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A DELAY-LINE CANCELLATION METHOD FOR CLUTTER ATTENUATION AND ELIMINATION OF BLIND SPEED

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Abstract

In this paper, a conceptual schematic for the search radar has been presented which offers clutter cancellation as well as blind speed elimination. It is assumed that the radar is performing conical scan in both azimuth and elevation. For such cases, strong clutter signals are likely to be intercepted from off-boresight angles. A pulse-to-pulse comparison method is presented where the radar transmits and receives SUM beam during the first pulse and DIFFERENCE beam in the second pulse. The detected voltages for the echoes received during the pulse intervals are subtracted from each other and the negative voltage at the output of subtractor is discarded. This result in a narrow beam pointed in the direction of angle of arrival. This method, in receive only mode, can also be used for calibration of large phased arrays.

Keywords — SUM pattern, DIFFERENCE pattern, delay line, clutter, blind speed.

1. INTRODUCTION.

Strong echoes from close ranges often impair the radar operation by saturating the receiver [1]. It is generally found that the radar beam which is pointed at an angle towards the sky is subjected to clutter echoes from nearby hills and other natural environments. We consider a case where a small planar array of isotropic radiators is located in such a way that it forms a pencil beam in azimuth and elevation. This array then can be rotated over 2π to give full azimuthal coverage [2] or in lieu of this, an electronic scanning mechanism can also be implemented. For such inclined radar systems, it is mandatory to remove close range clutter without blanking off the range gates. This can be theoretically done if all signals arriving at the receiver from an undesired angle are discarded. However, angle of arrival of desired target can be deciphered if the beam is electronically scanned in the direction of elevation also.

Skolnik [1] has outlined a clutter cancellation technique with delay-line cancellers. In this method, the bipolar videos from two successive sweeps of Moving Target Indicator (MTI) radar are subtracted from each other. The stationary clutter amplitude remains the same and therefore gets cancelled. However, amplitudes of echoes received from moving targets vary, giving rise to detectable signal. A single delay line filter removes clutter but unfortunately its frequency response function has zero response at pulse repetition frequency (PRF) and its multiples. This is known as blind speed. The MTI radar is an useful instrument for detection of moving targets if loss in Doppler space due to blind speed is ignored. Skolnik [1] has outlined that the blind speeds become troublesome when radar frequency is increased. Increasing PRF will remove blind speed from usable Doppler space; however, it will lead to range ambiguities. So, in a radar design, there is a trade-off between Doppler and range ambiguities.

In this paper, a conceptual variation of the same method as in [1] is outlined. In this presentation, it is shown that blind speeds are eliminated along with clutter cancellation. Thus as MTI radar can use lower PRF to eliminate the range ambiguities. In the present case, it is assumed that clutter echoes are received from off-boresight angles even for inclined beam. Using a single delay-line canceller, we subtract the echo received on DIFFERENCE beam from the echo received on SUM beam. This results in both positive and negative amplitudes at the detector output. It can be shown that positive amplitude corresponds to angle of arrival through boresight only and vice-versa. We discard the negative amplitude and therefore retain the signal of our interest. For the antenna array to be capable of electronic scanning, suitable phase weighting has been incorporated. This is accomplished by inserting time-delay units with each element. Suitable time-delay unit can be inserted by switching ON/OFF pin diode based SPDT (single pole double throw) switches. This is turn, converts the radar into a programmable system where phase tapering is controlled by a micro-controller. To the best of author's knowledge, the proposed schematic of utilization of SUM and DIFFERENCE pattern in pulse to pulse comparison has not been reported as yet. The present proposal has manifolds advantages over standard delay line cancellation techniques proposed in [1]: namely, clutter attenuation from off-boresight angles is complete, no effect of blind speed and narrower beam width for the given aperture size. Therefore the present proposal constitutes a new and improved delay-line schematic for an MTI radar. The detailed schematic is presented in the following section.

