

Highly Compact Impulse UWB Transmitter for High-Resolution Movement Detection

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Abstract—In this paper the hybrid integration of an FCC-compliant fifth-order Gaussian derivative impulse generator IC together with a compact ultra-wideband Vivaldi antenna is presented. The setup results in a compact FCC-compliant impulse UWB transmitter. Measurements of the impulse shape in time and spectral domain are shown. With this transmitter a movement detection and the precise measurement of the movement deviation value by a correlation measurement technique is presented. This shows the ability of the UWB radar system to operate as a movement detection sensor. The measurements include a breath rate measurement of a human being.

I. INTRODUCTION

When the FCC in 2002 allowed the unlicensed use of the frequency band from 3.1–10.6 GHz for low power systems [1], the interest arose to find new applications for impulse ultra-wideband (I-UWB) in the field of near-field communication and sensing. Impulse ultra-wideband is well suited for high resolution sensing because of its high bandwidth and, resulting from that, short-time impulses. This high resolution makes I-UWB interesting for the use in sensing and medical diagnostics. Applications are proposed to use I-UWB for tumor detection, for breath rate control or for heart-beat monitoring.

The idea behind medical diagnostics is to use the differences in permittivity and conductivity causing reflections at tissue boundaries and specific attenuation within the tissue. The reflection will be monitored and needs to be processed later on. The first (and strongest) reflection on tissues will occur when an impulse hits the air-skin boundary of a body. Air has a characteristic impedance of 377Ω and skin of approximately 60Ω in the range from 3.1–10.6 GHz, resulting in a reflection coefficient of $\Gamma \approx -0.72$ (c.f. [2]). A movement of the human body, which is for example caused by breathing, can be determined by monitoring the time delay of the reflected pulse.

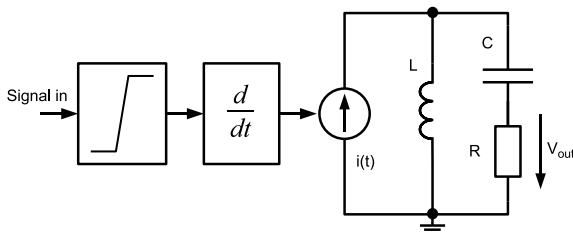


Fig. 1. Operation principle of the impulse generator circuit.

One goal, when using integrated circuits, is the miniaturization of all components. The integration in case of I-UWB has significant advantages. Discontinuities, caused e.g. by connectors, will cause reflections of the impulse. These reflections are overlapping the wanted signal, resulting in a much longer total system impulse

response. This is unwanted, especially when using the impulse for sensing applications, because it affects the spatial resolution. To overcome this disadvantage discontinuities in the signal path must be avoided as much as possible. A further advantage of keeping the dimensions small is to decrease dispersion effects.

In this paper the integration of a fully integrated impulse generator IC together with a compact, broadband, directional Vivaldi antenna is presented, resulting in a highly compact I-UWB transmitter. Measurements to show the compliance with the FCC mask are presented. It is demonstrated that this transmitter can be used as short-range movement detector with high resolution. Furthermore, a measurement is added that verifies the monitoring of breath-rate, caused by the movement of the abdomen, when a person is breathing.

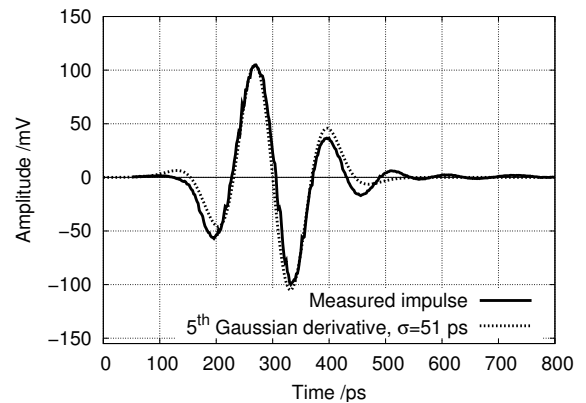


Fig. 2. Transient impulse shape measured on-chip compared with a 5th Gaussian derivative.

