

Read / Write Base Station IC

Description

IC for IDIC®*) read-write base stations

The U2270B is a bipolar integrated circuit for read-write base stations in contactless identification and immobilizer systems.

The IC incorporates the energy transfer circuit to supply the transponder. It consists of an on-chip power supply, an oscillator, and a coil driver optimized for automotive-

specific distances. It also includes all signal-processing circuits which are necessary to form the small input signal into a microcontroller-compatible signal.

The U2270B is well suitable to perform read operations with e5530-GT and TK5530-PP transponders and also performs read-write operations with TK5550-PP and TK5560-PP transponders.

Features

- Carrier frequency f_{osc} 100 KHz – 150 KHz
- Typical data rate up to 5 Kbaud at 125 KHz
- Suitable for Manchester and Bi-phase modulation
- Power supply from the car battery or from 5-V regulated voltage
- Optimized for car immobilizer applications
- Tuning capability
- Microcontroller-compatible interface
- Low power consumption in standby mode
- Power supply output for microcontroller

Applications

- Car immobilizers
- Animal identification
- Access control
- Process control
- Further industrial applications

Case: SO16 U2270B-FP

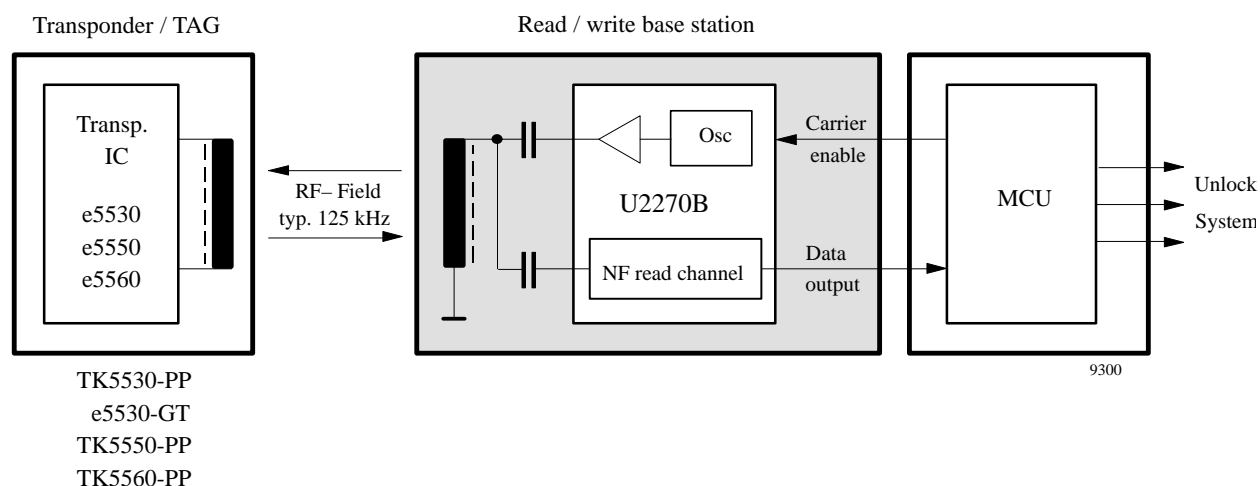


Figure 1.

*) IDIC® stands for **ID**entification **I**ntegrated **C**ircuit and is a trademark of TEMIC.

Pin Description

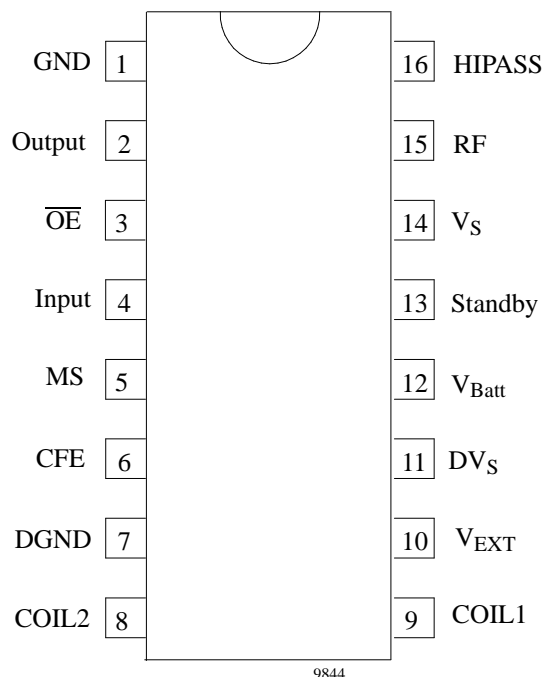


Figure 2. Pinning

Pin	Symbol	Function
1	GND	Ground
2	Output	Data output
3	\overline{OE}	Data output enable
4	Input	Data input
5	MS	Mode select coil 1: Common mode / Differential mode
6	CFE	Carrier frequency enable
7	DGND	Driver ground
8	COIL 2	Coil driver 2
9	COIL 1	Coil driver 1
10	V_{EXT}	External power supply
11	DV_S	Driver supply voltage
12	V_{Batt}	Battery voltage
13	Standby	Standby input
14	V_S	Internal power supply (5 V)
15	RF	Frequency adjustment
16	HIPASS	DC decoupling

Block Diagram

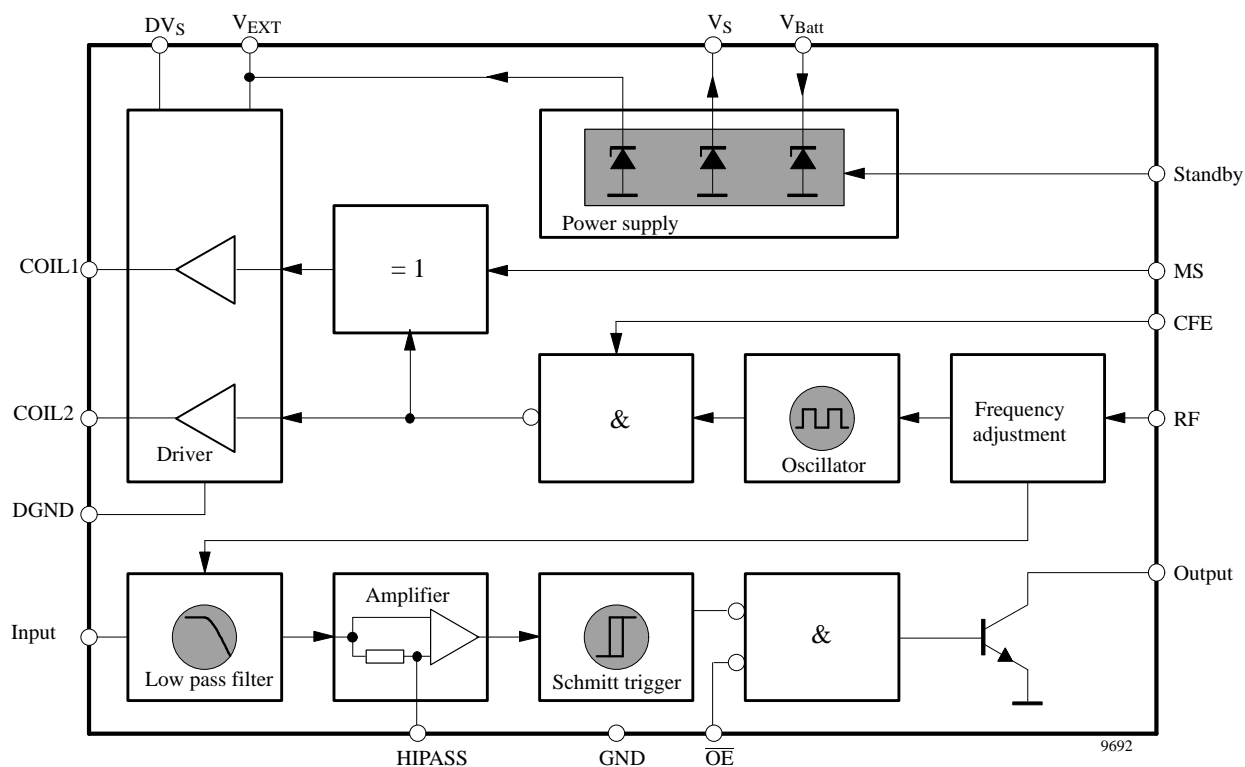


Figure 3.

Functional Description

Power Supply (PS)

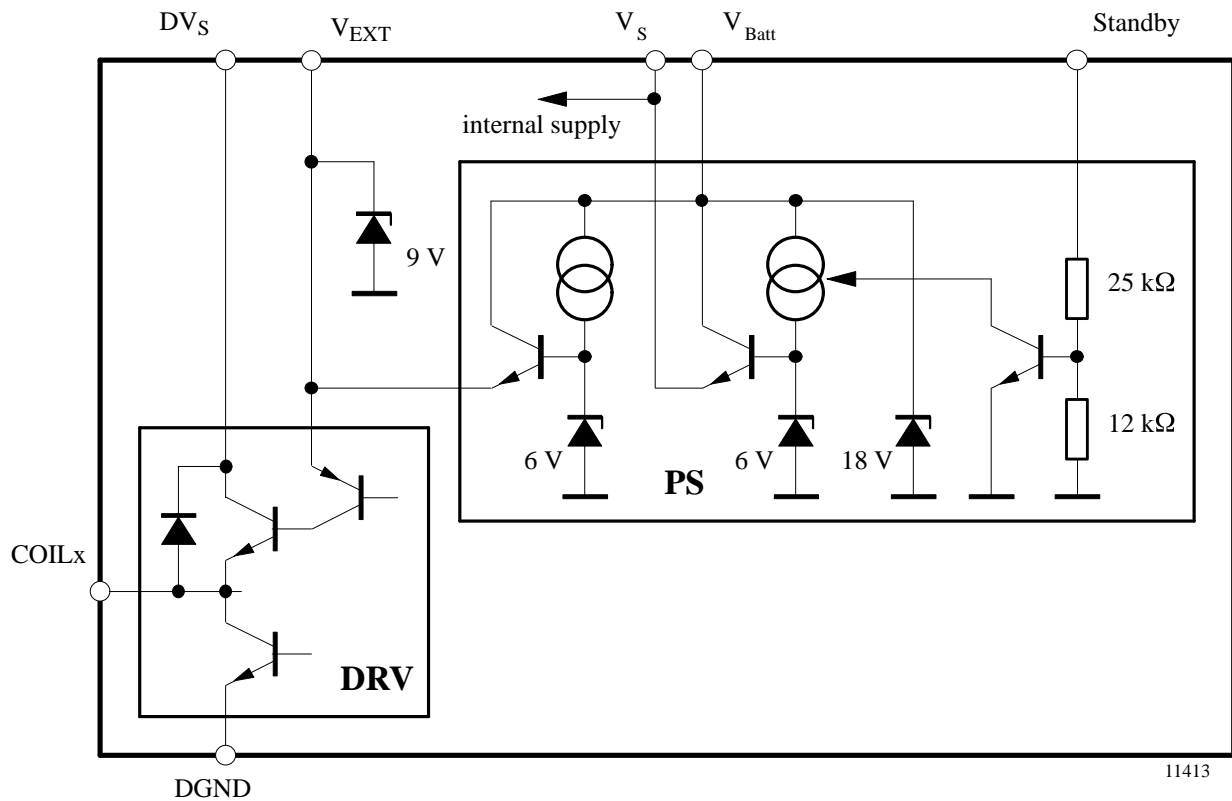


Figure 4. Equivalent circuit of power supply and antenna driver

The U2270 can be operated with one external supply voltage or with two externally-stabilized supply voltages for an extended driver output voltage or from the 12-V battery voltage of a vehicle. The 12-V supply capability is achieved via the on-chip power supply (see figure 4). The power supply provides two different output voltages, V_S and V_{EXT} .

V_S is the internal power supply voltage except for the driver circuit. Pin V_S is used to connect a block capacitor. V_S can be switched off by the pin **STANDBY**. In standby mode, the chip's power consumption is very low. V_{EXT} is the supply voltage of the antenna's pre-driver. This voltage can also be used to operate external circuits, i.e., a microcontroller. In conjunction with an external NPN transistor, it also establishes the supply voltage of the antenna coil driver, DVS .

The following section explains the 3 different operation modes to power the U2270B.

1. One-rail operation

All internal circuits are operated from one 5-V power rail. (see figure 5). In this case, V_S , V_{EXT} and DV_S serve as inputs. V_{Batt} is not used but should also be connected to that supply rail.

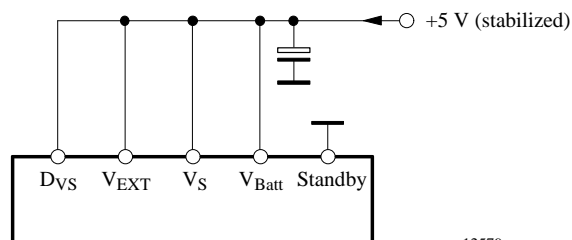


Figure 5.

2. Two-rail operation

In that application, the driver voltage, DV_S , and the pre-driver supply, V_{EXT} , are operated at a higher voltage than the rest of the circuitry to obtain a higher driver-output swing and thus a higher magnetic field, refer to figure 6. V_S is connected to a 5-V supply, whereas the driver voltages can be as high as 8 V. This operation mode is intended to be used in situations where an extended communication distance is required.

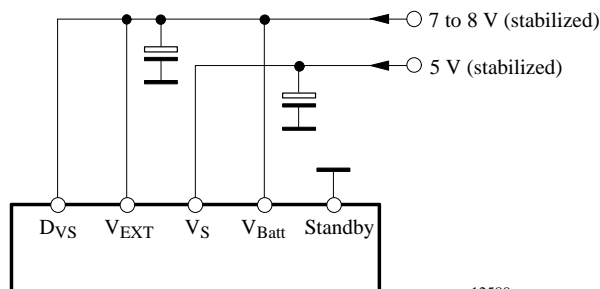


Figure 6.

3. Battery-voltage operation

Using this operation mode, V_S and V_{EXT} are generated by the internal power supply. (refer to figure 7). For this mode, an external voltage regulator is not needed. The IC can be switched off via the pin Standby. V_{EXT} supplies the base of an external NPN transistor and external circuits, i.e., a microcontroller (even in Standby mode).

Pin V_{EXT} and V_{Batt} are overvoltage protected via internal Zener diodes (refer figure 4). The maximum current into that pins is determined by the maximum power dissipation and the maximum junction temperature of the IC. For a short-time current pulse, a higher power dissipation can be assumed (refer to application note ANT019).

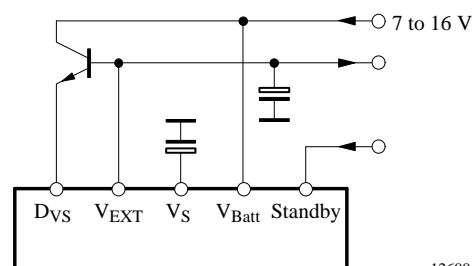


Figure 7.

Table 1. The following table summarizes the characteristics of the various operation modes.