2. ANTENNA ARRAY SCHEMATIC

The schematic diagram for a six element linear array is presented in Fig.1. A planar array can be constructed using similar mechanism of delay units. Each array element is connected to two DP3T (double-pole-three-throw) switches and one DPDT (double pole double throw) switch where the switches are controlled by voltage obtained from driver circuit, which translates the bit pattern obtained from micro-controller output [3]. A DP3T switch module can be constructed using PIN diodes. The control voltages (A, B, S) of the DP3T/DPDT switch are obtained through micro-controller. The limiting condition in this case is at-least and at-most one switch can be ON at a time. This condition therefore demands that some bit patterns to be redundant. It is seen that the delay-units follow a neat algorithm which permit the beam to swing in 49 distinct positions over the entire hemisphere. This is elaborated as follows. Each switch can offer three paths to the RF thus permitting three different phase shifts. Let such paths be designated as A_0, $A_1$and A_2. Similar is the case for 'B' switches for elements in the linear array is X direction. Apart from 'A' and 'B' the other switch controls are designated as S_0, S_1, S_0^* and S_1^*. If S_0 is ON, S_1 is OFF. Similar, it is in the case for S_0^*, and S_1. It is important to note that a micro-controller can be used to switch on/off for particular switch combination which will insert progressive phase difference between the elements. The speed of operation is limited by the response time of the switches. Fig. 1 also includes the amplitude weighting functions designated as w_n.

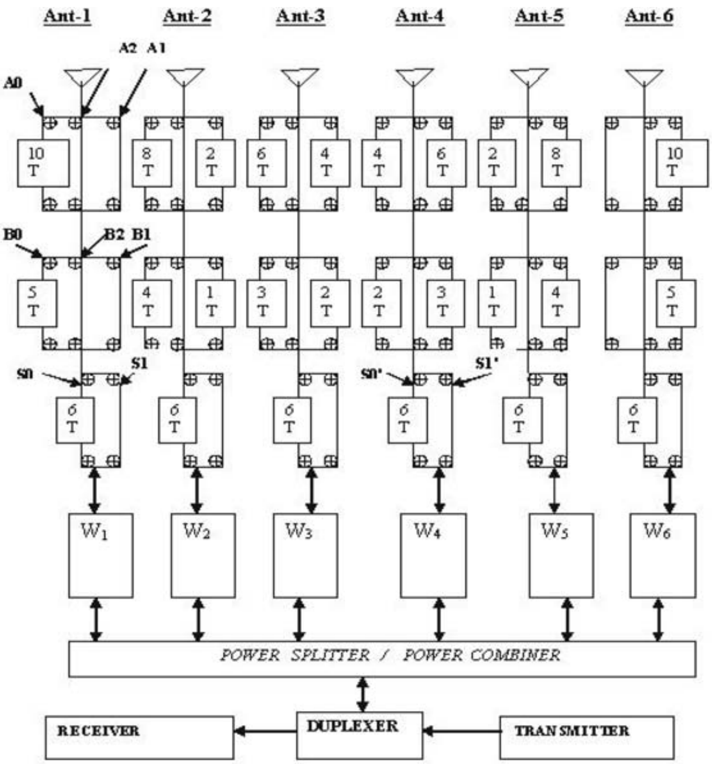

Fig. 1 The block diagram of radar incorporating the three layer time-delay units.

3. ARRAY FACTOR

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 [4]. 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:

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

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:

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

We obtain SUM-DIFFERENCE pattern from subtracting equation (2) from (1). In Fig. 2 the SUM, DIFFERENCE and the SUM-DIFFERENCE patterns are plotted. It is clearly seen that the beam width narrows for SUM-DIFFERENCE pattern. It is 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.