II. CIRCUIT COMPONENTS

A. Impulse Generator

A deeper insight into the impulse generator design can be found in [3], [4], here only a short repetition of the operation principle shall be given. The impulse generator consists of three main subcircuits. A block diagram of the circuit principle can be seen in Fig. 1. The first subcircuit is fed from the input control signal and is used to convert the input signal from a potentially long risetime signal into a rectangular signal with a short risetime. By differentiating the short risetime signal in the second subcircuit a short width Gaussian-like output impulse is formed. The corresponding negative impulse, coming from the falling slope of the rectangular signal is suppressed. In the third subcircuit the impulse forming takes

place. The Gaussian-like signal activates a transistor controlled LC-resonating arrangement. A transient impulse shape is obtained, which is very similar to a 5th derivative of a Gaussian impulse with a $\sigma \approx 51$ ps. The measured on-chip output impulse in time-domain can be seen in Fig. 2.

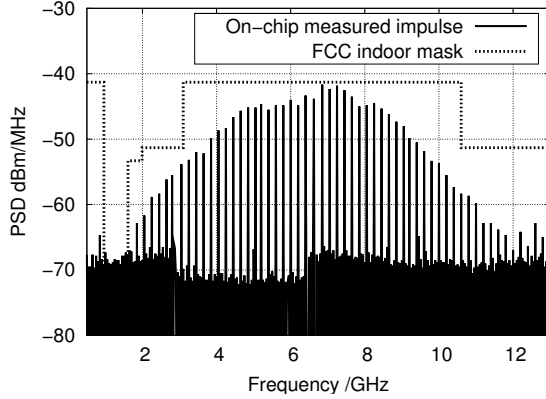


Fig. 3. Measured on-chip spectrum of the impulse generator IC.

The impulse generates a spectrum which fits the FCC UWB frequency allocation for indoor applications (c.f. [5]). The measured on-chip output signal in spectral domain can be seen in Fig. 3. Here a sinusoidal input control signal of 200 MHz was chosen. The circuit was fabricated in a low-cost 0.8 μm Si/SiGe HBT technology [6] and has an overall power consumption of 38 mW at a repetition rate of 200 MHz.

B. Vivaldi Antenna

A Vivaldi antenna consists of an exponentially tapered slot line on a substrate and has a very broadband behavior. In order to feed the antenna with a microstrip line, easing connection to the IC, a broadband transition to the slot line is needed. This can be achieved using a planar Marchand balun with circular open and short circuits in microstrip and slot line techniques [7]. On the used substrate, RO4003 with substrate height of 0.5 mm, a return loss of more than 10 dB is obtained in the desired frequency range from 3.1–10.6 GHz.

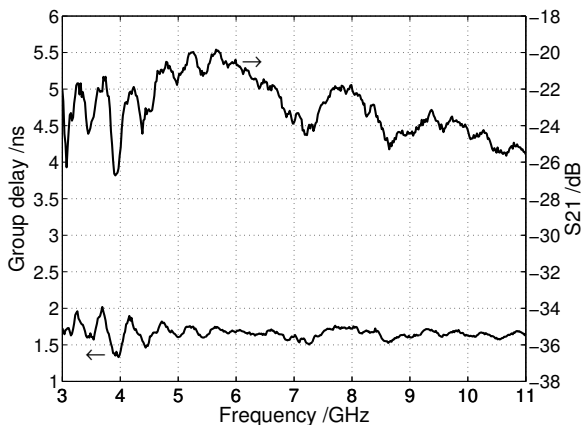


Fig. 4. The transmission and group delay characteristics versus frequency of the applied Vivaldi antennas with a separation of 24 cm.

