Extending the analogue performance of integrated

13.56 MHz Proximity reader chips

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ABSTRACT

We demonstrate a practical concept to extend the performance at the air interface of RFID Proximity readers using integrated reader chips. Our solution consists of an external, discrete circuit and we consider the transmit path as well as the receive path. We discuss important aspects for design and evaluate the quality improvement for a specific reader in some relevant characterization measurements.

Keywords: RFID, contactless reader, Proximity, electronic passport (e-PP)

INTRODUCTION

Applications for electronic documents like e-passports, electronic health cards, electronic driving licenses or electronic credit cards create an increasing demand for a contactless technology which is robust, secure and easy to handle. Radio Frequency Identification (RFID) in the 13.56 MHz frequency band is a mature technology, field-proven over more than 15 years, and able to satisfy this need. To give an example, the market expects a volume of up to 50 million contact less credit cards per year for North America only, and the number of e-passports in the field will be 135 millions until end of 2007. Austrian engineers are in the centre of this world-wide development as inventors of this technology. Products have to be compliant to international standards, such as ISO/IEC14443 ("Proximity, Smart Cards"), ISO/IEC15693 ("Vicinity, Smart Labels") and ISO/IEC18092 ("Near Field Communication, NFC").

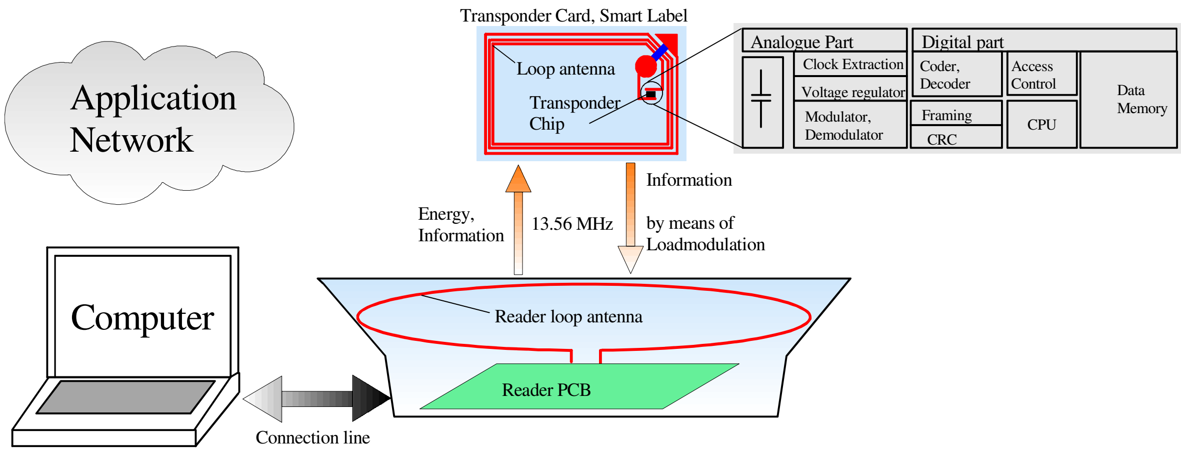

Fig. 1: Proximity RFID System concept.

1. Functionality of 13.56 MHz RFID Systems

An RFID scenario in principle consists of an application in a PC network environment, a standard compliant reader and a transponder card. Seen from the application point of view, the transponder mainly provides a Read/Write data memory, which is used by the application.

A bit more in detail, the process to get access to this memory is the following: When the transponder card comes into the reader operating field, it powers up. The reader then performs an anti-collision procedure to select one specific card out of possibly a number of cards in the reader operating range. Also, the data rates for the following application data transfer are selected out of a number of options for the downlink, which means the communication from reader to card, and for the uplink, meaning card to reader. Not all data rates may be supported either by the reader or the card, only the base data rate is mandatory. Encryption also may be used. All this is specified in the product standard, for example ISO/IEC 14443, which also specifies the underlying modulation concept for the air interface in part 2. The air interface actually is the part of the system which we aim to discuss in detail in this paper.

A transponder chip actually contains much more than just a memory. It is a complete system-on-chip consisting of a digital part for data processing and access control, an operating system of its own and an analogue part, delivering power supply, clock and data interface for the digital part. Also it provides the interface to the loop antenna and an integrated capacitor, to form an LC resonant circuit.

