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„RFID Made Easy“

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Contents

Abstract

This Application Note gives you a introduction on the design and use of Radio Frequency Identification (RFID) applications. It reflects current RFID technologies as well as RF theory and RF system design basics.

Having read "RFID Made Easy" you should be able to select the desired transponder. Furthermore the design of a basic reader can be realized.

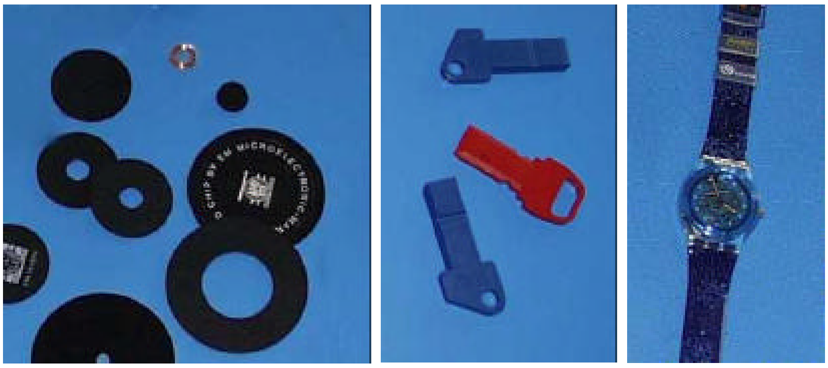
1 Introduction

The recent years showed an immense increase in quantity of Radio Frequency Identification (RFID) semiconductors such as transponders and transceiver circuits. Many system house companies with main forces in software or hardware design become more interested in that new technology. The high integration of RFID circuits allows a relativly easy implementation into any customer specific application. Nevertheless You will need some basic knowledge of RF theory to achieve the maximum performance in your system.

The aim of this RFID Design Guide is to give you the relevant guidelines for your design using standard integrated circuits.

1.1 EM Microelectronic-Marin SA transponder systems

The Contactless Identification activity began in 1989 and today comprises some 50 products in production, which are used in a huge quantity of application like Access Control, Animal Identification, Car Immobilization, Laundry Tagging, Logistic, Sports Performance etc [Bibliography B4].



a) b) c)

a) Transponders packed as disks
b) Transponders in keys
c) A transponder packed in a wrist-watch

EM-Marin' s know-how in RFIDs lays in its Ultra Low Power Technology, allowing Analog & Logical Structures, ROM and EEPROM Memories to be combined on the same chip [B6]. Thanks to this know-how acquired over the years, EM-Marin has been able to develop circuits for all ranges of frequency, Read Only circuits as well as Read / Write, ASIC or Standard Products.

The Standard Products are shown below:

Transponder Circuits :

H4001 :
- Operating frequency 100 - 150 kHz
- 64 bit memory array laser programmed
- Long reading distance

H4003 :
- Operating frequency 100 - 150 kHz
- 64 bit memory array laser programmed
- High speed option 2 to 5MHz
- On chip resonance capacitor 170pF±3%

H4006 :
- Operating frequency 13.56MHz
- 64+16 CRC bit laser memory array
- Miller encoding
- 94.5 pF ± 2% on chip Resonant Capacitor
- Optional Data Rate

P4022 :
- Supertag™ anticollision protocol
- Frequency independant
- 64 bit laser memory array

P4069 :
- 128 bit EEPROM
- OTP feature convert EEPROM words in Read Only
- 64 bit fixed code memory array laser programmed
- Data encoding : Manchester or Bi-phase
- Transmission reader to chip : 65% AM modulation
- Data rate : 2 or 4 Kbaud
- 75pF on chip Resonance Capacitor
- 100 to 150 KHz frequency range

H4002 :
- Operating frequency 100 - 150 kHz
- 64 bit memory array laser programmed
- On chip resonance capacitor 50pF

H4005 :
- Operating frequency 100 - 150 kHz
- 128 bit memory array laser programmed
- Bit coding according to ISO FDX-B
- On chip resonance capacitor 75pF

H4100 :
- Operating frequency 100 - 150 kHz
- 64 bit memory array laser programmed
- Manchester, Bi-Phase or PSK modulation
- On chip resonance capacitor 75pF
- Optional Data Rate

V4050 / P4150 :
- 1 KBit of EEPROM
- 32 bit Device Serial Number (Laser ROM)
- 32 bit Device Identification (Laser ROM)
- User defined Password
- User defined Read Memory Area at Power On
- User defined Write Inhibited Memory Area
- User defined Read Protected Memory Area
- 170 pF ± 2% on chip Resonant Capacitor
- On chip Rectifier and Voltage Limiter

A Transceiver Circuit :

P4092 :
- PLL which adapts carrier frequency to antenna resonant frequency
- No external quartz required
- 100 to 150KHz carrier frequency range
- Data transmission performed by Amplitude Modulation
- Multiple transponder protocol compatibility (H400X and V4050)
- Higher harmonics of frequency carrier for µC synchronization
- Sleep mode 1µA
- Antenna short circuit detection

Under development.

Table 1-1: EM-Marin Standard Products

1.2 Future trends in transponder systems

What will bring us the future in RFID? There are three main topics, where a constant improvement is taking place:

- Design and Technology
- Manufacturing methods
- Frequency spectrum allocation

The low power design is a master key to low price RFID chip production. With smaller structures the surface of the chip and the power can be reduced. Smaller chip surfaces will bring new assembly technologies, such as flip-chip technology. Working with higher frequencies such as 13.56MHz or higher will reduce the number of turns of the antenna, as well as the resonance capacity. Furthermore the data transmission rate can be increased. With higher frequencies, longer reading ranges occur. Thus, Multitag applications will become more important. Tradefares like Scantech are always presenting trendsetting products [Appendix A5].

EM-Marin will be able to profit from its 10 years experience in RFID chip-design and manufacturing.

