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A NOVEL BEAM-SWITCHING ALGORITHM FOR PROGRAMMABLE PHASED ARRAY ANTENNA

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Abstract—In this paper a programmable beam-switching algorithm for planar phased array antenna is presented. Using micro-controller the planar array can be steered over 49 directions over the complete hemisphere. Each element is connected to delay lines and switching module. The bits at micro-controller output after being amplified by driver circuit are fed to the switching modules which control the insertion of fixed phase tapering. Switching is performed on a unique set of delay lines to steer the beam in particular direction in the horizon. For high frequency application PIN diode is used as switch. In total 12 bits are used to select 49 beam positions with some bit patterns being redundant.

1. INTRODUCTION

A phased-array antenna is described in details in nearly all antenna textbooks. Beam steering in a phased-array is implemented by loading suitable phase tapering between the elements. Phase tapering among the elements can be inserted by addition of phase delay in the master oscillator used as local oscillator both in the transmit and receive path. On the other hand, phase tapering can also be implemented by inserting delay lines between successive elements in an array. In recent times, tapped-delay line antenna structures are being proposed to design wide-band adaptive arrays [1]. In an earlier work a method of generating phase distribution of beamforming and beam shaping in various elevation angles had been presented [2]. Karmakar et al. [3] has reported on the design and development of a dividing/phasing network for a compact switched beam array antenna for land vehicle mobile satellite communications. The device is formed by switched radial divider/combiner and 1-bit phase shifters and generates a sufficient number of beams for proper satellite tracking. Sanyal et al. [4] had earlier demonstrated a neat schematic where fixed delay lines are inserted between elements. Using an algorithm of selection, beam steering in four directions were demonstrated. This was done through microprocessor controlled programmable switching modules. In the present work, a beam steering planar array has been conceived. Using 12 bits a programmable switching module is able to steer beam in 49 directions over the hemisphere. The detailed schematic is presented in following section.

2. SCHEMATIC

Fig. 1 presents the schematic diagram of the micro-controller controlled switched-delay line phase shifting system for the control of phase shifts between N numbers of antenna elements and L number of levels in a phase array. The rectangular boxes represent the various delay elements in terms of a finite delay T. The delay elements are interconnected between the different levels by two pairs of switches which are PIN diodes for RF transmission. The delay elements are so chosen that the sum of the delays associated with 0 switch and 1 switch for all subsystems is $P\ (N-1)\ T$ where $P = 1, 2, 3, \ldots, L$. The logical status of the 0 and 1 switches are complementary. The power is fed to the system through a power splitter. In the following paragraph a compact antenna array consisting of six elements is considered and presented in details.