The reader usually consists on an integrated reader chip, a processor, a network interface, some external components and one loop antenna for energy and data transfer by means of inductive coupling. Also the reader antenna is part of a resonant circuit tuned to 13.56 MHz, to increase the antenna current and so to increase the *H*-field, to provide sufficient supply power for the passive transponder card.

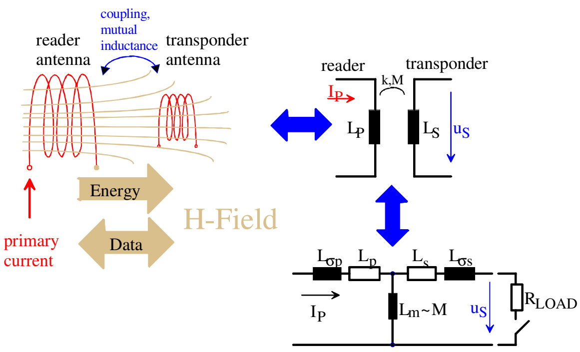

Fig. 2: Air interface principle of inductive coupled RFID Systems [6].

Basically these systems work like transformers. Any change of the load on the secondary side (transponder) results in a variation of the detected voltage on the primary side (reader antenna). The presence of a Transponder Card in principle changes the impedance, resonance frequency and Q-factor of the reader antenna circuit, known as *card loading effect*. The transponder card can also intentionally change the load by switching an additional load resistor on and off, and so change the card Q-factor. This causes the so-called *load modulation* and is used to transmit data from the card to the reader by the inductive coupling. It appears similar to amplitude shift keying, but as it is an external modulation, the modulation index depends on the point in space, where the superposed *H*-fields of reader and card antenna are measured.

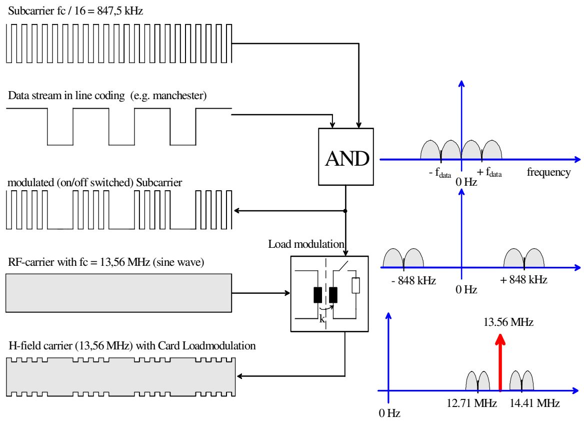

Fig. 3: Data transmission using load-modulation (ISO/IEC 14443, type A).

In the 14443 standard and for the base data rate of 106 kbit/s, the reader uses modified Miller coding of the framed data and modulates the 13.56 MHz *H*-field using ASK with 100 % modulation index (type A) or NRZ coding with ASK of 10 % modulation index (type B). The transponder card responds using Manchester coding of the framed data (type A) or binary phase shift keying (type B) applied on the sub-carrier of 847.5 kHz. The resulting logic-level signal is transmitted to the reader using the principle of load modulation, as shown in fig. 3. This allows to separate the small amplitude of the card load-modulation from the high amplitude of the 13.56 MHz carrier signal on the reader antenna, using filters in the frequency domain.

2. Properties and Leeway for improvement

The magnetic field offers the transmission medium for inductive coupled RFID systems. Thus the field intensity of the magnetic field strength *H* can be calculated by the law of Biot-Savart (1) at any point in space.

$$d\vec{H} = \frac{1}{4\cdot\pi}\cdot\frac{I\cdot d\vec{s}\times\vec{r}}{r^3} \qquad (1)$$

For a circular reader antenna as shown in fig. 4 it is best to use cylindrical coordinates in the (r, Φ) – plane at z = 0 to simplify the desired *H*-field characteristic determinations.