1.3 *Frequency spectrum*

RFID systems are regarded as radio emitting devices and therefore the international an domestic radio regulations are relevant. This means that the frequency selection is restricted to a number of fixed frequency bands. The most common frequencies used are 0... 135kHz, 400kHz, 6.78MHz, 13.56MHz, 27.125MHz, 40.68MHz, 433.29MHz, 869MHz, 915MHz, 2.45GHz, 5.8GHz and 24.125GHz [B3]. Frequencies are divided in the following ranges:

Freq. Range [Hz]	Wavelength λ [m]	Name	Abbr.
3 ... 300	10^8 ... 10^6	extremely low freq.	ELF
300 ... 3k	10^6 ... 10^5	ultra low frequency	ULF
3k ... 30k	10^5 ... 10^4	very low frequency	VLF
30k ... 300k	10^4 ... 10^3	low frequency	LF
300k ... 3M	10^3 ... 10^2	medium frequency	MF
3M ... 30M	10^2 ... 10^1	high frequency	HF
30M ... 300M	10^1 ... 10^0	very high frequency	VHF
300M ... 3G	10^0 ... 10^{-1}	ultra high frequency	UHF
3G ... 30G	10^{-1} ... 10^{-2}	super high frequency	SHF
30G ... 3000G	10^{-2} ... 10^{-4}	extremely high freq.	EHF

Table 1-2: Nomalized Frequency Ranges [B1]

In the US the 420MHz... 460MHz band was not favoured but therefore the 315MHz and 902MHz... 928MHz bands have been allocated. Due to the restricted use of this band for GSM mobile phones European regulations offered an appropriate frequency at 869MHz. The International Telecommunications Union (ITU), a Suborganisation of the United Nation Organisation situated in Geneva aims to harmonize these frequences worldwide [A1].

The maximum power allowed in the EU is 0.5 W_{ERP}. A tag at 0.5 W_{ERP} at UHF has a working range of about 30cm. 0.5 W_{ERP} is about 50'000 times below health reference level.

Relevant regulations concerning RFID sysstem are the ETSI standards EN 300220, EN 300330, EN 300440 and the EMC regulation EN 300683 [A3]. Based on those regulations CEPT introduced ERC 70-03 in 1997, which is now relevant for national regulations.

Frequency	**125 kHz**	**13.56 MHz**
Data rate	500 bit/s... 8 kbit/s	500 bit/s... 106 kbit/s
Coil windings	40... 300	1... 10
Reading distance	dependent of reader design	dependent of reader design
Anticollision	< 10 tags/s	< 50 tags/s
Security	independent of frequency	independent of frequency
Regulations	EN 300330 1)	EN 300330 1)

1) see also FCC PART 15: RADIO FREQUENCY DEVICES [A4].

Table 1-3: RFID system comparison

2 System principles

The following chapter is an introduction to the electromagnetic field theory that is used to design your RFID application. Most examples are calculated with a working frequency of f= 125kHz. Of course the theory covers also higher frequencies, but parasitic effects will be more delicate.

2.1 System setup

A basic RFID system setup consists of three parts:

- a single or multiple identification labels (transponders or tags),
- a transceiver interface, to communicate between the uC and the transponder,
- a data processing unit, such as a microcontroller.

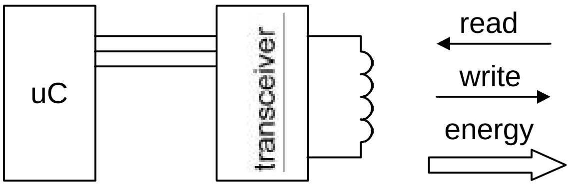


Figure 2-1: Basic RFID system setup

The reader (transceiver) is usually a fix mounted system, whereas the transponder is the moving part, e.g. in acces control, or animal tagging. The reader and the transponder are working as a wireless, magnetic coupled communication system, each with a resonance circuit tuned to the frequency as close as possible. The reader provides energy to the transponder by an electromagnetic field. By modulating this field, the reader can transmit (write) data to the transponder. The transponder will power up and return its on-chip data to the reader.

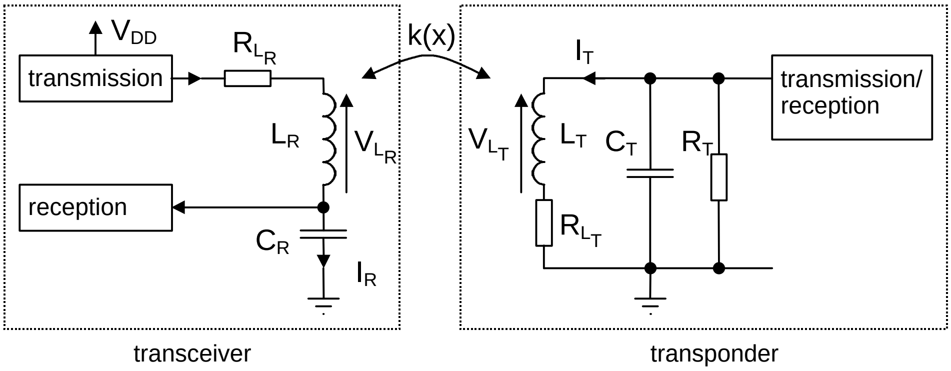


Figure 2-2: RFID system frontend [B4]

The above figure shows the more detailed analog front-ends of the transceiver and the transponder. Both circuits have to be tuned on a resonance frequency e.g. f= 125kHz. The reader is working in series resonance, the transponder with a parallel resonance circuit.

2.2 Electromagnetic field theory

Today, most common transponders are magnetically coupled devices. As we know, a magnetic field can be devided in a near (proximity) field and a far field. Inductive coupling is only possible in the near field. The communication range

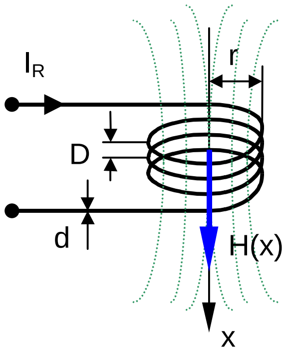
$$r_x \leq \frac{l}{2p} \qquad [m] \tag{1}$$

represents the physical limit of the working range, while the wavelength is

$$l = \frac{c}{f} \qquad [m] \tag{2}$$

and c=299.79km/s and f the magnetic field frequency.

To set up a proximity electromagnetic field (EF) usually a circular loop antenna wound of a numerous turns of fine wire is used. The reader antenna emits an EF of the strength H(x).



$$H_R(x) = \frac{I_R N_R r_R^2}{2\left(r_R^2 + x^2\right)^{3/2}} \qquad [\frac{A}{m}] \tag{3}$$

Figure 2-3: A short cylindric coil

Now we aim to optimize the reader antenna to a given reading range. We can see that the EF strength is maximized when the following setup is given:

$$r_R \cong \sqrt{2} \cdot x \qquad [m] \tag{4}$$

In other words, r_R has to be approximitely 40% bigger than the desired reading range x. This effect can mathematically be shown by derivating (3) with respect to the radius r_R.

The next figure shows where the maximum EF strength H as a function of the loop antenna radius r_R with a fixed distance x to the transponder antenna can be found.

