A Novel Single Card FMCW Radar Transceiver With On Board Monopulse Processing

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***Abstract* – This paper presents the design of a complete single card Frequency Modulated Continuos Wave (FMCW) radar transceiver system with a novel four-element active antenna array. Azimuth tracking ability is achieved at the intermediate frequency (IF) via a monopulse processor. The single card FMCW system provides a highly cost effective solution for radar ranging and tracking purposes such as collision avoidance and automated roadways without bulky expensive hardware.**

I. INTRODUCTION

With continued interest in automatic cruise control and automated highways FMCW radar systems have gained much attention. FMCW radar has the advantages of low transmission power due to a unity duty cycle, low component count as compared to pulsed radar, and the ability of radar to see through adverse weather conditions. Due to the continued interest in automated highways and automatic cruise control systems many advanced systems have been developed [1][2][3][4].

In this paper the design of a novel single card radar system with an ultra low component count is presented. The radar contains all necessary systems for generating, transmitting, and receiving signals on board. Monopulse azimuth tracking is implemented at the IF and very good linearity in ranging is obtained. A complete system is prototyped for under $150 US.

II. CARD RADAR DESIGN

The complete FMCW radar system's top side is shown in Fig. 1. The card measures 11 x 14 cm and is implemented on a single substrate. The circuit is assembled on RT/Duroid 6010 substrate (1.27 mm, ε_r=10.2). The frequency modulated signal originates from the VCO, as seen in Fig. 1, whose output power is +18 dBm from 5-6 GHz. The signal's phase is carefully maintained throughout the system through complete physical and electrical symmetry. The transmitted signals must be in phase in order to obtain accurate azimuth tracking. The generated signal

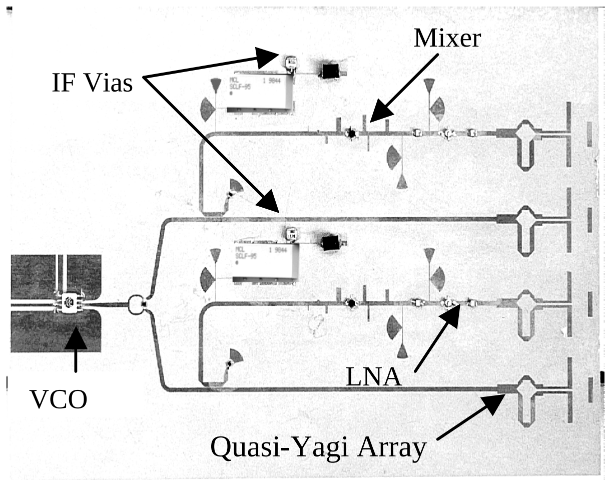

Figure 1: Photograph of top-side of single card FMCW radar.

is coupled into the drains of two MESFET drain mixers to serve as the local oscillator. The uncoupled portion of the signal is then transmitted towards the target. The time delayed reflection is received through a pair of low noise amplifiers and is then applied at the gate of each mixer as the RF signal. The FMCW beat frequency

$$f_b = \frac{4 f_m \Delta f}{c} R \qquad (1)$$

where f_m is the modulate rate, Δf is the modulation excursion, R is the range, and c is the speed of light, is taken from the drain of the mixers and is passed through to the backside circuitry by means of vias. For a highly accurate measurement of range a large modulation bandwidth is required. The modulation bandwidth is the product of the modulation rate and modulation excursion. The VCO is modulated at a rate of 10 KHz over its full bandwidth of 1 GHz. Thus, the beat frequency is 133 KHz per meter.

The backside circuitry consists of the monopulse processing system, as can be seen in Fig. 2. The backside circuitry consists of two IF amplifiers, a sum-difference circuit, and a modulating waveform generator to drive the VCO. The use of an IF monopulse processing system has two distinct

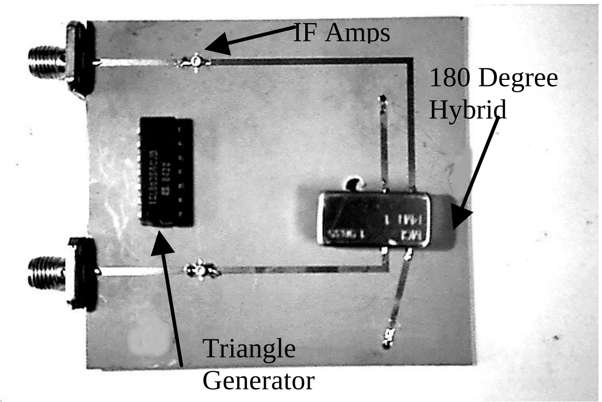

Figure 2: Photograph of back-side of single card FMCW radar.

advantages. First, the need for an electronically or mechanically scanned antenna array is eliminated. Secondly, signal processing is performed at a substantially lower frequency allowing the use of inexpensive, readily available components.

