

A NOVEL DIGITAL BEAMFORMER WITH LOW ANGLE RESOLUTION FOR VEHICLE TRACKING RADAR

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Abstract—In this paper we propose a digital beamformer utilizing the radar integrator method of detection. In the receive mode the digitized radar returns weights are allocated on the such a way that the first pulse reflect a SUM pattern and the subsequent three pulses reflect DIFFERENCE pattern. The pulses on DIFFERENCE pattern are added to each other and the net signal subtracted from signal received in SUM pattern. This results in very narrow beam which shows narrow spatial resolution. The schematic is presented and the results are shown.

1. INTRODUCTION

A beamformer forms one or more antenna beams anywhere within the arrays surveillance volume. Additionally, the beamformer adjusts the beam shape of the resulting beam(s) with the aid of amplitude and phase weights associated with each antenna element [1]. The array beam shape is defined by characteristics such as physical dimensions of array and amplitude/phase weights associated with each antenna element. Beamformers can have resistive network realization [2] or have transmission line realization [3]. The Butler matrix has also been used in many applications [4]. The Butler matrix consists of fixed phase shifts interconnected to hybrids and yields orthogonal beams. The lengths of the lines used are in units of $\pi/8$ radians and 180° hybrids are used. Digital beamforming can be implemented when the arrays operate in transmit or receive mode. In radar context, Digital Beamformers (DBFs) are mainly used on receive arrays [5]. DBFs have

advantages such as fast adaptive null forming, the generation of several simultaneous beams, array self-calibration etc.

In the radar system, detection is rarely done on a single pulse data [6]. “ N ” pulses usually illuminate a target and returns are integrated coherently before a target is detected [7–10]. There are integrator types like moving-window integrator [11], binary integrator [12] etc. In these methods an effective value of signal to noise ratio (SNR) is obtained equal to SNR attributed to single pulse multiplied by N .

The objective of this presentation is to utilize the radar technique of N pulse addition in digital beamforming method. In this paper, it is shown that four consecutive pulses (radar returns) are digitized, stored and addition/subtraction operation carried out. It is shown that by the method followed, it is possible to create a very sharp beam which offers a spatial resolution much better than the conventional $\lambda/2D$, where D is the aperture dimension.

The remainder of the paper is organized as follows. Section 2 describes the generation of SUM and DIFFERENCE patterns. Section 3 provides the schematic of generation of proposed beamformer. Finally, Section 4 conclude the work.

2. GENERATION OF SUM AND DIFFERENCE PATTERNS

Consider an array of an even number of elements $2M$ is positioned in the X - Y plane with Z axis being the direction of propagation. The inter-element spacing is d and M elements are placed on each side of origin. Assuming that the amplitude excitation is symmetrical about the origin, the normalized array factor for SUM pattern (for non-uniform amplitude and same phase in each element) is given as [13]:

$$(AFS)_{2M} = \frac{1}{M} \sum_{n=1}^M a_n \cos \left[\frac{(2n-1)}{2} kd \cos \left(\frac{\pi}{2} - \theta \right) \right] \quad (1)$$

where θ is measured from broadside direction. In the DIFFERENCE pattern, one half of the array has phase value of zero and the other half has phase value of π . The resultant array factor for DIFFERENCE pattern is [13]:

$$(AFD)_{2M} = \frac{1}{M} \sum_{n=1}^M a_n \sin \left[\frac{(2n-1)}{2} kd \cos \left(\frac{\pi}{2} - \theta \right) \right] \quad (2)$$

We obtain SUM-3×DIFFERENCE pattern from subtracting three times equation (2) from (1). In Fig. 1 the SUM, DIFFERENCE and

