UHF Wireless Data Transceiver
# Table of Contents

**Introduction** ..................................................................................................................................................................1

**Basics** ........................................................................................................................................................................2
  Legal Regulations .......................................................................................................................................................2
  Germany ..............................................................................................................................................................2
  Europe .................................................................................................................................................................2
  RS232 Interface ........................................................................................................................................................2

**Circuit Description** ................................................................................................................................................5
  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 λ/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.
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 ±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°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 µW 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°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 Xoff/Xon protocol. The RTS (Request to Send) and DTR (Data Terminal Ready) 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 V and -15 V and a logic ‘1’ of between +5 V and +15 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 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.
Circuit Description

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>
<thead>
<tr>
<th>TRX Mode</th>
<th>RTS</th>
<th>DTR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmit</td>
<td>+12 V</td>
<td>+12 V</td>
</tr>
<tr>
<td>Receive</td>
<td>-12 V</td>
<td>+12 V</td>
</tr>
</tbody>
</table>

Table 1. Transceiver modes
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 λ/4 antenna.

![Figure 4. Transmitter circuit diagram](image-url)
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:

\[ t_d = C5 \cdot 0.75 \, \text{k}\Omega = 100 \, \text{nF} \cdot 0.75 \, \text{k}\Omega = 75 \, \mu\text{s} \]
\[ t_h = 1.5 \cdot R3 \cdot C5 = 1.5 \cdot 100 \, \text{k}\Omega \cdot 100 \, \text{nF} = 15 \, \text{ms} \]

The delay time of 75 \mu s 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]:

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

For a data rate of 38.4 kbps (f_{\text{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.

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.
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 λ/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](image)

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 2⁵⁻¹ 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](image)

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](image)

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
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.
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

<table>
<thead>
<tr>
<th>Frequency</th>
<th>FTZ</th>
<th>ETSI</th>
</tr>
</thead>
<tbody>
<tr>
<td>867.8 MHz</td>
<td>-60 dBm</td>
<td>-36 dBm</td>
</tr>
<tr>
<td>1301.8 MHz</td>
<td>-45 dBm</td>
<td>-30 dBm</td>
</tr>
<tr>
<td>1735.7 MHz</td>
<td>-45 dBm</td>
<td>-30 dBm</td>
</tr>
</tbody>
</table>

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.

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.

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.

The variation across the temperature range is less than 5 dB.
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 it's 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 λ/4 Antenna

In some cases, the use of a λ/4 antenna may not be possible, such as when the usable space is rare. In this case a loop antenna may be used, since it's 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](image)

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](image)

It can be seen that the antenna gain of the λ/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, \( \eta \), can be calculated with the radiation resistance \( R_R \) and the loss resistance \( R_L \) (1).

\[
\eta = \frac{R_R}{R_R + R_L} \cdot 100\%
\]

(1)

\( R_R \) of a λ/4 antenna is 36.6 Ω. Therefore, \( R_L \) can be neglected. \( R_R \) of a loop antenna depends on the area, \( A \), and the operating wave length, \( \lambda \) [6]. For the realized loop antenna, \( R_R \) is calculated in (2).

\[
R_R = 31171 \Omega \left( \frac{A}{\lambda} \right)^2 = 31171 \left( \frac{0.07 \text{ m}^2}{300 \text{ mm}^2} \right)^2 \Omega = 11.6 \text{ m}\Omega
\]

(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](image)

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]:

\[
\sigma[\mu m] = 64 \cdot k_1 / \sqrt{f[MHz]} \]

(3)

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

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

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

\[
R_{\text{Copper}} = \frac{\rho_{\text{Copper}} \cdot 1}{\sigma_{\text{Copper}} \cdot W} = \frac{0.0175 \frac{\Omega \text{ mm}^2}{m \cdot 72 \text{ mm}}}{3.2 \mu m \cdot 1.5 \text{ mm}} = 0.2625 \Omega \]

(4a)

\[
R_{\text{Tin}} = \frac{\rho_{\text{Tin}} \cdot 1}{\sigma_{\text{Tin}} \cdot W} = \frac{0.11 \frac{\Omega \text{ mm}^2}{m \cdot 72 \text{ mm}}}{8.3 \mu m \cdot 1.5 \text{ mm}} = 0.636 \Omega \]

(4b)
where \( \rho \) = 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).