Operation Mode	External Components Required	Supply Voltage Range	Driver Output Voltage Swing	Standby Mode Available
1. One-rail operation	1 Voltage regulator 1 Capacitor	5 V \pm 10%	\approx 4 V	No
2. Two-rail operation	2 Voltage regulators 2 Capacitors	5 V \pm 10% 7 V to 8 V	6 V to 7 V	No
3. Battery voltage operation	1 Transistor 2 Capacitors Optional for load-dump protection: 1 Resistor 1 Capacitor	6 V to 16 V	\approx 4 V	Yes

Oscillator (Osc)

The frequency of the on-chip oscillator is controlled by a current fed into the R_F input. An integrated compensation circuit ensures a widely temperature and supply voltage independent frequency which is selected by a fixed resistor between R_F (pin 15) and V_S (pin 14). For 125 kHz a resistor value of 110 k Ω is defined. For other frequencies, use the following formula:

$$R_f = \frac{14375}{f_0 [\text{kHz}]} - 5 \text{ k}\Omega$$

This input can be used to adjust the frequency close to the resonance of the antenna. For more details refer to the applications and the application note ANT019.

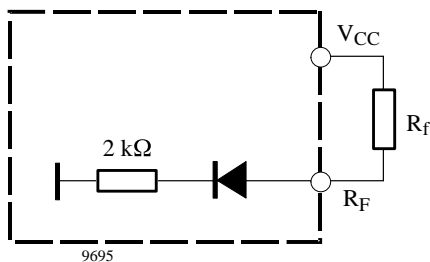


Figure 8. Equivalent circuit of Pin R_F

Filter (LPF)

The fully-integrated low-pass filter (4th order butterworth) removes the remaining carrier signal and high-frequency disturbances after demodulation. The upper cut-off frequency of the LPF depends on the selected oscillator frequency. The typ. value is $f_{osc}/18$. That means that data rates up to $f_{osc}/25$ are possible if Bi-phase or Manchester encoding is used.

A high-pass characteristic results from the capacitive coupling at the input Pin 4, as shown in figure 9. The input voltage swing is limited to 2 V_{pp}. For frequency response calculation, the impedances of the signal source and LPF input (typ. 220 kΩ) have to be considered. The recommended values of the input capacitor for selected data rates are shown in the chapter “Applications”.

Note: After switching on the carrier, the dc voltage of the coupling capacitor changes rapidly. When the antenna voltage is stable, the LPF needs approximately 2 ms to recover full sensitivity.

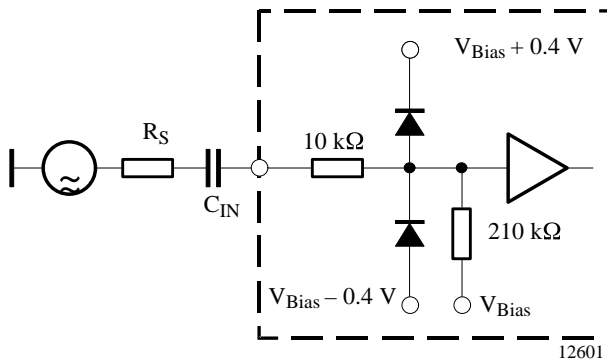


Figure 9. Equivalent circuit of Pin Input

Amplifier (AMP)

The differential amplifier has a fixed gain, typically 30. The HIPASS pin is used for dc decoupling. The lower cut-off frequency of the decoupling circuit can be calculated as follows:

$$f_{\text{cut}} = \frac{1}{2 \times \pi \times C_{\text{HP}} \times R_i}$$

The value of the internal resistor R_i can be assumed to be $2.5 \text{ k}\Omega$.

Recommended values of C_{HP} for selected data rates can be found in the chapter “Applications”.

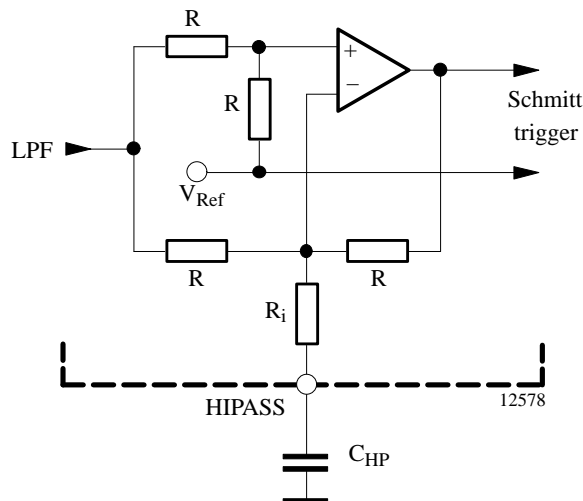


Figure 10. Equivalent circuit of pin HIPASS

Schmitt Trigger

The signal is processed by a Schmitt trigger to suppress possible noise and to make the signal μC compatible. The hysteresis level is 100 mV symmetrically to the dc operation point. The open-collector output is enabled by a low level at $\overline{\text{OE}}$ (Pin 3).

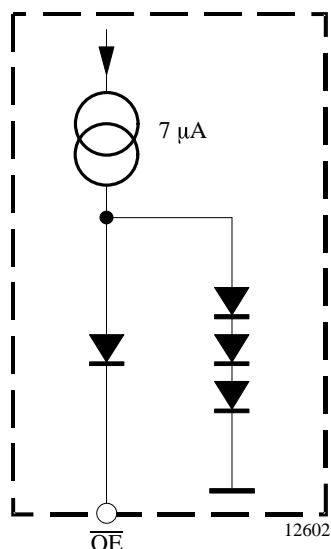


Figure 11. Equivalent circuit of Pin $\overline{\text{OE}}$

Driver (DRV)

The driver supplies the antenna coil with the appropriate energy. The circuit consists of two independent output stages. These output stages can be operated in two different modes. In common mode, the outputs of the stages are in phase. In this mode, the outputs can be interconnected, to achieve a high current output capability. Using the differential mode, the output voltages are in anti-phase. Thus, the antenna coil is driven with a higher voltage. For a specific magnetic field, the antenna coil impedance is higher for the differential mode. As a higher coil impedance results in a better system sensitivity, the differential mode should be preferred.

The CFE input is intended to be used for writing data into a read/write or a crypto transponder. This is achieved by interrupting the RF field with short gaps. The TEMIC write method is described in the data sheets of TK5550 and TK5560. The various functions are controlled by the inputs MS and CFE, refer to function table. The equivalent circuit of the driver is shown in figure 4.

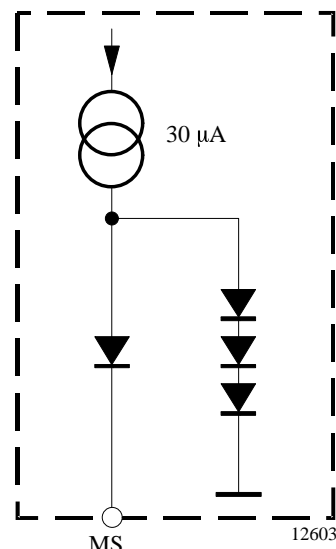


Figure 12. Equivalent circuit of Pin MS

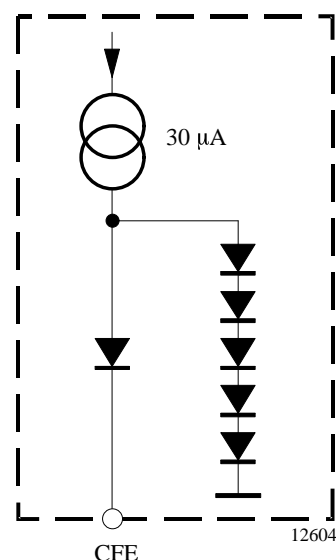






Figure 13. Equivalent circuit of Pin CFE

Function Table

CFE	MS	COIL1	COIL2
Low	Low	High	High
Low	High	Low	High
High	Low		
High	High		

OE	Output
Low	Enabled
High	Disabled

Standby	U2270B
Low	Standby mode
High	Active

Applications

To achieve the suitable application, consider the power supply environment and the magnetic coupling situation.

The selection of the appropriate power supply operation mode depends on the supply environment. If an unregulated supply voltage in the range of $V = 7\text{ V}$ to 16 V is available, the internal power supply of the U2270B can be used. In this case, the standby mode can be used and an external low-current μC can be supplied.

If a 5-V supply rail is available, it can be used to power the U2270B. In this case please check that the voltage is noise-free. An external power transistor is not necessary.

The application depends also on the magnetic coupling situation. The coupling factor mainly depends on the transmission distance and the antenna coils. The following table lists the appropriate application for a given coupling factor. The magnetic coupling factor can be determined using the TEMIC test transponder coil.

Magnetic Coupling Factor	Appropriate Application
$k > 3\%$	Free-running oscillator
$k > 1\%$	Diode feedback
$k > 0.5\%$	Diode feedback plus frequency altering
$k > 0.3\%$	Diode feedback plus fine frequency tuning

The maximum transmission distance is also influenced by the accuracy of the antenna's resonance. Therefore, the recommendations given above are proposals only. A good compromise for the resonance accuracy of the antenna is a value in the range of $f_{\text{res}} = 125\text{ kHz} \pm 3\%$. Further details concerning the adequate application and the antenna design is provided in the TEMIC application note ANT019 and in the TEMIC article "Antenna Design Hints".

The application of the U2270B includes the two capacitors C_{IN} and C_{HP} whose values are linearly dependent on the transponder's data rate. The following table gives the appropriate values for the most common data rates. The values are valid for Manchester and Bi-phase code.

Data Rate $f = 125\text{ kHz}$	Input Capacitor (C_{IN})	Decoupling Capacitor (C_{HP})
$f/32 = 3.9\text{ kbit/s}$	680 pF	100 nF
$f/64 = 1.95\text{ kbit/s}$	1.2 nF	220 nF

The following applications are typical examples. The values of C_{IN} and C_{HP} correspond to the transponder's data rate only. The arrangement to fit the magnetic coupling situation is also independent from other design issues except of one constellation. This constellation, consisting of diode feedback plus fine frequency tuning together with the two-rail power supply should be used if the transmission distance is in the range of $d \approx 10\text{ cm}$.

Application 1

Application using few external components. This application is for intense magnetic coupling only.

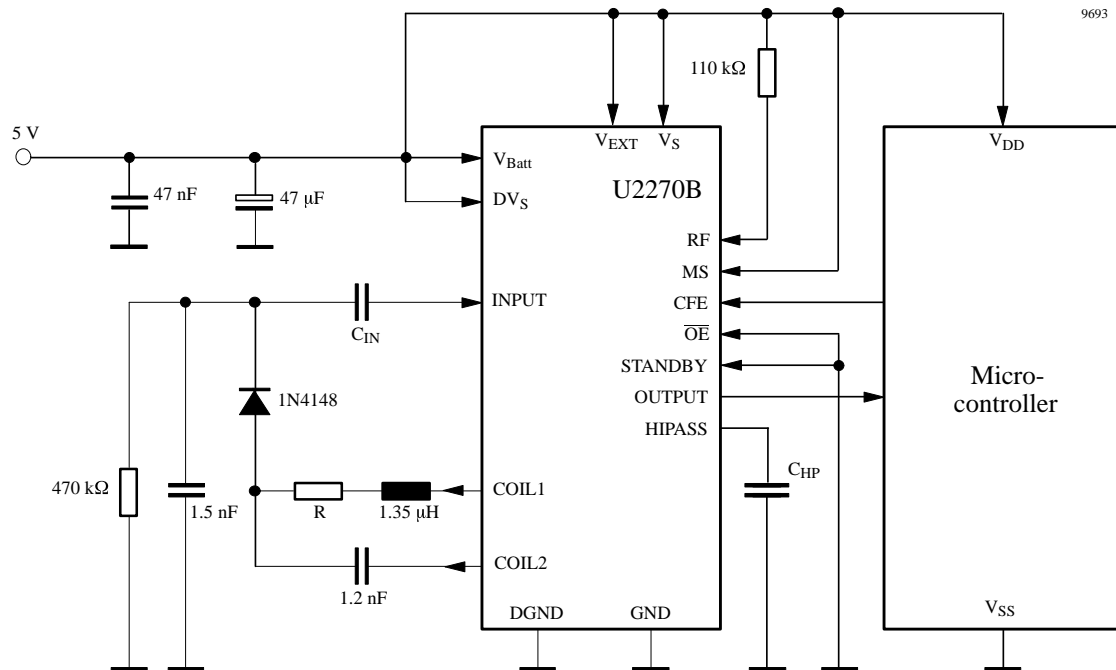


Figure 14.

Application 2

Basic application using diode feedback. This application permits higher communication distances than application 1.

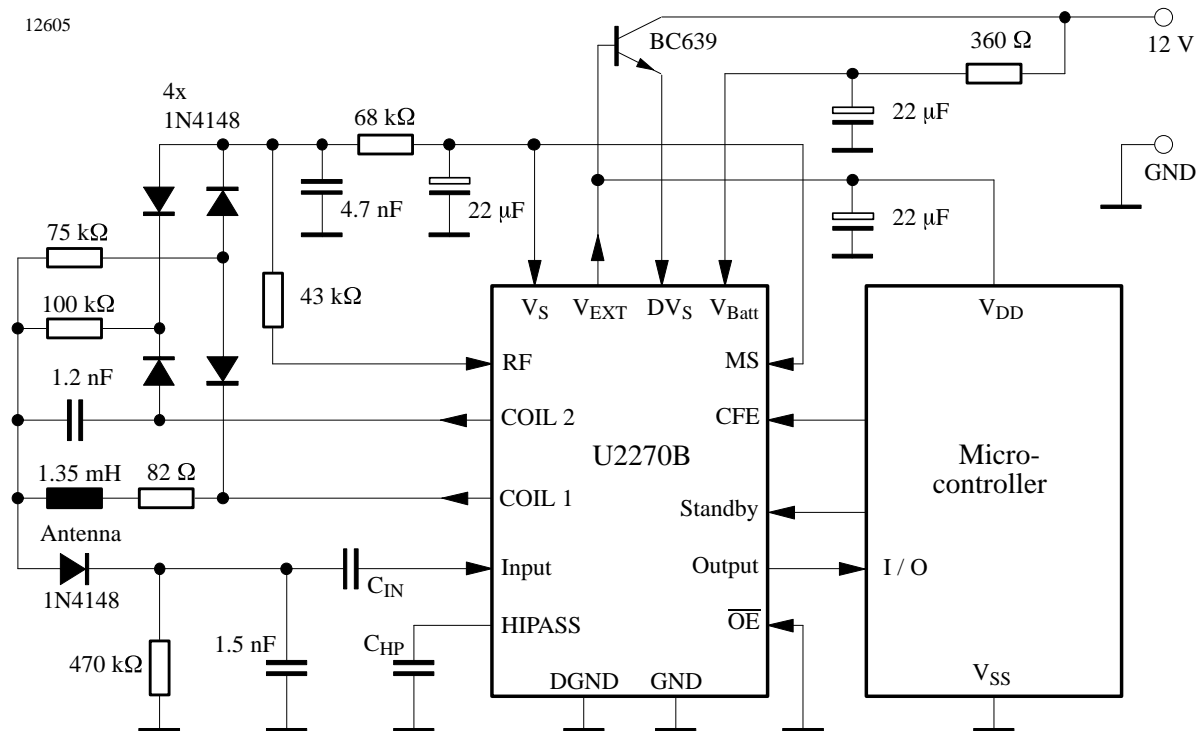
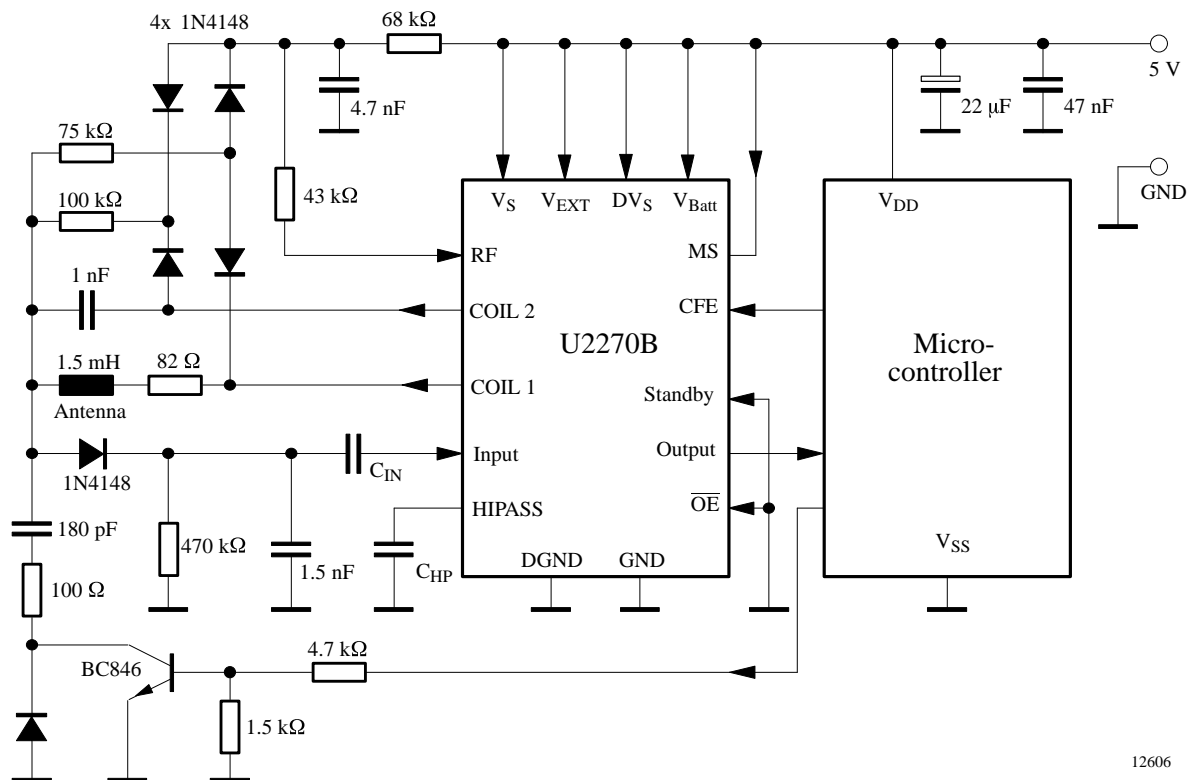