III. QAUSI-YAGI ANTENNA ARRAY

To achieve a planar circuit topology a printed antenna is required. In addition to the need for the antenna to be printed, it is required to have a high bandwidth (>≅ 20%) due to the large modulation excursion (1 GHz) and moderate gain. As a result of these requirements microstrip patch antennas are incompatible unless aperture-fed type antennas with multi-layered dielectric substrates are used. Thus we have chosen the novel uniplanar quasi-Yagi antenna presented in [5]. This antenna exhibits 50% bandwidth, 50 Ohm microstrip feed, gain of 6 dB, front to back ratio of 15 dB, and mutual coupling of less than –22 dB making it ideal for this application. The large bandwidth of the quasi-Yagi antenna allows a compact yet highly potent antenna array to be assembled on board without complex transitions. The use of the quasi-Yagi antenna in conjunction with a large modulation excursion allows very accurate range information to be obtained. Two of the four antennas shown in Fig. 1 are used as transmitters, and two for receivers. The radiation pattern from the array-factor of two transmitters is shown in Fig. 3.

IV. SYSTEM PERFORMANCE

The novel single card FMCW radar transceiver has a very linear ranging response for targets whose range is between 2 to 20 meters. The beat frequency versus target range is illustrated in Fig. 4. Correction

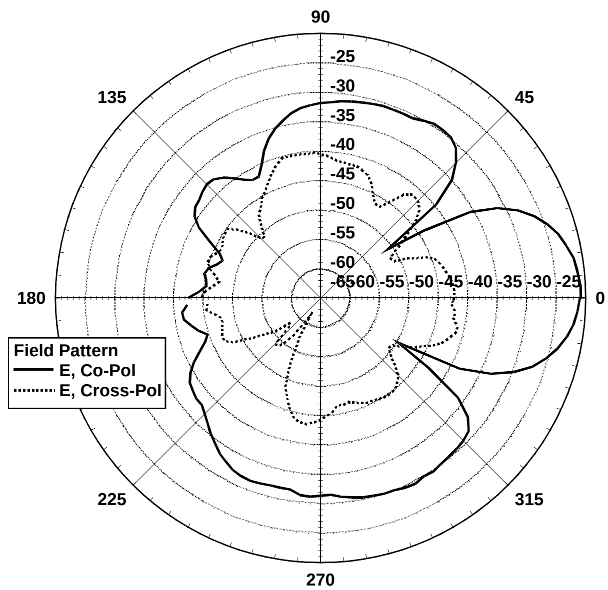

Figure 3: Quasi-Yagi antenna array radiation patterns.

of the non-linearity may be achieved by programming an EPROM to contain a corrected voltage driving waveform. This type of linearization adjusts for variations in the VCO's tuning linearity plus any other errors introduced throughout the system.

The lower directivity of the printed antennas, versus reflectors and large arrays, imposes an upper limit on the long distance ranging ability. The monopulse IF channels are presented in Fig. 5. The system has azimuth tracking ability of approximately +/- 10 degrees from bore-site. The ranging capabilities of this system suit it extraordinarily well to the lane changing and cornering aspects of automated cruise control and navigation systems. These applications are discussed in detail in the following section.

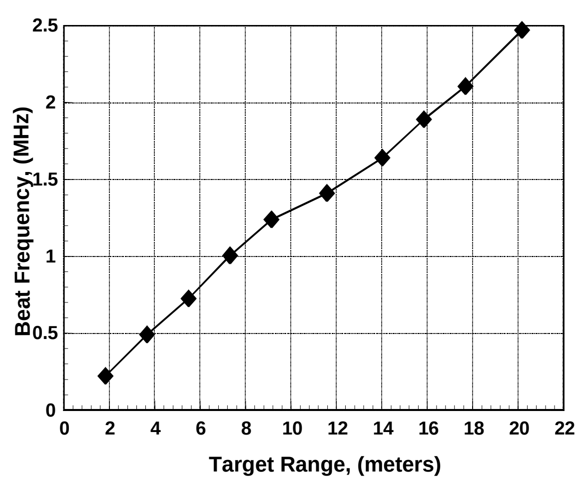

Figure 4: Beat frequency versus target range.

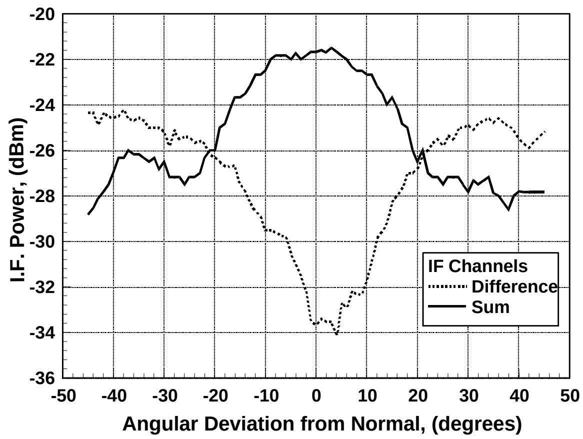

Figure 5: Monopulse patterns at the IF.

V. ALTERNATIVE DETECTION SYSTEM USING THE FMCW RADAR CARD

Many expensive high-performance radar ranging systems address the issue of forward looking target detection. Through the use of expensive multi-component systems, high levels of accuracy and long range ability have been achieved. However, to have a truly automated highway system or an automated cruise control system, more is required in terms of input to the decision making system.