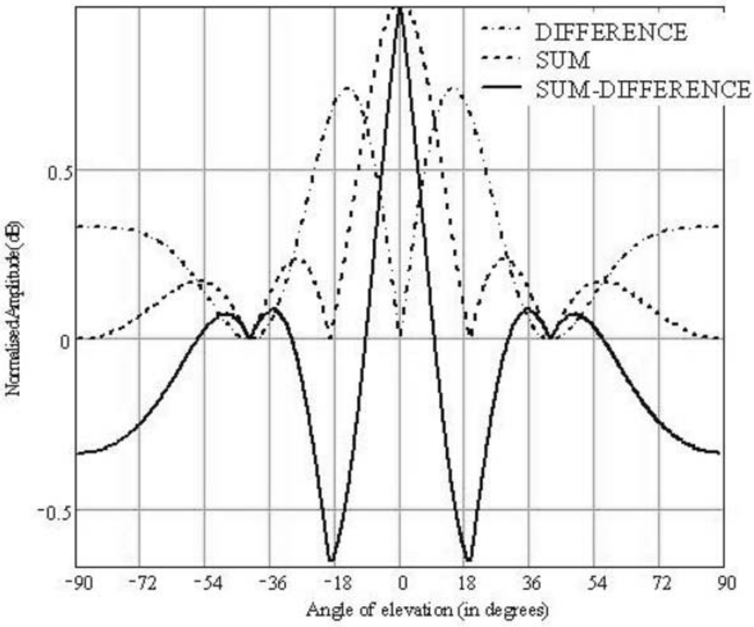

Fig.2 A display of SUM, DIFFERENCE and SUM-DIFFERENCE patterns for uniform illumination.

4. OPERATION

The conceptual schematic presented in this paper involves generation, transmission and reception of SUM beam during the first pulse period and DIFFERENCE beam in the second. The received echoes during the first pulse interval are delayed by T_p, the pulse interval time period. These echoes are then compared with fresh echoes received during the second pulse (using a DIFFERENCE beam). The compared value can be positive or negative depending on whether the echo received on DIFFERENCE beam is weaker or stronger than the echo received on SUM beam. The negative voltages are discarded and the positive voltages are processed further. In Fig. 3 the schematic diagram of the above proposed single-delay line canceller is outlined.

The method of generation of SUM and DIFFERENCE beams using programmable time-delay units as shown in the schematic diagram in Fig.1 along with their ability in scanning in azimuth and elevation are presented in details in literature [5]. This is briefly reproduced in the following paragraph.

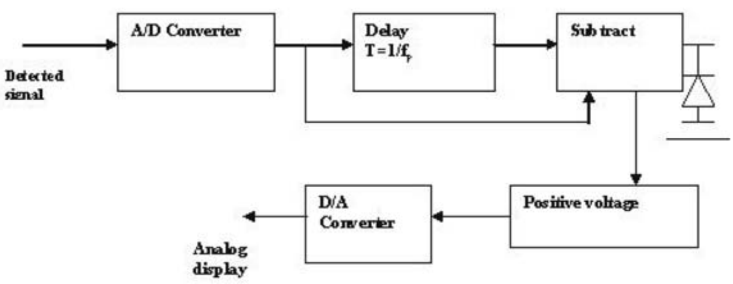

Fig. 3 The block schematic of single delay-line canceller.

4.1 *Generation of SUM pattern*

Consider the case when the progressive time delay is T. It is assumed that inter-element spacing $d = 0.5\lambda$ and the unit time delay $T = \pi / 6$. For this the switch controls required are: (0 = OFF, 1 = ON)

A_0	A_1	A_2	B_0	B_1	B_2	S_0	S_1	S_0^*	S_1^*
0	0	1	0	1	0	0	1	0	1

The RF traverses through the switch represented as A_2, B_1 and S_1/S_1*. The progressive delay will tilt the SUM beam to 9.6^0 west. To reverse the beam at 9.6^0 east, we alter the switch controls as follows.

A_0	A_1	A_2	B_0	B_1	B_2	S_0	S_1	S_0^*	S_1^*
0	0	1	1	0	0	0	1	0	1

Implementing control signals in this fashion introduce progressive time delay in -X direction. Thus, by toggling two control bits B_0 and B_1 result in beam scan from west to east. The beam can be placed looking at zenith by changing control bit A_2 & B_2 to “1”.

4.2 Generation of DIFFERENCE pattern

In this scheme, a DIFFERENCE pattern can be generated and centre null position scanned in steps on either side of zenith. Consider the control switch position as follows.

