circuit Description

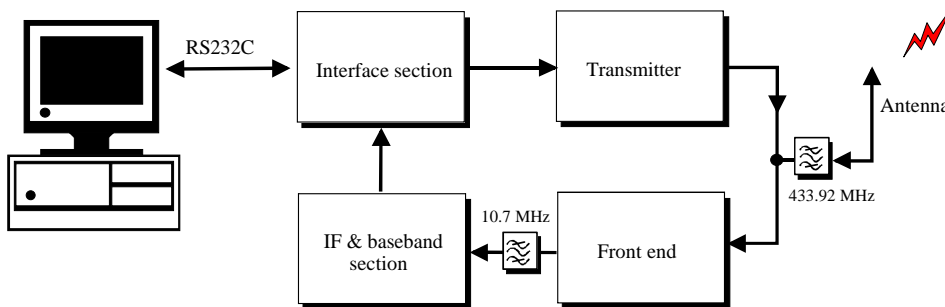


Figure 2. Transceiver block diagram

The transceiver can be divided into four main blocks as shown in figure 2.

1. The interface section connects the transceiver to the RS232C port and manages the power supply of the other three blocks. Furthermore, it switches the transmitter and it is responsible for the level conversion from RS232C level to TTL and vice versa.

2. The two-stage, SAW-stabilized transmitter is directly FM-modulated at the operating frequency of 433.92 MHz by the asynchronous data stream of the TxD signal line. The RF signal is fed into the antenna via a SAW filter, which is used in the transmit path to suppress harmonics. In the receive path, the same filter is used for image rejection, LO suppression and to improve the selectivity.

3. The front end converts the signal from the operating frequency at 433.92 MHz to the intermediate frequency at 10.7 MHz. The front end is switched off during transmission to save energy.

4. After passing the ceramic filter, the signal is first amplified in the IF and baseband section. Then it is

demodulated, filtered in the baseband and regenerated by using a clamping comparator. The IF and baseband section is also active during transmit mode to shorten switching time. Additionally, the reference voltage delivered from the IF integrated circuit U4311B-C is needed in the interface section.

Interface Section

While the RxD, TxD and DCD signal lines are used to transfer information, the RTS and DTR handshake lines must be set as shown in table 1. Due to the low-power concept of the transceiver, the RS232 handshake output voltage can be used for the power supply of the total transceiver. The circuit diagram shown in figure 3 can be divided into five functional sections.

Table 1. Transceiver modes

TRX Mode	RTS	DTR
Transmit	+12 V	+12 V
Receive	-12 V	+12 V

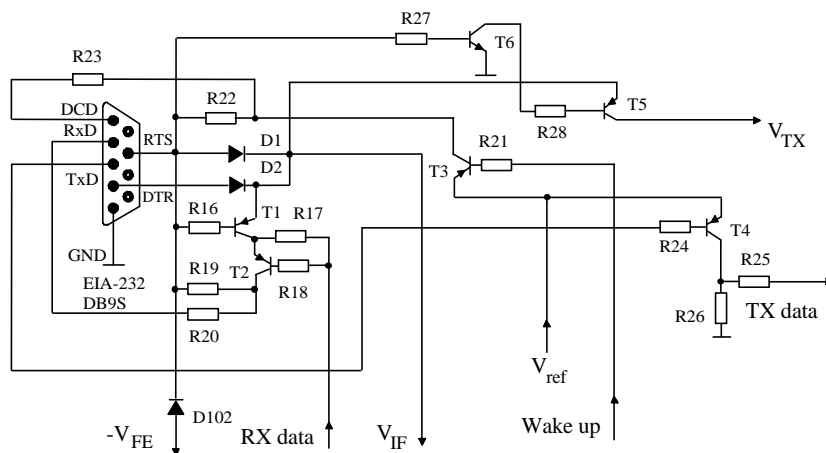


Figure 3. Interface section for UHF transceiver

1. The supply voltage for the IF and baseband section is rectified by D1 and D2. As more current is needed in the transmit mode, both handshake lines are set to +12 V. In receive mode, the use of these lines is also optimized. The front end is dc stacked by connecting its positive supply rail to dc ground. The front end's negative rail is connected via D102 to RTS (-12V in receive mode). Therefore the front end is switched off in transmit mode (+12 V in transmit mode).

2. The switch for keying the transmitter is formed by T5/T6 and R27/R28, which is controlled by RTS too.

3. T4 together with R24 to R26 is necessary to convert the bipolar RS232 levels of the TxD signal. For this operation, V_{ref} of the IF and baseband section is used (2.4 V). This reference voltage ensures that the transmitter's modulating voltage is stable within the total range of possible RS232 voltages (± 3 V to ± 15 V). This always guarantees a constant deviation.

4. To convert the TTL levels back to RS232 levels, T3 and R21 to R23 are utilized. The wake-up signal indicates if an RF signal is present. It is low (0 V) when there is an RF signal. In this case, T3 is switched on and the DCD input is set to high level. When there is no RF signal (wake up is high), T3 is off and the DCD input is low, because it's connected via R22/R23 to RTS.

5. In the same way the RX data delivered from the IF and baseband section is converted by T2 and R18 to R20 to the bipolar RxD signal. T1 and R16/R17 help to save current during transmit mode, as T1 switches off the level converter.

Transmitter

In figure 4, the SAW-based FM transmitter circuit is shown. If using a single-stage transmitter without additional filtering, the maximum output level is limited to approximately -20 dBm [1]. To get the required

operating range, a two-stage transmitter is used here. Besides the output power increased by the second stage, hand effects (frequency drift because of load change), which are a typical problem of single-stage SAW-based transmitters, are eliminated. D202 limits the supply voltage to about 5 V. The oscillator is built around T201 and is stabilized at 433.92 MHz with a SAW resonator (SAW201). One-port and two-port resonators can be used for the oscillator. In the circuit diagram, a configuration with a two-port resonator is shown. In contrast to a one-port resonator, both ports are connected together when using a two-port resonator. The data stream coming from the computer goes through a low-pass filter (R25 and C209) before it is fed to the varactor diode D201 (BB804 of Telefunken Semiconductors) which modulates the frequency of the oscillator in the tank circuit. The low-pass filtering helps to limit the transmitter's occupied bandwidth. Since the power of the RF signal produced by the oscillator is too low, it is amplified by T202. Both transistors within the transmitter are S852T transistors of Telefunken Semiconductors.

The signal is coupled to the amplifier via C208, which has to be adjusted. C208 influences the frequency of the tank circuit as well as the coupling of the oscillator and the amplifier. If it is aligned properly, the RF level at the output of T202 is approximately 1 mW. To fulfill the regulations, the RF signal must be filtered to suppress the harmonics. Usually, LC low-pass filters are used to get the proper harmonic suppression. The first harmonic at 868 MHz must be suppressed more than 40 dB. A good choice instead of an LC filter is a SAW filter. It can be used in low-power transmitters and needs no adjustment at all. L101, L102, C212 and C102 are fixed chip devices and form the matching circuit for SAW102.