The distance from source to receiving point *P* is given in equation 2:

$$r_{SR}(\Phi, x_R, y_R, z_R)^2 = (x_S + a\cdot\cos(\Phi) - x_R)^2 + (y_S + a\cdot\sin(\Phi) - y_R)^2 + (z_S - z_R)^2 \qquad (2)$$

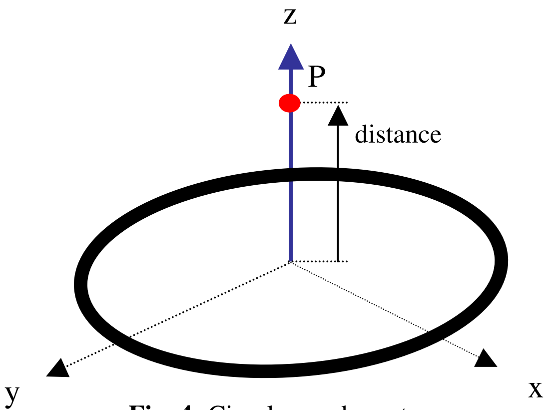

Fig. 4: Circular reader antenna.

Using this derivation the z-component of the H-field can be calculated for any receiver point in space according to

$$H_z(x_R, y_R, z_R) = \frac{I_A \cdot a}{4 \cdot \pi} \cdot \quad (3)$$

$$\int_0^{2\pi} \left\{ \frac{e^{-i \cdot \beta \cdot r_{SR}}}{r_{SR}^{\ 2}} \cdot \left(i \cdot \beta + \frac{1}{r_{SR}} \right) \cdot \left[a + (x_S - x_R) \cdot \cos(\Phi) + (y_S - y_R) \cdot \sin(\Phi) \right] \right\} d\Phi$$

The H_z-field strongly depends on the distance of the point P to the reader antenna. For example an increasing distance z will result in certain decrease of the H-field. A similar decrease will occur when increasing the distance in x or y direction. This behaviour limits the operating distance since a certain threshold value of the magnetic field strength is needed for full functionality. Generally 13.56 MHz proximity RFID systems operate in a range of 10 cm.

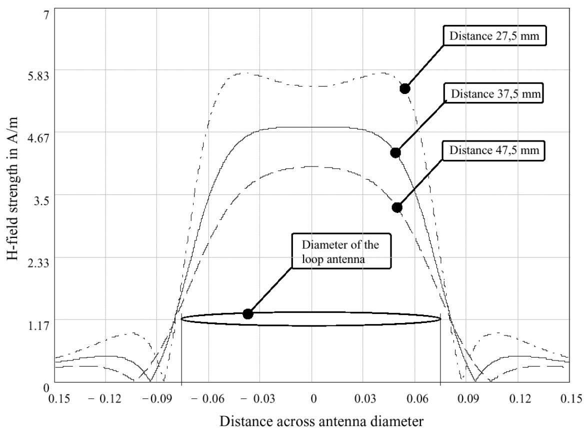

Fig. 5: *H*-field distribution over reader antenna.

As any current, active or reactive, causes an H-field, a reader antenna is operated in a resonant circuit to increase the emitted H-field for a limited driver power. A parameter describing the resonance circuit, the Q-factor of the reader antenna, has a deep impact on the transfer behavior. A higher Q-factor for the reader antenna circuit results in a higher amplitude for the H-field, but it also increases the time constants for modulation pulses. As the antenna and matching circuit (shown in fig. 9) can be seen as a second-order resonant circuit, the signal envelope follows the following relation for the falling (4) and the rising edge (5):

$$u_F(t) = e^{-t \cdot \frac{f_C \cdot 2\pi}{Q}} \quad (4)$$

$$u_R(t) = 1 - e^{-t \cdot \frac{f_C \cdot 2\pi}{Q}} \quad (5)$$

In other words, if the same 100% ASK modulated RF carrier is transmitted trough two reader antennas of different Q-factors, the signals received by the transponder demodulator will have different characteristics. The antenna using a low Q-factor (e.g. Q=20) generates a field of lower strength but therefore just slightly influences the time constants of the pulses used for data transmission.