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

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 \( R_{\text{Copper}} \) (4a) and \( R_{\text{Tin}} \) (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.
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 tantal 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 kΩ
R2  33 kΩ
R3  100 kΩ
R4  220 kΩ
R5  22 kΩ
R6  1 MΩ
R7  0 Ω
R8  100 kΩ
R11 18 kΩ
R12 220 kΩ
R14 22 kΩ
R15 22 kΩ
R16 100 kΩ
R17 100 kΩ
R18 100 kΩ
R19 10 kΩ
R20 1 kΩ
R21 100 kΩ
R22 10 kΩ
R23 1 kΩ
R24 47 kΩ
R25 15 kΩ
R26 10 kΩ
R27 47 kΩ
R28 47 kΩ
R101 22 kΩ
R102 33 kΩ
R103 33 kΩ
R104 1 kΩ
R105 10 kΩ
R106 22 kΩ
R107 47 kΩ
R108 220 Ω
R109 1 kΩ
R110 100 Ω
R111 470 Ω
R201 15 kΩ
R202 4.7 kΩ
R203 220 Ω
R204 100 Ω
R205 1 kΩ
R206 1 kΩ
R207 22 kΩ
R208 4.7 kΩ
R209 220 Ω
C1  820 pF
C3  150 pF
C4  4.7 nF
C5  100 nF
C6  10 nF
C7  10 μF, 16 V
C8  100 nF
C9  10 μF, 6 V
C10 47 pF
C11 100 nF
C12 10 nF
C13 100 nF
C101 2.7 pF, 5%
C102 8.2 pF, 5%
C103 100 pF
C104 1 nF
C105 100 pF
C106 5.6 pF, 5%
C107 27 pF, 5%
C108 6.8 pF, 5%
C109 3.3 pF, 5%
C110 100 pF
C111 3.9 pF, 5%
C112 470 pF
C113 470 pF
C114 100 pF
C115 1 nF
C116 1 μF, 10 V
C117 100 pF
C118 100 pF
C119 100 pF
C201 10 nF
C202 100 pF
C203 100 pF
C204 39 pF
C205 8.2 pF, 5%
C206 3.3 pF, 5%
C207 15 pF, 5%
C208 1.4 pF to 3 pF, e.g., TZBX4Z030BA110, Murata
C209 100 pF
C210 10 nF
C211 1 pF, 5%
C212 2.7 pF, 5%
C213 100 nF
C214 1 μF, 16 V
L101 B82412-A3620-J, S+M
L102 B82412-A3620-J, S+M
L103 PCB coil
L104 LL2012-F22NK, TOKO
L105 SMD-fixed coil 470 nH
L106 SMD-fixed coil 470 nH

Issue: 04.95
### References

1. Bopp, Strohal

   **Components for Radio Frequency Based Remote Control Systems**
   TEMIC TELEFUNKEN microelectronic GmbH, ANT012 (issue 12.94)

2. Strohal

   **UHF Remote Control Systems:**
   **Receiver Front End and Complete Receiver Design Hints**
   TEMIC TELEFUNKEN microelectronic GmbH, ANT013 (issue 07.94)

3. Deutsche Bundespost ZZF, Referat S21

   **17TR2100: "Technische Richtline für Fernwirk-Funkanlagen kleiner Leistung des nichtöffentlichen mobilen Landfunks (nömL)"**, Februar 1989

4. ETSI TC-RES

   **ETS 300 220: Short range devices, Technical characteristics and test methods for radio equipment to be used in the 25 MHz to 1000 MHz frequency range**

5. Mäusl

   **Digitale Modulationsverfahren**
   Hüthig-Verlag 1991, 3. Auflage

6. Rothammel

   **Antennenbuch**
   Franckh-Kosmos Verlag 1991, 10. Auflage

7. Meinke, Gundlach

   **Taschenbuch der Hochfrequenztechnik**
   Springer-Verlag Berlin 1992, 5. Auflage, Band 1, B13

8. Niestroj, Zapsky, Lang

   **Kostengünstige und zuverlässige Fernsteuerungen durch OFW-Resonatoren**
   Siemens Components 4/90, pp. 142-145