The impedance at the antenna output is about 50 Ω . For optimum operation we recommend the use of a $\lambda/4$ antenna.

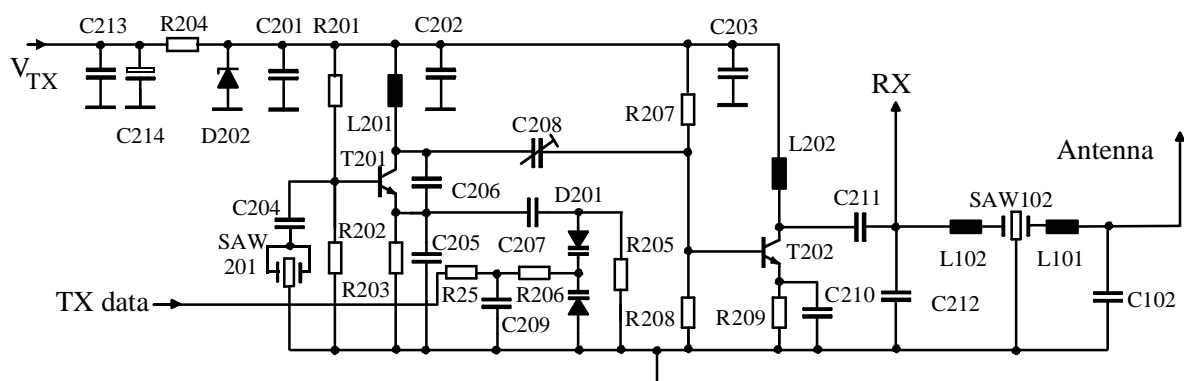


Figure 4. Transmitter circuit diagram

ANT015

Receiver

The receiver is a superheterodyne type with a 10.7 MHz IF. In between the IF/baseband and the front end sections, the ceramic IF filter fulfills two functions: concerning RF it couples and concerning dc it decouples.

Front End

The front end referred to here was introduced in TEMIC ANT013 [2]. Only the input filter and the inductor type have been changed to improve selectivity and to reduce alignment points (figure 5). SAW102 is a low-loss SAW filter which was specially designed as a front end filter for super-het receivers. With this type of filter, a much better image rejection and LO suppression – compared to fixed inductors – is possible. A similar characteristic can only be reached by using high-Q adjustable coils or helix filters. The SAW filter and its matching circuit needs no adjustment. The only remaining alignment point of the front end L103 was also removed. To get maximum sensitivity of the receiver, this coil had to be adjustable. But in a typical computer environment,

excess sensitivity leads to some problems. The noise floor near computers is high, so the IF IC's wake-up circuit will always detect that an RF signal is present. For good operation of the carrier detecting, a wake-up level of approximately -85 dBm is desirable. A fixed inductor with a lower Q is sufficient for L103. To reduce component cost, a printed coil was chosen in this case (see figure 9). This type of coil can be used without additional cost if there is enough PCB space available. A PCB coil should not be used within the oscillator – unwanted radiation may occur.

For more details about the front end or alternative frequencies to 433.92 MHz (e.g. 303.85 MHz), consult ANT013 [2]. For convenience, a rough circuit description is given here: The pre-stage formed by T101 and T102 is arranged in a cascode circuit. This pre-stage provides enough amplification of the RF signal and isolates the LO from the antenna input. T104 serves as a master excited mixer and the oscillator is built around T103. Both transistors are dc cascaded to reduce current consumption. All transistors within the front end are S852T of Telefunken Semiconductors, as they are well-suited for low-current operation.

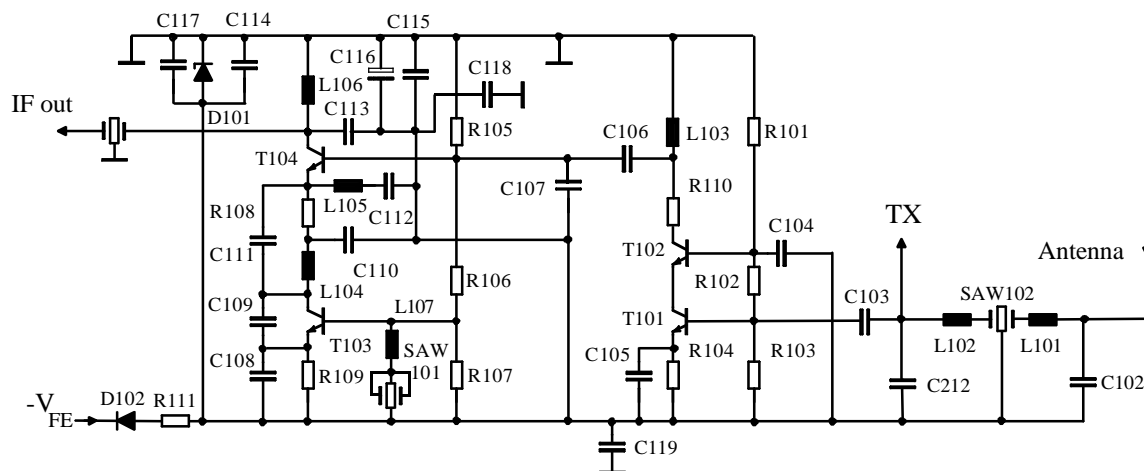


Figure 5. Front end section

IF and Baseband Section

The IF and baseband section shown in figure 6 is based upon the TEMIC IC U4311B-C, which was specially designed for super-het receivers. The integrated circuit includes the following functions:

- IF amplifier
- Logarithmic AM demodulator
- FM demodulator
- Wake-up circuit with mono-flop
- Operational amplifier
- Data comparator (non-inverting type)
- Voltage regulator

Beside the U4311B-C there is the U4313B (same IC except comparator is of inverting type) and the U4314B (only for AM without baseband processing). For more detailed information concerning TEMIC IF ICs, ANT012 [1] or data sheets should be consulted.

After the IF signal is filtered by the ceramic filter, it is fed into the IF amplifier (pin 9).

Since the IC is used in FM mode, the AM demodulator output (pin 8) can be used as a **Received Signal Strength Indicator (RSSI)**.

To complete the quadrature FM detector, the tuneable tank circuit LC, C10 and R14/R15 are added externally. With the tuneable LC tank, which is the only remaining alignment point of the receiver section, manufacturing tolerances of the SAW resonators can be compensated to some extent.

The wake-up circuit helps save current by switching the parts which are not needed to detect a relevant signal into standby mode.

