A NOVEL SCHEMATIC FOR CALIBRATION OF LARGE PHASED ARRAY ANTENNA USING PROGRAMMABLE TIME-DELAY UNITS

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Abstract—In this paper, a conceptual schematic for calibration of large phased array antenna is presented. Derived from an earlier work by the authors, the presentation demonstrates a simple yet innovative schematic of inserting time delay units with each element in the array which can be used to generate both SUM and DIFFERENCE pattern. Both these patterns are electronically steerable. The calibration is done using SUM-DIFFERENCE pattern. PIN switches are used to insert proper time delay units. Thus the schematic is completely programmable using a microcontroller to control the insertion of time delay. The details of the schematic is presented along with the generated antenna patterns.

1. INTRODUCTION

It is often required to calibrate phased-array antennas in relation to the beam pointing accuracy and sidelobe levels. Far-fields of smaller sized array antennas can be measured in anechoic chambers, however, for very large sized antenna arrays, far-field radiation pattern measurement remains an operational challenge. Lincoln laboratory has pioneered several phased-array calibration techniques [1, 2]. In [1], the use of inherent array mutual coupling to transmit and receive signals between pairs of elements in the array is done. In [2], planar near-field calibration and testing in the antenna reactive region was explored to accurately measure low-sidelobe level radiation patterns. The mutual-coupling calibration technique was experimentally verified by using the monopole phased array antenna. This calibration technique proved to be a fast and accurate way of measuring one-dimensional and two-dimensional patterns, compared to conventional far-field measurement techniques.

In an interesting approach to far-field measurements and calibration of very large sized array antenna, radio source has been used [3]. The noise temperature of the radio source Virgo-A (3C 274) was measured in the receive mode during its transit over the radar. The source under consideration should have appropriate right ascension and declination to be able to pass through the antenna array beam. The atmospheric radar had 256 Yagi elements operating at 53 MHz.

In this paper, a conceptual variation to similar far-field measurements is introduced. A two dimensional array with 36 elements is conceived with fixed time-delay units connected to each element in the array. Suitable time-delay unit can be switched on by micro-controller driven RF switches. Thus the beam can be inclined at a desired elevation angle electronically. Similarly, by suitable selection of time delay units, a difference pattern can be created. The SUM-DIFFERENCE pattern can be used to predict beam pointing accuracy. Similarly, from null-null measurements, an estimate of beam width of the SUM pattern can be obtained. A clock at 1 KHz can be used to control the micro-controller as well as the integrator-detector for measurement of noise temperature. The detailed schematic is presented in the following section.

2. PHASED-ARRAY ANTENNA SCHEMATIC

Fig. 1 presents the schematic diagram for a 6 element linear array. Planar array can be constructed using similar mechanism of delay units. The detailed schematic is presented in [4]. However, for sake of
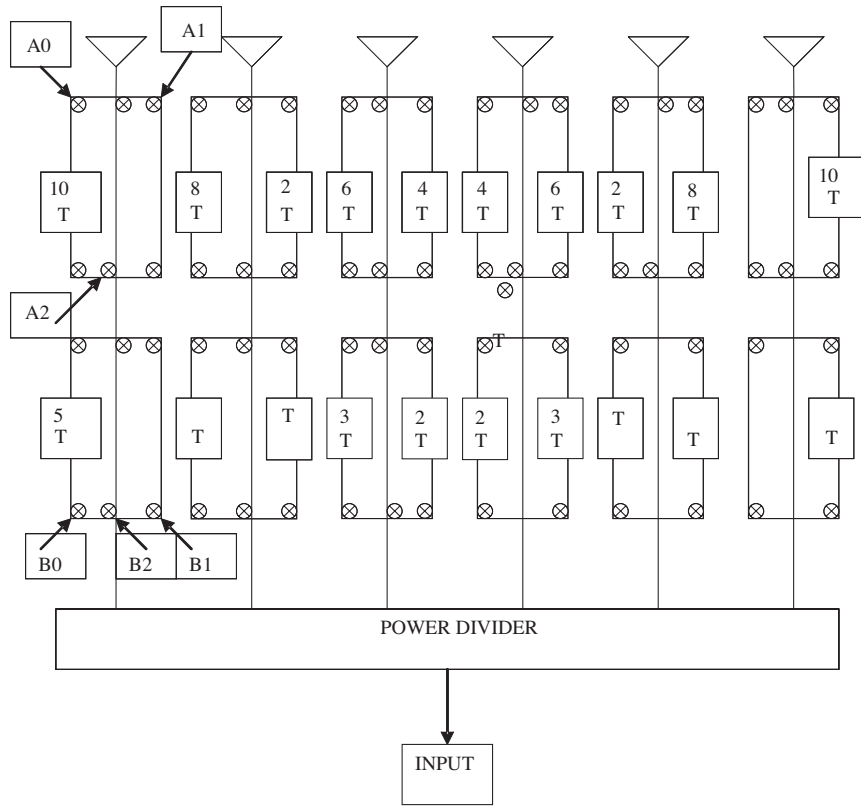
Figure 1. A two layer schematic of six element phased array antenna.