Figure 15.

Application 3

This application is comparable to application 2 but alters the operating frequency. This permits higher antenna resonance tolerances and/or higher communication

distances. This application is preferred if the detecting μC is close to the U2270B as an additional μC signal controls the adequate operating frequency.



12606

Figure 16.

Absolute Maximum Ratings

All voltages are referred to GND (Pins 1 and 7).

Parameters/Conditions Pin	Symbol	Min.	Typ.	Max.	Unit
Operating voltage Pin 12	V_{Batt}	V_S		16	V
Operating voltage Pins 8, 9, 10, 11 and 14	$V_S, V_{EXT}, DV_S, \text{Coil 1, Coil 2}$	-0.3		8	V
Range of input and output voltages Pins 3, 4, 5, 6, 15 and 16 Pins 2 and 13		-0.3 -0.3		$V_S+0.3$ V_{Batt}	V
Output current Pin 10	I_{EXT}			10	mA
Output current Pin 2	I_{OUT}			10	mA
Driver output current Pins 8 and 9	I_{Coil}			200	mA
Power dissipation SO16	P_{tot}			380	mW
Junction temperature	T_j			150	°C
Storage temperature	T_{stg}	-55		125	°C
Ambient temperature	T_{amb}	-40		105	°C

Thermal Resistance

Parameters/Conditions Pin	Symbol	Min.	Typ.	Max.	Unit
Thermal resistance SO16	R_{thJA}			120	K/W

Operating Range

All voltages are referred to GND (Pins 1 and 7)

Parameters/Conditions Pin	Symbol	Min.	Typ.	Max.	Unit
Operating voltage Pin 12	V_{Batt}	7	12	16	V
Operating voltage Pin 14	V_S	4.5	5.4	6.3	V
Operating voltage Pin 10 Pin 11	V_{EXT} DV_S	4.5		8	
Carrier frequency	f_{osc}	100	125	150	kHz

Electrical Characteristics

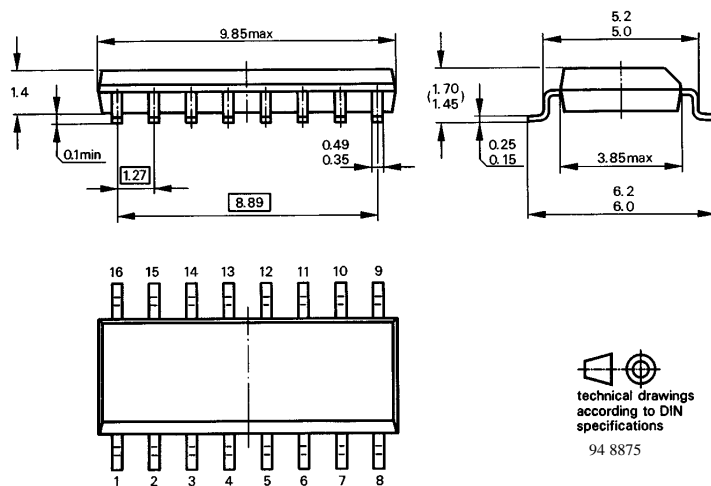
Test conditions (unless otherwise specified): $V_{Batt} = 12\text{ V}$, $T_{amb} = -40\text{ to }105^\circ\text{C}$

Parameters	Test Conditions / Pins	Symbol	Min.	Typ.	Max.	Unit
Data output – collector emitter saturation voltage	Pin 2 $I_{out} = 5\text{ mA}$	V_{CEsat}			400	mV
Data output enable – low level input voltage – high level input voltage	Pin 3	V_{il} V_{ih}	2.4		0.5	V V
Data input – clamping level low – clamping level high – input resistance – input sensitivity	Pin 4 $f = 3\text{ kHz (squarewave)}$ $\text{gain capacitor} = 100\text{ nF}$	V_{il} V_{ih} R_{in}	10	2 3.8 220		V V k Ω mV pp
Driver polarity mode – low level input voltage – high level input voltage	Pin 5	V_{il} V_{ih}	2.4		0.2	V V
Carrier frequency enable – low level input voltage – high level input voltage	Pin 6	V_{il} V_{ih}	3.0		0.8	V V
Operating current	Pin10, 11, 12 and 14 5 V application without load connected to the coil driver	I_S		4.5	9	mA
Standby current	Pin 12 12 V application	I_{St}		30	70	μA
V_S – Supply voltage – Supply voltage drift – Output current	Pin 14	V_S dV_S/dT I_S	4.6 1.8	5.4 4.2 3.5	6.3	V mV/K mA
Driver output voltage – One rail operation – Battery voltage operation	$I_L = \pm 100\text{ mA}$ $V_S, V_{EXT}, V_{Batt}, DV_S = 5\text{ V}$ $V_{Batt} = 12\text{ V}$ Pins 8 and 9	V_{DRV} V_{DRV}	2.9 3.1	3.6 4.0	4.3 4.7	V_{PP} V_{PP}
V_{ext} – Output voltage – Supply voltage drift – Output current – Standby output current	Pin 10 IC active standby mode	V_{EXT} dV_{EXT}/dT I_{EXT} I_{EXT}	4.6 3.5 0.4	5.4 4.2	6.3	V mV/K mA mA
Standby input – low level input voltage – high level input voltage	Pin 13	V_{il} V_{ih}	3.1		0.8	V V
Oscillator – Carrier frequency	RF-resistor = 110 k Ω (application 2), REM 1.	f_0	121	125	129	kHz
Low pass filter – Cut off frequency	Carrier freq. = 125 kHz	f_{cut}		7		kHz
Amplifier – Gain	$C_{HP} = 100\text{ nF}$			30		
Schmitt trigger – Hysteresis voltage				100		mV

REM 1.: In application 1. where the oscillator operates in the free running mode, the IC must be soldered free from distortion. Otherwise, the oscillator frequency may be out of bounds.

Dimensions in mm

Package: SO16



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Electronic Immobilizers for the Automotive Industry

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Introduction

In recent years increasing numbers of car thefts have highlighted the urgent need for effective and safe protection in the automobile industry. TEMIC introduced the industry's first single-chip reader IC for an automotive immobilizer anti-theft system in November 1994. Since 1995, insurance companies have insisted on new cars being protected against theft by an immobilizer. An electronic immobilizer with an integrated transponder security system for cars is a form of passive theft protection because the transponder does not need a battery as power is supplied by the reader.

The U2270B combines flexible coil driver circuitry, a highly integrated NF read channel and on-chip power supply. Along with TEMIC's e5530 transponder, the U2270B can be used to create a complete, compact and effective anti-theft system with minimum components.

This application note is a guide for designing an immobilizer which incorporates the U2270B. First of all, the magnetic coupling is explained and the parameters that are relevant for appropriate reading distance are identified. Next, solutions to overcome constellations with no modulation at the reader side are described. Then, the designer is guided through the application procedure. The dimensioning of the peripherals and the selection of the appropriate antenna adjustment strategy to guarantee the requested reading distance are discussed. In the following chapter, typical application examples are presented and a selection of the peripherals as well as the method of the antenna adjustment are described. A description of the adequate signal-detection software is given for applications where antenna adjustment is performed through a microcontroller.

System Design Considerations

Magnetic Coupling

Energy Transfer to the Transponder

The U2270B serves as an interface between the transponder and the microcontroller which compares the received data. This interface operates in two directions. In one direction, energy is transferred from the reader to the transponder. The reader creates a magnetic field via a reader air coil called the reader antenna (see figure 1). The reader coil is part of a resonant circuit tuned to the operating frequency. The antenna is energized by using series resonance. The resulting low impedance enables the driver circuit to transfer the energy with relatively low voltage which is limited in most automotive applications.

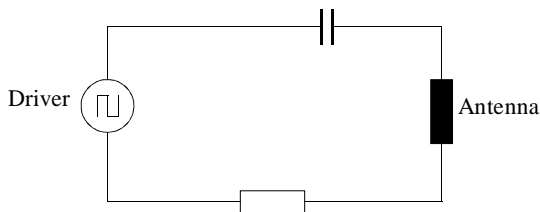


Figure 1. Reader antenna circuit

Modulation

The magnetic field generated by the reader induces a voltage in the transponder's resonant circuit which supplies the transponder IC. The current in the transponder coil generates a magnetic field which is superimposed to the reader's field. If the transponder's

supply voltage is high enough, it begins to transmit by damping the resonant circuit in accordance with the data signal. The resulting signal strength mainly depends on the transponder coil's (ferrite antenna) characteristics and the amplitude shift caused by damping. This is shown in figure 2.

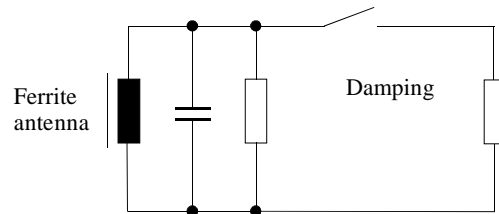


Figure 2. Equivalent circuit of the transponder (simplified)

Demodulation

Data is transferred in the other direction from the transponder to the microcontroller. The signal from the transponder is very small compared to the reader voltage. This leads to slight voltage modulation at the reader coil. The reader antenna operates in parallel resonance for the incoming signals, ensuring high sensitivity and pre-selection (bandpass) of the useful frequency band. Due to the high voltage across the reader coil, demodulation has to be external (see figure 3). The signal is fed into the INPUT pin of the reader IC via a rectifier and decoupling capacitor. The LF read channel amplifies and conditions the signal to convert it into the appropriate digital output data.

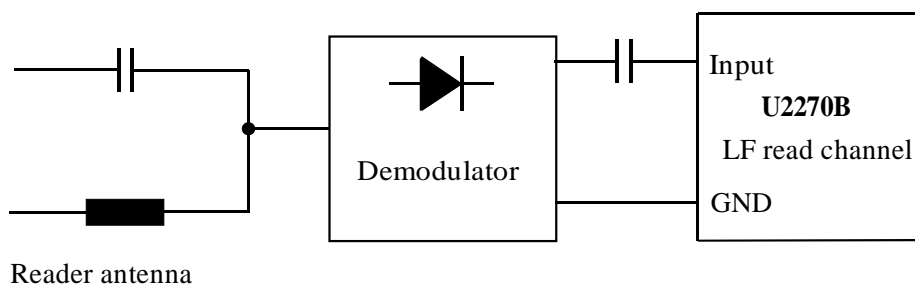


Figure 3. Demodulation path

Reading Distance

Energy Transfer Vs. Signal Detection

For correct operation, the transponder needs a minimum magnetic field intensity to generate internal supply voltage. If the existing frequency is different to the transponder's resonant frequency, the field intensity must be higher, depending on the transponder's resonance curve. The magnetic field intensity on the axis of a free-air (short cylindrical) coil can be calculated by the formula below. Furthermore, the formula for calculation of the coil's inductance is also given.

$$H = \frac{I \times N}{2 \times r \left(1 + \frac{d^2}{r^2} \right)^{1.5}}$$

$$L = N^2 \times r \times \pi \times \mu_0$$

$$(\mu_0 = 1.257 \times 10^{-6})$$

- H: Magnetic field intensity
- I: Current through the coil
- N: Number of turns
- r: Radius of the coil
- d: Distance between center of the coil and the transponder
- L: Inductance of the coil

To ensure detection, the modulated signal must exceed the sensitivity level of the read channel. The presence of interfering signals (electromagnetic interference, EMI) should be considered. The ratio between the reader and transponder voltage for both directions can be described using the parameters coupling factor, inductance and Q factor of each reader and transponder. They are given by the following formulas:

$$U_T = U_R \times k \times \sqrt{\frac{L_T}{L_R}} \times Q_T$$

$$\Delta U_R = \Delta U_T \times k \times \sqrt{\frac{L_R}{L_T}} \times Q_R$$

- U_T : Transponder voltage
- U_R : Reader voltage
- k: Coupling factor (common for both directions)
- L_R : Reader inductance
- L_T : Transponder inductance
- Q_T : Transponder Q factor
- Q_R : Reader Q factor
- ΔU_R : Modulated (differential) voltage at the reader coil
- ΔU_T : Modulation voltage at the transponder

The coupling and Q factors improve transmission in both directions. Q factors are limited by physical and design conditions and are mentioned in the following chapters. A compromise must be found as far as the inductances are concerned because they have opposite effects in both directions

Avoidance of Zero Modulation

The formulas above are valid if the resonant circuits of reader and transponder are aligned to the oscillator frequency. If the resonant circuits are off resonance, the modulated signal fed back from the transponder will not be in phase to the reader (self-induced) voltage. This can lead to the following effects:

- Amplitude modulation on the reader voltage will be lost if the phase shift is 90° (zero modulation).
- The signal will be inverted if the phase shift is more than 90°.