A_0	A_1	A_2	B_0	B_1	B_2	S_0	S_1	S_0^*	S_1^*
0	0	1	0	1	0	0	1	1	0

The progressive time delay units in positive X direction are 0, T, 2T, 9T, 10T, 11T. This results in a DIFFERENCE pattern with null position at 9.6^0 in the west. The delay units for null at zenith is 0, 0, 0, 6T, 6T, 6T. In Fig.4, the SUM and DIFFERENCE patterns in scanned mode are presented. It can be observed that the DIFFERENCE beam along with the SUM beam is electronically steerable in steps decided the time delay unit *T*. So far we have considered all the weighting functions to be normalized to 1. For such uniform illumination, the SUM, DIFFERENCE and the SUM-DIFFERENCE beams are plotted in Fig. 2. It is seen that if the target is stationery or slowly moving with respect to inter pulse period (IPP) and angle of arrival is through boresight (± 8^0 around zenith), the output of the delay-line canceller which is equivalent to SUM-DIFFERENCE beam will be of positive amplitude. Signals received from angles beyond this give negative amplitudes and are neglected. It is however, possible to lose desired target if the target is approaching radar with high velocity and angle of arrival is less than but close to the corners that is 8^0. For example, if within the duration of measurement, the received power in the SUM beam is less than the received power in DIFFERENCE beam due to change in range for an approaching target, the target will be discarded. A 0.1dB margin in the received powers will tolerate a maximum unambiguous radial velocity of 60 km/sec and 1dB margin will correspond to 560 km/sec.

It is seen from Fig. 2 that at certain angles of arrival between 30^0 and 60^0, the received signal from SUM-DIFFERENCE gives positive amplitude. To overcome this ambiguity, it is necessary to select a SUM beam pattern with shows nearly complete side lobe cancellation. This can be done using side lobe cancellers (SLC) which introduce suitable amplitude tapering [6] between each antenna elements. For simplicity, one can use binomial weights which will create an array factor with no sidelobes, provided that the element spacing $d \leq \lambda/2$. The binomial weights are chosen from the rows of Pascal’s triangle. For $N = 6$, the normalized weights are:

W_1	W_2	W_3	W_4	W_5	W_6
0.1	0.5	1	1	0.5	0.1

With the given amplitude tapering, the beam patterns that results are displayed in Fig. 5. From the SUM-DIFFERENCE pattern shown in Fig. 5, we see that the usable range is ± 12^0. By usable, it is meant that only the signal received within this angular range is accepted. In Fig. 6, we take a closer look at the half-power beamwidths for SUM beam (uniform), SUM beam (with SLC) and SUM-DIFFERENCE beam. Thus clutter signals received beyond the usable range of ± 12^0 of boresight are rejected. It is seen that the beam narrows from given array size when SUM-DIFFERENCE is used.

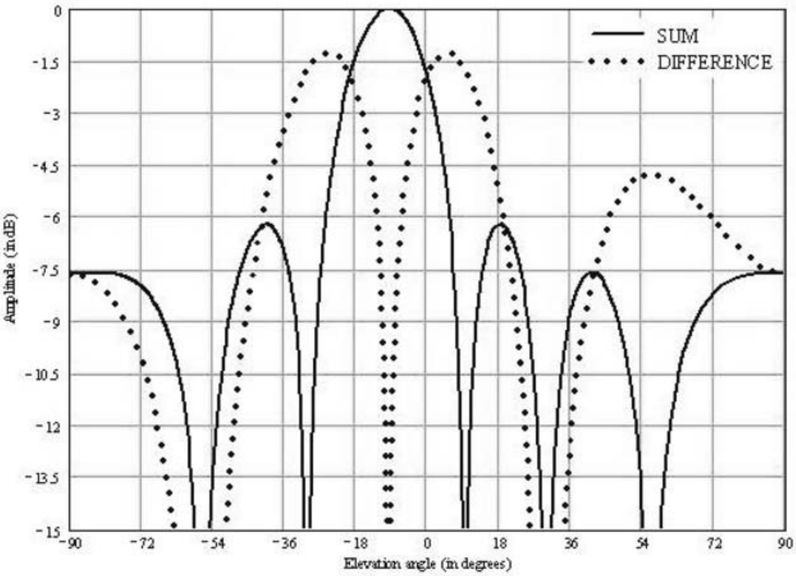

Fig. 4 SUM and DIFFERENCE beams in scanning mode.