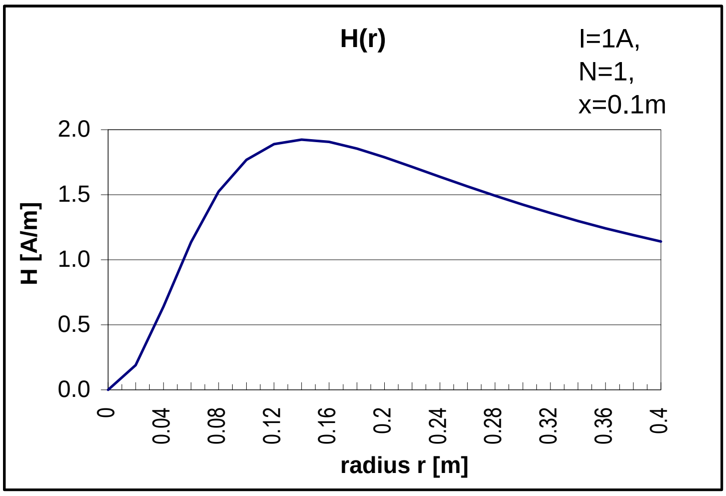


Figure 2-4: The magnetic field strength H(r)

If you are designing the antenna of the reader, consider that you match the desired minimum H_{min} of the transponder.
The next illustration shows the EF strength for different loop antenna diameters as a function of the reading distance x.

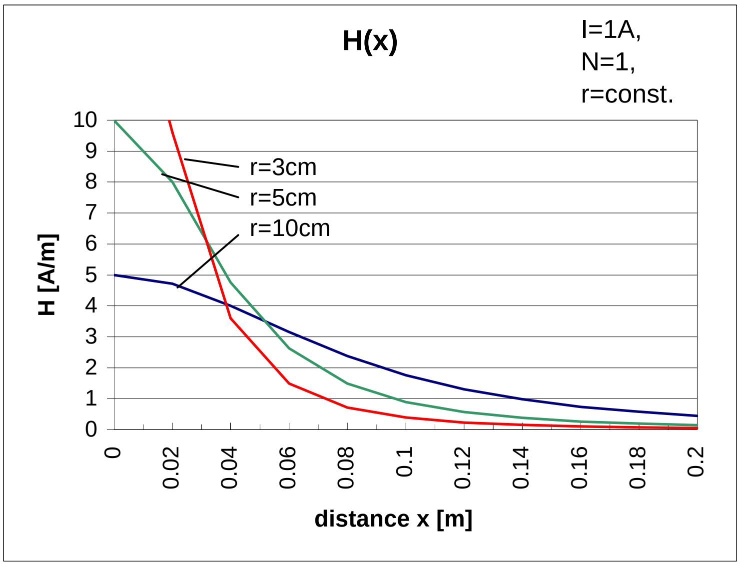


Figure 2-5: Normalized H(x) with three different reader antenna diameters

Fig. 2-5 visualizes the effect, that H(x) is falling faster by decreasing the reader antenna radius.

2.3 *Magnetic field and inductivity*

This chapter discribes the calculation of the inductivity L of a certain antenna. The inductivity is basically a pure issue of material and geometry.

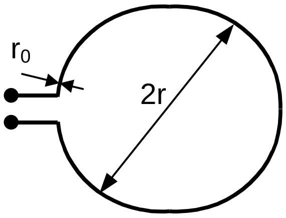
By using Biot-Savart the flux density B is given by

$$B_R(x) = m \cdot H = \frac{m \cdot I_R N_R r_R^2}{2\left(r_R^2 + x^2\right)^{3/2}} \qquad [\frac{Vs}{m^2} = T] \tag{5}$$

Knowing that the magnetic flux is

$$\Phi = \frac{L \cdot I}{N} = B \cdot A \qquad [Vs] \tag{6}$$

we aim to isolate the inductivity L. For most RFID applications a circular reader coil will be used and therefore the simple formula, where the factor 1.9 in formula (7) is given by experiance [B2]:



$$L = m_0 \cdot N^{1.9} \cdot r \cdot \ln\left(\frac{r}{r_0}\right) \qquad [\frac{Vs}{A} = H] \tag{7}$$

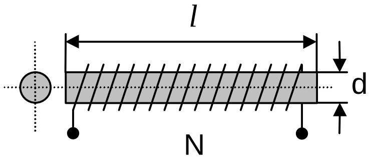
$$\frac{r_0}{2r} << 0.7 \tag{8}$$

The magnetic field constant is

$$m_0 = 4 \cdot p \cdot 10^{-7} \qquad [\frac{Vs}{Am}] \tag{9}$$

For RFID applications the reader antenna inductivity L is usually in the range of 350μH... 500μH. These values fit well for with transponders using flat circular or square air coils, such as credit card and acces applications.

Other forms of antennas exist, such as the ferrite core antenna with a varying directional performance. Such antennas may be required in applications like immobilizers, where the overall tag volume must be respected to a given distance performance in a system with fixed geometry. An appropriate formula for such coils is:



$$L = \frac{m_0 \cdot m_r \cdot p \cdot N^2 \cdot d^2}{4 \cdot l} \qquad [H] \tag{10}$$

Where μ_r represents the permeability of the ferromagnetic material, which is a 2'000 and more, depending on the material.

As shown above, the antenna inductivity can be evaluated with practical formulas. As they are empirical, they will only give you an approximate value, which means, that you have to measure the antenna and adjust the value.

2.4 *Transformer principles and magnetic coupling*

This chapter aims to calculate the coupling factor k of an RFID system. The coupling factor is a major key to a proper working RFID application.

As we saw before, RFID applications with passive transponders are used in close coupling (proximity field) mode. Therefore the transformer theory will help to calculate the necessary parameters.

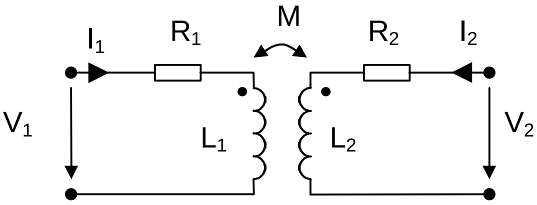


Figure 2-6: Transformer model

$$V_1 = I_1(R_1 + jwL_1) + I_2 jwM \qquad [V] \tag{11}$$

$$V_2 = I_2(R_2 + jwL_2) + I_1 jwM \qquad [V] \tag{12}$$

M is the mutual inductivity of the transformer and k represents the magnetic coupling factor.

$$M = k\sqrt{(L_1 \cdot L_2} \qquad [H] \tag{13}$$

We aim to determine k as only dependent of pure geometric parameters. We need further the induced voltage in a coil if entered in an EF.

$$v = N\frac{d\Phi}{dt} = -N \cdot B \cdot A \cdot w \cdot \sin(w \cdot t) \qquad [V] \tag{14}$$