Fig. 2 presents the schematic diagram for a six element linear

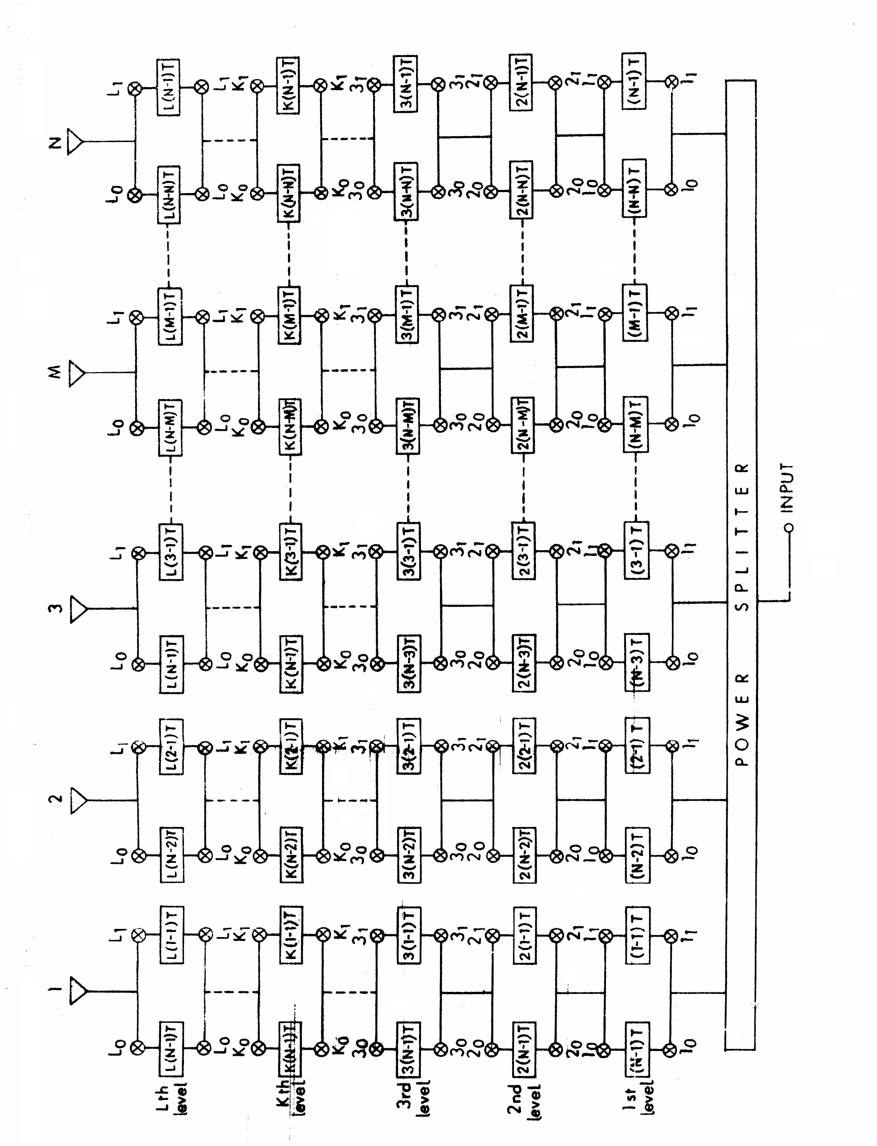

Figure 1. Schematic diagram of N element linear antenna array with L levels of switched-delay units.

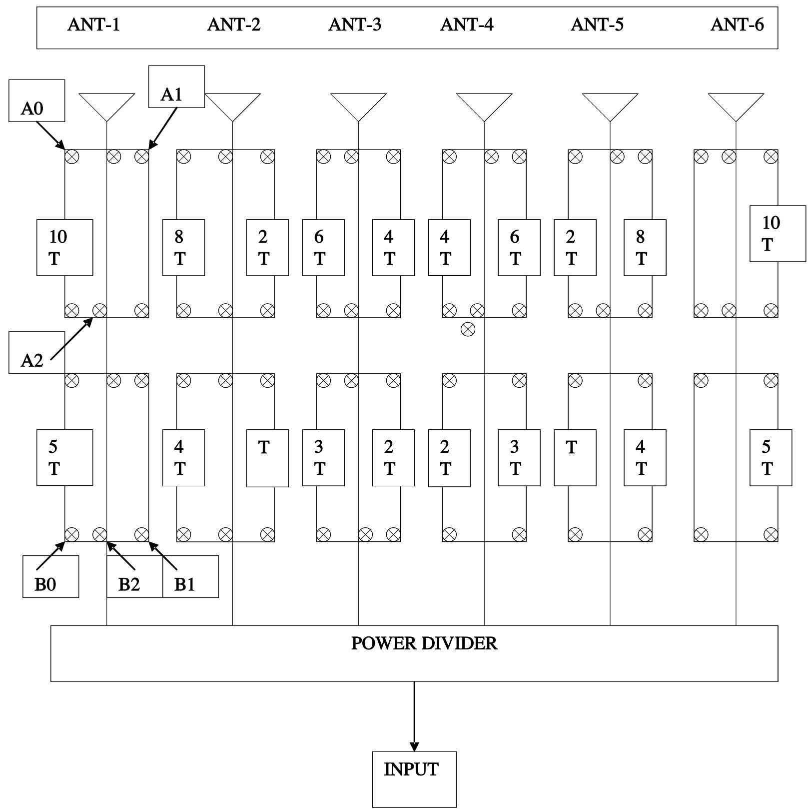

Figure 2. A six element linear array with delay distribution.

array. Each 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, C) 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. The antennas in planar array are arranged in two dimensional matrix form. It can be considered as an array of linear arrays. Here for heuristic approach, 6×6 planar array is taken into account. So there are six numbers of linear arrays separated by fixed distance 'd' and for each linear array, antenna elements are also separated by a distance 'd'.