The antenna's main radiation direction is in the direction of the tapered slot and the antenna gain increases with frequency. For

3.1 GHz a gain of 3 dBi is achieved and the maximum value is 9.3 dBi. As the group delay of the signal from the antenna is quite constant over frequency, the antenna is well suited for impulse radiation. This is demonstrated by a measurement, where the transmission behavior between two Vivaldi antennas is determined. There, the antennas are facing each other and are separated by 24 cm. As can be seen in Fig. 4 the amplitude and the group delay are constant over frequency, as desired. The small variations over frequency are supposed to be caused by the antenna matching behavior, multiple reflections at the metallic antenna holders and parasitic radiation on the feeding structure, occurring at lower frequencies in particular.

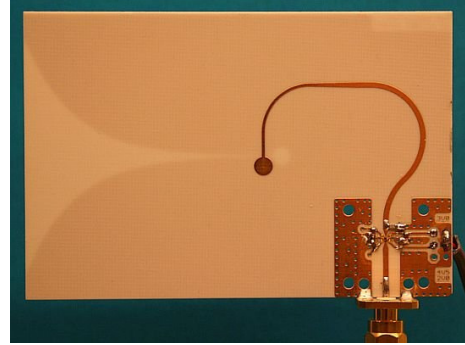


Fig. 5. Photograph of the highly compact I-UWB transmitter.

C. Integration

In Fig. 5 a picture of the Vivaldi antenna together with the mounted impulse generator IC can be seen. The input of the impulse generator is connected by a microstrip line to a connector. Here, a signal source for the control signal can be supplied. The impulse generator output is connected directly to the feeding line of the antenna. Because the output capacitance of the impulse generator was found to be very sensitive with respect to electro-static discharge (ESD), a resistance of 150 Ω was placed in parallel to the 50 Ω microstrip line, which had only neglectable influence on the impulse shape. In a redesigned version this protection resistance will be placed directly on-chip. To provide a good AC grounding of the supply lines capacitances of different value and technology were placed in parallel to the supply lines and ground plane. The size of the complete I-UWB transmitter is 6 x 9 cm².

III. ULTRA-WIDEBAND MEASUREMENTS

A. Measurement Setup

The measurement setup consists of the described transmitter, which is fed by a 200 MHz sinusoidal signal from a signal source. This causes the impulse generator to generate impulses with a repetition rate of 200 MImpulses/s. On the receiving side a plain Vivaldi antenna is connected directly to a Tektronix CSA803 sampling oscilloscope. The sampling oscilloscope is triggered by a 10 MHz synchronisation reference from the signal source. The measurements were done in a cubic anechoic box with side dimensions of 0.6 m each and one side opened for arranging the equipment.

B. Transmission Measurements

First the transmission of a 200 MHz impulse train was measured. Therefore the antennas were placed at a distance of 15 cm facing each other. The measured transient result of the transmitted Gaussian derivative impulses can be seen in Fig. 6. It is very similar to a 7th

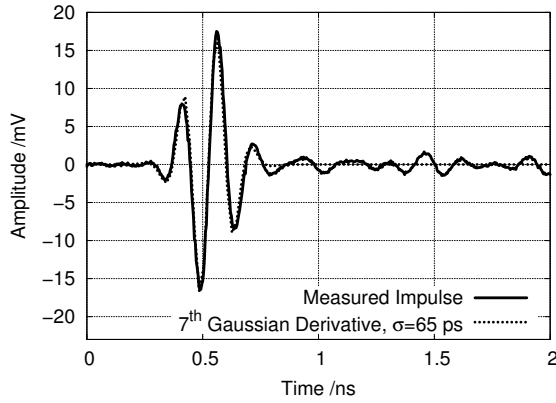


Fig. 6. Received impulse compared with a calculated 7th Gaussian derivative impulse.

Gaussian derivative with a $\sigma \approx 65$ ps and has a negligible ringing. In Fig. 7 the spectrum of the measured impulse train at the output of the receiving antenna can be seen. The spectral shape fits the allocated FCC indoor mask.

