

Modulated Backscattering transponder to increase the detectability of pedestrians with automotive radar at 24 GHz

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Abstract

With the purpose of improving the detection of pedestrians and bicycles by automotive radars, a prototype of modulated backscattering transponder at 24 GHz has been designed and implemented. The transponder integrates a commercial MMIC amplifier connected between two series-feed patch array antennas. The differential radar cross section is calibrated with a corner reflector. Experimental results show the feasibility of the detection of the transponder under strong clutter in range-velocity maps.

1 Introduction

The future generations of vehicles will provide a radar for advanced driver assistance systems (ADAS) purposes. However, other applications such as the detection of pedestrian and bicycle collisions, which can occur under poor lighting or bad weather conditions can be exploited [1][2]. Recently, an integration of radar sensors in vehicles at 24 GHz, much more economical than those that work at 77 GHz millimeter band has been done. There are some problems to detect pedestrian at this band mainly for their low RCS (-11 dBsm [3]) that is significantly lower than a standard car (18 dBsm) or a motorcycle (5-8 dBsm) [4]. On the other hand, the clutter level originated from the road or the metallic objects can hide the presence of people, such as workers repairing the roads or travelers and bikes circulating on the sides, owing to their low speed.

In this work a modulated backscattering tag to increase the pedestrian RCS and the introduction of a phantom Doppler shift for a better detection in front of the clutter interference were done.

2 Transponder design

Fig. 1 shows the topology of the modulated transponder composed by an GaAs pHEMT MMIC amplifier HMC342LC4 from Analog Devices connected between two patch antennas. The amplifier gain is 19 dB at 24 GHz and the current consumption 43 mA at 3V. The RCS is modulated switching the bias voltage using a lowfrequency switch that is controlled by a low-frequency oscillator that generates a square wave. A prototype is made using 16 mil height Rogers 4003 substrate. An array of 7 elements series feed has been designed for the input and output antenna. Fig.2 shows the measured reflection coefficient using a pcb end launch connector (2.92 mm (K) connector from Southwest Microwave). The array is simulated with Ansys HFSS simulator. Fig.4 shows a gain of 14 dBi and a side lobe levels better than 11.35 dB.



Figure 1. Block diagram of the transponder (top) and image of a prototype of transponder (bottom).



Figure 2. Measured amplifier gain and input and output reflection coefficients.



Figure 3. Measured reflection coefficient of the antenna array.



Figure 4. Simulated gain for the antenna array.

3 Transponder validation

A frequency continuous-wave radar (FMCW) that is capable of measuring simultaneously the range and the relative speed of the target is usually used as automotive radar. The radar interrogates the scene with a chirp signal $(x_c(t))$ of duration *T* which sweeps the frequency between f_{min} and f_{max} (radar bandwidth B= f_{max} - f_{min}). The radar detects the reflected wave from the target. The received signal is delayed by the round trip time delay between the transmitter and the target, $\tau=2d/c$ (with *c* is the wave propagation velocity). The switching rate of the modulated transponder presented in this work (see Fig.1) is f_m . Consequently, the radar cross-section of the transponder is modulated with a periodic signal of frequency f_m . The reflected signal can be written according to [5][6] as:

$$x_R(t) = \sum_{l=0}^{\infty} A' x_c (t - lT - \tau) p(t)$$
⁽¹⁾

Where A' is the amplitude of the signal that comes from target, and p(t) is the modulating waveform. Assuming that the radar cross-section of the modulated transponder varies between two levels depending on f_m , p(t) can be approximated by a square wave. This periodic signal with period $T_m=1/f_m$ can be expressed using Fourier series [5]:

$$p(t) = \sum_{n=-\infty}^{n=+\infty} c_n e^{j2\pi n f_{mt}}$$
(2)

where c_n are the Fourier coefficients. For simplicity only the first harmonic will be considered since the higher harmonics (|n|>1) fall quickly below the noise floor. The output of the baseband output after the IF mixer and filter is schematically shown in Fig.6 (see [5][6]). The spectrum at baseband (Fig.6) show a signal at the same frequency than the clutter (structural mode) and two new peaks spaced $\Delta f' = \mu 2\tau = \mu 4d/c$, centered at the modulating frequency f_m . Therefore, the distance to the modulated transponder can be determined using:

$$d = c\Delta f'/(4\mu) \tag{3}$$



Figure 5. Spectrum at the IF-output as a function of the beet frequency. (a) for non-modulated target and (b) with modulated transponder.

