Spectral Smoothing by Multiple Radar Pattern Multiplication for Improved Accuracy

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***Abstract*—This paper presents a novel technique for improving radar accuracy. In particular, by studying the product of multiple radar beam pattern spectrums from different radar sub-module views, a refined and improved total radar response can be obtained. We examine this radar signal processing approach using a 24GHz frequency-modulated continuous wave (FMCW) radar system equipped with broadband 1.5GHz substrate integrated waveguide (SIW) antenna arrays to ensure high range resolution. The transmitter is defined by 4 sawtooth signals generated by separated radar sub-modules, each having a multiple input multiple output (MIMO) configuration with 4 receivers at each radar sub-module. The measured spectral multiplication of the individual radar sub-modules results in a signal quality improvement of more than 10dB when compared to a MIMO radar configuration with the same architecture.**

***Index Terms*—MIMO, SIW antenna, FMCW Radar, Digital Beamforming, Automotive**

I. Introduction

Millimetre-wave radars have seen a rapid expansion especially in the automotive industry. Driver assistance systems require accuracy and predictability while making driving more enjoyable and safe. Millimetre-wave radars play an important role for target detection and localisation since they operate also in adverse weather conditions [1]. The use of virtual radar applications is widespread in the automotive industry and the research community with either synthetic-aperture radar (SAR) and multiple-input multiple output (MIMO) processing prevailing with architectures having high resolution [2].

The novelty of this work consists in the use of a composite radar system formed of multiple radar sub-modules and the use of beam pattern spectral multiplication for improved radar accuracy. MIMO apertures have been used due to the known advantage of reduced footprint in comparison to an equivalent uniform linear array with the same number of elements. The employment of substrate integrated waveguide (SIW) antenna arrays has been chosen to allow for increased bandwidth with less radiation losses than a patch antenna array at 24GHz [3].

The spectrum beam pattern multiplication technique is introduced in Section II to highlight its benefits. The radar hardware and signal processing are described in Figs. 1-3 and Section III outlines the structure and setup of the MIMO radar configurations. In Section IV, a comparative radar study between conventional MIMO processing and our proposed spectrum multiplication technique using measured data is reported. In the last section some conclusions are drawn.

II. Spectrum Beam Pattern Multiplication Technique

In this work, the radar system has been designed so that a target is seen from multiple views. For example, after receiver beamforming, the spectral beam pattern return generally takes the form of a sinc function. In optics, by comparison, it is known that smoothing of spectral data can occur as a result of applying sinc, sinc^2 and Lorentzian functions [4]. According to [4], the best smoothing function is the sinc function for spectral data. Similarly when considering radar beamforming, sinc functions based on the multiplication of radar beam patterns can provide a smoother response with the precondition that target returns are above the noise level.

Multiplying the sub-module radar beam patterns results in smoothing of each sub-radar view. The result converges to a combined sinc function with the peaks increasing and the troughs decreasing in magnitude. This characteristic is advantageous in radar beam pattern analysis since the target levels are increasing in magnitude while the side lobe levels decrease, refining radar accuracy.

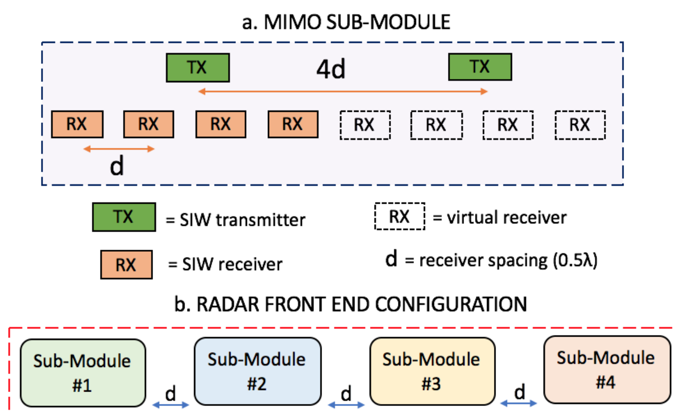

Fig. 1. Representation of the radar: a. sub-module b. complete radar.

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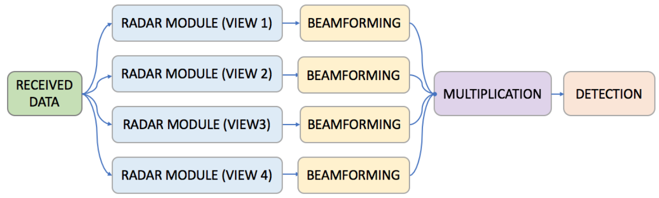

Fig. 2. Radar signal processing approach where multiplication is employed in the spectral domain.