completion, the essence is presented as follows.

Each array element is connected to two DP3T (double-pole-three-throw) switches where the switches are controlled by voltage obtained from driver circuit, which translates the bit pattern obtained from micro-controller output. A DP3T switch module can be constructed using PIN diodes. The control voltages (A, B) of the DP3T 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 shift. 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 and 'C' & 'D' switches for

subarrays in Y direction. Using a micro-controller, the user can switch on/off particular switch combination which will insert progressive phase difference between the elements. Such is shown in Table 1. In article [4], the schematic diagram for larger arrays consisting of "N" elements is also shown.

Table 1. Switching Pattern for 6×6 planar array.

T=Unit delay

| A0/C0	A1/C1	A2/C2	B0/D0	B1/D1	B2/D2	Progressive Delay
0	0	1	0	0	1	0
0	0	1	0	1	0	T in East/South Direction
0	1	0	0	0	1	2T in East/South Direction
0	1	0	0	1	0	3T in East/South Direction
1	0	0	0	0	1	-2T in West/North Direction
1	0	0	0	1	0	-T in West/North Direction
1	0	0	1	0	0	-3T in West/North Direction

For application in array calibration using a radio source, it is needed to switch the beam East, West and Zenith. For such beam tilt in a single plane, it is required to keep the progressive phase difference in the Y (North-South) direction as $0T$ (where T is the delay unit). Progressive phase difference is inserted in the East-West direction only. Along with the SUM pattern, it is required that the DIFFERENCE pattern should also be displaced to East, West and Zenith. Due to this necessity, the delay matrix is altered and presented in Fig. 2. In this case, an additional DPDT switches with $6T$ delay is inserted in series with each element. The switch controls are designated as S_0, S_1, S_0^* and S_1^*. If S_0 is ON, S_1 is OFF. Similar is the case for S_0^*, and S_1^*.

In the following sections, algorithms for generation of scanning SUM and DIFFERENCE patterns are demonstrated. For all such cases, it is assumed that:

Inter-element spacing $d = 0.5\lambda$ and the unit time delay $= \pi/6$.

3. GENERATION OF SUM PATTERN

We take the example of beam swings in three directions namely 20° East, Zenith and 20° West as was the requirement in ST radar [3]. Three such measurements of radio source transit consecutively over
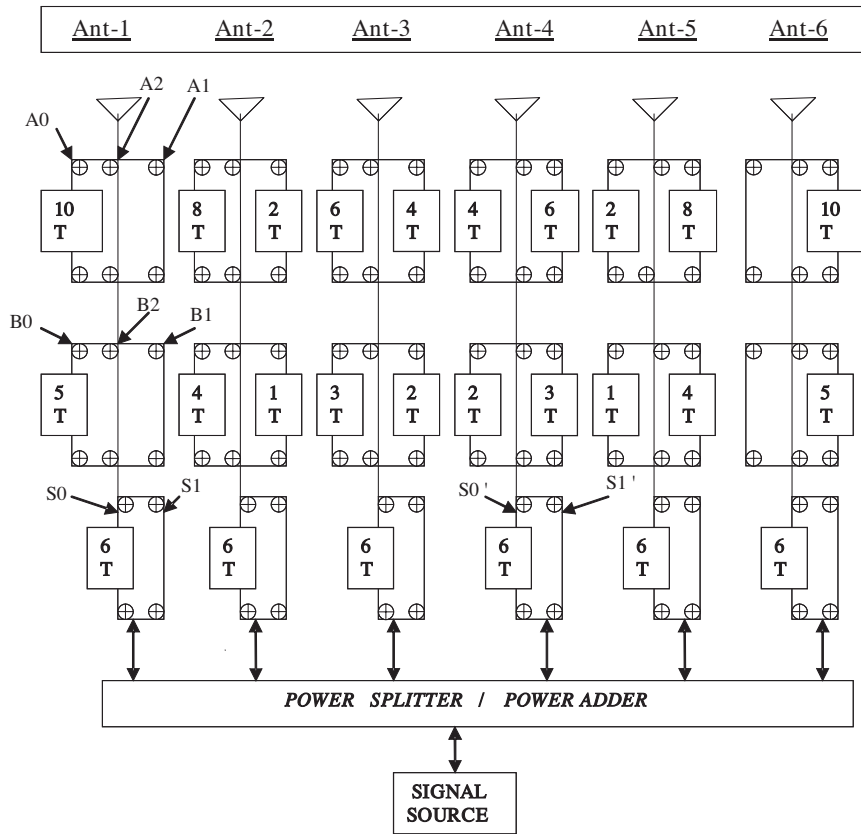
Figure 2. A revised three layer schematic of six element phased array antenna.