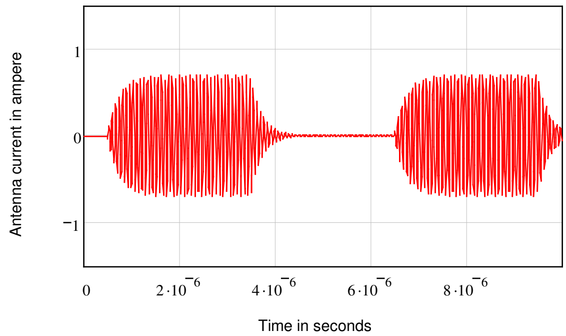

Fig. 6: Downlink data transmission pulses for reader antenna of Q = 20.

The antenna using a higher Q-factor (e.g. Q=60) generates a higher amplitude but therefore time constants for rising and falling edges increase, for the same 100 % ASK modulation provided by the reader output stage.

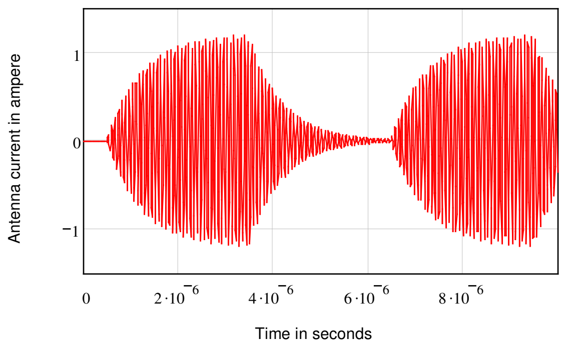

Fig. 7: Downlink data transmission pulses for reader antenna of Q = 60.

These points have led to compromises, since both properties, the H-field and the pulse shapes have to be adjusted by varying just the Q-factor of the PCD antenna. Additionally to increase the *energy range* by an increase of the reader antenna driver current at the same time means to decrease the *information range* over which the reader can detect card load-modulation due to the fact that a higher carrier is not only introduced to the transponder, but also to the receiving path of the reader where it appears as noise. This problem gained leeway for improvement, due to the fact that not all properties can be optimized at the same time.

For proper system function it is necessary that

- the transponder gets enough energy for operation,
- data from the reader is detected correctly and
- the reader can receive the card response properly.

An increase in communication distance can only be achieved if all these parameters are increased accordingly and in accordance to the standard. For our solution, we decided first to decrease the Q-factor of the reader antenna, to produce very clear modulation pulses. As the output power of integrated reader chips is limited due to small structures (which are restricted to low voltages and low thermal power dissipation), this requires an external power amplifier. Thermal reasons also require to integrate very power efficient (> 90 %) amplifiers in reader chips, which in turn are non-linear so they have to be adjusted to meet the specifications by appropriate chip register settings. For our solution we did the opposite and used a very linear, broadband amplifier, which allows to transmit different modulation indexes and all currently specified data rates without changing the original register settings, on the expense of a lower efficiency. Higher carrier amplitude and less sensitivity to load-modulation requires better filtering for the RX-path finally. As the carrier frequency is determined from a stable quartz oscillator for most readers to meet emission limits (one of the few external components), it is possible to use a second, equal quartz to design a very narrow band-stop filter for carrier suppression.

3. Power Amplifier and Band Stop Filter

Prior to design such an amplifier system all claims have to be defined accurately. Factors such as a low supply voltage, the desired output power and impedance, the operating range, the bandwidth, the behavior at miss-matching, the linearity, the power added efficiency, EMC compliance, costs and availability of the components play an important rule and have therefore to be considered carefully. In detail the amplification system for e-PP operations demands linearity, allowing the use of different modulation indexes, a wide bandwidth for high data rates, overload capability and no thermal influence. In return it does not necessarily need high power added efficiency or to be a low cost solution.

The following circuit that arose from a research was found to be the most suitable solution for e-PP applications.
The 13.56 MHz amplifier is working in a four-quadrant operation using a push-pull AB amplifier and 12 V(DC) power supply. The collector currents of small signal NPN and PNP transistors used in this application are limited to few hundred mA. So a certain number of them are connected in parallel for each stage, to increase the overall output current and withstand shorts and open loops. This circuit acts as an emitter follower so parasitic capacities are not multiplied by the factor of voltage gain and therefore just appear single for each transistor. So a number of transistors can be placed in parallel until the parasitic capacity is not negligible compared to the impedance of the antenna any more. This circuit turns out not only to be stable within a temperature range from -30 up to 85 °C but also exhibits a wide bandwidth.