R3 and C5 determine the delay and hold time of the mono-flop:

$$t_d \approx C5 \cdot 0.75 \text{ k}\Omega = 100 \text{ nF} \cdot 0.75 \text{ k}\Omega = 75 \mu\text{s}$$

$$t_h \approx 1.5 \cdot R3 \cdot C5 = 1.5 \cdot 100 \text{ k}\Omega \cdot 100 \text{ nF} = 15 \text{ ms}$$

The delay time of 75 μs prevents the IF and baseband section switching into active mode through the occurrence of short time interferences. If the delay time is extended, the suppression of interferences may be better. The probability of collisions when using several transceivers, however, will rise and the effective data rate drops. If a smaller RX/TX switching time is needed, the hold time may be reduced by changing R3. The level at pin 10 indicates the actual operating mode and can be used for carrier detection. The level in standby mode is high and switches to low in active mode.

For optimum system performance, a second-order, low-pass filter is built with the help of the internal high performance operational amplifier. To get a minimum cut-off frequency at the low end, a quasi dc-coupled data filter is used (see figure 7).

The needed bandwidth B is calculated below [5]:

$$B = \frac{1}{2} f_{\text{Bit}} (1 + r) = 0.5 \cdot 38.4 \text{ kHz} \cdot (1 + 0.5) = 28.8 \text{ kHz}$$

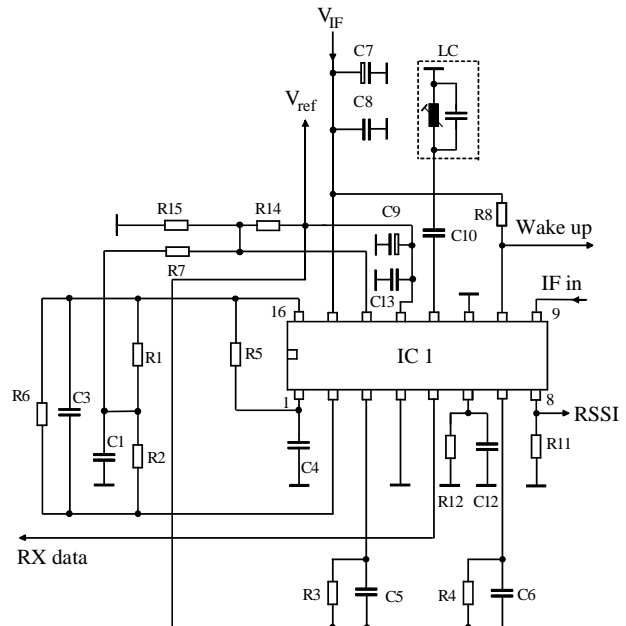


Figure 6. IF and baseband section

For a data rate of 38.4 kbps (f_{Bit}), the highest possible fundamental frequency in the case of a 0-1-0-1 sequence would be 19.2 kHz. Assuming an ideal low-pass filter, the necessary minimum bandwidth is 19.2 kHz. In the case of the real low-pass filter, a roll-off factor of $r = 0.5$ was taken into consideration [5]. This guarantees that the receiver's performance will not drop at the maximum data rate.

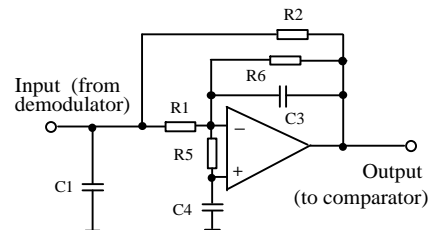


Figure 7. Quasi dc-coupled data filter

The output of the data filter is connected directly to the non-inverting data comparator. This comparator has a level-dependent hysteresis and works as a data regenerator. It clamps the reference voltage to the middle of the signal's minimum and maximum peaks. The time constants are determined by R4/C6 (max. peak) and R12/C12 (min. peak). The time constant is large compared to the data rate in order to suppress hum and noise.

The band gap voltage of 2.4 V is available at pin 13. In case this pin is not externally loaded, the supply current of the IF and baseband section is 1 mA in standby mode and 3 mA in active mode.

ANT015

PCB Layout of Transceiver

A printed circuit board has been developed which includes all sections of the complete transceiver and a loop antenna.

The PCB is double-sided (figures 8 and 9). Most components are placed on the upper side (SMD side), except the SAW devices and the tantal capacitors. Additionally, the PCB is prepared for filter capacitors at the RS232 lines. The PCB coil is also placed on the lower side.

The loop antenna can be connected instead of a $\lambda/4$ antenna if a smaller operating range is adequate. A detailed consideration of the loop antenna is given in the appendix. The PCB has been prepared to mount extra shielding at the transmitter section. The measurements described in the chapter 'Transmitter section' have been done without extra shielding. The demo circuit board fits into a standard plastic case which is shown on the report's cover.

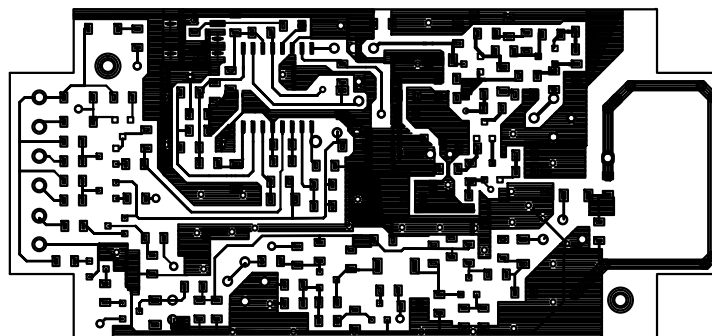


Figure 8. PCB layout, SMD component side

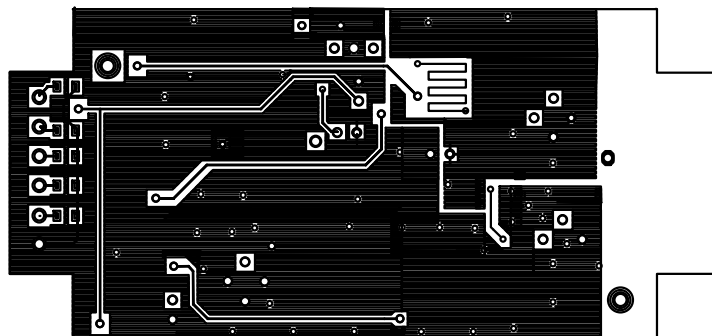


Figure 9. PCB layout, discrete component side

Measurement Results

Receiver Section

Some measurements have been done to characterize the overall performance of the data receiver. The measurement configuration is described more detailed in ANT012 [1] and ANT013 [2].

The AM demodulator voltage at pin 8 was measured versus the RF input level. The resulting curve shown in figure 10 illustrates the dynamic characteristic of the receiver.