The transponder can be detected performing a range analysis from a conventional FMCW. To this end, the modulating frequency must be higher than the frequency shift produced by the Time Of Arrival (TOA). A Fast Fourier Transform (FFT) is made to obtain the spectrum of the IF signal. To improve the resolution and to reduce the lobe side bands a zero padding and window technique are performed. The level of the peaks is proportional to the differential radar cross-section that can be expressed as [6][7]:

$$RCS_{dif} = \frac{\lambda^2}{4\pi} G_{Rx} \cdot G \cdot G_{Tx} \cdot m \tag{4}$$

Where λ is the wavelength (=*c*/f), G_{Rx} and G_{Tx} are the gain of the receiving antenna and transmitting antenna, *G* is the gain of the amplifier and *m* is the modulation factor that depends on the Fourier coefficients c_n (2). The value of *m* is $1/\pi^2$ for a square waveform. Hence an increase of the amplifier or antenna's gains increases the *RCS*_{dif}. On the other hand, the periodic activation of the transponder lets to separate the signal response respect to the clutter.

To calibrate the differential RCS of the transponder a triangular trihedral corner reflector [8] [9] was used. The RCS of a triangular trihedral reflector is expressed as [8]:

$$\sigma_{corner} = \frac{\pi d^4}{3\lambda^2} \tag{5}$$

Where *d* is the edge length of the triangular aperture and λ is the wavelength. The RCS of the corner reflector of 8 inch edge length (SAJ-080-S1 from Sage Millimeter, Inc.) is 10.58 dBsm at 24 GHz. Fig.6 compares the measured spectrum at baseband of the signals obtained from a corner reflector, the transponder (f_m =1.5 kHz) and a pedestrian using the **a** (Siversima RS3400K) FMCW radar, transmitting between 24 GHz and 25.5 GHz and T=75 ms. RCS of a pedestrian at 24 GHz is about -11 dBsm [3]. The differential RCS of the transponder is -12 dBsm, considering a gain of 14 and 19 dB of the antennas and the amplifier respectively.

The use of range-velocity maps [10] lets to detect the transponder too. The principle of working consists on digitalizing at f_s (sampling frequency) the received IF signal by an ADC, in the fast-ramp based FMCW radar, for then saving the samples into a matrix x(k,l), k=1...N,

l=1..L. The range-frequency map from two dimensional FFT of a frame x(k,l) which is composed by L chirps with N samples by chirp is obtained. In order to reduce the side-lobe interference and to improve the resolution, windowing and zero padding are used.



Figure 6. Normalized measurement of a reference corner, a pedestrian and the transponder modulated at 1.5 kHz at 1.6 m.



Figure 7. Range-Doppler response for the transponder at 1.5 m with the modulation off (top) and on (bottom) for f_m =500 Hz.



Figure 8. Range-Doppler response for the transponder at 1.5 m with the modulation off (top) and on (bottom) for f_m =1000 Hz

The 24 GHz FMCW radar EVAL-DEMORAD from Analog Devices was used to obtain the range-velocity maps. Fig.7-8 show the measured range-velocity maps at a modulation frequency of 500 Hz and 1000 Hz respectively. The transponder is close to a corner reflector to avoid the detection of the non-modulated transponder. However, results show the transponder when a modulation is considered.

5 Conclusions

This work presents the design of a modulated backscattered transponder at 24 GHz that can be used to improve the radar cross section, enabling the detection in range or in range-velocity maps of pedestrian or other objects that can be masked by strong static clutter. In addition, the transponder can be used to calibrate the radar response for car manufacturers in small chambers avoiding the reflections of walls in indoor environments.

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7 References

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