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# Radio Frequency Identification (RFID) in medical environment: Gaussian Derivative Frequency Modulation (GDFM) as a novel modulation technique with minimal interference properties

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*Abstract*— **Radio Frequency Identification (RFID) systems in healthcare facilitate the possibility of contact-free identification and tracking of patients, medical equipment and medication. Thereby, patient safety will be improved and costs as well as medication errors will be reduced considerably.**
**However, the application of RFID and other wireless communication systems has the potential to cause harmful electromagnetic disturbances on sensitive medical devices. This risk mainly depends on the transmission power and the method of data communication.**
**In this contribution we point out the reasons for such incidents and give proposals to overcome these problems. Therefore a novel modulation and transmission technique called Gaussian Derivative Frequency Modulation (GDFM) is developed.**
**Moreover, we carry out measurements to show the inteference properties of different modulation schemes in comparison to our GDFM.**

## I. INTRODUCTION

During the last years the application of Radio Frequency Identification (RFID) systems is rapidly growing among different industries like logistic and automotive. In particular healthcare is expected to become one of the most significant areas for its use. The possibility of contact-free identification and tracing improves patient safety [3]. Also by tracking of medical equipment and medication, costs and medication errors can be considerably reduced [6]. However, the application of RFID and other wireless communication systems in healthcare environment, especially hospitals is still disputed [5]. The reason is the potential of harmful electromagnetic interferences on sensitive care equipment. Hence, medical devices can be influenced in their operating mode, which poses a risk for the patients.

Based on the elaborated reasons for disturbances a modulation and transmission technique will be developed to avoid such hazardous incidents. This modulation scheme enables the usage of auto identification systems in proximity of sensitive measuring equipment. Additionally, the new technology provides a continuous control of its own functioning to prevent system manipulation.

This paper is organized as follows: In Section II we give an overview of the RFID technology and the commonly used modulation schemes . Section III points out how disturbances on medical devices arise and derives the novel modulation technique. In order to show the interference properties of GDFM we analyze in Section IV results of the measured diode characteristic, before drawing the conclusions in Section V.

## II. TECHNOLOGY OVERVIEW

All RFID systems consist of readers and transponders (tags) attached to the objects, which are to be identified. They differ especially in their technology of data transmission and their type of transponder. If the transponder is passive, its enegry is harvested from the reader's magnetic or electromagnetic field. To ensure this method of power supply, the reader has to send enough power and additionally the distance between reader and transponder is limited.
An active transponder has an internal power supply, this enables it to communicate autonomously and increases the operating distance between reader and tag.

RFID systems in general are based on digital modulation schemes like Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK) and Phase Shift Keying (PSK).
In passive systems the reader uses a modulation, which guarantees a continuous energy supply of the tag. Thus a so-called Pulse Pause Code (PPC) is used for data transmission, which is a special coding method based on On-Off Keying (OOK) as a simple form of ASK [1]. The transponder by contrast does not actively communicate. Instead load modulation and backscattering is used for communication back to the reader. By inductive coupling the load modulation appears as an amplitude modulation at the reader's antenna.
In comparison, an active RFID transponder features the advantage of autonomous power supply. This leads to the following advantages: a decrease in transmission power, free choice of modulation techniques and an increase in the communication range.

## III. PROBLEMS IN MEDICAL ENVIRONMENT AND SOLUTIONS

The electromagnetic fields caused by wireless communication systems are coupled into the connection cables and

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motor coils of medical equipment. Those cables (one up to two meters long) and the coils are working like antennas. The frequency range reaches from 50 kHz up to several GHz. Although this spectrum is apart from frequencies of biosignals (up to 10 kHz), they can be disturbed by an unwanted amplitude demodulation at the amplifier input of the measuring device. The reasons for this demodulation is explained in the following.

### *A. Disturbance of medical devices*

Measured bioelectrical signals are very weak, therefore medical devices include amplifiers. Transistors are placed at the amplifier input as active components.