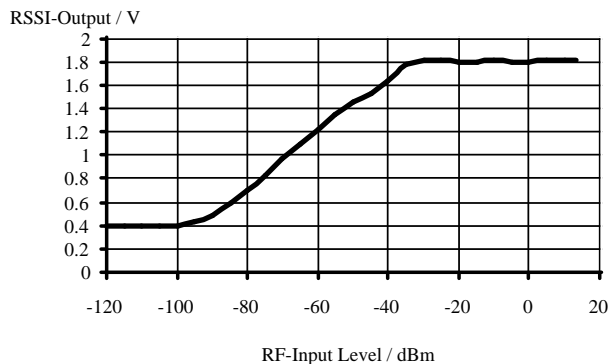


Figure 10. RSSI voltage versus input level

The linear range of the AM demodulator is 60 dB. The voltage at pin 8 may be used as an RSSI. The total dynamic range of the FM receiver is more than 100 dB. The front end can handle input levels higher than +10 dBm. The maximum input level is limited because of the maximum power level a SAW filter can stand. The typical wake-up level is approximately -85 dBm. At lower input levels the IF and baseband section switches into standby mode. At an input level of -85 dBm, the bit error rate is below 10^{-4} . For the BER curve shown in figure 11, the IF and baseband section was forced to stay in active mode via the mode control input (pin 3). A **Pseudo Random Sequence (PRS)** of 2^5-1 with a transmission rate of 10 kbps was used to modulate the signal generator. FM deviation was set to 22.5 kHz.

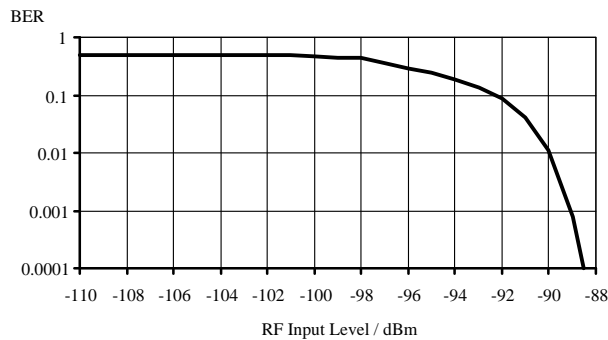


Figure 11. Bit error rate for a 10 kbit/s PRS

The frequency response of the data filter (circuit diagram see figure 7) was measured at an RF input level of -42 dBm. In figure 12, the active second-order Bessel type low-pass filter response can be seen.

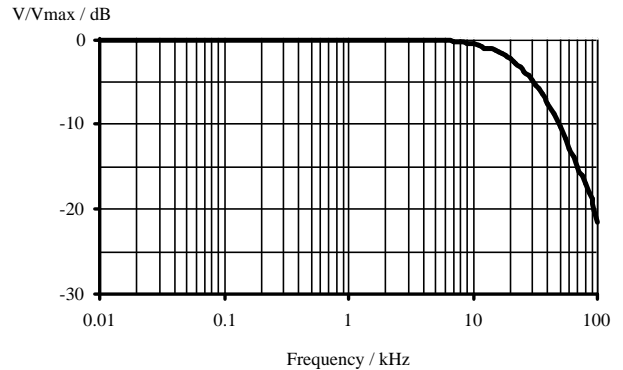


Figure 12. Frequency response of the data filter

The 3 dB cut-off frequency is approximately 23 kHz which fits to the calculations done in the chapter 'IF and Baseband Section'.

One important consideration relating the legal regulations is the emission from the local oscillator at the antenna output. The level measured at 423.23 MHz is lower than -65 dBm. According to the FTZ regulations, a maximum of -60 dBm is allowed, and under the ETSI regulations, -57 dBm are allowed.

Additionally, the transceiver must work well in a temperature range from -25°C to +55°C. The receiver exhibits stable operation within this temperature range and the LO radiation is nearly constant.

As far as selectivity, the far-off and in-band selectivity must be distinguished. The far-off selectivity is determined by the SAW filter in the front end. The highest sensitivity regarding interfering signals in a super-het receiver is at the image frequency. At 412.52 MHz, no strong interference signal is expected. At the image frequency 21.4 MHz below the operating frequency, the suppression is more than 40 dB. All other spurs below (e.g. subharmonics) are rejected more than 90 dB. For a good receiver performance, the rejection close to the operating frequency is an important requirement.

For this measurement, the linear dynamic range of the AM demodulator was used. The curve in figure 13 shows the overall frequency response including the ceramic IF filter. The RF input level was set to -34 dBm.

Both the 3 dB bandwidth of 300 kHz and the 20 dB bandwidth of approximately 600 kHz are determined by

ANT015

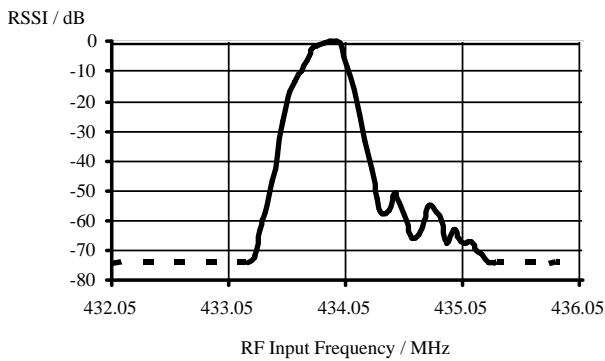


Figure 13. Overall response, RF input level -34 dBm

the ceramic filter. The ripple around 434.6 MHz is also caused by the ceramic filter. Due to their bandwidth (typically 600 to 950 kHz depending on manufacturer), the SAW filters provide additional suppression approximately 1 MHz away from the center frequency. The total suppression reaches more than 70 dB.

For values higher than -74 dB, the curve is dotted to indicate the AM demodulator's linear range end. However, the suppression is much better than 74 dB at the dotted curve. Many other low-cost, low-current receiver solutions for UHF, e.g. AM systems, have problems at this point because suppression at $f_c \pm 1$ MHz is only approximately 20 dB.

Transmitter Section

To give an impression of the transmitter's performance, some diagrams were produced with a spectrum analyzer, connected to the antenna output.

Figure 14 shows the unmodulated carrier. The output power is -4.5 dBm at 433.928 MHz. This power is enough for the desired operating range.

Though the output power can vary by some dB due to components tolerances, there is no danger that the power exceeds +10 dBm, which is the maximum allowed radiated power according to the ETSI regulation.

Another important parameter of a transmitter is the deviation. The deviation of SAW-based transmitters is limited due to the given modulation capability. The deviation of the measured transmitter is ± 12 kHz (see figure 15, data rate = 2400 bps).

Next, the transmitter was modulated, using the maximum transferable data rate of 38.4 kbps. The modulated spectrum was measured using the start and stop frequency recommended by the ETSI specification.

The response is shown in figure 16.