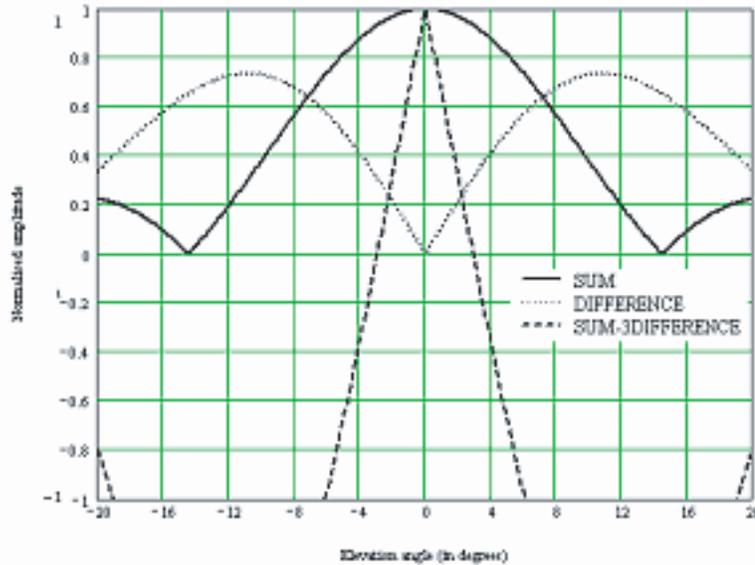


Figure 1. A display of SUM, DIFFERENCE and SUM-3×DIFFERENCE patterns for uniform illumination.

the SUM-3×DIFFERENCE patterns are plotted. It is clearly seen that the beam width narrows for SUM-3×DIFFERENCE pattern. It also generates negative amplitude over a large range of elevation angles. By controlling the progressive phase difference between the elements, all the three beams can be squinted to give a maximum radiation in a given direction [13, 14].

The numerical values of 3 dB beamwidth with null depth are presented in Table 1. For such computation we have considered eight elements only with spacing. The conventional beamwidth is $\lambda/2D$, where D is the dimension of the array.

From Table 1, it is seen that even for imperfect null depth the resultant beamwidth does not vary significantly. For application in vehicle tracking radar, let us consider the SUM pattern only illuminating a moving vehicle at a distance of 30 m. The radar's footprint will be 9 m, whereas for the proposed case the footprint will be 1.6 m, therefore the proposed radar will be able to resolve to moving targets nearby each other.

For example, if 10 ns is considered the pulse width, the interpulse period is 50 ns then the range resolution should be the order of 1.5 m and maximum detectable range is 75 m. The dwell time on a moving

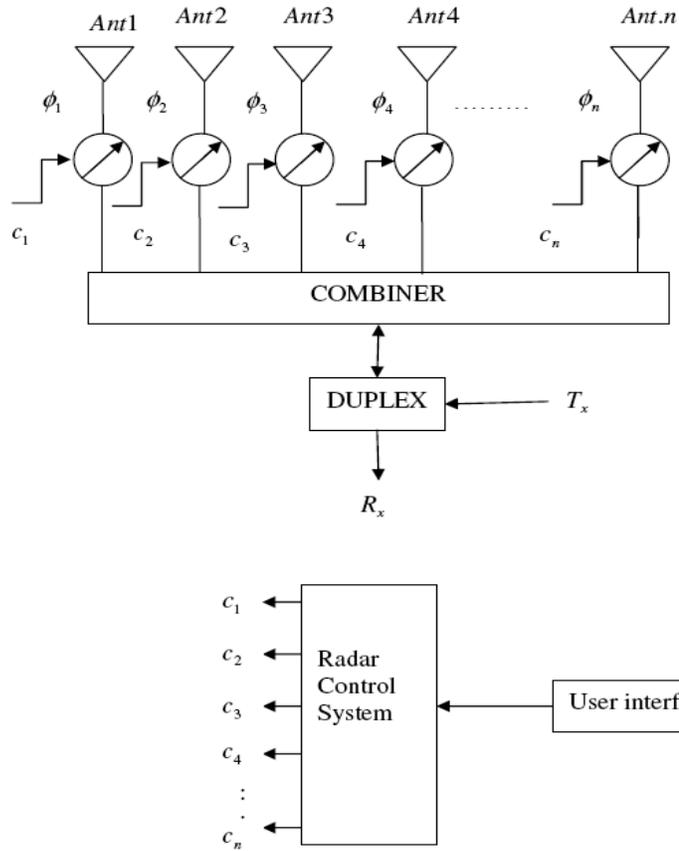


Figure 2. Schematic of the generation of the SUM and DIFFERENCE pattern in real time.

target for four pulse integration will be 200 ns. Considering highest speed of vehicle is 120 km/h, the vehicle will move $6.66 \mu\text{m}$, which is insignificant.

When radar is operating, microcontroller system controls the $c_1, c_2, c_3, \dots, c_n$ phase shifters and these signals $c_1, c_2, c_3, \dots, c_n$ controls the phase shift of each antenna as shown in Fig. 2. For SUM pattern the phase differences $\phi_1, \phi_2, \phi_3, \dots, \phi_n$ are zeros and for the DIFFERENCE pattern the phase difference for one half elements is zero and for the rest half elements is π . So this is operation in real time.