a period of time give an accurate representation of beam pointing accuracy.

Consider the case when the beam needs to be placed at 20° West for record of source transit. The switch controls required are: $(0 = \text{OFF}, 1 = \text{ON})$

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

From Fig. 2 it is seen that such generation of control signals introduce $2T$ delay in $+X$ direction. The time delay steps are $0, 2T, 4T, 6T, 8T, 10T$ in the $+X$ direction. Such algorithm results in a

scan of SUM pattern at an angle of 19.471° West.

The resultant beam pattern is shown in Fig. 3.
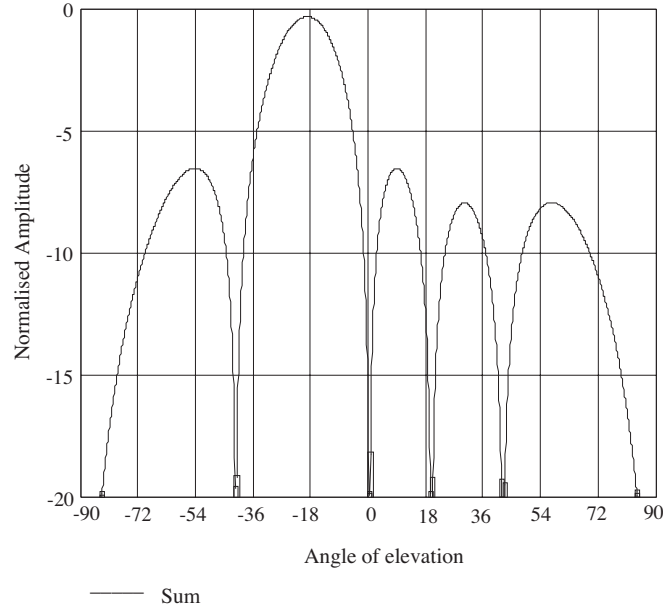
Figure 3. A display of SUM pattern at 20 degree west direction.

Similarly a progressive $2T$ delay in $-X$ direction will result in scan of SUM pattern at an angle of 19.471° East. To achieve this sequence the switch controls are:

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

Just toggling two control bits A_0 and A_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. GENERATION OF DIFFERENCE PATTERN

In this unique 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	1	0	0	0	1	0	1	1	0