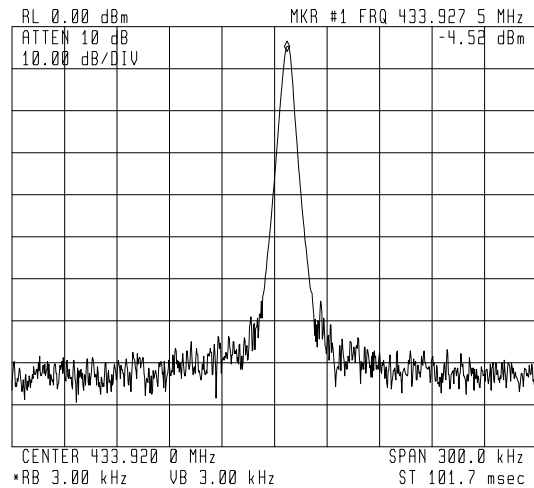


Figure 14. Unmodulated carrier

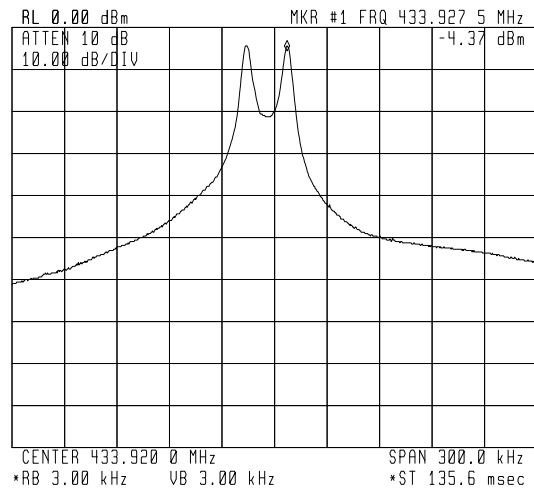


Figure 15. Modulated spectrum

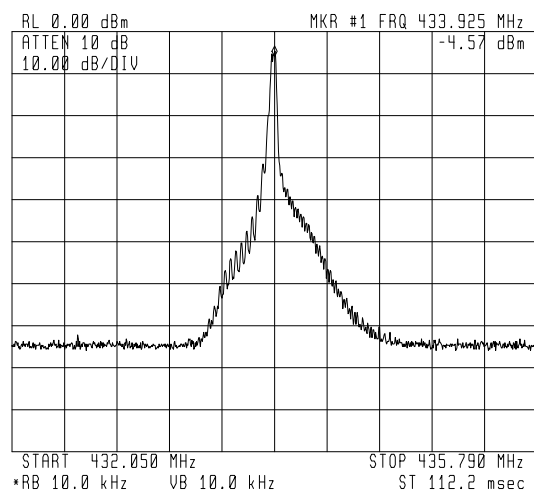


Figure 16. Modulated spectrum (38.4 kbps)

The spectrum meets the FTZ- and ETSI regulations. As no channels must be considered when using low-level transmitters, the bandwidth is only limited by the ISM band.

The maximum allowed power at the harmonics is shown in table 2.

Table 2. Maximum allowed power of harmonics

Frequency	FTZ	ETSI
867.8 MHz	-60 dBm	-36 dBm
1301.8 MHz	-45 dBm	-30 dBm
1735.7 MHz	-45 dBm	-30 dBm

The harmonics measured are below the much stricter FTZ regulation (17TR2100). The spectrum up to the third harmonic is shown in figure 17. The maximum allowed power is indicated by the dotted lines.

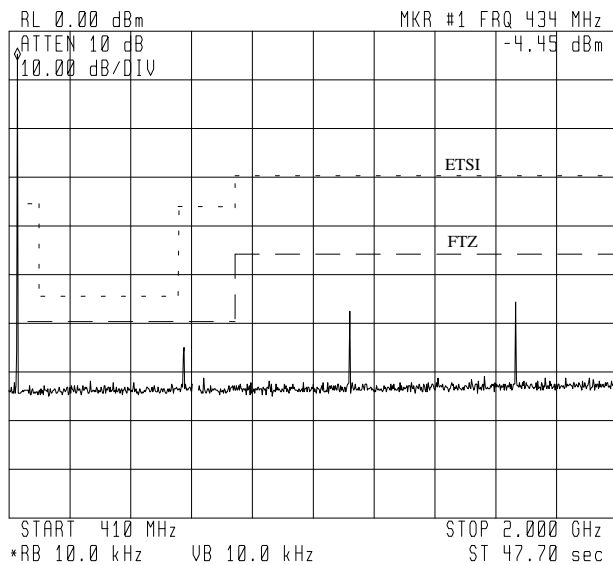


Figure 17. Harmonic radiation

According to the I-ETS 300 220 regulation [4], the transmitters must work well in a temperature range from

-25°C to +55°C. The transmitter operation is stable within this temperature range. The frequency change versus the temperature is shown in figure 18.

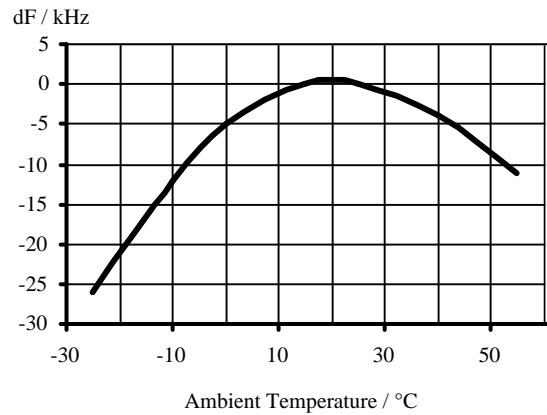


Figure 18. Frequency change versus temperature

The curve shows the typical characteristic of a SAW-based resonator. The maximum change of frequency is 25 kHz. Due to the wide band receiver concept, this change can be neglected. The wide band concept is necessary not only because of the temperature drift, but also because of the manufacturing tolerances of the SAW devices.

The output power of the SAW transmitter depends on the ambient temperature as shown in figure 19.

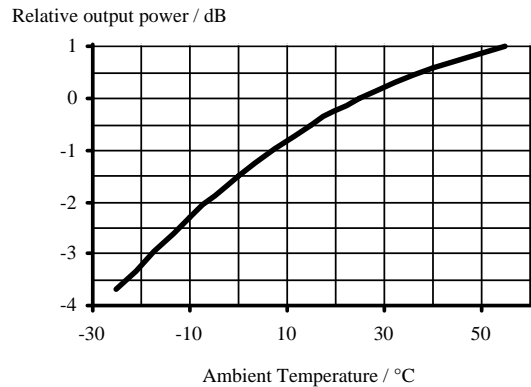


Figure 19. Output level versus temperature

The variation across the temperature range is less than 5 dB.

ANT015

Conclusion

This application note introduced a complete UHF wireless data transceiver based upon the integrated circuit U4311B-C, the UHF transistors S852T and the varactor diode BB804.