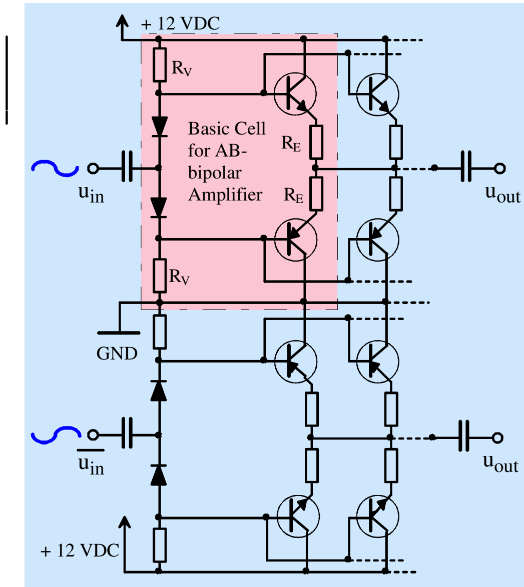

Fig. 8: 13.56 MHz AB Amplifier in a four-quadrant operation.

This amplifier system is directly connected to a matching network for the antenna. It consists of two capacitors placed as demonstrated in fig. 9 and an external resistor for decreasing the Q-factor of the antenna to the desired value.

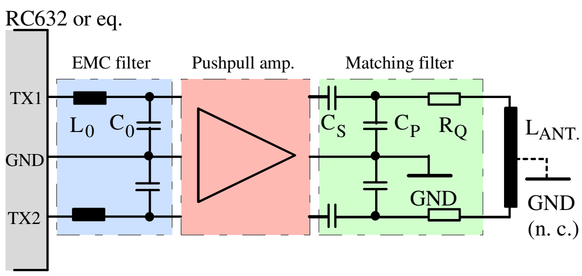

Fig. 9: Antenna matching.

Since such RFID systems use just one antenna for transmitting and receiving data not only the transmitted signal has to be amplified (to increase the energy distance) but also the receive path must be made more sensitive (to increase the information distance accordingly). In fact band-stop filters eliminate objectionable spectral parts so that even with a higher carrier to side-band level ratio information coming from a smart card can be detected and recognized properly. Due to the fact that a crystal consists of a serial and a parallel resonance frequency it can perform as a filter by simply using additional resistors and capacitors as shown below. The serial capacitance can be used for fine adjustment of the frequency to be attenuated and the relation of the resistors determines the level of attenuation.

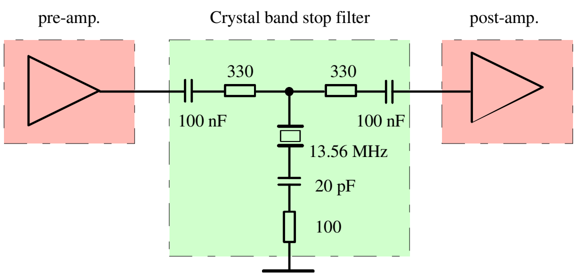

Fig. 10: Band stop filter (typical component values included).

When designing such a band stop filter it has to be considered that only the carrier should be attenuated but not the sidebands in order to avoid loss of information.

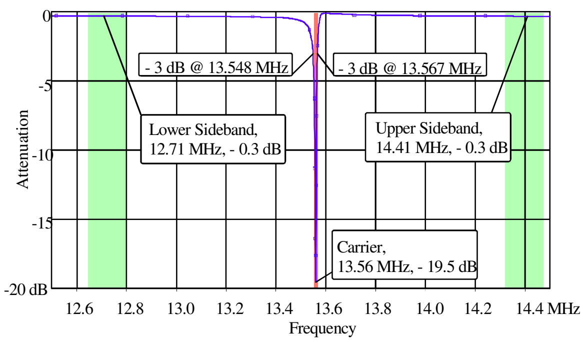

Fig. 11: Quartz band stop frequency response.

That in turn requires the filter to be very narrow. By using a quartz, a stop-bandwidth of only 6 kHz is achieved as shown in fig. 11.