Combining (5), (9), (10), (11) and (12) we get the magnetic coupling factor between the reader and the transponder antennas. The angle *q= 0* if both antennas are in parallel.

$$k = \frac{r_R^2 \cdot r_T^2 \cdot \cos(q)}{\sqrt{r_R \cdot r_T} \cdot \left(r_R^2 + x^2\right)^{3/2}} \qquad [1] \tag{15}$$

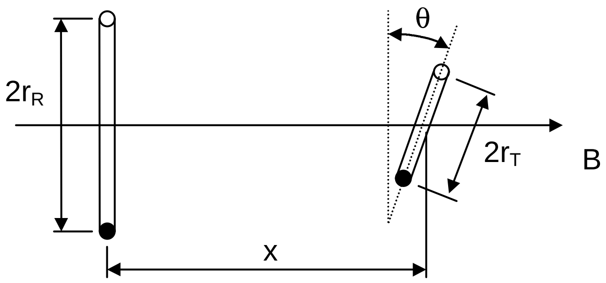


Figure 2-7: Parameters influencing the coupling factor k

The coupling factor is a major key to a proper working RFID application. The best system performance will be achieved with k=1. Thus, studying (15) closer, we can see, that k can be maximized by:

- *Minimizing q between both antennas*. If the transponder is moving and has not a fixed position like in application such as sports or animal tagging, this parameter is especially sensitive.
- *Matching the sizes of the antenna areas*. The coupling factor can be maximized if both antennas have the same area.
- *Minimizing the reading-distance x*. As closer the transponder to the reader is, as better is the coupling between the antennas.

The following figure shows the coupling factor falling with rising distance x:

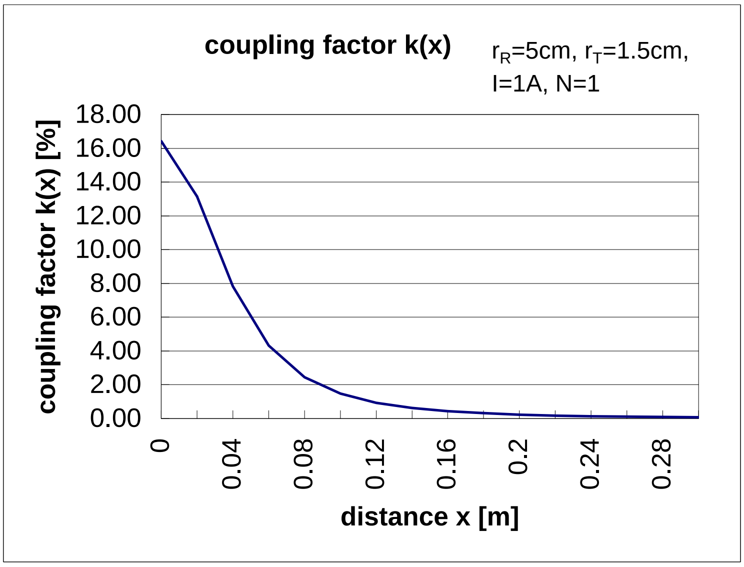


Figure 2-8: Magnetic coupling factor k for a fixed antenna setup

To summarize we notice, that the coupling factor k is simply a geometrical parameter, not influenced by any electrical values.

2.5 Quality factor, phase shift and bandwith

As well as the coupling factor we just discussed before, the quality factor Q of the reader antenna is a key parameter to a good RFID system performance. The selection of an appropriate quality factor Q has influence on:

- the reading distance,
- the antenna damping and
- the reception bandwith.

Firstly, the quality factor can be calculated by:

$$Q = \frac{f_0}{\Delta f} \qquad [1] \tag{16}$$

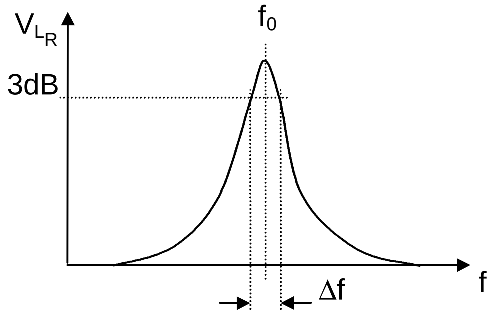


Figure 2-9: Series resonance curve

Secondly, the quality factor Q can also be expressed by circuit parameters of the reader antenna setup.

$$Q_R = \frac{2 \cdot p \cdot f_0 \cdot L_R}{R_{L_R}} \qquad [1] \tag{17}$$

Furthermore the resonance voltage at the coil is:

$$V_{L\,R} = Q \cdot \frac{2 \cdot V_{DD}}{p} \qquad [V] \tag{18}$$

For this reason we can measure 50V ... 100V at the reader antenna, depending on what quality factor Q and supply voltage V_{DD} we choose.

The following step will be, to optimize the transmission parameters of the „transformer system“. To design the as big as nescessary, not as possible, we proceed as followed:

$$V_{LT} = V_{LR} \cdot Q_T \cdot k \cdot \sqrt{\frac{L_T}{L_R}} \cdot \cos(j) \qquad [V] \qquad (19)$$

The minimum voltage V_T desired by the transponder can be found in the datasheet of the chosen transponder. But it is usually limited by clamping diodes to a value of V_{Tmax}= 18V_{pp}.

Now as we have two independent resonant circuits, running as a series resonance (reader) and a parallel resoncance (transponder) it can occur, that they are not exactly tuned to the desired frequency. Reasons may mostly be:

- Temperature effects and
- Component (L, R, C) tolerancies.

To imagine the influence of some percents of drift the following formula was visualized [B2]:

$$j = -\left[\arctan Q_R \cdot (\Omega - \frac{1}{\Omega})\right] \cdot \frac{180}{p} \qquad [°] \qquad (20)$$

$$\Omega = \frac{f_T}{f_R} \qquad [-]$$

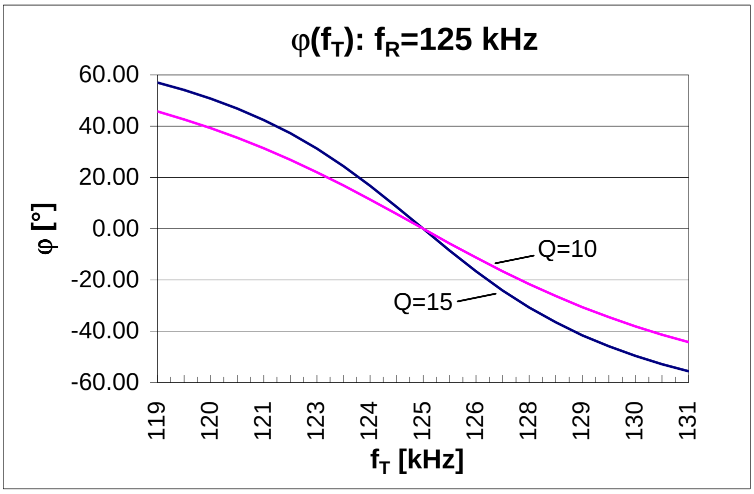


Figure 2-10: Phase shift φ between two resonant circuits

If φ becomes 90° the transmitted transpondersignal is beeing cancelled. No signal can be detected therefore. To avoid such effects, precise components, especially capacitors should be used. Furthermore the quality factor Q should be held as low as possible, as you can see in (20).