Beside the U4311B-C there is the U4313B (same IC except comparator is of inverting type) and the U4314B (only for AM without baseband processing). For more detailed information concerning TEMIC IF ICs, ANT012 [1] or data sheets should be consulted.

These devices provided by Telefunken Semiconductors for RF-based communication make it possible to find cost-saving solutions for a great variety of applications.

Because of the low-power and low-cost concept, solutions are now possible which were restricted to wired communication in the past. When comparing the cost of wiring with those of wireless technology, a reduction of the total system price can be expected.

Due to the European efforts towards unifying regulations for short range radio equipment, it will not be necessary to develop new transceivers for each country.

The system described here (using an RS232 interface to supply a transceiver unit) is flexible. That means that the customer can adapt the circuit for special requirements.

The transceiver was optimized for data rates up to 38.4 kbps. The data rate may be increased, but be aware that the performance level will drop and the effective

data rate is also limited by the time the computer needs to process the transmitted data (e.g. error recognition).

The transceiver circuit has been tested on the presented PCB layout as first samples in the laboratory and worked well. Due to the reduction of alignments, aspects of high-volume production were also taken into consideration.

Some measurement results have been shown to characterize the transceiver's performance. The total dynamic range is more than 100 dB and the receiver is tough against interference.

Additionally, measured parameters according to FTZ- and ETSI regulations have been presented. The transceiver fulfills both within the stipulated temperature range. Two different types of antenna can be used. For short range application, the loop antenna is sufficient, while the $\lambda/4$ antenna guarantees an operating range up to 100 m under optimum conditions.

The tolerances and temperature drift of the SAW resonators cause no problems due to the wide IF bandwidth. For an improvement of the system's performance, the IF bandwidth has to be smaller and, therefore, frequency tolerances must be reduced. The best solution is to use TEMIC's RF transmitter IC, which uses a crystal for its frequency reference. Not only is the frequency tolerance smaller when using this PLL-based transmitter, but the modulation capability is also improved.

Appendix

Comparison between Loop and $\lambda/4$ Antenna

In some cases, the use of a $\lambda/4$ antenna may not be possible, such as when the usable space is rare. In this case a loop antenna may be used, since its main advantage is its small size. In this chapter, the theoretical background of the loop antenna is described so as to understand the specific problems which occur when using it.

The loop antenna is coupled to the output of the SAW-matching circuit via C101 (figure 20). Together with the inductance of the loop, the capacitors C101/C102 are resonant at 433 MHz.

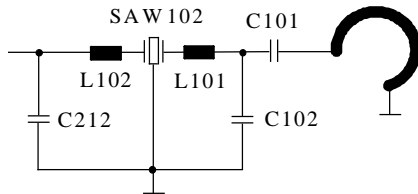


Figure 20. Loop antenna coupling

When different antenna types are compared, the isotropic antenna is used as reference antenna with an antenna gain of 0 dB.

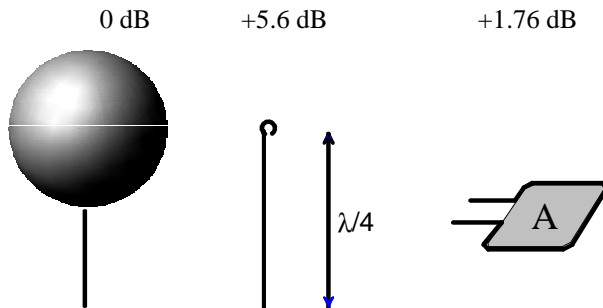


Figure 21. Antenna gain

It can be seen that the antenna gain of the $\lambda/4$ antenna is 3.4 dB higher than the gain of the loop antenna [6]. As 3.4 dB can not explain the reduction of the operating range, the antenna efficiency must also be taken into consideration. The efficiency, η , can be calculated with the radiation resistance R_R and the loss resistance R_L (1).

$$\eta = \frac{R_R}{R_R + R_L} \cdot 100\% \quad (1)$$

R_R of a $\lambda/4$ antenna is 36.6Ω . Therefore, R_L can be neglected. R_R of a loop antenna depends on the area, A,

and the operating wave length, λ [6]. For the realized loop antenna, R_R is calculated in (2).

$$R_R = 31171 \Omega \cdot \left(\frac{A}{\lambda^2}\right)^2 = 31171 \cdot \left(\frac{300 \text{ mm}^2}{0.7^2 \text{ m}^2}\right)^2 \Omega = 11.6 \text{ m}\Omega \quad (2)$$

The radiation resistance of a loop antenna is much smaller: therefore, the loss resistance can not be neglected. At 433 MHz, the skin effect determines the loss resistance. A sectional view of the PCBs copper line is shown in figure 22.

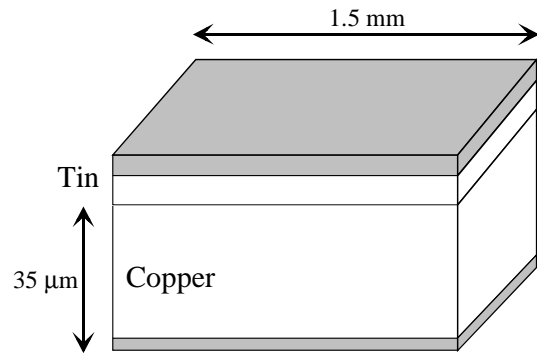


Figure 22. Sectional view copper line

As 1.5 mm is large compared to 35 μm , only the upper and lower side have been considered.

The PCB is tin-plated on the upper side. So the conducting surface height must be calculated twice [7]:

$$\sigma[\mu\text{m}] = 64 \cdot k_1 / \sqrt{f[\text{MHz}]} \quad (3)$$

$$\sigma_{\text{Copper}} (k_1 = 1.03) = 3.2 \mu\text{m} \quad (3a)$$

$$\sigma_{\text{Tin}} (k_1 = 2.7) = 8.3 \mu\text{m} \quad (3b)$$

Based on the conducting surface height, the loss resistance of the lower side (copper) and the top side (tin) can be calculated (4a/b).

$$R_{\text{Copper}} = \frac{\rho_{\text{Copper}} \cdot l}{\sigma_{\text{Copper}} \cdot w} = \quad (4a)$$

$$\frac{0.0175 \Omega \text{ mm}^2 / \text{m} \cdot 72 \text{ mm}}{3.2 \mu\text{m} \cdot 1.5 \text{ mm}} = 0.2625 \Omega$$

$$R_{\text{Tin}} = \frac{\rho_{\text{Tin}} \cdot l}{\sigma_{\text{Tin}} \cdot w} = \frac{0.11 \Omega \text{ mm}^2 / \text{m} \cdot 72 \text{ mm}}{8.3 \mu\text{m} \cdot 1.5 \text{ mm}} = 0.636 \Omega \quad (4b)$$

ANT015

where ρ = resistivity

l = loop length

w = copper line width

$$R_L = \frac{R_{\text{Copper}} \cdot R_{\text{Tin}}}{R_{\text{Copper}} + R_{\text{Tin}}} = \frac{0.263 \Omega \cdot 0.636 \Omega}{0.263 \Omega + 0.636 \Omega} = 0.186 \Omega \quad (5)$$

It can be seen that the loss resistance is sixteen times higher than the radiation resistance. This will cause a very low efficiency rate (6).

$$\eta = \frac{R_R}{R_R + R_L} \cdot 100\% = \frac{11.6 \text{ m}\Omega}{11.6 \text{ m}\Omega + 0.186 \Omega} = 5.9\% \quad (6)$$

An efficiency rate of 5.9% means a loss of 12.3 dB. Together with the antenna gain, the difference between a $\lambda/4$ and a loop antenna is 15.7 dB.