Table 1 shows the various solutions possible to avoid the effects mentioned above.

Power Supply Environment

The reader IC also incorporates an internal power supply. This enables the user to operate the system not only from an unregulated supply voltage in the range of 7 V up to 16 V, but also from an existing 5-V supply rail. If internal stabilization is used, the U2270B can be set to a power-down mode, via the pin STANDBY, where the supply current is very low.

Table 1. Comparison of the various solutions available to avoid zero modulation

Possible Solutions to Avoid Zero Modulations	Remarks
<ul style="list-style-type: none"> Alignment of the resonant circuits and the oscillator frequency 	<ul style="list-style-type: none"> Not possible if more than one transponder is used Not suitable for mass production
<ul style="list-style-type: none"> Reduction of the Q factor of the reader and/or the transponder resonant circuits 	<ul style="list-style-type: none"> Less phase shift at equal frequency deviating Reading distance is reduced (see "Antenna Design"*)
<ul style="list-style-type: none"> Alternating the oscillator frequency in steps within the tolerance range 	<ul style="list-style-type: none"> Troublesome if the resonant frequencies of reader and transponder are quite different*
<ul style="list-style-type: none"> Controlling the oscillator frequency to be equal to the resonance of the reader antenna 	<ul style="list-style-type: none"> Additional control circuit required Tolerance considerations are only 2 dimensional instead of 3 dimensional Antenna design is easier (see "Oscillator Control Loop")
<ul style="list-style-type: none"> As above, plus alternating the reader resonance frequency by a switched capacitor 	<ul style="list-style-type: none"> Less tolerance restriction (see "Reader Application with Tuning")

* Note: If the reader-resonant circuit is driven off resonance, the (FM) noise of the oscillator is converted into an AM noise which is detected by the demodulator. The increasing noise level leads to lower reading distances.

Application Procedure

Dimensioning of the Peripherals Oscillator Control Loop

Controlling the oscillator frequency to be equal to the resonance of the reader antenna has several advantages. (refer to table 1) This approach is therefore proposed for the applications described in this chapter. The frequency control is achieved by applying an oscillator control loop incorporating a phase detector.

Figure 4 shows the equivalent circuit of the oscillator control loop, figure 5 shows the waveforms of the driver outputs coil 1, coil 2 and the corresponding antenna voltage, measured between R_1 and R_2 .

- T_1 : low cycle of coil 1 output
- T_2 : low cycle of coil 2 output
- T_{2a} : time interval of T_2 where the antenna voltage is negative
- T_{2b} : time interval of T_2 where the antenna voltage is positive
- A_a : integral of the antenna voltage during T_{2a}
- A_b : integral of the antenna voltage during T_{2b}

The oscillator control loop is a phase control loop that controls the phase shift between driver voltage and antenna voltage. The feedback current through D_1 and D_2 controls the oscillator frequency in such a way that a 90° phase shift between the above mentioned voltages is achieved. In this condition, the reader antenna is driven at its resonant frequency.

During T_1 , no feedback information is transferred through D_1 and D_2 into C_1 . In the meanwhile, D_3 and D_4 are conducting. Therefore, D_1 and D_2 are reverse biased.

During T_2 , feedback information can be transferred through D_1 or D_2 . During T_2 , a current flows through R_2 and D_1 out of C_1 . If the antenna voltage is positive (during T_{2b}) current flow occurs through R_1 and D_2 .

The resulting current into C_1 is the sum of the currents during T_2 . If the resonant frequency of the antenna is higher than the oscillator frequency, the phase shift and therefore T_{1a} and T_{2b} change. T_{2a} is reduced and T_{2b} is increased accordingly. As a result, the control current (sum of A_a and A_b) differs from zero and becomes positive. This results in an additional current into pin RF and in a higher oscillator frequency until $f_{res} \approx f_{osc}$. The control loop operates proportional, the loop gain is ≈ 15 for the proposed application in the data sheet. A higher Q factor of the reader antenna results in a higher loop gain. The damping effect of R_1 and R_2 should be considered as it lowers the Q factor of the reader antenna.

Signal Detection

The useful signal appears as a very small amplitude modulation of the reader antenna voltage. The demodulator consists of a diode, a charge capacitor and two resistors for charging and discharging. The high-pass function of the capacitive coupling (C_2) has to be matched to the transponder code used (see figure 6).

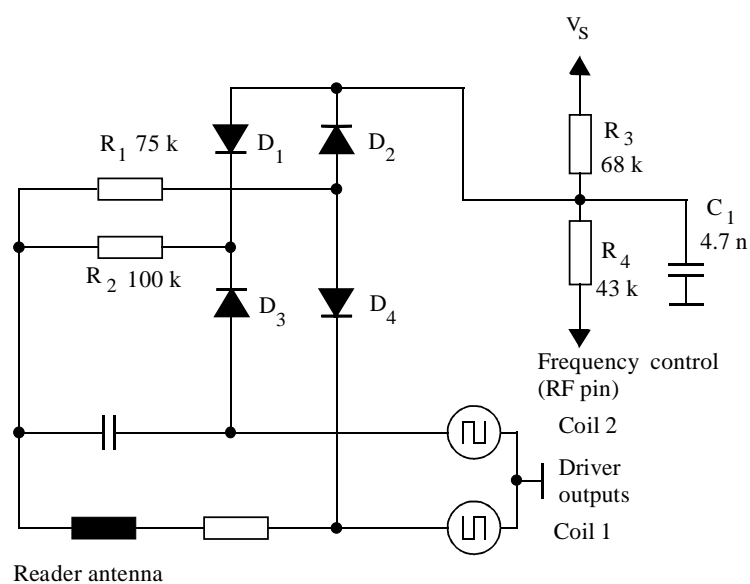


Figure 4. Function principle of the oscillator control loop

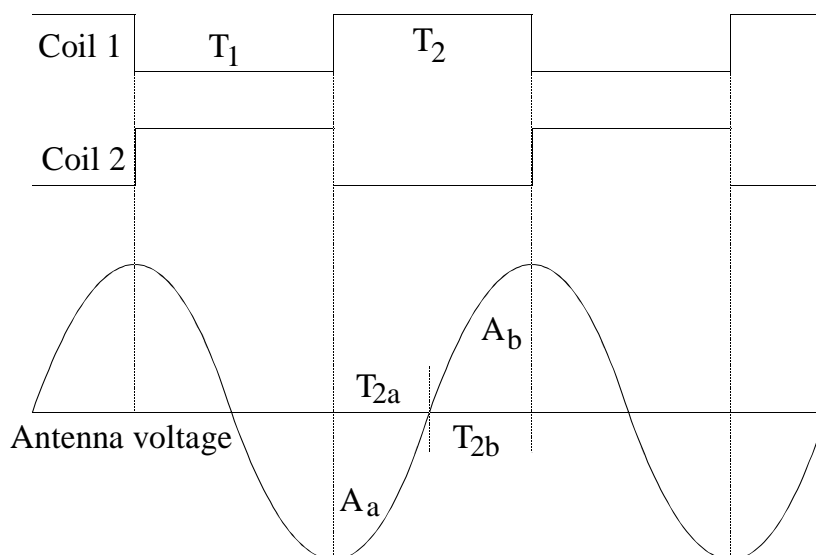


Figure 5. Relevant signals of the oscillator control loop

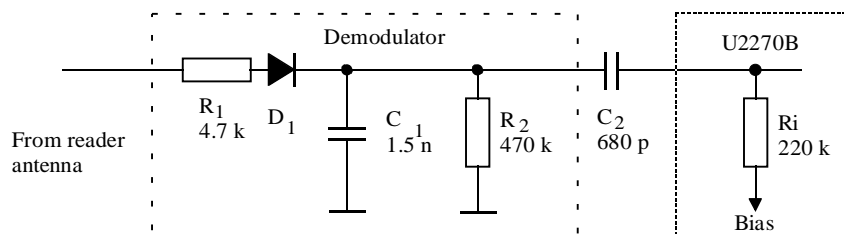


Figure 6. Demodulator with high-pass coupling

The component values are given for a bit rate of approximately 4 kbit/s using bi-phase or Manchester encoding (see figure 6). If a lower data rate is used the value of C₂ should be increased accordingly. After demodulation, the signal is filtered and amplified by the read channel inside U2270B. The gain and lower cut-off frequency of the integrated amplifier can be set via the pin GAIN. If maximum gain is required, the pin GAIN is connected via a capacitor (C_{Gain}) to ground. For a lower gain, a resistor (R_{Gain}) is connected in series to the capacitor. The gain (G) and the cut-off frequency (f_{Out}) can be calculated by the formulas below. The value of R_i can be assumed as being 2.5 kΩ.

$$G = 30 \times \frac{R_i}{R_i + R_{Gain}}$$

$$f_{cut} = \frac{1}{2 \times \pi \times C_{Gain} \times (R_i + R_{Gain})}$$

Power Supply and Load Dump Protection

The system can be operated from either a 5-V stabilized supply or an unregulated voltage in the 7-V up to 16-V range, for example, from a vehicle's battery. A protective resistor should be used (see "Typical Application") to withstand overvoltage conditions. The minimum resistance can be determined by the following equations:

Assumptions:

- R_{THJA}: 120 K/ W
Thermal resistance junction to ambient
- T_{JMAX}: 150°C (maximum junction temperature)
- U_Z: 18 V internal clamping voltage
- R_Z: 90 Ω internal resistance of the clamping diode
- U_{IN}: Maximum continuous input voltage
- U_{IN_LD}: Maximum input voltage 'load dump'
- T_{amb}: ambient temperature
- F: Factor depending on the duration of a load dump pulse; F = 2 if t < 500 ms, F = 3 if t < 200 ms

$$P_{tot} = \frac{T_{JMAX} - T_{amb}}{R_{THJA}} \quad \text{Power dissipation continuous}$$

$$P_{tot_LD} = F \times P_{tot} \quad \text{Power dissipation load dump}$$

$$R_{Prot} \geq \frac{U_{IN} - U_Z}{\sqrt{\frac{P_{tot}}{R_Z} + \left(\frac{U_Z}{2R_Z}\right)^2} - \left(\frac{U_Z}{2R_Z}\right)} - R_Z$$

Protective resistor continuous

$$R_{Prot} \geq \frac{U_{IN_LD} - U_Z}{\sqrt{\frac{P_{tot_LD}}{R_Z} + \left(\frac{U_Z}{2R_Z}\right)^2} - \left(\frac{U_Z}{2R_Z}\right)} - R_Z$$

Protective resistor load dump

This calculation considers a worst-case situation, since it is performed using R_{THJA}. Thermal resistance is lower in normal applications as the IC is mounted on a PC board.

Antenna Design

Since the resonant frequency of the reader antenna is defined by the system, the parameters to be determined are:

- Inductance of the coil
- Q factor of the resonant circuit

The inductance depends on the coil dimensions and the number of turns (see "Energy Transfer vs Signal Detection"). The inductance value of the reader antenna must be set so as to balance the energy transfer and the signal detection. If the parameters of the transponder are known, the coupling factor can be calculated. Resonant frequencies of reader antenna and transponder are equal. Therefore, the formula given in the chapter "Energy Transfer vs. Signal Detection" is re-arranged:

$$k = \frac{U_T}{U_R \times Q_T} \times \sqrt{\frac{L_R}{L_T}} \quad \text{Coupling factor}$$

$$\Delta U_R = \Delta U_T \times k \times \sqrt{\frac{L_R}{L_T}} \times Q_R \quad \text{Modulation voltage of the reader antenna}$$

The Q factor of the reader antenna depends on the loss resistance of the coil and iron losses if the coil is mounted on a lock cylinder. To be independent of the peripheral parameters (i.e. mounting accuracy, lock cylinder material) a serial resistor should be added. A high Q factor improves signal transmission, but if it is too high the transient response could have a negative effect on the data signal. Values of the Q factor up to 15 do not affect the data signal.

Frequency Tolerance Considerations

The resonant frequencies of reader antenna and transponder(s) are not equal in most applications and result in the following effects (see "Avoidance of Zero Modulation"):

- The internal supply voltage of the transponder is reduced due to its resonant curve.

- The amplitude modulation of the reader voltage is lost if the phase shift is 90°, (zero modulation) or the signal is inverted if the phase shift is more than 90°.

In order to maintain proper operation for the immobilizer system, the following conditions must be fulfilled:

- The transponder needs enough power to operate.
- The phase shift between reader voltage and modulation voltage must be below 90°.

The transponder voltage can be calculated if the maximum (requested) tolerance between the resonant frequencies is known.

$$\varphi = \arctan\left(Q_T \times \left(1 + \frac{\text{Tol}}{100}\right) - \frac{1}{\frac{1}{Q_T} \times \left(1 + \frac{\text{Tol}}{100}\right)}\right)$$

$$U_T = U_R \times k \times \sqrt{\frac{L_T}{L_R}} \times Q_T \times \cos(\varphi)$$

U_T : Transponder voltage

U_R : Reader voltage

k : Coupling factor (common for both directions)

L_R : Reader inductance

L_T : Transponder inductance

Q_T : Transponder Q factor

Tol: Tolerance between resonant frequencies (in %)

φ : Phase shift between reader and transponder voltages

The phase shift between reader and transponder voltages is also very important for achieving potential zero modulation. If the transponder modulates slightly, zero modulation can occur at a phase shift of $\varphi > 45^\circ$. This also means that if the system is operated in such a way that guarantees φ to be less or equal to 45° , zero modulation cannot occur. The maximum tolerance where this requirement can be fulfilled is given with:

$$\text{MaxTol} = \left(\frac{1}{2} \times \frac{\left(1 + \sqrt{1 + 4 \times Q_T^2}\right)}{Q_T} - 1 \right) \times 100$$

MaxTol: Maximum tolerance for a given Q factor to avoid zero modulation

Q_T : Transponder Q factor

If $\text{MaxTol} > \text{Tol}$ (the desired maximum tolerance), zero modulation cannot occur. The transponder can be operated at its lowest possible supply voltage respectively magnetic field strength. This is shown in the data sheet.

If $\text{MaxTol} < \text{Tol}$, there are three possible solutions to avoid the likelihood of zero modulation:

- 1: Usage of more accurate frequency-determining components for the reader antenna and/ or the transponder. The maximum value for the tolerance between the resonant frequencies is MaxTol, as calculated with the above formula.
- 2: Alternating the reader resonance frequency by means of a switched capacitor. Two different resonance frequencies can be selected, (see "Application with Tuning") resulting in double the value for the maximum tolerance compared to $1 (2 \times \text{MaxTol})$.
- 3: Lowering the Q factor of the transponder: This is achieved by applying enough magnetic field so that the transponder's internal clamping diode conducts. This internal diode limits the maximum internal supply voltage to protect the IDIC. The reduction of the Q factor depends on the current flow through that diode. The required Q factor to avoid zero modulation can be calculated with the following formula:

$$Q_T = 100 \times \frac{100 + \text{Tol}}{(\text{Tol} \times (200 + \text{Tol}))}$$

Q_T : required transponder Q factor

Tol: Maximum (desired) tolerance between resonant frequencies (in %)

The voltage of the transponder is determined by the transponder's internal clamping diode. This means that the magnetic field must be significantly higher with this solution compared to solutions 1 and 2. The required coupling factor can be determined with the following formula:

$$k = \frac{U_T}{U_R \times Q_T \times \cos(\varphi)} \times \sqrt{\frac{L_R}{L_T}}$$

k : Coupling factor (common for both directions)

U_T : Transponder voltage (clamping voltage in this case)

φ : Phase shift between reader and transponder voltages
[$\cos(\varphi) = \cos(45^\circ)$ in this case]

U_R : Reader voltage

L_R : Reader inductance

L_T : Transponder inductance

Q_T : Reduced transponder Q factor corresponding to the formula above

Application Examples

Overview

A wireless immobilizer or identification system consists of two sub-systems – the transponder and the reader system. The U2270B enables the design of reader systems with less components. It enables a microcontroller or digital logic to read and to process the identifier or the key code from a transponder.