Table 1. Beamwidth with null depth.

Null depth (in dB)	Beamwidth (degree)
-20	2.84
-18	3.20
-16	3.21
-14	3.21
-12	3.21
-10	3.21

3. SCHEMATIC OF GENERATION OF PROPOSED BEAMFORMER

The schematic diagram of proposed digital beamformer is shown in Fig. 3. In this the received analog signal is digitized using analog to digital converter and the digitized data is then shifted using 'D' type flip-flops after each pulse duration. After receiving four consecutive pulses, the addition of second, third and fourth pulse is subtracted from first pulse using parallel adder and parallel subtractor respectively. The corresponding timing diagram is shown in Fig. 4. The pulse is transmitted from the radar and received after time τ . T_s is the inter pulse period of transmitting pulses, so after each T_s the pulses are received. The time moments, at which we receive the first four pulses are $\tau, \tau + T_s, \tau + 2T_s, \tau + 3T_s$. Between two consecutive pulses we have large number of range gates. So it is difficult to implement it by using thousands of flip-flops. Hence, we have proposed to use array concept for storing these ranges.

Consider the first received pulse is SUM and consecutive three pulses are DIFFERENCE. Five single dimensional arrays are taken named Arr1, Arr2, Arr3, Arr4, ResArr. We are storing these large number of range gate values in Arr4, Arr3, Arr2 and Arr1 respectively. Result of SUM-3×DIFFERENCE i.e., Arr1-(Arr2+Arr3+Arr4) is stored in ResArr, hence it reduces the complexity of using thousands of flip flops. Before taking the new values, all the arrays are reset to zero. This logic is shown with the help of flow chart in Fig. 5.

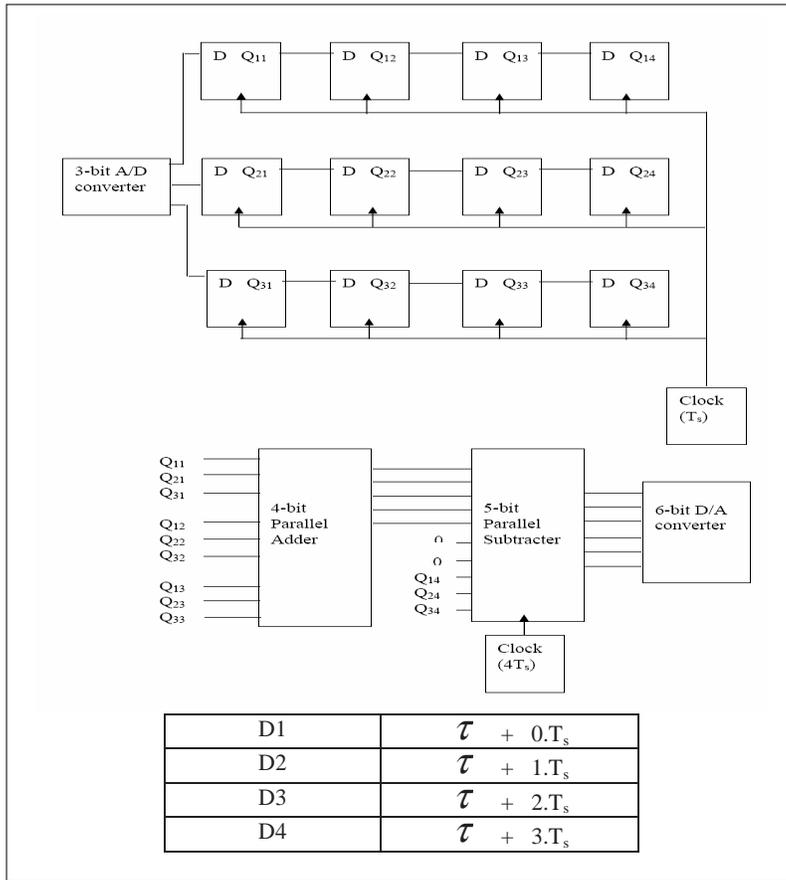


Figure 3. Schematic diagram of digital beamformer.