What can be done to improve the loop antenna? One approach is to increase the radiation resistance. This can only be done by increasing the area of the loop antenna. But in the same step the inductance of the loop will be

increased. There is a limit for the inductance, because a manageable capacitor must be found to fit the resonance condition at 433 MHz. For the loop used in the PCB layout shown in figure 8, a parallel capacitance of approximately 2 pF is needed. When a smaller capacitance is needed, it will be difficult to manage the ratio of C101/C102 for impedance matching.

What else can be done to improve the efficiency rate? Comparing R_{Copper} (4a) and R_{Tin} (4b), it seems that it might be better not to use tin on the top side of the PCB. The efficiency rate will rise to 8.2% (i.e. loss of 10.9 dB). But also consider that the copper can oxidize. In this case, the loss will be 13.7 dB. Another possibility might be to use silver (-10.7 dB), but the improvement is only 1.6 dB.

So it can be seen that whatever is done, there will always be a significant difference in efficiency rate between a $\lambda/4$ and a printed loop antenna.

The difference might become smaller if using a silver or gold plated wire, but in either case mechanical problems will appear.

Complete Circuit Diagram

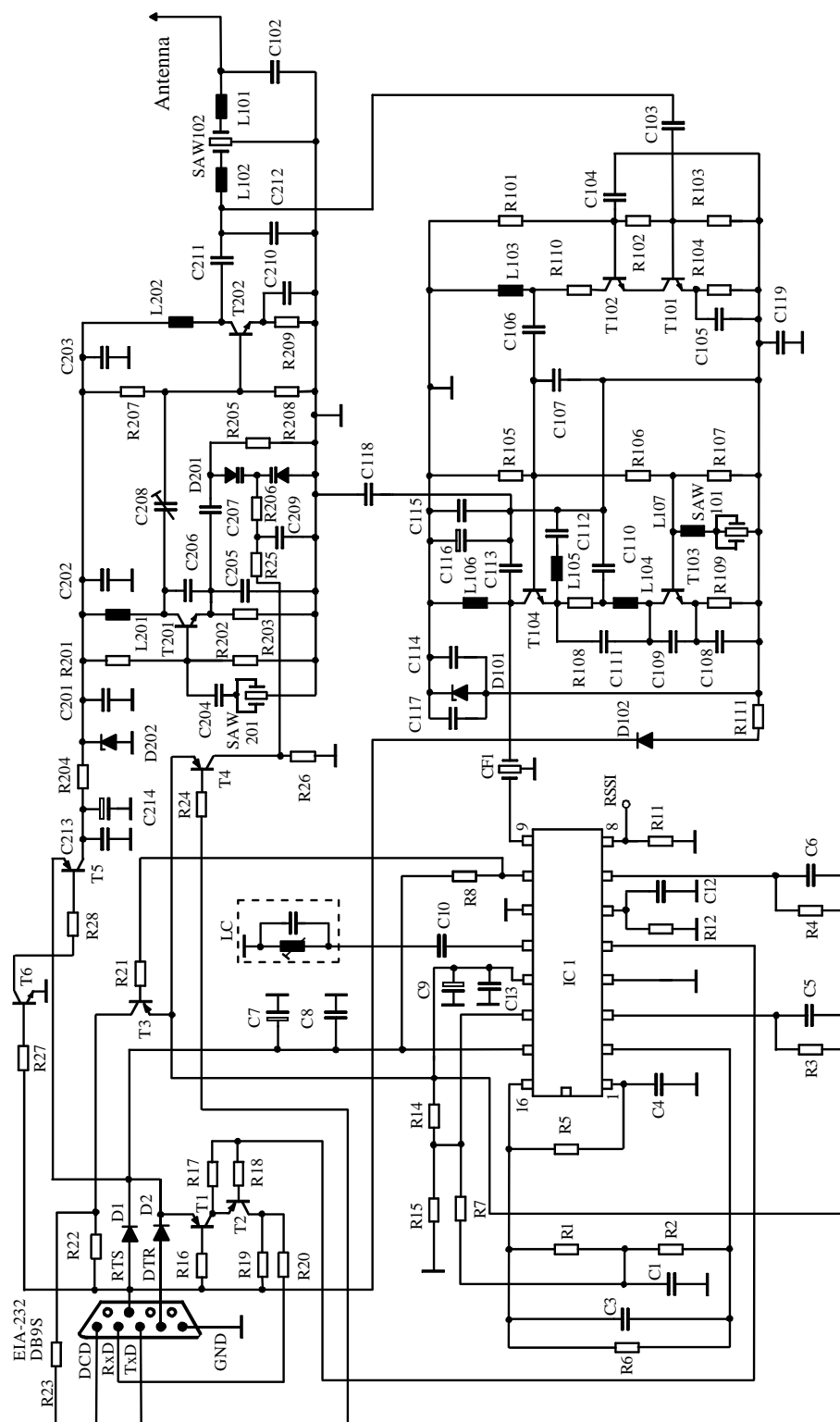


Figure 23.

ANT015

Circuit and Alignment Description

In the circuit diagram shown in figure 23, the oscillator within the transmitter and the front end is equipped with a two-port resonator. Please notice that the same type of resonator for the transmitter as well as for the front end's local oscillator should be used for optimum performance.

The PCB shown in figure 8 is prepared for both one-port and two-port resonators. As they have to be mounted in a different way, there are four holes. Two-port resonators must be fixed so that their cases are oriented in the same way the SAW filter is placed (look at figure 24 for the non-filled squares). One-port resonators must be turned with an angle of 90° in a clockwise direction when looking at the PCB from the SMD side (in figure 24 look for the filled squares). Besides the SAW resonators and SAW filter, only the tantalum capacitors have to be placed on the ground side of the PCB. The ceramic IF filter may be placed on the upper or lower side. Additional filter capacitors can be placed close to the RS232 lines if interference from the

computer occurs. For better suppression of interference use ferrite pearls on the RS232 line wires at the transceiver side.