The progressive time delay units in $+X$ direction are $0, 2T, 4T, 12T, 14T, 16T$. This results in a DIFFERENCE pattern with Null position at $19.471°$ in the West. Figure 4 displays the pattern. Similar to changing the control bits A_2 & B_2 to "1" result in a DIFFERENCE pattern at boresight. The delay units for null at zenith is $0, 0, 0, 6T, 6T, 6T$.
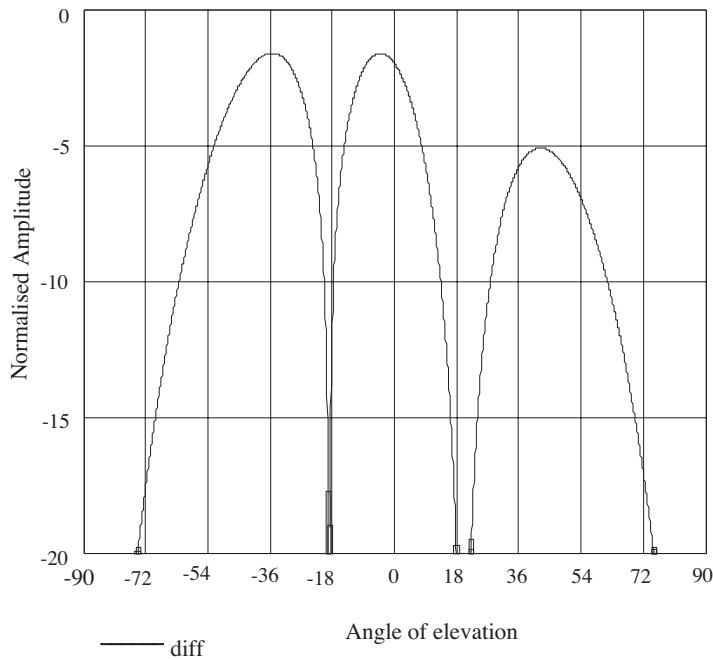

Figure 4. A display of DIFFERENCE pattern at 20 degree west direction.

5. SCHEMATIC FOR SUM-DIFFERENCE

For measurement of beam pointing accuracy of less than $0.5°$, a broad beam SUM pattern will not suffice. It is necessary to have a sharply pointed beam looking up at the target. This can be generated using SUM-DIFFERENCE pattern. Toggling the control bits in

synchronization to a 1 KHz clock, the alternate SUM pattern and DIFFERENCE pattern are obtained and the difference in amplitude of the detected signal is taken. The same plot for beams in West direction is shown in Fig. 5. In Fig. 5, the SUM, DIFFERENCE and SUM-DIFFERENCE plots are overlapped. It is evident that for the resultant narrow beam, the measurement of beam pointing accuracy is much more meaningful.
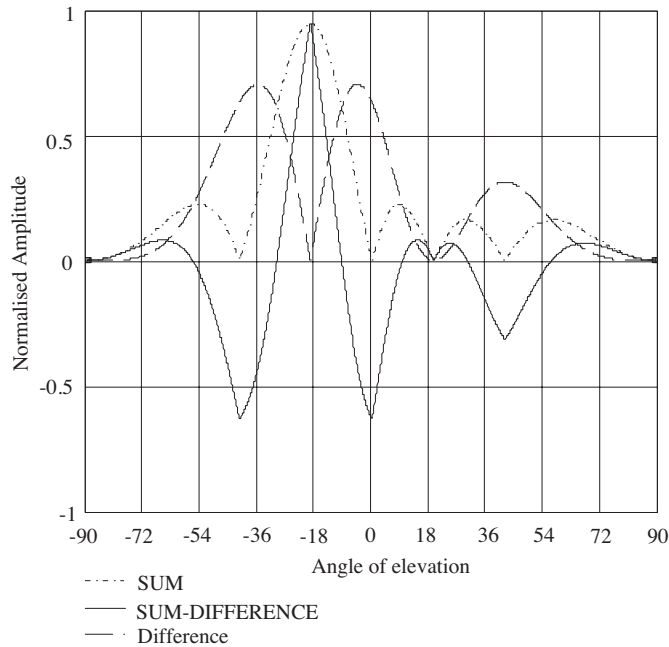

Figure 5. All the patterns are overlapped at 20 degrees west.

The block diagram for obtaining SUM-DIFFERENCE pattern is given is Figure 6. When the control bits are configured for SUM pattern (irrespective of look angle), the synchronous integrator/detector circuit is switched on by clock pulses and output is fed to adder. The vice-versa happens with DIFFERENCE pattern. The difference of these two outputs are taken and plotted on a chart recorder.
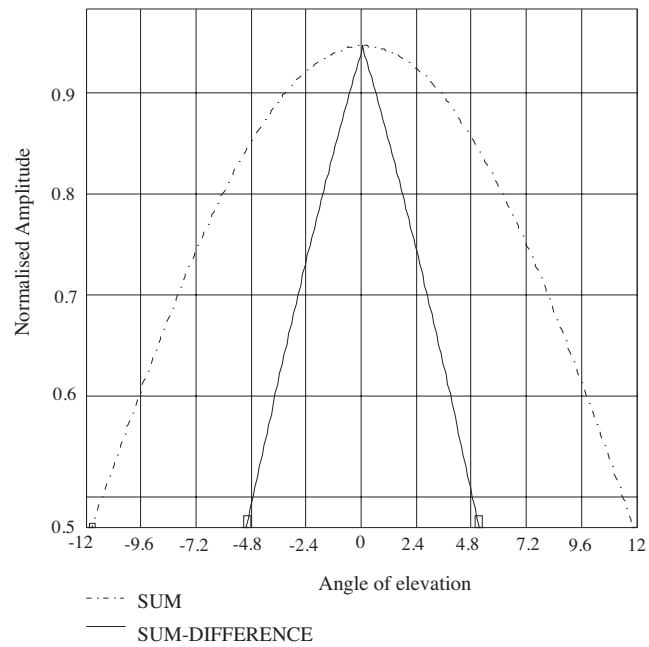
6. RESULTS