This chapter describes typical applications for the U2270B and describes how to decode the transponder signal. All considerations are made for the TEMIC transponder e5530 at a frequency of 125 kHz.

Typical Reader Application

This circuit is suitable for systems with a small range or small tolerances of reader and transponder resonant circuits. The application shown in figure 7 is a proposal for a 12-V supply voltage. The microcontroller is supplied by the internal power supply of the U2270B.

Reader Application with Tuning

This application (see figure 8) allows the tuning of the reader antenna circuit. Thus, reader and transponder antennas with larger tolerances can be used. The microcontroller is able to minimize the difference between reader and transponder resonant frequencies. This

improves the communication range and avoids zero modulation.

Data Decoding

The identifier or key code of the normal transponders is encoded as a Manchester or bi-phase code and the clock for the baud rate is generated by the transponder from the oscillation at the reader antenna. A typical transponder code can be seen in figure 9.

Figure 9 shows the timing of the Manchester and bi-phase code in an ideal situation. However, the timing of the code at the decoder input is affected by various effects of modulation, demodulation and noise in most applications. There is a jitter at the rising and falling edge of the data signal. Additionally, the clocks of the transponder signal and the decoder system are asynchronous. The decoder should evaluate the reader output signal with the method shown in figure 10 to achieve a maximum range and minimum errors.

The reader output signal is shown in figure 10. The valid time intervals (worst-case considerations) are related to one edge of the data signal. Table 2 provides the pulse lengths for the reader output signal. If the decoder operates with this timing, guaranteed decoding of the Manchester- (see figure 11) or the bi-phase code (see figure 12) is possible.

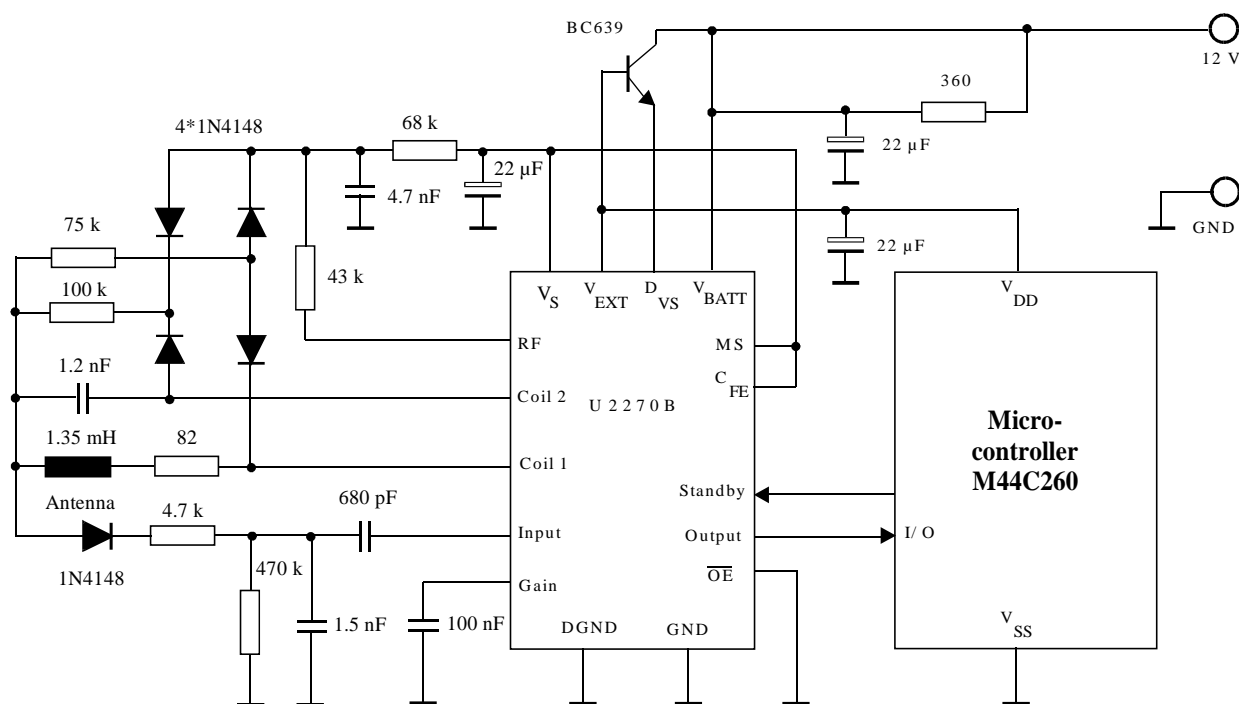


Figure 7. 12-V application for small reading range requirements

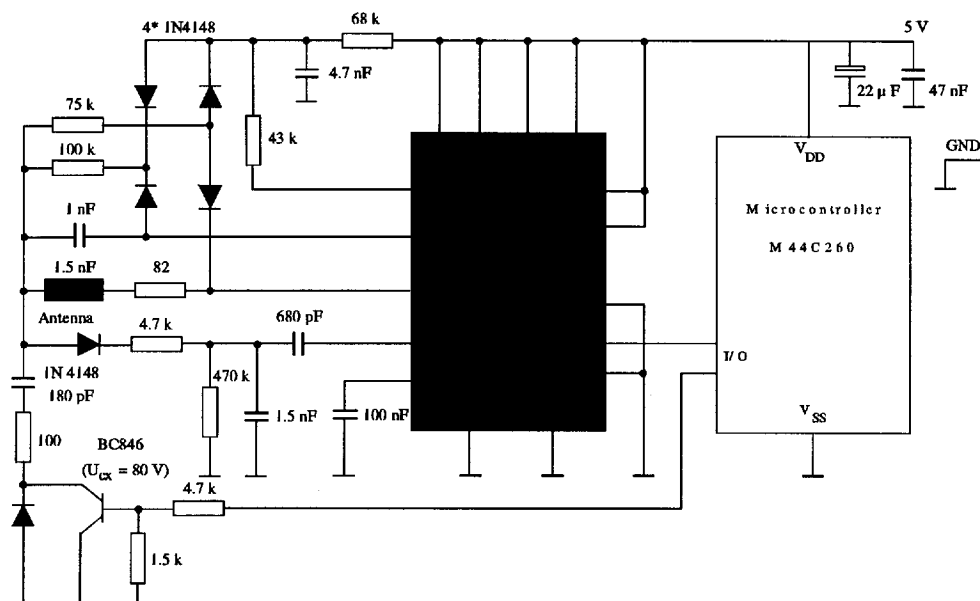


Figure 8. 5-V application for enhanced reading-range requirements

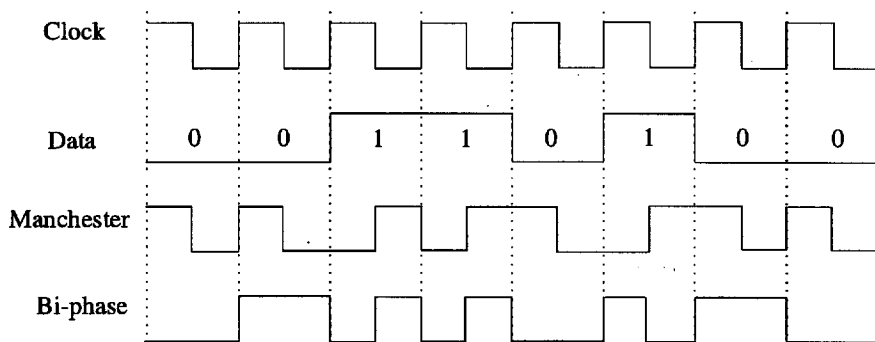


Figure 9. Manchester and bi-phase code

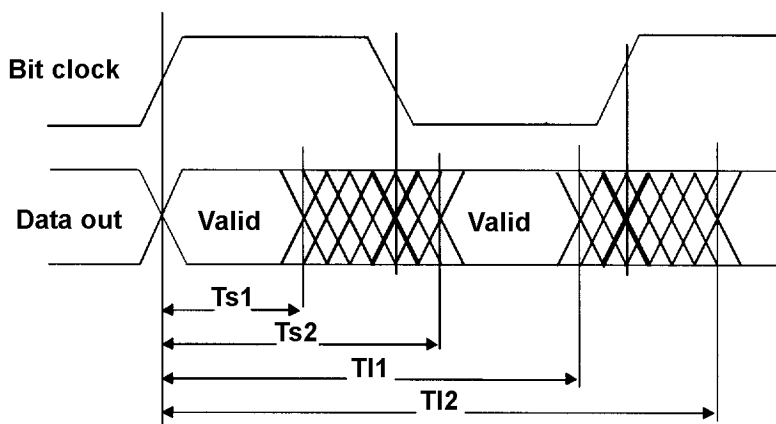


Figure 10. Valid time frame for the reader-output signal

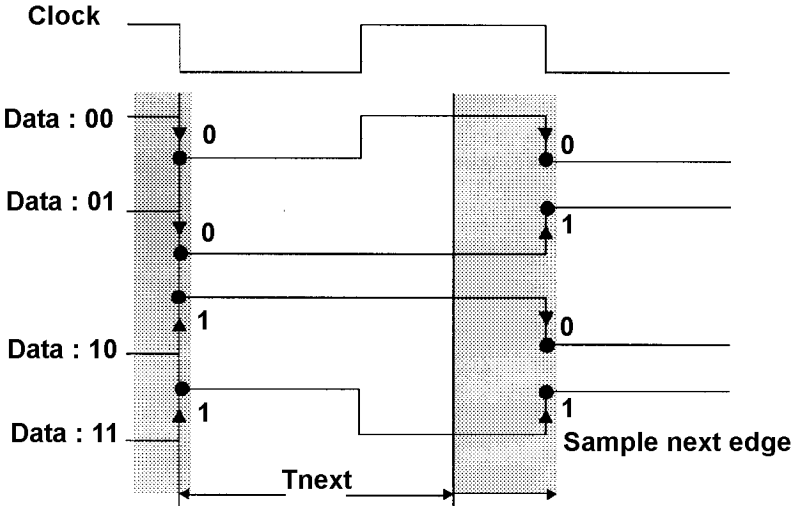


Figure 11. Decoding of Manchester code

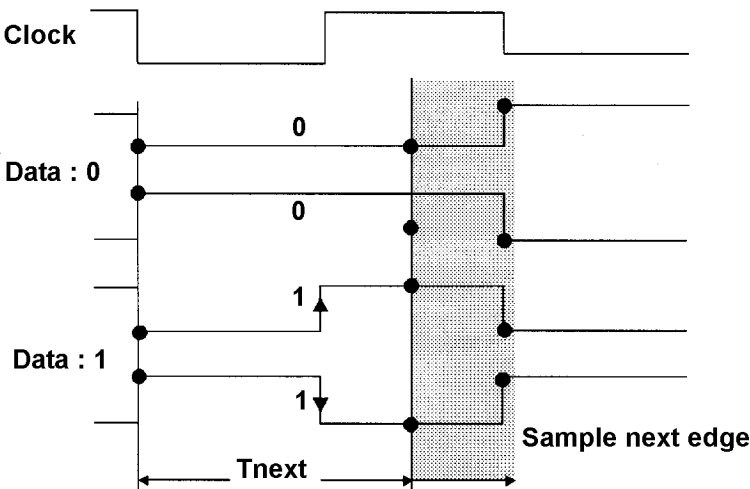


Figure 12. Decoding of bi-phase code

Table 2. Pulse lengths for the reader output signal

Description	Symbol	Value	Units	Condition
Short pulse length minimum	t_{S1}	90	μs	$f_{Osc} = 125\text{ kHz} \pm 3\%$
Short pulse length maximum	t_{S2}	180	μs	"
Long pulse length minimum	t_{L1}	210	μs	"
Long pulse length maximum	t_{L2}	300	μs	"

To decode the Manchester or bi-phase code, the clock of the transponder and the decoder must first be synchronized. The codes are encoded as a signal with two frequencies f_{clock} and $2 \times f_{clock}$. A positive or negative pulse with the length of one clock period must be

detected for the synchronization. After that, the bit-stream can be decoded. The flowcharts in figures 13 and 14 show how to decode the transponder signal for Manchester and bi-phase encoding and also indicate error detection.