In order to have a fully automated system for highways or cruise control, data in addition to the forward looking range / velocity are required. One must be aware of the presence of objects in the vehicle's blind-spots, to the sides of the vehicle and at the rear of the vehicle. A blind-spot is the location along side and roughly in the middle of a vehicle in which the usual combination of mirrors does not provide coverage. Blind spots are a common cause of side swipe accidents during highway lane changes.

By locating several sensors at various locations on a tractor trailer, as seen in Fig. 6, an advanced detection system is readily assembled.

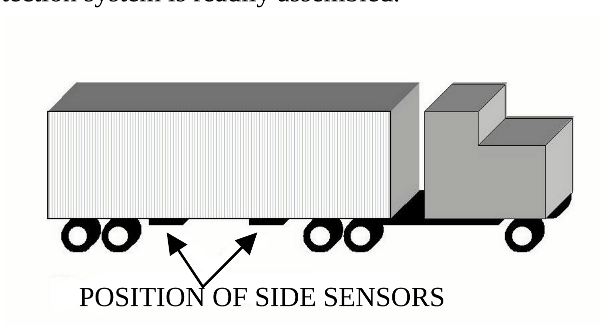

Figure 6: Location of two single card FMCW radars along a tractor trailer.

A typical highway situation is shown in Fig. 7. It is clear that by assembling a system of several single card FMCW radar sensors on the frame of a trailer one will obtain exceptional coverage. A truck outfitted with five single card FMCW sensors will have a robust detection scheme capable of detecting cars, motorcycles, trucks, and other obstacles such as close range buildings, in all directions.

The use of the novel single card FMCW radar system as a side and rear detection element provides distinct advantages. The expense of implementing a system of four or five cards is minimal. Due to the low cost of implementation, the FMCW card radar is highly attractive to corporations which have large fleets of delivery and work vehicles. With conventional systems, which require more installation space and a protected environment, the installation of several radar units into each vehicle is prohibitive and impractical.

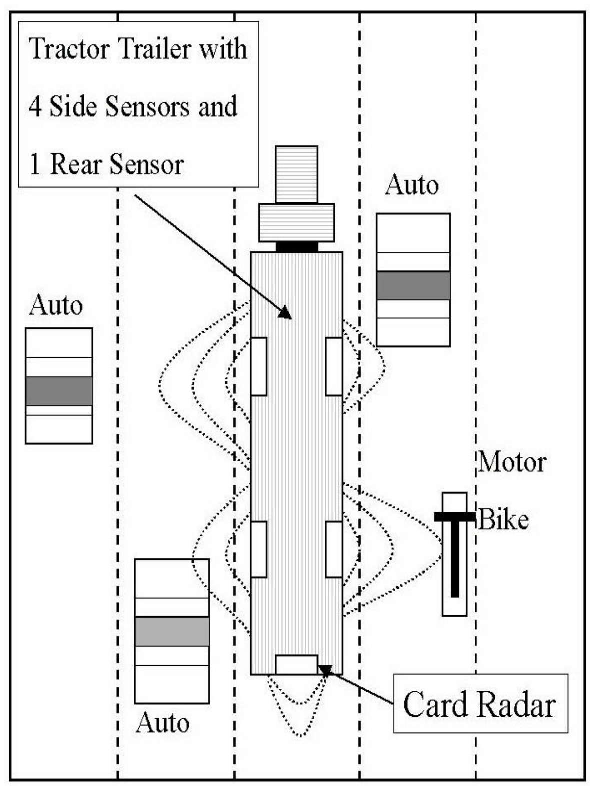

Figure 7: Application of the single card FMCW radar system to a typical highway traffic situation.

VI. CONCLUSION

A novel single card FMCW radar transceiver with on board monopulse processing is demonstrated. The complete system is fabricated on one Duroid substrate with the monopulse processing circuit on the backside. The single card FMCW radar is capable of accurate ranging of targets within 20 meters and azimuth tracking to +/- 10 degrees. The complete system is prototyped for under $150 US.

Monopulse processing at the IF allows the use of inexpensive components and simplifies signal processing issues. The monopulse processing at the IF also allows the radar system to operate without electrically or mechanically steered antennas. This is highly advantageous in applications, such as automotive and trucking, where the radar transceiver is vulnerable to harsh weather conditions and impacts.

Through the use of a novel quasi-Yagi antenna array the antenna system is printed on the same substrate as the remainder of the circuitry. This provides a low weight and rugged design. The antenna array's characteristics suit it to applications such as FMCW radar which requires relatively large bandwidths.

The low cost of the complete FMCW radar transceiver, less than $150 US, enables the use of several cards on one vehicle. This principle is demonstrated for a large tractor trailer on which five sensors may be mounted to cover all possible trouble spots.

The novel single card FMCW radar transceiver with on board monopulse processing demonstrates that complete radar sensing coverage of a highway situation may be done effectively and inexpensively.

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VII. ACKNOWLEDGEMENTS

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VIII. REFERENCES

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