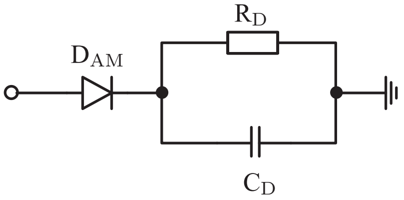


Fig. 1. The input stage of a measuring amplifier can be represented by all electronic components of an amplitude demodulator.

On the one hand the transistor's PN junction at the base-emitter path acts like a diode defined as $\mathrm{D_{AM}}$, which is shown in Figure 1.

On the other hand the PN junction in forward direction functions as a capacitance ($\mathrm{C_D}$) (up to a couple of nano Farad). Moreover, the transistors of the input stage are assembled with resistors ($\mathrm{R_D}$) for adjusting the operating parameters. Thus, the input stage of a measuring amplifier comprises all necessary electronic components of an amplitude demodulator, which can be seen in Figure 1. This is the reason why all high-frequency signals with varying amplitude are unintentionally demodulated, even if the amplitude is not modulated on purpose and only changed by variable propagation conditions.

To conclude, the measurements of biomedical signals are affected by every radio frequency (RF) oscillation with variable envelope. Effective protection measures against electromagnetic disturbances can hardly be realized. A common solution in measuring and telecommunications technology is to reequip the inputs of the measuring amplifier with lowpass filters. However, such filters highly reduce the amplifier's input impedance, which is not acceptable for medical devices [2].

The consequence is a banning of mobile radio systems in medical areas.

### *B. GDFM - Gaussian derivative frequency modulation*

As turned out before, the disturbances are caused inter alia by the use of high transmission power. Moreover fast changes between On/Off switching in connection with sharply rising edges support the occurrence of such incidents on medical equipment. To avoid those different triggers a novel modulation technology is required. The obtained RFID technique is active, which accompany the advantage of lower power consumption. For having a constant envelope in the time domain we use a frequency modulation (FM). Thereby, a sinusoidal signal is modulated in frequency by a source signal. The following equation describes the course of an angle modulated signal depending on time $t$:

$$u(t) = U_{\mathrm{C}} \cos[\psi(t)] = U_{\mathrm{C}} \cos[\psi(u_{\mathrm{s}}(t))], \tag{1}$$

where $U_{\mathrm{C}}$ is the amplitude of carrier signal, $\psi(t)$ is the phase angle and $u_{\mathrm{s}}(t)$ is the source (wanted) signal, which varies the instantaneous frequency of the sinusoidal carrier. It is a nonlinear modulation, because the relation between $u_{\mathrm{s}}(t)$ and $u(t)$ is nonlinear.

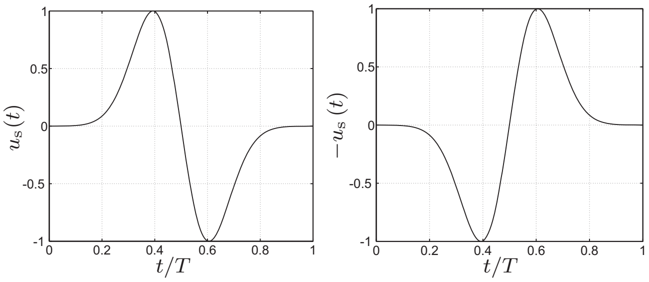
The phase angle and the instantaneous frequency is defined by

$$\psi(t) = 2\pi \int_{-\infty}^{t} f_{\mathrm{i}}(\tau) d\tau. \tag{2}$$

Here, the instantaneous frequency

$$f_{\mathrm{i}}(t) = f_{\mathrm{C}} + k_{\mathrm{FM}} u_{\mathrm{s}}(t) \tag{3}$$

is given as the sum of the carrier frequency $f_{\mathrm{C}}$ and the source signal $u_{\mathrm{s}}(t)$ with the amplitude $k_{\mathrm{FM}}$ [4]. The unmodulated carrier frequency $f_{\mathrm{C}}$ is oscillating proportionally to the wanted signal, between the maximum value $f_{max}$ and the minimum value $f_{min}$.