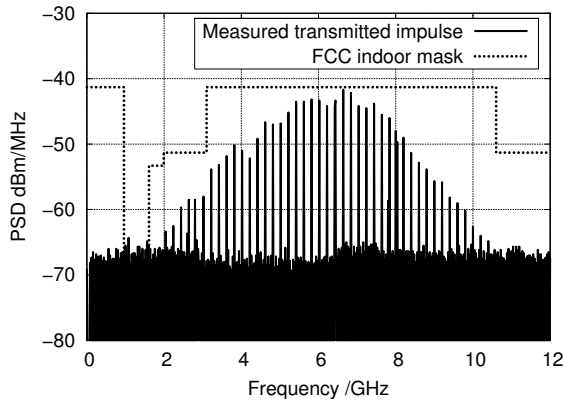


Fig. 7. Measured spectrum of the received impulse.

C. Measurements of Moving Objects

For the measurement of moving objects the antennas were placed in a collinear arrangement with a separation distance of 10 cm. An aluminium plate of $12 \times 15 \text{ cm}^2$ was placed at a distance of approximately 15 cm on a movable sledge. This sledge can be moved forward and backward by a rotating plate with an eccentrically mounted lever, resulting in a sinusoidal movement. Here a rotation speed of approximately 18 rounds per minute (rpm) was used. The reflection at the plate causes a visible movement of the reflected impulse in the data screen of the sampling oscilloscope. From the sampling oscilloscope the measured signal was transferred to a personal computer with a transfer rate of 3 Hz. This transfer rate is limited by the transfer speed of the instrument. To increase the transfer rate a different sampling device would be necessary. The measured data was processed immediately on the computer similar to a method proposed in [8], but in contrast to a continuous wavelet transform (CWT) a much simpler cross-correlation procedure has been applied.

The measurement procedure consists of two steps. In the first step a background signal was determined, in absence of the metal plate.

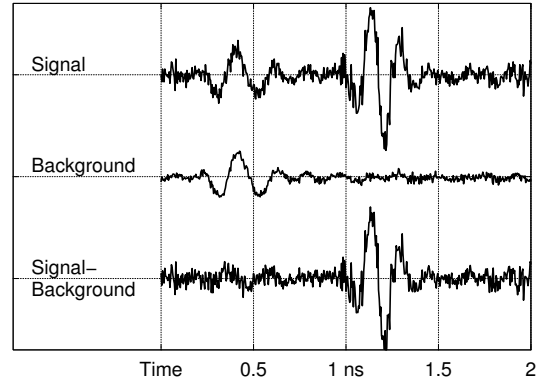


Fig. 8. Procedure of background removal from the original measured signal.

The background signal contains all static reflections and the crosstalk impulse of the direct coupling. In the presented measurement a mean of 30 background data sets was used. In the second step the measurements with the moving target are done. The background signal is subtracted from every data set to improve the measurement process. In Fig. 8 the procedure of background removing can be seen. The peak-to-peak amplitude of the highest reflected impulse is approximately 20 mV.

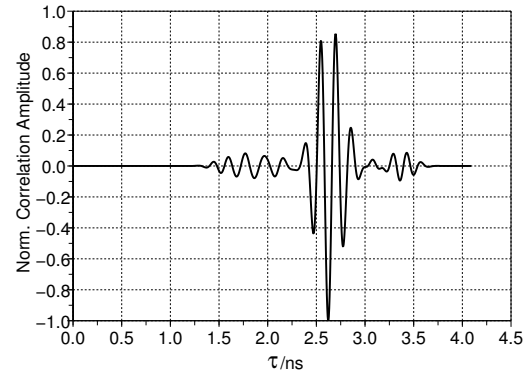


Fig. 9. Correlated signal of the reflection at the metal plate.