For the placement of the diodes, the cathode rings are indicated in figure 24.

If some extra TX shielding is required, the board has been prepared to mount sheet metal at the transmitter section.

C101 is only needed if the loop antenna is used.

Testing and tuning can be done easily. First, the transmitter must be frequency-locked by tuning C 208 until deviation and RF output power is properly set. Next, the LC tank circuit of the receiver needs to be adjusted until the data can be demodulated.

For testing and tuning, standard measurement equipment can be used. Alternatively, it is possible to use only a computer and an oscilloscope and test the transceiver in an "RF loop back mode". In this case, the front end needs to be powered externally during transmission (remove D102). Then the transceiver should receive its own transmitted data without problems.

Component Placement

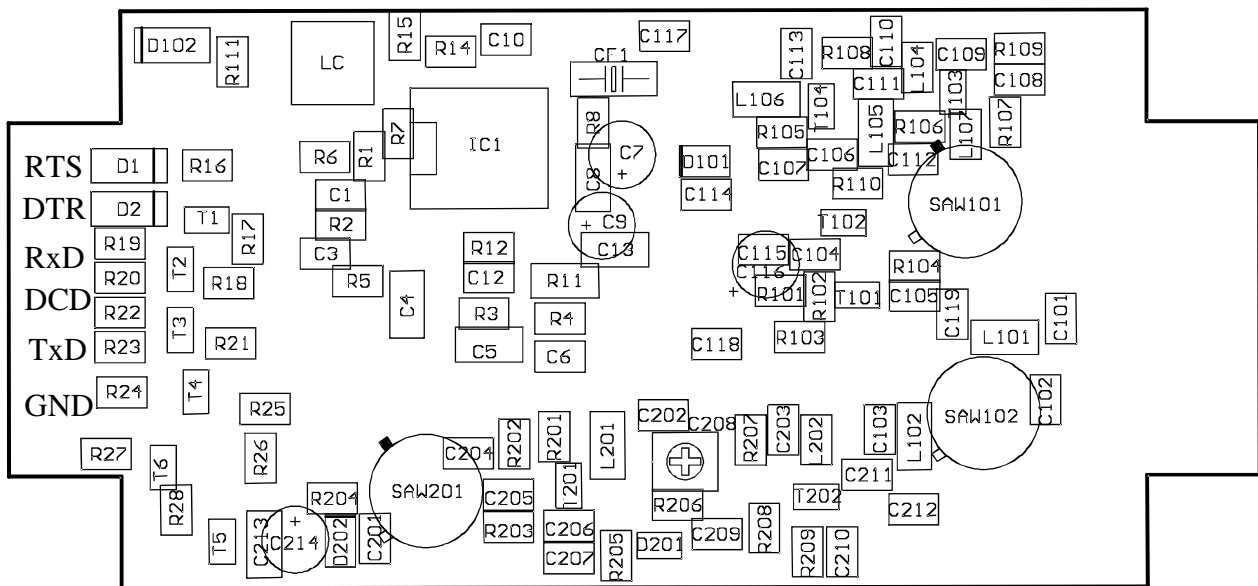


Figure 24. Component placement of transceiver, view: SMD component side

Component List

Circuit arrangement according to figure 23, placement as shown in figure 24. All chip components are of size 0805 (100 nF capacitor are of size 1206). Resistors have a manufacturing tolerance of 5%. All capacitors, if not otherwise specified, have a tolerance of 20%.

R1	5.6 k Ω	C3	150 pF
R2	33 k Ω	C4	4.7 nF
R3	100 k Ω	C5	100 nF
R4	220 k Ω	C6	10 nF
R5	22 k Ω	C7	10 μ F, 16 V
R6	1 M Ω	C8	100nF
R7	0 Ω	C9	10 μ F, 6 V
R8	100 k Ω	C10	47 pF
R11	18 k Ω	C12	10 nF
R12	220 k Ω	C13	100 nF
R14	22 k Ω	(C101	2.7 pF, 5%)
R15	22 k Ω	C102	8.2 pF, 5%
R16	100 k Ω	C103	100 pF
R17	100 k Ω	C104	1 nF
R18	100 k Ω	C105	100 pF
R19	10 k Ω	C106	5.6 pF, 5%
R20	1 k Ω	C107	27 pF, 5%
R21	100 k Ω	C108	6.8 pF, 5%
R22	10 k Ω	C109	3.3 pF, 5%
R23	1 k Ω	C110	100 pF
R24	47 k Ω	C111	3.9 pF, 5%
R25	15 k Ω	C112	470 pF
R26	10 k Ω	C113	470 pF
R27	47 k Ω	C114	100 pF
R28	47 k Ω	C115	1 nF
R101	22 k Ω	C116	1 μ F, 10 V
R102	33 k Ω	C117	100 pF
R103	33 k Ω	C118	100 pF
R104	1 k Ω	C119	100 pF
R105	10 k Ω	C201	10 nF
R106	22 k Ω	C202	100 pF
R107	47 k Ω	C203	100 pF
R108	220 Ω	C204	39 pF
R109	1 k Ω	C205	8.2 pF, 5%
R110	100 Ω	C206	3.3 pF, 5%
R111	470 Ω	C207	15 pF, 5%
R201	15 k Ω	C208	1.4 pF to 3 pF, e.g., TZBX4Z030BA110, Murata
R202	4.7 k Ω	C209	100 pF
R203	220 Ω	C210	10 nF
R204	100 Ω	C211	1 pF, 5%
R205	1 k Ω	C212	2.7 pF, 5%
R206	1 k Ω	C213	100 nF
R207	22 k Ω	C214	1 μ F, 16 V
R208	4.7 k Ω	L101	B82412-A3620-J, S+M
R209	220 Ω	L102	B82412-A3620-J, S+M
C1	820 pF	L103	PCB coil
		L104	LL2012-F22NK, TOKO
		L105	SMD-fixed coil 470 nH
		L106	SMD-fixed coil 470 nH

L107	LL2012-F39NK, TOKO	T201+T202	S852T, TEMIC
L201	LL2012-F22NK, TOKO	IC1	U4311B-CFL, TEMIC
L202	LL2012-F39NK, TOKO	CF1	SK107 M0-A0-10X, TOKO or SFE10.7MA20-A, Murata
D1	LS4148, TEMIC		614BG-0073GW, TOKO
D2	LS4148, TEMIC	LC	R2531 (423.22 MHz), S+M or RO2065, RFM
D101	DTZ 5.1A, Rohm	SAW101	B3530 (433.92 MHz), S+M or RF1172, RFM
D102	LS4148, TEMIC		R2632 (433.92 MHz), S+M or RO2023, RFM
D201	BB804, TEMIC	SAW102	
D202	DTZ 5.1A, Rohm		
T1-T5	BC857	SAW201	
T6	BC847		
T101-T104	S852T, TEMIC		

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