In Figure 7, the shape for the projected beams, SUM AND SUM-DIFFERENCE, are zoomed in and analyzed. The tip of the beam is projected exactly at $\theta = 0°$ The half power beamwidth for the
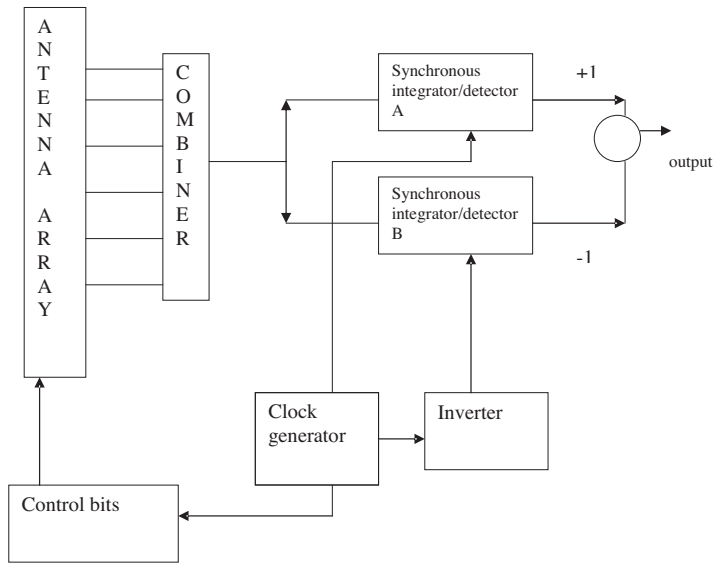
Figure 6. Block diagram of generation schematic for SUM-DIFFERENCE.

Figure 7. A closer look at SUM and SUM-DIFFERENCE patterns.

SUM-DIFFERENCE beam is 10° approximately whereas for the SUM pattern alone the beamwidth is 24°. The step size of scan is T delay. For the present case, when $T = \pi/6$, the scan angle step is 9.6°. This can be reduced by choosing a smaller T. Since the RF switches are electronically operable, a micro-controller programmable routine could be used to control the generation of requisite beams and their scanning. The complete table is summarized in Table 2. From SUM to DIFFERENCE in the same scan angle only two bits are required to be toggled, whereas from DIFFERENCE (in one scan angle) to SUM (in another scan angle) four bits are required to be toggled.

Table 2. Control bit patterns for beam switching.

A_0	A_1	A_2	B_0	B_1	B_2	S_0	S_1	S_0^*	S_1^*	Nature of beam and its position
1	0	0	0	0	1	0	1	0	1	SUM; 20^0 East
1	0	0	0	0	1	1	0	0	1	DIFFERENCE, 20^0 East
0	0	1	0	0	1	0	1	0	1	SUM, ZENITH
0	0	1	0	0	1	0	1	1	0	DIFFERENCE, ZENITH
0	1	0	0	0	1	0	1	0	1	SUM, 20^0 West
0	1	0	0	0	1	0	1	1	0	DIFFERENCE, 20^0 West

7. CONCLUSION

With a single layer of digital phase shifters in a radar, generation of SUM-DIFFERENCE beam requires an extra hardware which alternately inserts 0 degrees and 180 degrees in the two halves of a linear array. In the present case, however, the normal radar schematic need not be changed. Just electronically switching on and off RF paths, at fixed intervals of time result in the required operation. The whole sequence is programmable. Another unique possibility of this schematic is scanning of DIFFERENCE pattern resulting in a automated tracking system.

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