The obtained signal with removed background is now correlated with a 7th Gaussian derivative with a variance $\sigma = 65$ ps. In Fig. 9 one correlated signal can be seen. The absolute maximum of the correlation function is negative, which indicates that a phase reversal has taken place by the reflection at the metal plate. When the metal plate is moving, the maximum of the correlation signal moves with respect to the position of the metal plate. The relative distance Δs can be calculated by

$$\Delta s = \frac{c_0 \cdot \Delta \tau}{2}, \quad (1)$$

where c_0 is the speed of light and $\Delta \tau$ the difference in time of arrival between the maximum of two data sets. Therewith, the assumption that the antennas are arranged very close to each other is made and therefore the angular error can be neglected. The theoretical precision of the measurement can be determined by using the time resolution of the datapoints in the sampling oscilloscope. Here a time window of

2.044 ns was used. Divided by the 511 datapoints a time resolution of 4 ps between each data point is resolved in the sampling oscilloscope. By using (1) a best case resolution of 0.6 mm could be achieved, using the simple maximum detection algorithm. In Fig. 10 a measurement of a relative movement of approximately 5 mm can be seen as an example of a movement detection in the millimeter range.

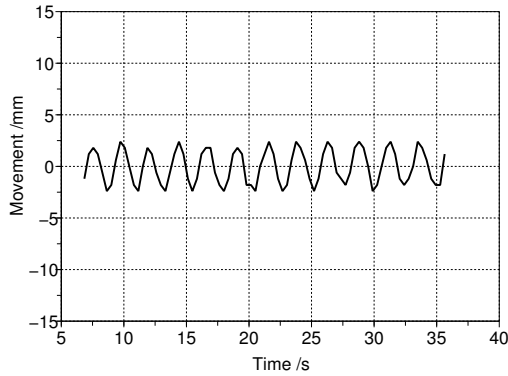


Fig. 10. Relative movement measurement with a displacement of ± 2.5 mm in time domain.

D. Measurements of Breath Rate

As mentioned earlier a reflection of approximately 72 % occurs at the air-skin boundary. Therefore, a movement of the skin (which is e.g. caused by the movement of the abdomen when breathing) can be monitored. To verify this, the same measurement setup was used for this breath rate measurement and a background removal procedure was applied as well. The antennas were placed to target the region of the abdomen. In Fig. 11 the time domain can be investigated and in Fig. 12 the spectrum of the measured breath rate is presented.

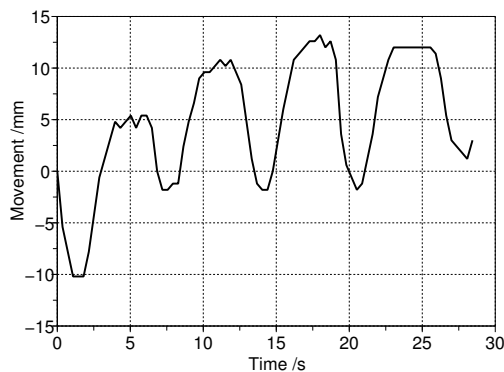


Fig. 11. Time domain signal of the breath rate measurement.

IV. CONCLUSION

The hybrid integration of an FCC-compliant 5th Gaussian derivative impulse generator and a broadband planar Vivaldi antenna was presented. It was shown that the transmitted impulse is FCC compliant; the close integration of pulsing circuit and antenna achieves very low time-domain ringing. The I-UWB transmitter could be used as a high precision, short-range movement detector. This was shown by

sensing the movement of a metal plate with a displacement of 5 mm. Furthermore, the application as breath rate sensor was verified by the same measurement setup.

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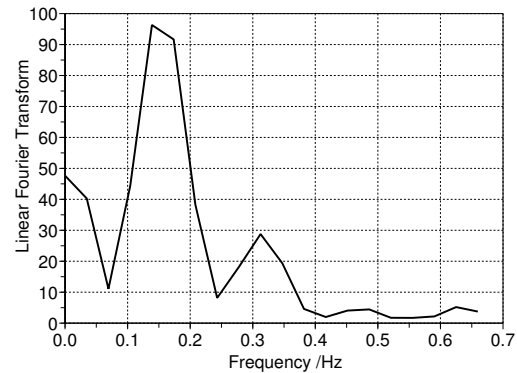


Fig. 12. Normalized linear spectrum of the breath rate measurement.

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