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Orthogonal Beam Forming Network – A Novel Approach

Ajay Thakare[1] Dr. Rajendra Shelke[2]

[1] **Sipna College of Engineering and Technology, Amravati, Maharashtra, India**

[2]**PRMIT and Research, Badnera, Amravati**

Abstract

One dimensional feed network has operational limitations when it performs beam scanning. It can receive signal energy only from the radio sources that lie on the fixed vertical broadside plane y=0. In case the radio source lies outside of this y=0 plane, the whole beam pattern needs to be tilted on either side of the broadside plane, depending upon the position of the source, which is physically very difficult. To meet such a requirement, we need to have a new feed network that can form multiple beams that cover maximum area of the radio sources therein. We designate such a feed network as '2- Dimensional feed network'. This feed network is used in conjunction with NxN element two-dimensional antenna array. In this paper, an attempt is been made to theorize the formation of simultaneous beams in two orthogonal planes x=0 and y=0. Using this theory a simple two dimensional feed network that can form four simultaneous beams in two such orthogonal planes is designed and developed

Keywords: *Beam forming network, One dimension, Orthogonal beam formation, Scanning techniques in antenna beam forming system.*

1. Introduction

Beam formation by a single linear N-element antenna array placed along X-axis is already known to understand how N simultaneous, independent beams are formed at N independent output ports of one dimensional Feed Network. It is seen that such a one dimensional linear array of N antennas forms a single broadside beam, if coherent signal of equal amplitude is fed to each of its antenna elements. But when its equi-spaced antenna elements are excited with uniform amplitude but with progressive phase delay, it radiates a wavefront at certain angle in space, forming a tilted beam in required direction. In other words, the direction of the main beam can be controlled by controlling the amount of the phase delay with which phases of the antenna currents increase progressively. Alternatively, a tilted beam is formed if incident wavefront excites antenna currents of equal amplitudes whose phases increase progressively by constant amount. In Butler Matrix feed system, simultaneous incidence of such N wavefronts form N simultaneous beams at its N beam (output) ports.

This principle of Butler Matrix's beam forming employed in a single linear antenna array is extended further to the2-D feed system connected to two linear antenna arrays placed orthogonally in 2-dimensional XY plane to understand the beam formation therein. This aids us to understand how 2-D Feed System channelizes all the received energy to a definite beam port if a planar wavefront coming from a distant radio source incident on the elements of two linear orthogonally placed antenna arrays.

2. Proposed Beam forming feed Network

To understand beam formation, consider two linear antenna arrays to which 2-DFeed Network is connected. Let us place them along two orthogonal axes of the Cartesian coordinate system that is along X-axis and Y-axis. The layout of such two orthogonally placed antenna arrays is shown in Figure 1.

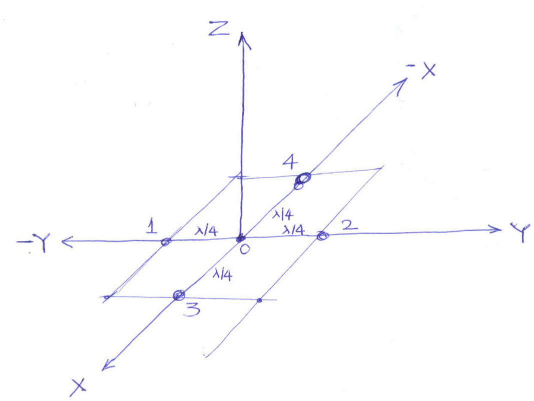

Fig. 1 Beam incident layout.

Let each linear antenna array consists of two antenna elements spaced a distance 2d (‘d’ is in terms of λ) apart. Specifically speaking, the antenna elements numbered 1 and 2 are placed along Y-axis at 1 (0,-d) and 2 (0,d) and antenna elements numbered 3 and 4 are placed along X-axis at 3 (3,0) and 4 (-d,0) of the Cartesian coordinate system. In spherical co-ordinates, they are placed in equatorial plane at 1 (d,90^0, 270^0), 2 (d,90^0, 90^0), 3 (d, 90^0, 0^0) and 4 (d, 90^0, 180^0). The combination of these two linear antenna arrays results into 2-dimensional antenna array of four elements, with, its array normal pointing towards zenith, that is along Z-axis. Such an array of orthogonally placed antennas is connected to a 4-element 2-D Feed System. We call this feed system as ‘2-D Feed Network’. In Figure 2 is shown a sketch of 2-D Feed Network connected with 2x2 antenna array.

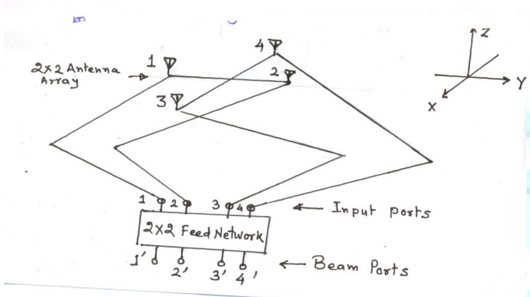

Fig. 1 Four element 2-D Feed System.