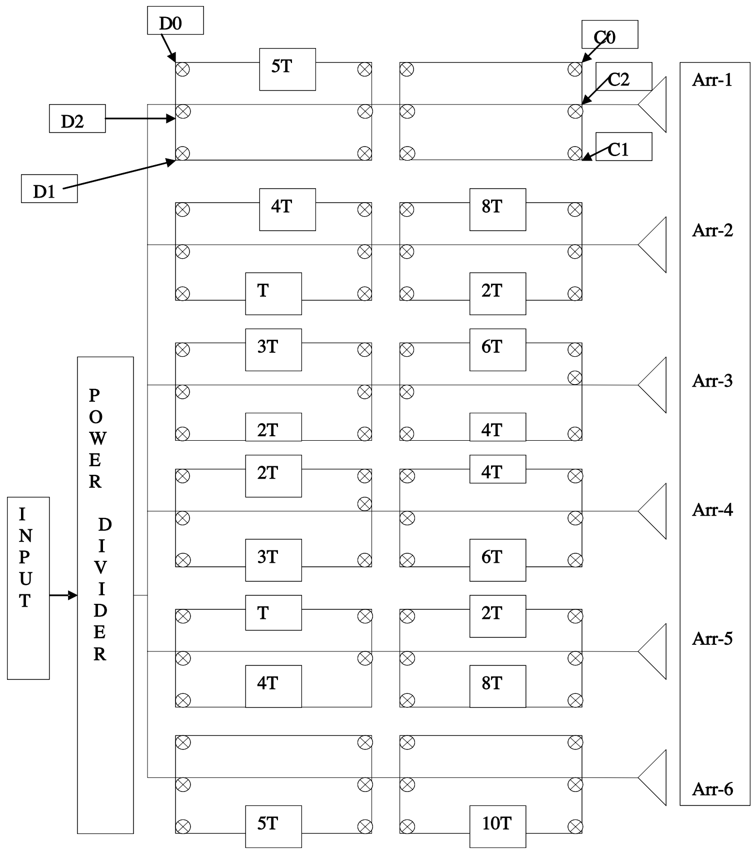

Figure 3. A six by six element planar array with delay distributions.

This two dimensional array is fed by delay line circuits in $\pm X$ (East-West) direction (as shown in Fig. 2) and $\pm Y$ (North-South) direction. This is displayed in Fig. 3. The corresponding PIN diode switches are designated by "A" & "B" (in series) and "C" & "D" (in series) for the planar array. The RF inputs from the antennas are fed to all the inputs of "A" switches and RF outputs of "A" switches are combined and fed to "B" switches. Thus, for RF to traverse the complete path, one switch each from A & B is to be closed. Similar is the case for C & D. The controls of "A" switch, for example, are designated by A_0, A_1, A_2. A typical switching pattern of the A_0, A_1, A_2 (C_0, C_1, C_2) & B_0, B_1, B_2 (D_0, D_1, D_2) is shown in the Table 1. From Table 1, it is seen that the beam can be tilted in both East-West and North-South directions using independent control of A-B and C-D switches

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

respectively. As stated earlier, only one switch is ON at any instant for "A", "B", "C" and "D" switches, keeping all others OFF. Therefore nine combinations are offered for each series (A-B and C-D) , out of which two combinations are redundant (as it is duplicating $+T$ & $-T$ delay). So effectively, forty-nine beam positions can be achieved in such way for a planar array. To keep the beam in center position, the following bit pattern is taken in account:

$$A_0 = 0,\ A_1 = 0,\ A_2 = 1,\ B_0 = 0,\ B_1 = 0,\ B_2 = 1$$
$$\&\qquad C_0 = 0,\ C_1 = 0,\ C_2 = 1,\ D_0 = 0, D_1 = 0,\ D_2 = 1$$

For other beam positions, first Y direction array is loaded with suitable delays by switching C & D appropriately then X direction linear array are switched on using A & B bit pattern.