Finally, we want to have a look at the reception bandwith of the reader [B5].
The transponder mostly receives its commands by a AM signal generated by the reader. Often, the modulation index of the AM is 1 or 100%. Considering a communication data rate of 2kbit/s generates the typical sidebands of 125kHz ± 2kHz.
The selection of an appropriate quality factor, as dicussed before in this chapter and the limitation of the communication bandwith can be visualized in the following figure.

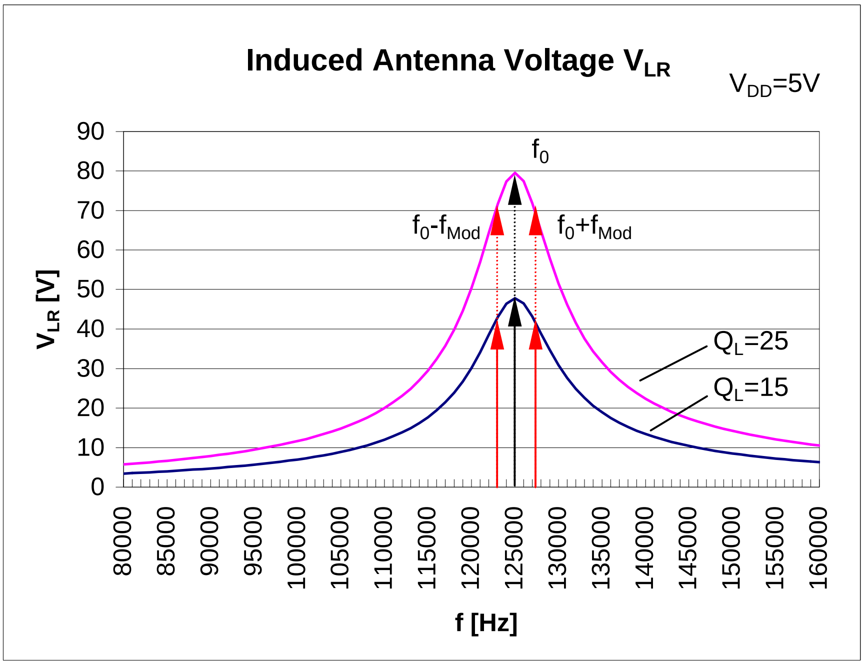


Figure 2-11: Induced antenna voltage

Figure 2-11 shows the induced voltage on the reader antenna for two different quality factors. Rising Q is mostly limited by component and temperature tolerances. Thus, tuning becomes more critical with a higher Q.

Once again the following guidelines should be considered:

- maximize the coupling factor k.
- maximize the reader qulitiy factor Q_R, as much as it the transponder data bandwith and the reader antenna drivers permit.
- maximize the transponder qulitiy factor Q_T.
- maximize the transponder inductivity L_T.

3 Antenna desgin

This chapter describes how to design your reader or transponder antenna. Antenna coils can be configured in many different ways. It mostly depends on the purpose of the application and the constraints given by the mechanical setup (i.e. car immobilizer or handheld reader). Usually thin wire is used for antennas at 125kHz, with about 40 turns and more. For 13.56MHz often printed circuit boards or thin film technology is used to place one to about seven turns. At frequencies in the microwave range, such as 2.45GHz, antennas are commonly designed as dipoles, according to the corresponding wavelength.

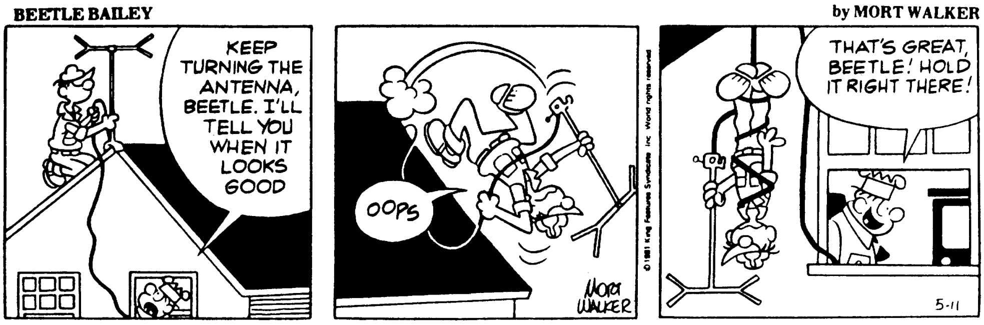


Figure 3-1: Siting an antenna system

Thus, although this is not quite an orthodox method, it has some practicability. Of course there are more appropriate ways to setup the antenna and the analog frontend in RFID applications. Therefore the following guidelines will help to design your system more efficiently.

As we have seen in the precedent chapters, there are several parameter to take in account, while designing an RFID application. We have to find a compromise between e.g. the quality factor Q_R at the reader and the induced voltage at the transponder. Designing an RFID application is a recursive procedure. Once the resonance frequency is fixed, the following diagram can be taken as a guideline. Nevertheless it is an iterative procedure:

Step:	Action:	param. given:	param. to calculate:
1	determine a transponder (e.g. H4001). 1)	V_{Tmin}, r_T, L_T, N_T, Q_T	R_T
2	fix the mechanical parameters.	r_R	H_{min}, B_{min}
3	determine the inductivity and the quality factor of the reader ant.	L_R, Q_R	R_{L_R}, N_R
4a	either you fix the max. reader current.	I_R	x, R_R
4b	or you try to maximize the distance. remember the formula (4).	x	I_R, R_R

1) Usually the transponder is a complet set of the chip and the antenna and resonance capacitor. Therefore mechanical and electrical parameters, such as the antenna diameter, the quality factor etc. are given.

Table 3-1: Design flow procedure

3.1 General resonant circuit parameters

As mentioned earlier, RFID data and energy transmission is based on magnetically coupled resonance circuits.