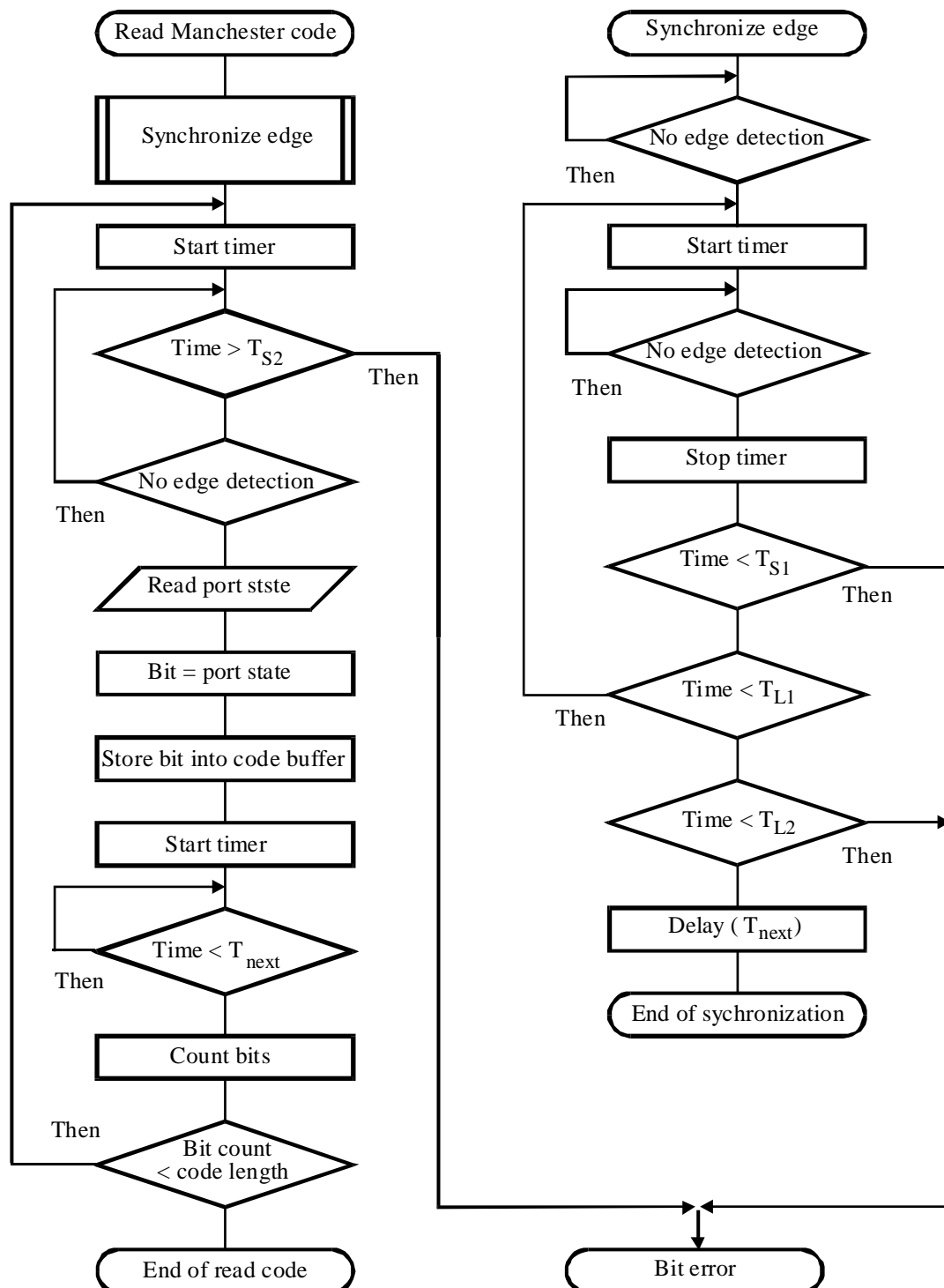


Figure 13. Decode flowchart for Manchester code

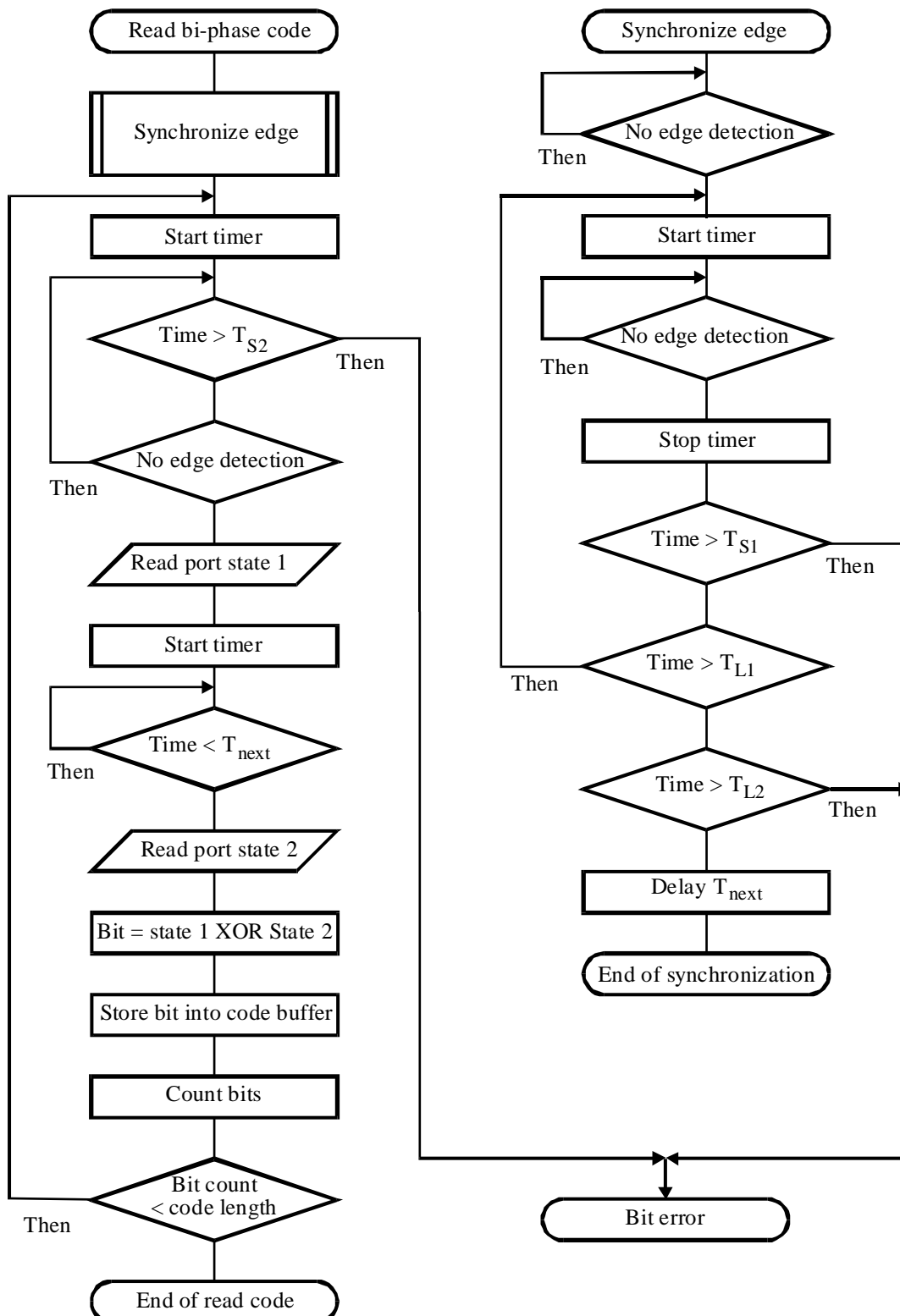


Figure 14. Decode flowchart for bi-phase code

In figures 13 and 14, the following time constants are used to evaluate the reader signal:

Table 3. Time constants for evaluating the reader signal

Used Time Constants ($f_{osc} = 125 \text{ kHz} \pm 3\%$)		
Symbol	Value	Unit
$TS1 = t_{S1}$	90	μs
$TS2 = t_{S2}$	180	μs
$TL1 = t_{L1}$	210	μs
$TL2 = t_{L2}$	300	μs
$T_{next} = t_{S2}$	180	μs

The complete process of reading a transponder is shown in figure 15. If the standby option is used the microcontroller must wake up the reader via the standby pin. Then it must synchronize and read the bits. The reading is not synchronized with the beginning of the code. Therefore, the first bit of the identifier must be found by searching the 8-bit header code (TEMIC transponder) in the code buffer. This allows very fast access to the identifier because the microcontroller can start reading at any place within the bit stream. If all bits are free of errors and the identifier is also correct, the read access is finished. If there is a bit error or a bad identifier the microcontroller can repeat the reading. In applications with a tunable reader antenna, the controller should change the antenna adjustment before it starts to read again. After the read access, the reader can then be switched into standby mode.

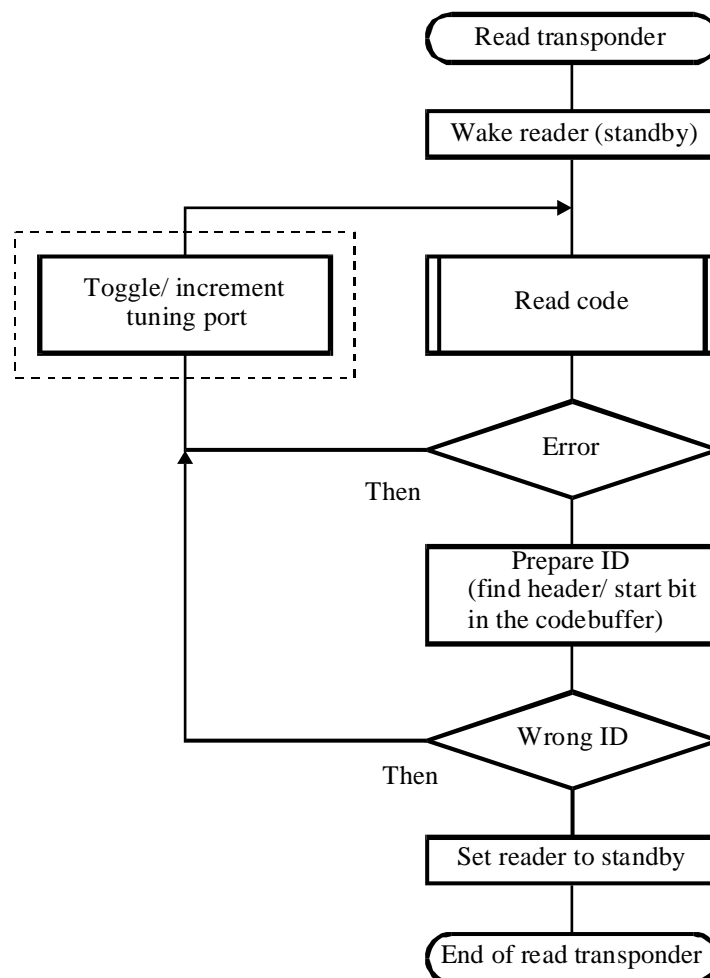


Figure 15. Decode flowchart for read code

U2270B Antenna Design Hints

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How to Meet the Actual Frequency Tolerance Situation.....	7
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General Information

The reader antenna is a series resonance circuit consisting of an inductor, a capacitor and a resistor (see figure 1).

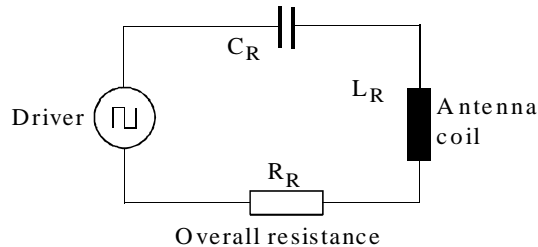


Figure 1. Equivalent circuit of the reader antenna

The antenna is characterized by its resonant frequency and its Q factor. The resonant frequency f_0 is the operating frequency of the ID system. This frequency is determined by the inductor and the capacitor of the antenna and can be calculated using the following formula:

$$f_0 = \frac{1}{2 \times \pi \times \sqrt{L_R \times C_R}}$$

This frequency is selected to $f_0 = 125$ kHz. The Q factor, Q_R , represents the bandwidth, B, of the antenna and also the ratio between the reader antenna voltage (U_R) and the sinusoidal content of the antenna's driver voltage (U_{DRV}).

$$B = \frac{f_0}{Q_R} \quad U_R = U_{DRV} \times Q_R$$

The sinusoidal content of the antenna's driver voltage is determined by the peak-to-peak square-wave driver output signal (U_{DRVpp}) of the U2270B. Note that this value is twice the measured driver output voltage swing in the differential mode.

$$U_{DRV} = \frac{4}{\pi} \times U_{DRVpp}$$

A higher Q factor results in a higher reader-antenna voltage and therefore enhances the energy transfer to the transponder. The drawback of a higher Q factor is the reduced bandwidth of the antenna. A smaller bandwidth can reduce the induced data signal volt-

age in accordance with the transponder's data rate.

In most automotive applications, the reader antenna is situated very close to the lock cylinder material. This material can have a major influence on the antenna coil inductance and on the Q factor of the coil. A higher Q factor results in a higher possible influence due to the lock cylinder material. If this is the case, the Q factor can vary with variations of the lock-cylinder material and with the mounting accuracy of the antenna coil. Therefore, the Q factor should not be set to a value of $Q_R > 15$.

A good compromise regarding this scenario is a Q factor of $Q_R = 12$. This value is proposed for all described applications and is also used in the TEMIC demo kit. Nevertheless, there are other non-automotive applications where other values could be preferred. If this is the case the Q factor should be kept within $Q_R = 5 - 15$.

The determination of the antenna inductivity is described in the following chapters. If that inductivity is determined, the Q factor can be calculated by using the following formula:

$$Q_R = \frac{2 \times \pi \times f_0 \times L_R}{R_R}$$

Note that R_R is the overall resulting series resistance. R_R includes the losses due to the lock-cylinder material, the copper losses of the coil and the external series resistor R_6 . (see ID demo kit, page 6) An exact formula to determine R_6 cannot be given due to the unknown influence of the lock cylinder material. The Q factor can be changed by varying the series resistor R_6 . A lower value for R_6 results in a higher Q factor for the antenna. A value of $R_6 = 100 \Omega$ is recommended to start with. This value can now be decreased to achieve the desired Q factor. The antenna's Q factor can be monitored by the antenna voltage. When using the demoboard, this Q factor is achieved at an antenna voltage of $V_R = 130$ V_{pp}.

Antenna Design Procedure

The resonant frequency of the reader antenna shows a certain tolerance due to the limited accuracy of the frequency-determining antenna components, the influence of the lock cylinder material, and the mounting accuracy of the coil. This chapter describes the design of the reader antenna under that condition in respect to the actual magnetic coupling situation.

The first step in designing the antenna is to increase the magnetic coupling factor, k , as much as possible. A good coupling factor enhances the energy transfer from the reader antenna to the transponder but also increases the signal voltage of the information that is sent back to the reader antenna by the transponder. This issue is very important as it can help to achieve a more cost-effective overall system design. This topic is described in detail in the chapter "Optimizing the Magnetic Coupling Factor".

With the value of k , determined in the chapter mentioned above, the transponder voltage and the modulated voltage at the reader coil can be calculated according to the TEMIC Application Note ANT019 (page 3). Due to deviations of the resonance frequency of the reader antenna and that of the transponder antenna, the data signal voltage at the reader coil may be decreased or could even disappear. This

behavior is described in the TEMIC Application Note ANT019 pages 3 and 6-7.

Depending on the actual coupling factor k and the desired antenna tolerances, the appropriate strategy is selected to avoid negative consequences due to that effect. Depending on the selected strategy, the antenna is operated with a fixed frequency or with one of two frequencies which is selected by the decoding μC . In this case, an output port of the μC is required to control the appropriate alternative. The procedure of selecting the suitable strategy is described in the chapter "How to Meet the Actual Frequency Tolerance Situation". The determination of the inductivity of the reader antenna is also part of this chapter. A lower value for the inductivity allows higher tolerances for the resonant frequencies of the antennas, but also results in a higher supply current for the system.

If the reader antenna can be operated with a fixed frequency, the design is finished. If it is necessary to switch between two different frequencies, their values must be determined. This topic is described in the chapter "How to Meet the Actual Frequency Tolerance Situation". Table 1 summarizes the antenna design in a flow chart.

Table 1. Antenna design procedure

1. Setting the fixed conditions ($Q_R=12$, antenna driver in differential mode)		
2. Optimizing the magnetic coupling factor k . (from the chapter "Optimizing the Magnetic Coupling Factor")		
3. Selecting the strategy to meet the actual frequency tolerance situation		
3.1 Operating the antenna with a fixed frequency is possible	3.2 The antenna is operated with two alternating frequencies	3.3 The system cannot be operated under the actual antenna tolerance/magnetic coupling factor condition
L_R is determined according to the chapter "How to Meet the Actual Frequency Tolerance" $C_R = \frac{1}{L_R \times (2 \times \pi \times f_0)^2}$	L_R and two different values for C_R are determined according to the chapter "How to Meet the Actual Frequency Tolerance"	The magnetic coupling factor must be increased or the antenna tolerance must be decreased for a secure design

Optimizing the Magnetic Coupling Factor

The coupling factor depends only on the mechanical dimensions of the coil arrangement (diameters, reading distance, coil orientation) and the magnetic materials close to the coil. The coupling factor does not depend on the inductance of the reader antenna or the transponder coil.