For a planar phased array, the following relations hold true [2]

$$\beta_x = -kd_x \sin\vartheta_0 \cos\phi_0 \tag{1}$$

and

$$\beta_y = -kd_y \sin\vartheta_0 \sin\phi_0 \tag{2}$$

where θ_0 is the elevation angle measured from zenith and ϕ_0 is the azimuth angle measured from $+X$ (East) direction in anti-clockwise rotation. Here β_x and β_y are progressive phase shift, d_x and d_y are inter-element spacing in X & Y direction respectively. For this case, $d_x = d_y = d$.

Solving simultaneously

$$\tan\phi_0 = \frac{\beta_x}{\beta_y} \tag{3}$$

$$\sin^2\vartheta_0 = \left(\frac{\beta_x}{kd}\right)^2 + \left(\frac{\beta_y}{kd}\right)^2 \tag{4}$$

For the present case, analysis is carried out considering $d = 0.78\lambda$ and any arbitrary frequency. We also consider that unit delay T corresponds to a phase shift of $\pi/4$ radians.

3. PROGRAMMABLE BEAM TILT

In this section, some typical bit patterns are considered and beam tilt on the X-Y plane radiating in Z-direction computed.

(1) We consider one case where the bit patterns are:

$$A_0 = 0,\ A_1 = 0,\ A_2 = 1,\ B_0 = 1,\ B_1 = 0,\ B_2 = 0$$
$$C_0 = 0,\ C_1 = 1,\ C_2 = 0,\ D_0 = 0, D_1 = 1,\ D_2 = 0.$$

For the above case, the progressive delays are T in West $(-X)$ direction and $3T$ in South $(-Y)$ direction. Substituting the values of $\beta_x = -\pi/4$ and $\beta_y = -3\pi/4$ in expressions (3) and (4) we get

$$\theta_0 = 30.449^\circ \text{ from Zenith and } \phi_0 = 71.565^\circ \text{ (towards North)}$$

So the resultant beam is tilted at 30.449° from broadside direction at 71.565° on East-North direction. The simulated beam pattern is shown in Fig. 4.

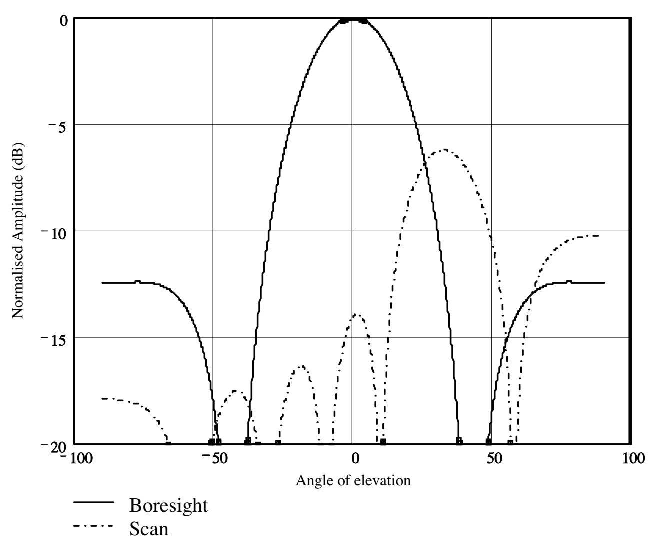

Figure 4. Simulated beam pattern for scanned array in comparison to boresight pattern. ($\theta_0 = 30.449^\circ$ from Zenith and $\phi_0 = 71.565^\circ$ (towards North)).

(2) Another example is as follows:

$$A_0 = 0,\ A_1 = 1,\ A_2 = 0,\ B_0 = 1,\ B_1 = 0,\ B_2 = 0$$
$$C_0 = 1,\ C_1 = 0,\ C_2 = 0,\ D_0 = 0, D_1 = 0,\ D_2 = 1.$$

For the above bit pattern, the progressive delays are T in East ($+X$) direction and $2T$ in South ($-Y$) direction. Substituting the values of $\beta_x = \pi/4$ and $\beta_y = -2\pi/4$ in expressions (3) and (4) we get

$$\theta_0 = 21^\circ \text{ and } \phi_0 = 116.565^\circ$$

So the beam is placed on North-West direction at 21° from zenith. The simulated beam pattern is shown in Fig. 5.