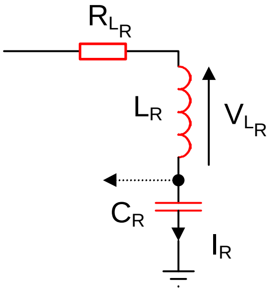


Figure 3-2: Series resonance circuit at the reader side

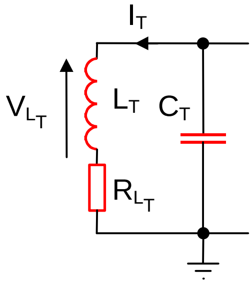


Figure 3-3: Parallel resonance circuit at the transponder side

Mathematically can be shown, that in a resonance circuit we have

$$w_0^2 \cdot L \cdot C = 1 \qquad [1] \tag{21}$$

and therefore the resonance frequency will be:

$$f_0 = \frac{1}{2 \cdot p \cdot \sqrt{L \cdot C}} \qquad [Hz = s^{-1}] \tag{22}$$

To become more specific on each resonance circuit, basic formulas for each case are shown below [2]:

Series resonance		**Parallel resonance**	
$R_S = \frac{V_S}{I_S} \quad [\Omega]$	(23)	$G_P = \frac{I_P}{V_P} \quad [S = \frac{A}{V}]$	(26)
$Z_S = \sqrt{\frac{L_S}{C_S}} = w_S \cdot L_S \quad [\Omega]$	(24)	$Y_P = \sqrt{\frac{C_P}{L_P}} = w_P \cdot C_P \quad [S]$	(27)
$Q_S = \frac{Z_S}{R_S} = \frac{1}{R_S} \cdot \sqrt{\frac{L_S}{C_S}} \quad [1]$	(25)	$Q_P = \frac{Y_P}{G_P} = \frac{1}{G_P} \cdot \sqrt{\frac{C_P}{L_P}} \quad [1]$	(28)

While Q_S is the multiplying factor for the generator voltage, Q_P is the factor for the current.

Here we remember (14), (18) and combining them with (28), hence we get the induced voltage at the transponder coil:

$$V_T = Q_T \cdot N_T \cdot B \cdot A_T \cdot w_T \cdot \cos(q) \qquad [V] \tag{29}$$

q is still the angle between both antennas, according to Figure 2-7, and *cos(q) =1* if they are in parallel.

Using desing flow procedure from Table 3-1, we can now calculate a complete system.

Example 3-1:
For a given transponder coil, we want to calculate the miminum magnetic flux density B_{min}. Considering the following transponder parameters as given:

f_0 =	125kHz	frequency
L_T =	9.5mH	inductivity
R_T =	480Ω	coil resistance
N_T =	433	number of turns
d_T =	27mm	coil diameter, circular shaped
V_{Tmin} =	3.5V_{PP} *(e.g. H4001)*	minimum voltage at transponder
θ =	0°	angle between antennas

$$B_{\min} = \frac{V_{T_{PP}}}{Q_T \cdot N_T \cdot A_T \cdot w_T \cdot \cos(q)} \qquad [T] \tag{30}$$

$$Q_T = \frac{w_T \cdot L_T}{R_T} = \frac{2p \cdot 125kHz \cdot 9.5mH}{480\Omega} = \underline{15.54}$$

$$A_T = \frac{d_T^2 \cdot p}{4} = \frac{(27mm)^2 \cdot p}{4} = \underline{0.57 \cdot 10^{-3} m^2}$$

$$B_{\min} = \frac{3.5V_{PP}}{15.5 \cdot 433 \cdot 0.57 \cdot 10^{-3} m^2 \cdot 2p \cdot 125kHz \cdot \cos(0)} = 1.17 \underline{\underline{\frac{mV_{PP}}{m^2}}}$$

3.2 Antenna parameters

Supposing the mechanical dimensions for the reader antenna in an application are given. The required B-field from Example 3-1 can be taken for that specific transponder. There are two parameters of interest, depending on the application requirements, either the current I_R or the distance x.

Combining (5) and (30) result in:

$$I_R(x) = \frac{2B_{\min} \cdot \left(r_R^2 + x^2\right)^{3/2}}{m_0 \cdot N_R \cdot r_R^2} \qquad [A] \tag{31}$$

or in:

$$x(I_R) = \sqrt{\left(\frac{I_R \cdot m_0 \cdot N_R \cdot r_R^2}{2B_{\min}}\right)^{2/3} - r_R^2} \qquad [m] \tag{32}$$

Example 3-2:
Using the values from Example 3-1, the necessary parameters for the reader can be calculated now:

f_0 =	125kHz	frequency
L_T =	9.5mH	inductivity
R_T =	480Ω	coil resistance
N_T =	433	number of turns
d_T =	27mm	coil diameter, circular shaped
V_{Tmin} =	3.5V_{PP} *(e.g. H4001)*	minimum voltage at transponder
θ =	0°	angle between antennas
V_{DD} =	5V	reader supply voltage (DC)
r_R =	3cm	reader antenna radius
r_0 =	0.2mm	reader antenna wire (initial value)
L_R =	400uH	reader antenna inductivity
I_{R_P} =	100mA	reader antenna current amplitude
Q_R =	15	reader antenna quality factor

The number of turns of the reader coil can be calculated:

$$N_R = \left(\frac{400mH}{4p \cdot 10^{-7} \cdot 30 \cdot 10^{-3} m \cdot \ln\left(\frac{30 \cdot 10^{-3}}{0.1 \cdot 10^{-3}} \right)} \right)^{1/1.9} = \underline{52.6}$$

We take $\underline{N_R=53}$.

$$V_{LR} = \frac{2 \cdot Q_R \cdot V_{DD}}{p} = \frac{2 \cdot 15 \cdot 5V}{p} = \underline{47.7V}$$

The coupling factor k(x) is either valuated by (15), or it can be measured in-system as:

$$k(x) = \frac{V_T}{V_R} \cdot \sqrt{\frac{L_R}{L_T}} \qquad [1] \qquad (33)$$

As the coupling factor We consider both resonance circuits tuned to the exact frequency, then the the signal phase between both circuits will be *j=0* and the voltage at the transponder according to (33) and taking *k=0.1*:

$$V_T = 5V \cdot \frac{4}{p} \cdot 15 \cdot 0.1 \cdot \sqrt{\frac{9.5mH}{400mH}} = \underline{46.6V}$$

Finally, the total resistance at the reader R_R is beeing the sum of all partial resistances, such as:

- driver resistance
- contact resistance at the antenna
- copper resistance

Therefore the maximum current can be drawn, if [4]:

$$I_R(x) = \frac{V_{DD}}{R_R + w_R \cdot L_R \cdot k^2(x)} \qquad [A] \qquad (34)$$

Calculating an RFID system is quite an iterative process. Once You have calculated a system, build it up, measure and compare these values with the calculation results.