4. Overall amplification system

The block diagram in fig. 12 shows the complete amplifier system placed in between the reader chip RCxxx and the appropriate antenna. It consists of the transmitting path (TX) and the receiving path (RX). The main part of the amplifier stage is built around a class A/B amplifier working in a four-quadrant operation. It delivers the amplified current to the antenna to generate a higher magnetic field. A filter network before this amplifier stage acts as a matching network/impedance transformation and as an EMC filter in order to attenuate higher frequency components to form a sinus waveform out of the square wave signal coming from the reader chip. The receiver path is also accomplished by two parts, consisting of a 13.56 MHz quartz and a dual operational amplifier (OA). The quartz acts as a band-stop filter which decreases the 13.56 MHz carrier, so that the sideband levels can be further amplified by the second OA without overload. The first OA acts as a buffer amplifier which decouples the signal from the antenna to the band-stop filter.

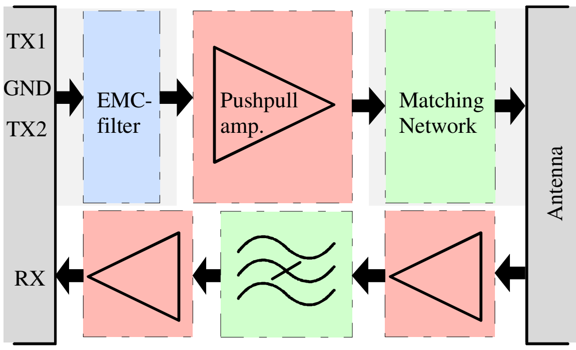

Fig. 12: Overall block diagram.

5. Improvement of Performance

The following diagrams can assist considerations, how an external circuitry can improve the analogue performance of Proximity reader chip characteristics compared to the properties achieved without amplifiers. It can be observed that the magnetic field strength was increased by the amplification system (red dotted line), as compared to the original system (black solid line). The reading distance for 1.5 A/m, measured under maximum card loading conditions, was increased from nearly 40 mm to almost 60 mm.

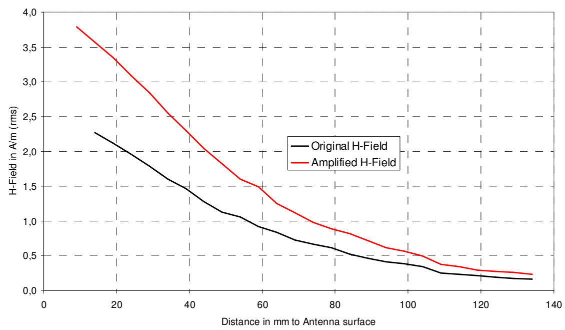

Fig. 13: Reader H-field vs. operating distance.

One more important feature of this amplification system is that high edge steepness can be achieved with the use of antennas with lower quality factor. Moreover no ringing effects or overshoots can be observed as shown in following scope measurement screenshots for ISO/IEC 14443-2 communication.

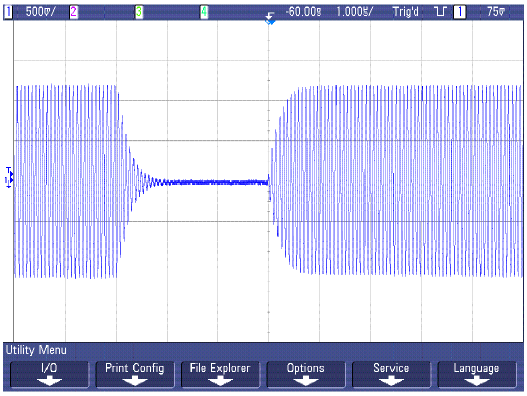

Fig. 14: Reader pulse shape properties of 14443-2 type A communication at 106 kbit/s (1 µs/Div.).

At bit rates of 848 kbit/s and even higher rates no communication problems will occur due to the well shaped pulses.