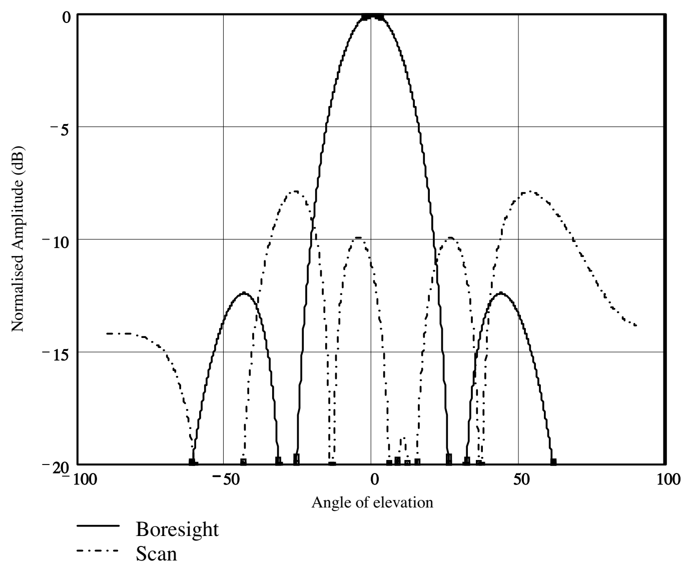

Figure 5. Simulated beam pattern for scanned array in comparison to boresight pattern. ($\theta_0 = 21^\circ$ and $\phi_0 = 116.565^\circ$).

4. ALGORITHM

An algorithm followed for programmable beam steering is presented in Fig. 6. 16 bit micro-controller is required in this regard. Among 16 bits, 4 bits are redundant and filled with zero and rest are for the 12 PIN diodes. Each time a new beam position is required, micro-controller is loaded with particular data corresponding to On/Off position of

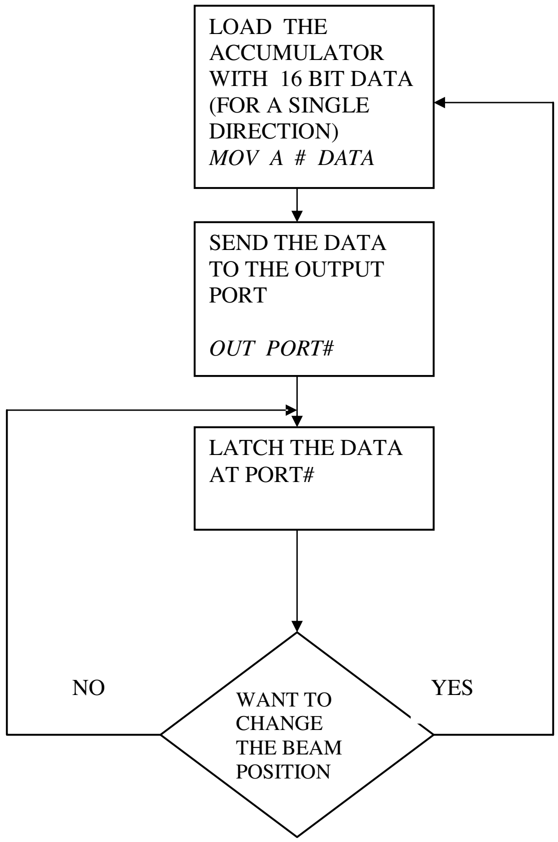

Figure 6. Flow chart of the user defined programmable beam-tilt.

the switching matrix. This algorithm can be altered for incorporating automatic beam-steering in specified directions after a user specified delay. Such a system will be very useful in tracking operations e.g. tracking a radio-star over a period of transit. The algorithm described above has been implemented on an PIC micro-controller kit by an assembly language program which is omitted in this text for brevity.

5. CONCLUSION

In this text a conceptual design mechanism of programmable beam-steering antenna array is presented. Using micro-controller to control the insertion of progressive phase delay between successive antenna elements, results in complete electronic control over beam tilt. The algorithm displayed in this text is simple to implement. However it has got significant potential in tracking radars. The delay magnitudes attached to each element is chosen according to a prescribed rule i.e., "B" series delays units are half of corresponding "A" series delay units. Similarly there is a progressive increase or decrease of delay units by $2T$ in "A" series and T in "B" series as one moves from element to element. It can be safely assumed that a more complicated distribution with similar elegance can be devised for larger arrays. A potential application of this methodology is phase-centre scanning for target simulators.

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