Mostly, You will spend a nice piece of time tuning your antenna setup to assure, it will not only run on your prototype but also in the production series. Practical tips can be found in the next chapter.

3.3 Antenna fine tuning

Having built the RFID reader, you will have to tune the system due to component tolerances, temperature effects etc. A very efficient way to tune the resonance circuit, even while the system is running is, by displaying the resonance voltage on a simple oscilloscope. As shown in the following figure, resonance is reached, if the leap on the sinewave is exactly at the maximum/minimum. The lower trace shows V_{Drv}, the output stage of the reader:

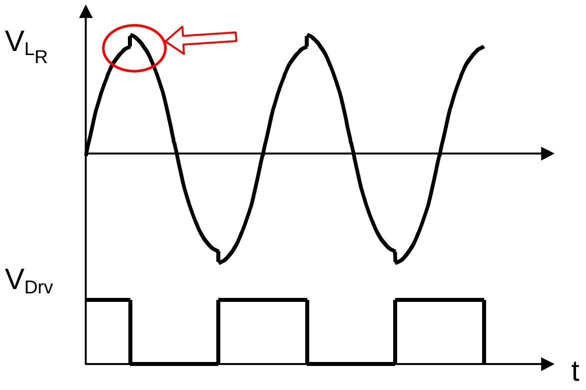


Figure 3-2: Tuning the resonance circuit

The tuning can be done by either changing the capacitor or the inductivity.

Another possibility of circuit tuning offers a comfortable spectrum analyzer. Thus, there is no need to tune the system while its running. It suits well for series production tests.

4 Data Coding/Encoding

4.1 *Data Modulation*

Transmitter (Tag)

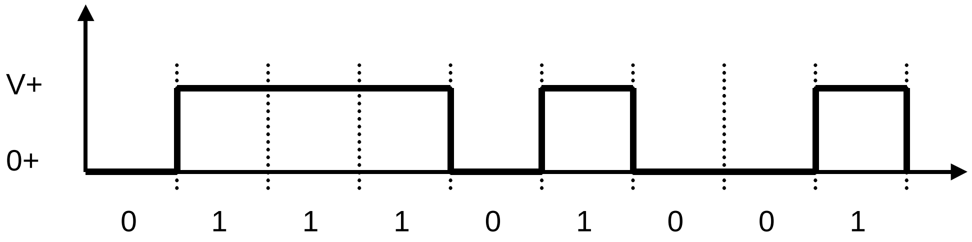
The tag is responsible for 'encoding' i.e inserting clocks into the datastream according to a select coding scheme.

Receiver (Reader)

Receiver is responsible for 'decoding' i.e. separating clocks and data from the incoming embedded datastream.

4.1.1 Non-return to Zero Modulation (NRZ)

Description



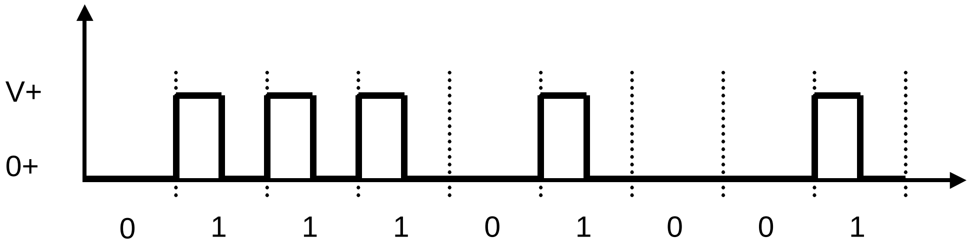
Low level = 0V
High level = +V

For each bit, there are n clocks (data rate).

- Requires time coordination: Longs strings of '0' and '1' do not produce any transitions which may create problems in error detection and recovery.
- High DC level (average of ½ Volts).

4.1.2 Return to Zero Modulation (RZ)

Description



Low level = 0V
High level = +V during the first half of the bit and 0 during the second half.

- DC average is only ¼ Volts.
- Requires time coordination

4.2 *Biphase Coding*

Biphased data streams have gererally a signal change in the middle of each bit, independant of the value. Therefore the signal does not necessarily return to zero.

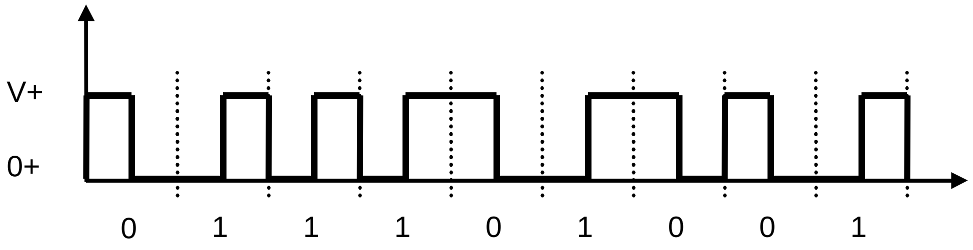
The advantages of the biphase method are:

- *Synchronisation*: Since there is a predictable transition for each bit, the receiver can synchronize on this edge. These codes are also known as *self-clocking*.
- *Error immunity*: To cause an error, the noise must invert both, the signal before and after the transition.

4.2.1 Manchester Coding

This code is self-clocking

- There is a *transition in the middle* of each bit period
- *A 1 to 0 transition* represents a '0' bit
- *A 0 to 1 transition* represents a '1' bit



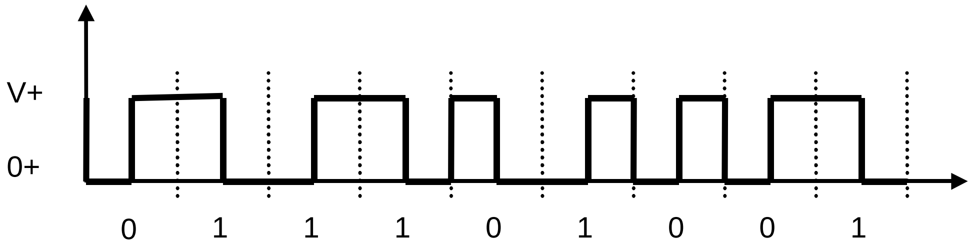
The mid-bit transition is used as clock as well as data.