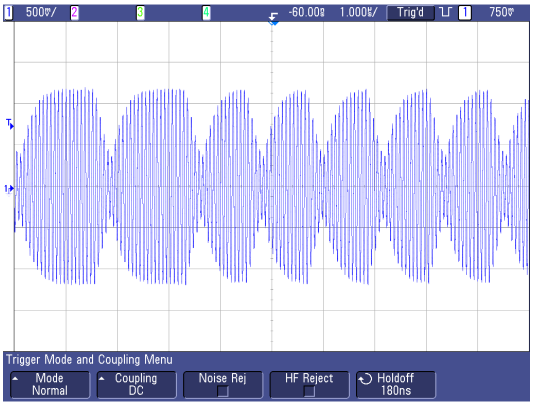

Fig. 15: Reader pulse shape properties of 14443-2 Type-A communication at 848 kbit/s (1 µs/Div.).

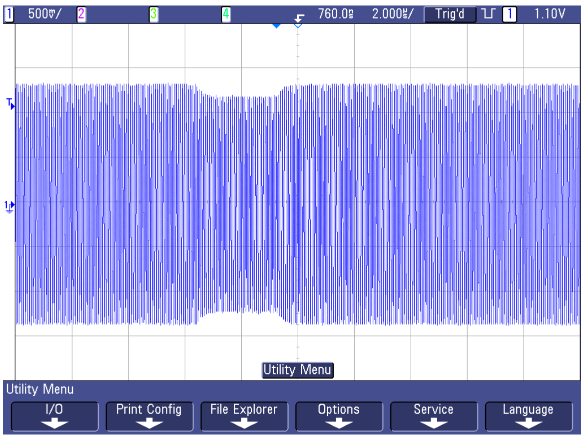

Fig. 16: Pulse shape properties of ISO/IEC 14443-2 Type-B communication (1 µs/Div.).

One more feature of this amplification system is high linearity so Type-B communication is also supported. Low modulation indexes like 10% are transmitted as depicted in fig. 16.

Not only the output signal has been increased but also the received signal has been modified which makes the system more sensitive. ISO/IEC 14443 requires a minimum sensitivity to the levels of the sidebands *E* depending on the magnetic field *H* according to equation 6:

$$E = \frac{18}{\sqrt{H}} \qquad (6)$$

Thus the reader must be more sensitive to card load modulation sideband levels than the limit specified in the standard depending on the *H*-field strength. As fig. 17 shows, this requirement can be met easily.

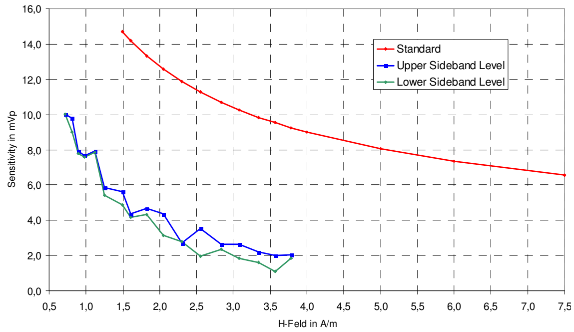

Fig. 17: Sensitivity vs. H-Field.

This system also provides a temperature stable solution for data transmission between the reader and the transponder. This feature illustrates a considerable improvement compared to the directly matched operation of the reader chip and the antenna.

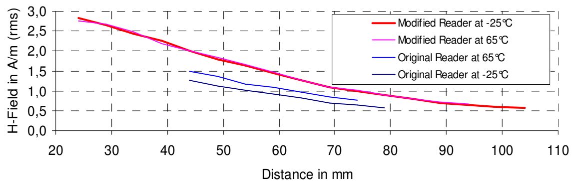

Fig. 18: *H*-Field vs. distance at - 25°C and 65°C.

6. Conclusions

We have demonstrated a solution to improve the analogue performance of RFID readers based on integrated reader chips using a discrete extension circuit. A high quality system improvement requires not only an increase of the RF output power, but also an increase in the sensitivity of the receiver path. Using the proposed solution we were able to extend several quality parameters, among others the emitted *H*-field strength, the edge steepness of the reader modulation pulses, the sensitivity in the receive path and we could reduce the dependency on temperature and mismatch caused by the card loading effect. Using the 1.5 A/m limit for the minimum *H*-field specified in the 14443 standard we could increase the operating volume for a reader from 40 to 60 mm, and for the practical case of more energy-efficient transponder cards we were able to increase the communication range by a factor 2 from typically 80 mm up to 160 mm.

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