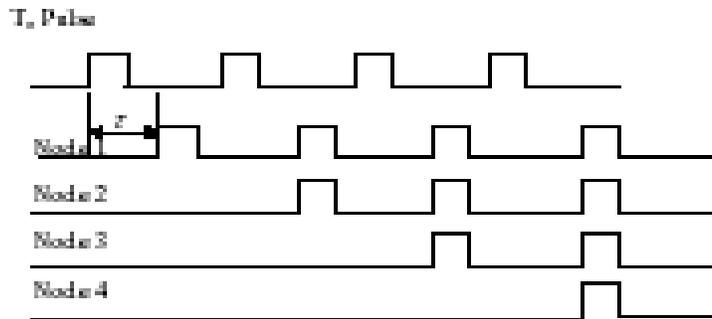


Figure 4. Timing diagram with respect to transmitting pulse.

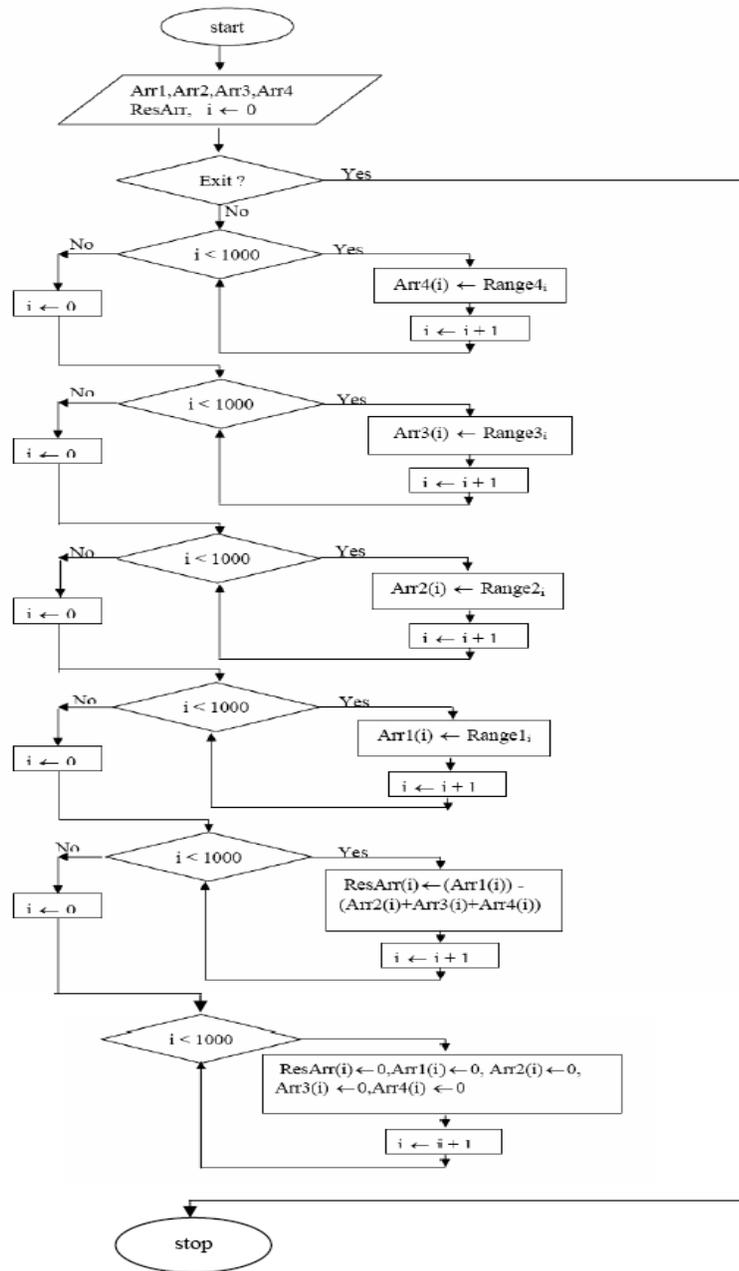


Figure 5. Flow chart for storing ranges.

4. CONCLUSION

In this paper we have shown a new technique of implementing a digital beamformer which produces exceptionally narrow footprint. The concept used here is SUM-3×DIFFERENCE, where SUM is the signal received after reflection from moving object and DIFFERENCE is the surroundings of moving object. This results in very narrow beam. Assuming that the target is approaching/receding the radar from broadside direction. The data received from each range gate is stored in a single dimensional array. The addition/subtraction is performed in real time on these stored numbers. The net result of such operation displays negative values in amplitude over a large range of elevation angle other than broadside. If negative values are discarded, we will have a very narrow visible angle along with elimination of signal received from direction other than desired angle.

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