- The residual DC value is eliminated by having both polarities for every bit
- The bandwith required could be twice the bit rate (Efficiency of this code can be as low as 50%)

4.2.2 Differential Manchester Coding

This code is self-clocking

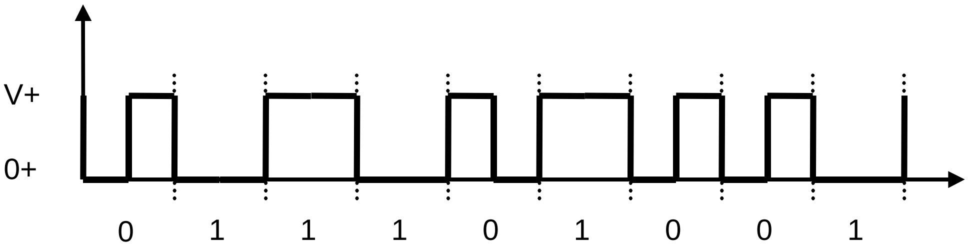
- There is a *transition in the middle* of each bit period
- *A transition at the start* of the bit period represents a '0' bit
- *No transition at the start* of the bit period represents a '1' bit



The mid-bit transition is used only to provide clocking.

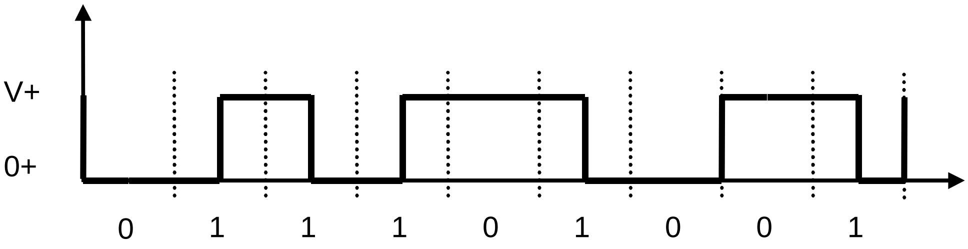
4.2.3 Differential Biphase Coding

- There is a *transition at the start* of each bit period
- *A '0' bit has generally a transition* in the middle of the bit period (pos. or neg.)
- *A '1' has no transition* in the middle of the bit period



4.3 Miller Coding

- There is a transition in the middle of a bit period, if it is a bit '1'
- There is no transition at the start of the bit period, if the bit is '0', followed by a '1' bit
- There is a transition at the start of the bit period, if the bit '0' is followed by a '0' bit



This code is very efficient, regarding the desired bandwith (half of the desired bandwith of Manchester Coding).

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Glossary

Anticollision	Ability of an RFID system to avoid data collision of multiple transponders in the electromagnetic field of a single reader.
Keying	Keying means turning a transmitter on and off.
Reader	device or system to read the identification code of a Read-Only transponder or to program and read a Read/Write transponder.
RFID	Radio Frequency Identification.
Tag	Packed, embedded transponder. Also referred to as data carrier, label, RFID-card, identifier.
Transponder	Subassembly consisting at least of an antenna and a semiconductor, containing the desired functionality. Further components, such as capacitors, diodes etc. may be required to complete the resonant circuit or provide other elements like voltage limitations etc.

θ	deg.	Angle between the reader and the transponder antenna.
μ_r	-	Permeability of ferromagnetic materials.
A	m^2	Antenna surface.
B	T	Magnetic flux density.
C_R	F	Capacity of the reader resonance circuit.
C_T	F	Capacity of the transponder resonance circuit.
f_0	Hz	Resonance frequency.
GND	V	Power supply ground.
H	A/m	Electromagnetic field strength
I_R	A	Reader antenna current.
I_T	A	Transponder antenna current.
k	-	Coupling factor of between two antennas.
L_R	H	Reader antenna inductivity.
L_T	H	Transponder antenna inductivity.
M	H	Mutual inductivity.
N_R	-	Number of windings of reader antenna.
N_T	-	Number of windings of transponder antenna.
Q_R, Q_S	-	Quality factor of the reader antenna (series resonance).
Q_T, Q_P	-	Quality factor of the transponder antenna (parallel resonance).
r_0	m	Antenna wire radius.
R_{L_R}	Ω	Copper resistance of the reader antenna inductivity.
R_{L_T}	Ω	Copper resistance of the transponder antenna inductivity.
r_R	m	Reader antenna radius.
V_{DD}	V	Power supply voltage at the antenna driver.
V_R	V	Voltage at the reader resonance circuit.
V_T	V	Voltage at the transponder resonance circuit.
x	m	Distance between reader and transponder antenna.
μ_0		Magnetic field constant is $\mu_0 = 4\pi\ 10^{-7}$ A/Vs.
c		The speed of light in vacuum is c= 299.79 km/s.

Appendix

Institutes:

[A1] **International Telecommunication Union (ITU)**
Place des Nations
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Switzerland
Tel.: +41 22 730 51 11
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homepage: http://www.iut.int

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homepage: http://www.iso.ch

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homepage: http://www.fcc.gov

Trade fairs:

[A5] **SCANTECH Europe**
Trade Fare for Automatic Data Capture and Mobile Computing
homepage: http://www.scantech-europe.com

Copper Wire List

Copper wire for diameters 0.020 to 0.530mm1):

diameter d [mm]	surface A [mm^2]	equiv. res. δ [Ω/m]
0.0202)	0.000314	54.88
0.025	0.000491	35.12
0.032	0.000804	21.44
0.036	0.001018	16.94
0.040	0.001257	13.72
0.045	0.001590	10.84
0.050	0.001964	8.781
0.056	0.002463	7.000
0.063	0.003117	5.531
0.071	0.003959	4.355
0.080	0.005027	3.430
0.090	0.006362	2.710
0.100	0.007854	2.195
0.112	0.009852	1.750
0.125	0.01227	1.405
0.132	0.01368	1.260
0.140	0.01539	1.120
0.150	0.01767	0.9756
0.160	0.02011	0.8575
0.170	0.02270	0.7596
0.180	0.02545	0.6775
0.190	0.02835	0.6081
0.200	0.03142	0.5488
0.212	0.03530	0.4884
0.224	0.03941	0.4375
0.236	0.04374	0.3941
0.250	0.04909	0.3512
0.265	0.05515	0.3126
0.280	0.06158	0.2800
0.300	0.07069	0.2439
0.315	0.07793	0.2212
0.335	0.08814	0.1956
0.355	0.09898	0.1742
0.375	0.1104	0.1561
0.400	0.1257	0.1372
0.425	0.1419	0.1215
0.450	0.1590	0.1084
0.475	0.1772	0.09730
0.500	0.1964	0.08781
0.530	0.2206	0.07815

1) by Von Roll-Isola Cable and Wire, Breitenbach, Switzerland.
2) diameters in bold face meet CEI 182-1 recommendation.

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Notes