III. FMCW MIMO Design

In this work, a frequency-modulated continuous wave (FMCW) radar development platform with MIMO capability has been selected. The composite radar system formed by 4 sub-modules has been designed to allow multiple spectrum multiplication of the individual radar patterns. The MIMO sub-module radar configuration can be observed in Fig. 1.a. In this case, the radar sub-module is formed by 2 transmitters (2TX) and 4 receivers (4RX), forming 8 virtual elements in total. Each separate radar view contributes to the rendering of an image of the target. By combining the data from 4 radar sub-modules, we are able to obtain a 32-element virtual array. MIMO radar configurations allow for large virtual arrays to illuminate the target, while being small in size. The configuration of the radar sub-modules are depicted in Fig. 1.b. The 0.5λ distance between multiple views is the same as the inter-element spacing (d) since that preserves the uniformity of the virtual linear antenna array.

To process the receiver data, the digital beamforming network will first process radar responses individually and then apply a beamforming algorithm for each view. The spectral beam pattern for each response is then multiplied, after which target detection takes place for the composite radar system. The process is illustrated in Fig. 2. The system has been measured in a calibrated anechoic chamber with a metallic target. The setup of a radar sub-module can be seen in Fig. 3.

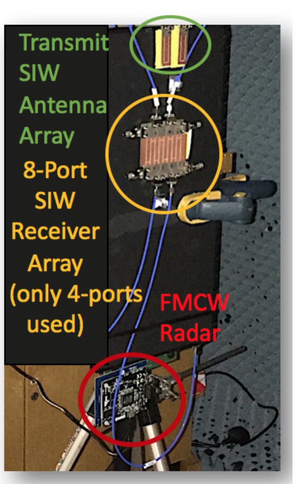

TABLE I
RADAR SPECIFICATIONS

Number of Modules	4
Sub-Module Transmitters	2
Sub-Module Receivers	4
Virtual Array Elements	32
Carrier Frequency	24GHz
Bandwidth	1.5GHz
Sweep Period	5ms
ADC resolution	12-bit
Half-power Beamwidth	14°
Range resolution	10cm

Fig. 3. FMCW MIMO radar sub-module calibrated in an anechoic chamber (left), system specifications are noted in Table I. (right).

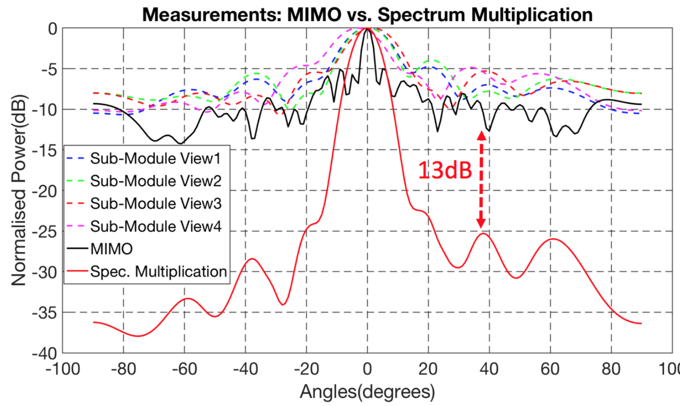

Fig. 4. Measurements for a target at broadside for MIMO radar (4TX by 8RX elements) and spectral beam pattern multiplication (4 sub-radars with 2TX by 4RX for each).

Also, the complete radar list of specifications can be found in Table I, while more information about the radar system will be made available at the time of the conference.

IV. Spectrum Pattern Multiplication Measurements

The modular beampatterns, their spectral multiplication and the MIMO response are plotted in Fig. 4. The side-lobe level improvement by the proposed method is 13dB. The beam pattern of the MIMO response is seen to have a smaller half-power beamwidth than the multiplication technique. This is caused by the sub-radar antenna array aperture length of 4 elements while the virtual array for the MIMO radar will have the resolution of an equivalent 32-element array at the receiver. Also, the angular resolution of each sub-radar module can be improved by increasing the number of elements. As a result of this change, the half power beamwidth of their pattern multiplication decreases.

V. Conclusion

The proposed spectral beam pattern multiplication technique has been investigated against a frequency modulated continuous wave (FMCW) multiple-input multiple-output (MIMO) radar system working at 24GHz. This technique was compared to a conventional 32-element MIMO system and offers a 13dB side-lobe level improvement while preserving sub-modular angular resolution.

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