To improve the coupling factor, the transmission distance to be selected should be as small as possible. If the transponder cannot be placed in the axis of the reader coil, the magnetic field strength vector is not in parallel to the transponder coil axis. If this is the case, please check for the best transponder orientation.

If the reading distance is fixed due to mechanical constraints, the reader antenna coil diameter and also the magnetic coupling factor k can be optimized for that specific distance.

$$H = \frac{U_R}{4 \times \pi \times f_0 \times \sqrt{\pi \times \mu_0}} \times \frac{1}{\sqrt{L_R}} \times \left(\frac{r}{r^2 + d^2} \right)^{1.5}$$

H Magnetic field strength

U_R Reader coil voltage

f_0 Operating frequency

μ_0 Magnetic field constant

$$\mu_0 = 1.257 \times 10^{-6} \frac{Vs}{Am}$$

L_R Reader coil inductance

r Radius of the antenna coil

d Reading distance

The formula on the left hand side provides the magnetic field strength on the transponder. The first part of the formula is fixed in all applications. The term in the middle indicates the dependence of the selected coil inductance, and the term on the right describes the dependence on the mechanical situation. As the magnetic coupling factor, k , depends on the mechanical dimensions of the coil arrangement, it is proportional to the term on the right. Figure 2 illustrates how the magnetic field strength and the coupling factor varies for a given fixed reading distance if the coil radius is changed. The diagram corresponds to the following conditions:

$U_R = 130 \text{ V}_{ss}$ Reader coil voltage

$f_0 = 125 \text{ kHz}$ Operating frequency

$L_R = 737 \text{ } \mu\text{H}$ Reader coil inductance

$r = 5 - 55 \text{ mm}$ Radius of the antenna coil (varied parameter)

$d = 20 \text{ mm}$ Reading distance of the transponder

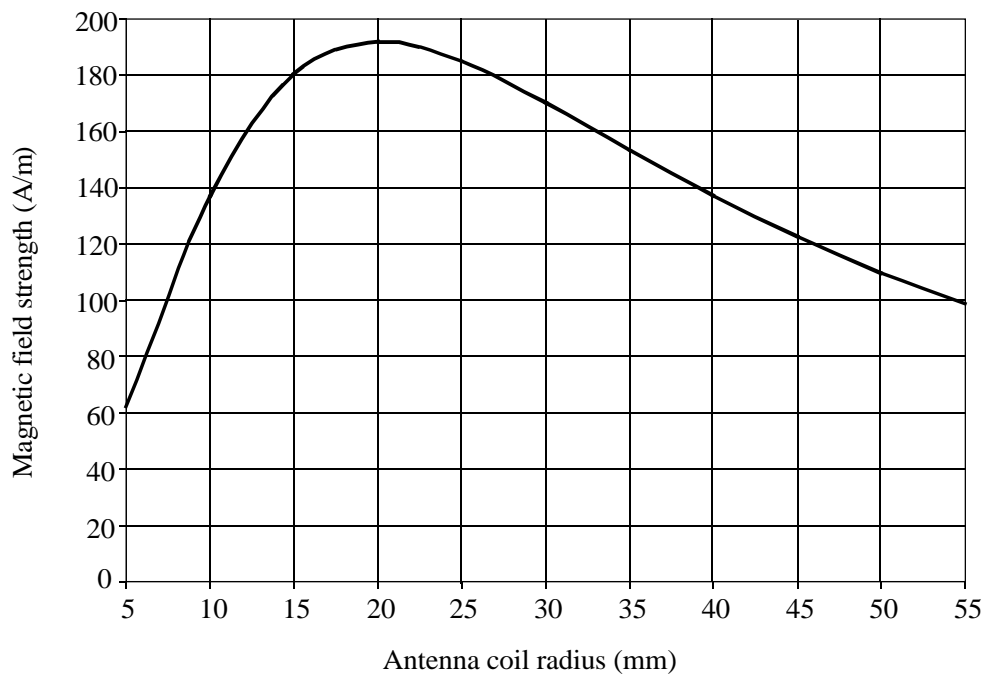


Figure 2. The magnetic field strength via the coil radius of the reader antenna

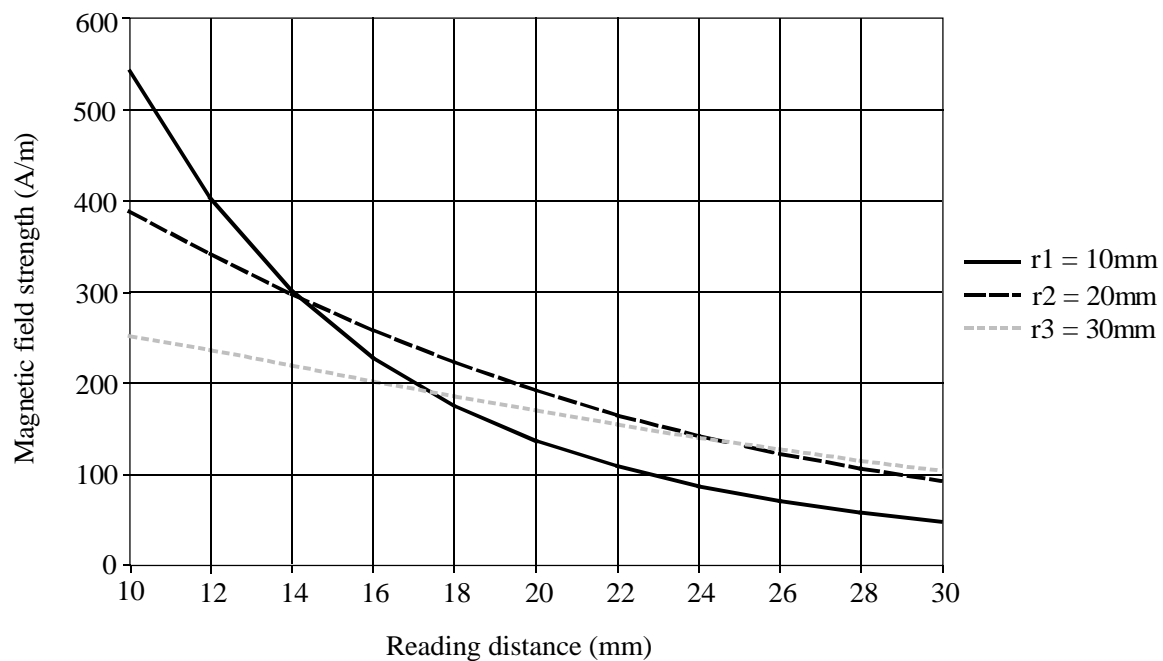


Figure 3. The magnetic field strength via the reading distance for various radius

The maximum magnetic field strength for a given reading distance is achieved when the coil radius is equal to the reading distance. If this is the case, the magnetic field is

$$H_{\max} = 192 \text{ A/m for } r = 20 \text{ mm.}$$

Figure 3 shows the magnetic field strength via the reading distance for various coil radiuses. Coil 2 ($r_2 = 20 \text{ mm}$) is optimized for a reading

distance of $d = 20$ mm. The corresponding parameters are:

$U_R = 130$ V _{SS}	Reader coil voltage
$f_0 = 125$ kHz	Operating frequency
$L_R = 737$ μ H	Reader coil inductance
$r_1 = 10$ mm	Radiuses of the antenna coils

$r_2 = 20$ mm

$r_3 = 30$ mm

$d = 10 - 30$ mm Reading distance of the transponder

$$H_n(d) = \frac{U_R}{4 \times \pi \times f_0 \times \sqrt{\pi \times \mu_0}} \times \frac{1}{\sqrt{L_R}} \times \left(\frac{r_n}{r_n^2 + d^2} \right)^{1.5}$$

Magnetic field strength at the transponder

Figure 3 shows that the coil with the smallest diameter displays the highest magnetic field strength at small distances, but the lowest value at a distance of $d > 18$ mm. The coil with

the largest diameter shows the lowest decline vs. an increasing transmission distance but starts from a low value. Coil 2 has the best performance for $d = 20$ mm as the radius is determined as $r = d$.

Determination of the Magnetic Coupling Factor

In order to determine the coupling factor, TEMIC provides a test transponder coil (TTC) with the same characteristic as the antenna coil of a TEMIC plastic transponder. This TTC can be placed at the actual transponder location. The voltage across the TTC coil can then be measured while the actual reader antenna is being operated by a signal generator. The corresponding coupling factor can be determined by using the measured voltage U_T together with the coil inductivities and the reader antenna voltage. Figure 4 shows the setup for the measurement.

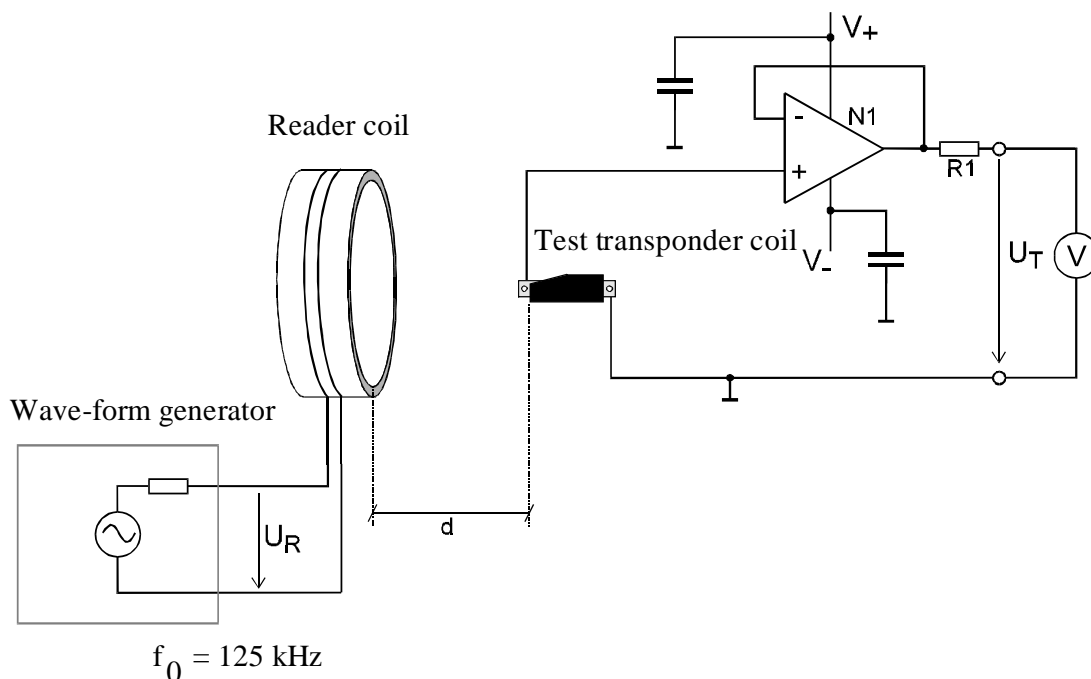


Figure 4. Circuit diagram to determine the magnetic coupling factor
(N1: TL081 or LF 356N, R1: 100 to 500 Ω)

Figure 5 shows the electrical model of the TTC together with the connected measurement equipment. C_{Para} is the internal parasitic capacitance in parallel to the coil. C_{Cable} and C_{Probe} are the load capacitances of the connected measurement equipment. These capacitances have an influence on the measured voltage.

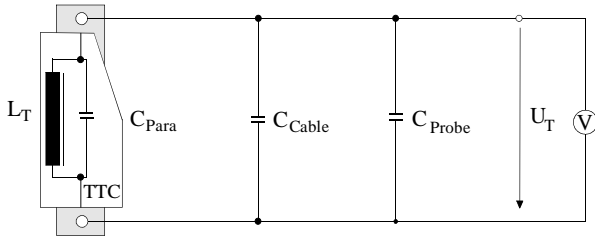


Figure 5. Electrical model of the TTC with the load capacitances of the probe ($C_{\text{Para}} = 20 \text{ pF}$)

To compensate that effect, a correction factor A_k can be determined to achieve an accurate result. A_k can be calculated using the formula on the right hand side of the page, or can be read from the diagram shown in figure 6. If the input capacitance of the measurement equipment is $(C_{\text{Cable}} + C_{\text{Probe}}) < 30 \text{ pF}$, the equipment can be directly connected to the

TTC. In this case, the buffer OP amplifier is not needed.

$$A_k = 2 - \frac{1}{1 - \omega^2 \times C_{\text{GES}} \times L_T}$$

$$C_{\text{GES}} = C_{\text{Para}} + C_{\text{Probe}} + C_{\text{Cable}}$$

A_k Correction factor (< 1)

ω $2 \times \pi \times 125 \text{ kHz}$

L_T Transp. coil inductance (3.95 mH)

Using the formula below, the coupling factor k can now be calculated.

$$k = A_k \times \frac{U_T}{U_R} \times \sqrt{\frac{L_R}{L_T}}$$

A_k Correction factor

U_T Transponder coil voltage

U_R Reader coil voltage

k Coupling factor

L_T Transponder coil inductance

L_R Reader coil inductance

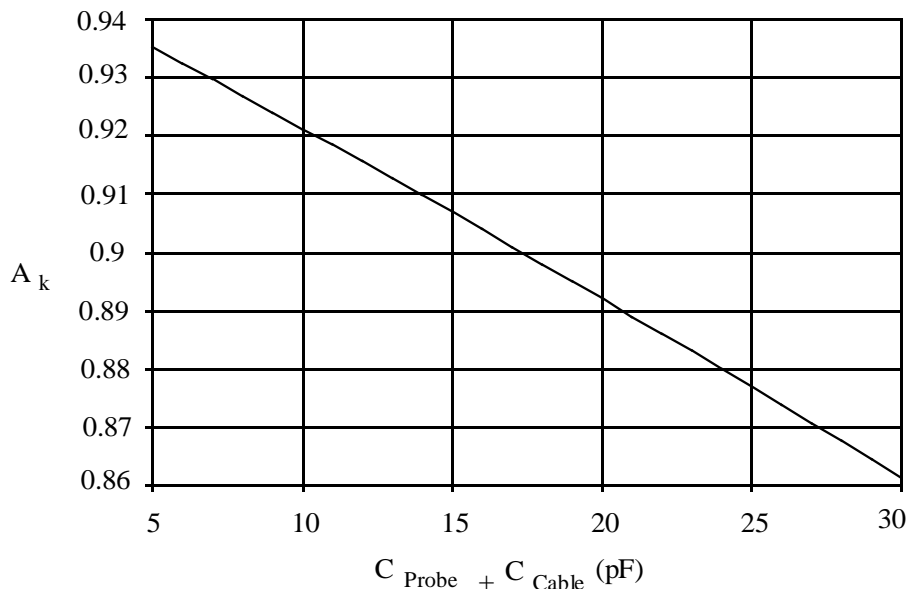


Figure 6. Diagram to determine the correction factor A_k

How to Meet the Actual Frequency Tolerance Situation

According to the chapter "Optimizing the Magnetic Coupling Factor", the magnetic coupling factor is now set to the highest possible value. One of two operation modes can be selected depending on that value and the resonant frequency tolerances of the transponder and the reader antenna.