(a) Symbol for a "1" bit (b) Symbol for "0" bit (inverted "1")

Fig. 2. Our GDFM uses the first derivative of a Gaussian impulse as source signal. In a binary sequence the one is the first derivative, whereas the zero is represented by the inversion of this symbol. $T$ is the symbol duration.

The time function $u_{\mathrm{s}}(t)$ can be described by

$$t_H = T_H/2 = T/8$$

as a function of the half-value duration $T_H$ and the symbol duration $T$. Our source signal $u_{\mathrm{s}}(t)$ is chosen to be the first derivative of a Gaussian impulse shifted by $t_V = T/2$ according

$$u_{\mathrm{s}}(t) = \frac{\mathrm{d}\mathrm{e}^{-\pi\left(\frac{t-t_V}{t_H}\right)^2}}{\mathrm{d}t} = (-1)^b \, 2\pi \left(\frac{t-t_V}{t_H}\right) \mathrm{e}^{-\pi\left(\frac{t-t_V}{t_H}\right)^2}, \tag{4}$$

where $b \in \{0, 1\}$, which is defind as the binary value (Figure 2). Thus, a binary one ($b = 1$) is characterized by the first derivative of a Gaussian impulse (Figure 2(a)). Figure 2(b)

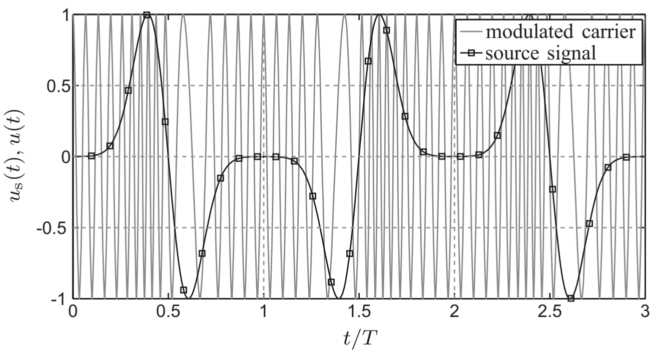


Fig. 3. A part of the data sequence ”1 0 1” represented by our Gaussian derivative symbols (black squared) is shown. The corresponding GDFM modulated carrier is plotted in gray.

represents the inverted first derivative of a Gaussian impulse if $b = 0$.

This waveform confers the advantage of a continuous change in frequency, thus it prevents from fast frequency shifting. From the latter four formulas (1, 2, 3, 4) we can conclude:

$$u(t) = U_{\mathrm{C}} \cos \left[ 2\pi f_{\mathrm{C}} t + k_{\mathrm{FM}} \mathrm{e}^{-\pi \left( \frac{t-t_V}{t_H} \right)^2} \right]. \qquad (5)$$

The modulated carrier $u(t)$ (gray) and its source signal $u_{\mathrm{s}}(t)$ (black squared) is depicted in Figure 3. The slow increase and decrease of the carrier frequency according to the source signal’s characteristic is very well recognized.

## IV. EXPERIMENTAL RESULTS

### *A. Measurements*

As already explained in Section III-A, a measurement amplifier consists of transistors, whose PN junction can be seen as a diode.

That is the reason why we carry out experiments on a diode with different modulation schemes. The influence by different modulations, frequencies and power can be shown by the shift of a diode characteristic .

The test circuit of our measuring setup is shown in Figure 4. The test circuit consists of RF and DC part for elimination of influences between measurement devices and protecting the AC devices from DC voltage and vice versa. These parts are separated by two bias tee modules in dashed squares (a) and (b) in Figure 4. The RF part is matched to 50 Ω for elimination of reflections. The device under test (DUT) is placed between these two modules. In our case the DUT is a general purpose high speed switching diode ”1N4148”.