5. BLIND SPEED

It is shown in [1] that the response of a single-delay line canceller goes to zero whenever the moving targets have Doppler frequencies at the pulse repetition frequency (PRF) and its multiples. This happens because the amplitude of the signals received from pulse to pulse is assumed to remain the same. However, in the present proposition we examine the operation of a single delay-line canceller with unequal amplitudes as would happen when different beam patterns are utilized from pulse to pulse. The received signal (voltage) in SUM beam with delay is:

$$V_1 = K\sin\{\omega_d(t - T_p) - \phi_0) \quad (3)$$

and the received signal in the Difference beam is:

$$V_1 = K'\sin\{\omega_d t - \phi_0) \quad (4)$$

Where $\phi_0 = 4\pi R_0 / \lambda$ and ω_d is the angular Doppler frequency. After subtraction of equation (4) from equation (3), we get:

$$V_1 - V_2 = \\ K\cos\phi_0\{\sin\omega_d t[\cos\omega_d T_p - K'/K] - \sin\omega_d T_p \cos\omega_d t\} - K\sin\phi_0\{\cos\omega_d t[\cos\omega_d T_p - K'/K] \\ - \sin\omega_d T_p \sin\omega_d t\}$$

The above frequency responses have amplitudes, $\cos\omega_d T_p - K'/K$ and $\sin\omega_d T_p$, both of which needs to be zero for blind speeds. However, if K’ < K then it is not possible. Therefore, in the present schematic blind speeds are eliminated.

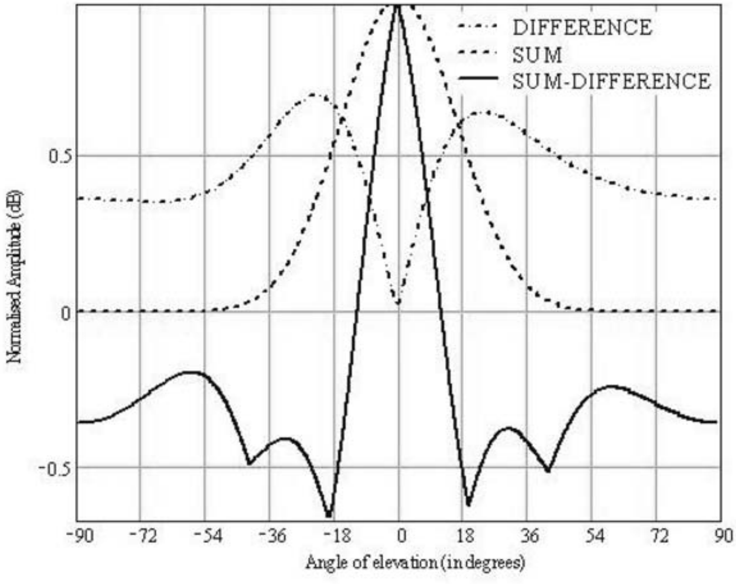

Fig. 5 All the beam patterns with binomial weighting function.

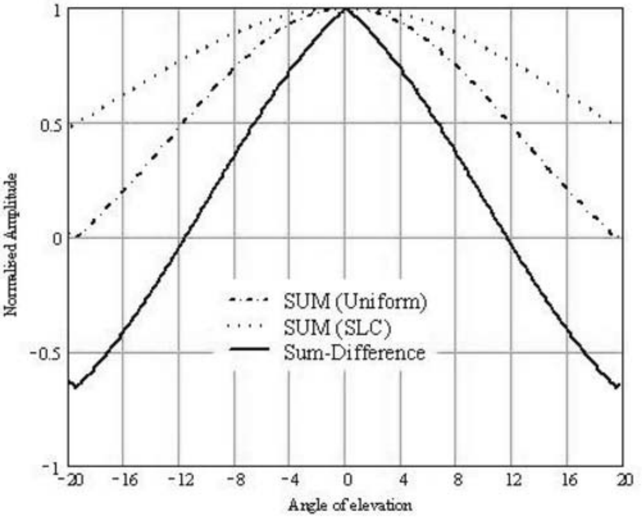

Fig. 6 A closer look at SUM and SUM-DIFFERENCE patterns.

6. CONCLUSION

The concept of SUM-DIFFERENCE pattern has been illustrated for calibration of large phased array [5]. This presentation has outlined how this method can be used in radar systems for elimination of clutter as well as blind speed. The narrow beam produced by SUM-DIFFERENCE focuses the look angle over a small footprint. This can then be electronically scanned using a micro-controller to control the insertion of time delays with each element. The whole sequence is programmable. The presented conceptual schematic eliminates clutter as well as blind speed as contrary to method outlined in the literature. The present proposal, therefore, demonstrates a new and improved version of delay line cancellation technique.

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