Operation Mode 1

The reader antenna is operated with a fixed frequency of $f_{osc} = 125 \text{ kHz}$. This mode is preferred due to the following reasons:

- Less external components
- An additional μC pin is not required
- Faster detection time

Operation Mode 2

The reader antenna is operated with two alternating frequencies. The differences to operation mode 1 are:

- Allows higher resonant frequency tolerances at the same magnetic coupling factor
- The decoding μC selects and controls the preferred operating frequency

Figure 7 and figure 8 help to decide whether to choose mode 1 or mode 2. This figure shows the maximum tolerable total antenna tolerances for different magnetic coupling factors k and for different inductivities L_R of the reader coil. The total antenna tolerance hereby is the sum of the reader antenna frequency tolerance and the transponder resonant frequency tolerance.

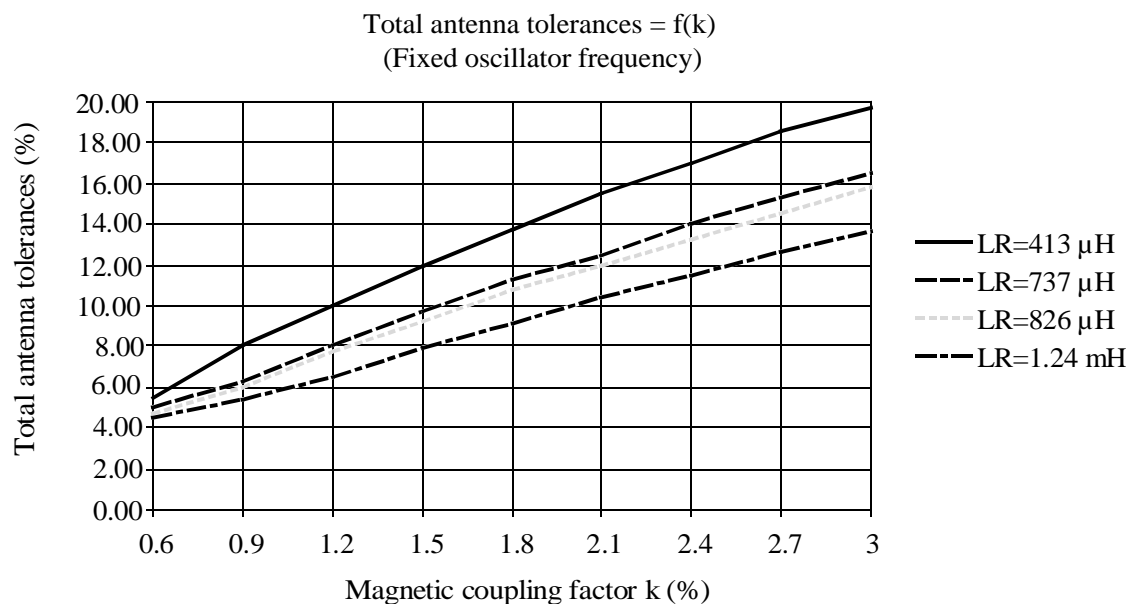


Figure 7. Determination of L_R for the fixed frequency mode

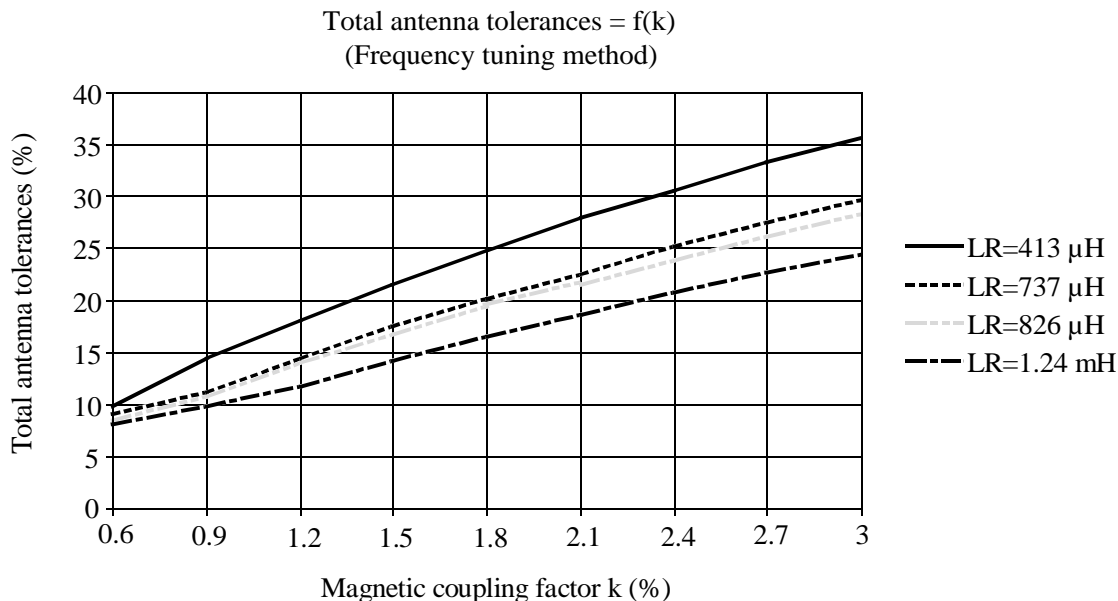


Figure 8. Diagram to determine L_R for altering operating frequencies

The plots in figure 7 and 8 indicate that the tolerable tolerances increase with a higher magnetic coupling factor and with a lower reader antenna coil inductivity. Note that a lower reader antenna inductivity results in a higher antenna current. The maximum antenna current is limited to $I_{Rpp} = 400$ mA due to the antenna driver current capability of the U2270B. If the reader antenna coil voltage is considered, the reader antenna inductance is not able to be decreased to values of $L_R < 413 \mu H$.

The total antenna tolerances together with the actual magnetic coupling factor define a specific point in both figures 7 and 8. Plots that are above that point correspond to antenna coil inductances that match the corresponding operation mode. Any inductivity between $L_R = 413 \mu H$ and the inductivity indicated by that point can be used. Operation mode 1 is preferred if both modes can be used. If mode 1 is used, the antenna capacitance can be calculated using the formula:

$$C_R = \frac{1}{L_R \times (2 \times \pi \times f_0)^2} \quad f_0 = 125 \text{ kHz}$$

If mode 2 is used, the reader antenna is operated with two alternating frequencies. The two frequencies and the corresponding capacitors (see figure 9) can be determined by using the maximum antenna frequency tolerances.

$$C_{R1} = \frac{1}{L_R \times (2 \times \pi \times f_1)^2}$$

$$f_1 = 125 \text{ kHz} - 0.44 \times (|Tol_R(\%)| + |Tol_T(\%)|)$$

$$C_{R2} = \frac{1}{L_R \times (2 \times \pi \times f_2)^2}$$

$$f_2 = 125 \text{ kHz} + 0.44 \times (|Tol_R(\%)| + |Tol_T(\%)|)$$

$Tol_R(\%)$ Frequency tolerance of the reader antenna in %

$Tol_T(\%)$ Frequency tolerance of the transponder antenna in %.

As the capacitors C_{R1} and C_{R2} act in parallel the switched capacitor C_{RP} can be determined as being:

$$C_{RP} = C_{R2} - C_{R1} \quad (\text{see figure 9})$$

If no coil inductance of $L_R \geq 413 \mu\text{H}$ can be used in mode 1 or mode 2, the magnetic coupling factor must be increased or the reader antenna tolerance must be decreased to enable a successful design.

Note that the graphs in figure 7 and 8 are only valid for applications using the TEMIC reader IC U2270B together with any read-only TEMIC transponder. These graphs should not be used for any other component combinations because they were designed for TEMIC transponder applications only.

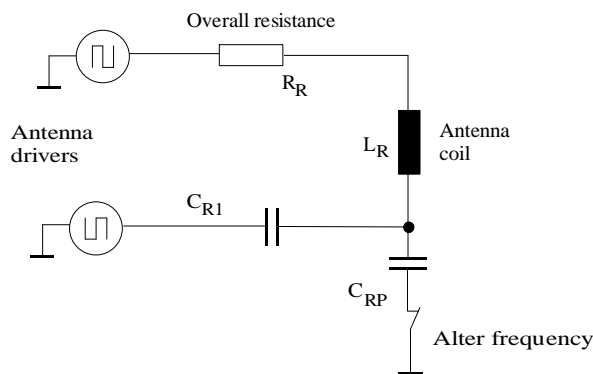


Figure 9. Equivalent circuit of the frequency altering reader antenna

Example

The TEMIC ID demonstration kit including the reader board, the reader antenna and the TEMIC read only plastic transponder is intended to assist the understanding of the ID system as it offers the possibility of verifying all physical parameters such as antenna voltage and coupling factor etc.

Moreover, the kit serves as a fictive antenna design example to illustrate the design procedure. The following assumptions and constraints apply for this design example:

Radius of the reader coil:	15 - 25 mm
Frequency tolerance of the reader coil:	$\pm 3\%$
Frequency tolerance of the TEMIC plastic transponder	$\pm 4\%$
Minimum reading distance	20 mm

The first step in designing the reader antenna is to increase the magnetic coupling factor as much as possible. In this example the radius of the reader antenna can be varied to maximize this factor for the minimum reading distance of $d = 20 \text{ mm}$. According to the chapter "Optimizing the Magnetic Coupling Factor", the ideal antenna radius is calculated as being: $r = d$, resulting in a value $r = 20 \text{ mm}$.

The next step is to determine the magnetic coupling factor using the TEMIC test transponder coil (TTC) as described in the chapter "Determination of the Magnetic Coupling Factor". Figure 10 shows results of the measurements versus the reading distance.

Here, a coupling factor of $k = 1.2\%$ can be extracted for the required transmission distance of $d = 20 \text{ mm}$. In the next stage, the required operation mode is selected according to the chapter "How to Meet the Actual Frequency Tolerance Situation". The total antenna tolerance is the sum of the tolerances of reader and transponder antenna, summarizing to $\pm 7\%$ in this example.

According to figure 7, it is possible to select the operation mode using a fixed frequency. Only the plot of the reader coil with $L_R = 1.24 \text{ mH}$ is below the point that is determined by $k = 1.2\%$ and the total antenna tolerance of $\pm 7\%$. Any reader coil inductance between $L_R \approx 850 \mu\text{H}$ and $L_R = 413 \mu\text{H}$ can be selected. In this example, $L_R = 737 \mu\text{H}$ is chosen. By using the formula:

$$N \approx \sqrt{\frac{L_R}{r \times \pi \times \mu_0}}$$

L_R	Reader coil inductance
r	Radius of the reader coil
μ_0	Magnetic field constant:
	$\mu_0 = 1.257 \times 10^{-6} \frac{\text{Vs}}{\text{Am}}$

the required number of turns of the reader coil is determined as being $N = 97$. As this is only an approximation formula, please check via measurements. The capacitance of the reader antenna is determined by means of the following formula:

$$C_R = \frac{1}{(2 \times \pi \times f_0)^2 \times L_R}$$

C_R	Reader antenna capacitance
L_R	Reader coil inductance
f_0	Operating frequency

In this example the capacitance is calculated to be $C_R = 2.2 \text{ nF}$.

Table 2 summarizes all relevant parameters together with the applicable formulas as a reference to measurements with the demoboard.

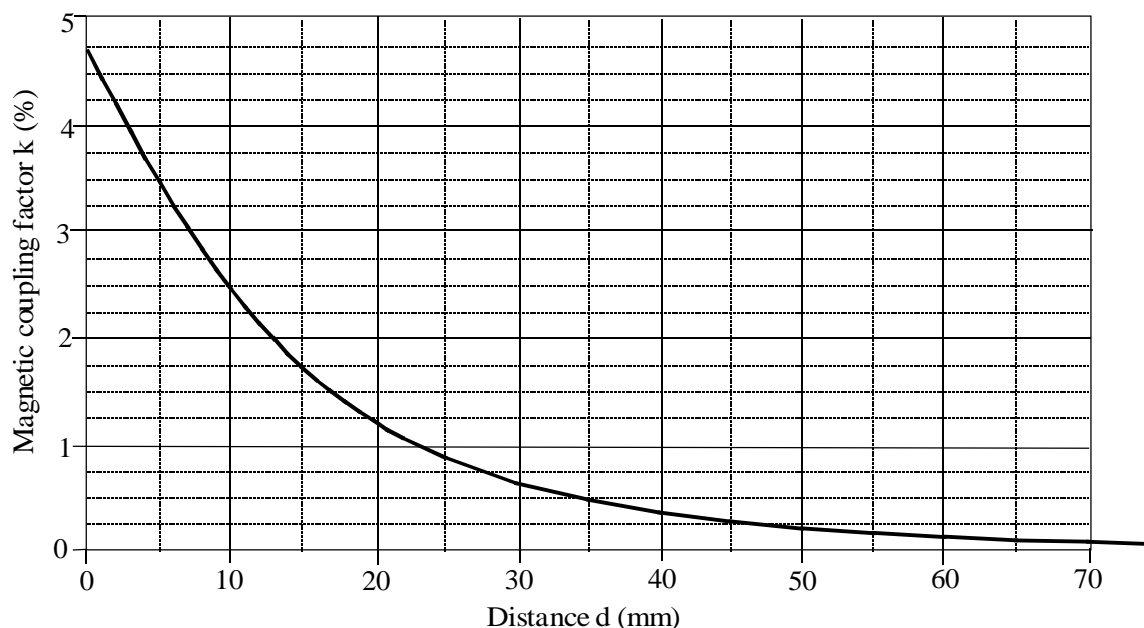


Figure 10. Magnetic coupling factor vs. transmission distance

Table 2. Summary of relevant parameters

Parameter	Design Criteria	Value
Sinusoidal content of the antenna driver voltage	$U_{\text{DRV}} = \frac{4}{\pi} \times U_{\text{DRV pp}}$ $(U_{\text{DRV pp}} = 8.5 \text{ V in differential mode})$	10.8 V (pp)
Q factor of the reader antenna (Q_R)	Fix for most automotive applications See the chapter "General Information"	12
Reader antenna voltage	$U_R = U_{\text{DRV}} \times Q_R$	130 V (pp)
Reader coil radius (r)	Optimized for maximum magnetic coupling factor	20 mm
Reader coil inductance (L_R)	Designed according to the chapter "How to Meet the Actual Frequency Tolerance Situation"	737 μH
Number of turns	$N \approx \sqrt{\frac{L_R}{r \times \pi \times \mu_0}}$	97
Reader antenna capacitance (f_0)	$C_R = \frac{1}{(2 \times \pi \times f_0)^2 \times L_R}$	2.2 nF
Operating frequency	Fixed frequency according to chapter "How to Meet the Actual frequency Tolerance Situation"	125 kHz
Reader coil current	$I_R = \frac{U_R}{2 \times \pi \times f_0 \times L_R}$	224 mA (pp)
Supply current	$I_s = \frac{I_R}{\pi}$	72 mA
Magnetic field strength at d = 20 mm and $f_0 = 125 \text{ kHz}$	$H = \frac{U_R}{4 \times \pi \times f_0 \times \sqrt{\pi \times \mu_0}} \times \frac{1}{\sqrt{L_R}} \times \left(\frac{r}{r^2 + d^2} \right)^{1.5}$ $H = \frac{N \times I}{2 \times r \times \left(\frac{d^2}{r^2} + 1 \right)^{1.5}}$	$192 \frac{\text{A}}{\text{m}}$ (pp)