The DUT is biased via two low pass filters (dashed squares (c) and (d)) for reducing the noise from the DC source. The applied biasing voltage was driven up to 800 mV in 20 mV steps. A serial resistor is used as protection from shorting the diode by the low resistance of the DC source. The values of the DC current and voltage are measured with two digital multimeters interconnected with a computer.

During the measurements we impose a continuous wave (CW) as a reference, as well as modulated signals like OOK and our proposed GDFM on our testing circuit. The induced power is 0 dBm (1 mW) at a transmitting frequency of 100 MHz.

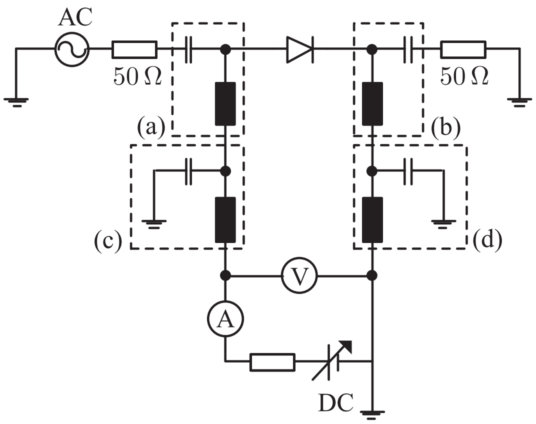


Fig. 4. This is the test circuit of our diode measuring setup. The dashed squares (a) and (b) are two bias tee modules. The two low passes are in the dashed squares (c) and (d).

The results are plotted in Figure 5. At a fixed current of 1.5 mA the original diode characteristic shows a voltage of 645 mV (black solid line). The CW leads to 523 mV at the same current, which represents a shift of -122 mV. This is illustrated by the dark gray curve with circles. Nearly the same voltage of 520 mV is caused by our GDFM (-125 mV). which is plotted in light gray with triangles. In contrast to these values, OOK (dashed line with squares) initiates the highest voltage shift of -237 mV (408 mV/ 1.5 mA) in comparison to the original characteristic.

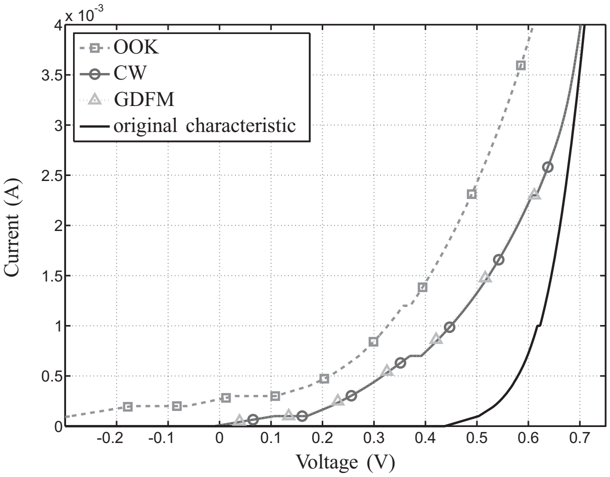


Fig. 5. The shift of the diode chracteristic depends on different modulation schemes. The original diode characteristic is the black solid line without any shifts on the right of this diagramm. CW (dark gray circles) and the novel GDFM modulation (light gray triangles) lead to a small shift (≈ -125 mV). By contrast, OOK causes the highest voltage shift of -237 mV compared the original diode characteristic. This curve is on the left as a dashed line with squares.

## V. CONCLUSION

The results show that conventional RFID pulse modulation (like OOK) affects semiconductor devices like diodes most strongly, whereas our GDFM has an effect comparable to an unmodulated CW.

The better prerequisites for a disturbance-free communication are a constant envelope and a continuous varying frequency. Furthermore, our technology is based on an active RFID system, which allows a lower transmission power. An additional approach is a slow rising and falling of On/Off switching operations. All in all, the outcome is promising for our GDFM regarding electromagnetic compatibility in healthcare environment.

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