Such a 2-D Feed Network has four input ports 1, 2, 3 and 4 and four output ports 1’, 2’, 3’ and 4’. Its input ports are connected to four orthogonally placed antenna elements 1, 2, 3 and 4. In other words, the antenna ports 1, 2, 3 and 4 act as input ports to the 2-D Feed Network.

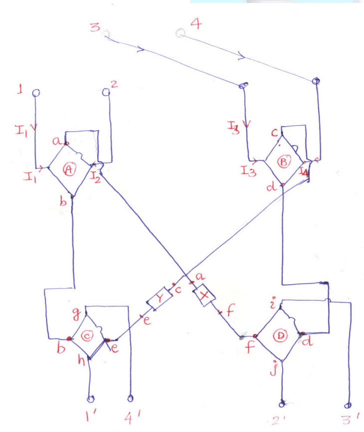

Fig. 3 Feed Network System.

Figure 3 details the proposed, 4-element 2-D Feed Network system. Made with basic components like hybrid rings and fixed phase shifters, this 2-D Feed Network works on the principle of Butler Matrix that employs phase scanning. It consists of two pairs of hybrid rings, wherein the signals fed to them undergo a constructive or destructive interference resulting into their channelization to definite output ports. The fixed phase shifters used in the network introduce additional phase shift in the signals in order to make them in phase or 180^0 out of phase so that, constructive or destructive interference takes place in the hybrid rings. In this way the antenna currents generated by simultaneous incidence of planar wavefronts coming from different radio sources in space get channelized to definite, independent output ports. Since 2-D Feed Network has four output ports, it can form four simultaneous beams at its four output ports 1’, 2’, 3’ and 4’. In other words, the simultaneous incidence of four planar wavefront on the antenna aperture get channelized to four independent output ports of the network, forming four simultaneous beams in four different directions in space.

2.1 Theoretical Analysis of Orthogonal Beam Formation

In this section, we have theorized the formation of four simultaneous beams in two orthogonal planes by 2-D Feed System. With the help of these theoretical beam formations, four beam forming 2-D Feed Network has been designed and developed .

Consider a distant radio source ‘S’ (see Figure 4) in space located in φ = 90 ^{0} plane on the right hand side of the array normal at ‘S’ (r,θ,φ=90^0). Let this source ‘S’ (r,θ,90^0) emits a planar wavefront that finally incidence on the aperture of two-dimensional antenna array spread in equatorial plane.

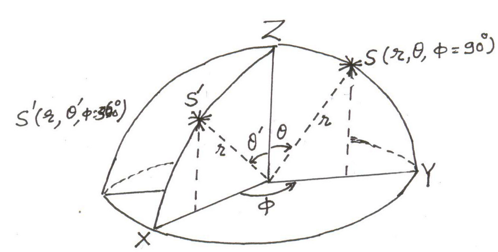

Fig. 4 Radio Source in spherical Co-ordinate System.

Such a wavefront is also shown in Cartesian co-ordinate system in Figure 5. It is seen that this wavefront is incident from the right side direction on the antenna array. Let such inclined planar wavefront coming from certain direction in space incident on the antenna array making certain angle α with its aperture spread in XY plane. Let θ be the angle that the incident wavefront makes with the array normal that lies along the Z-axis. Here θ=90-α. The wavefront reaches first at the antenna element 2 a bit earlier than its arrival at the antenna elements 3, 4 and 1. So far its incidence times at antenna elements 3, 4 and 1 are concerned, the wavefront is seen to reach the element 1 a bit latter than its falls on elements 3 and 4.

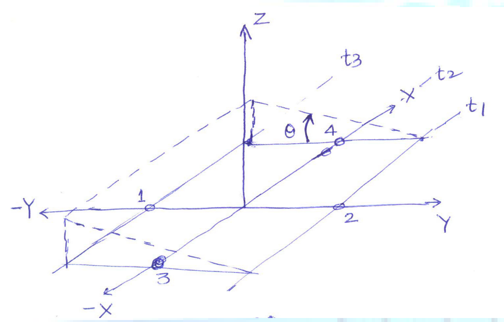

Fig. 5 Planar wavefront incident on 2-D antenna array.

The time plot of this planar wavefront incident on the array is also shown in Figure 5. It shows the incident times of the planar wavefront at antenna elements 1, 2, 3 and 4. Let t_1, t_2, t_3 and t_4 be the times of incidence on the antenna elements 1, 2, 3 and 4 respectively.

2.2 Mathematical Analysis

Referring to Figure 5, as wavefront lags at antenna elements 1, 3, and 4 with regards to element 2, for $t_2< (t_3, t_4$ and $t_1)$, we get, $\Delta t = t_3-t_2= t_4-t_2$, as $t_3 = t_4$.
Similarly, the wavefront is delayed by Δt' to reach to antenna element 1 as compared to element 2, we get, $\Delta t' = t_1- t_2$
Since the wavefront reaches first at elements 3 and 4 compared to element 1, Δt' > Δt.
Since the incident wavefront reaches antenna elements 1, 2 3, and 4 at different times, the uniform currents it excited in the antenna elements will have different phase angles. Let i_1, i_2, i_3 and i_4 be the antenna currents of equal amplitude and constant inter element phase delay Δφ.
The current equations are:

$$i_1 = A_1.e^{j\varphi 1} \quad (1)$$

$$i_2 = A_2.e^{j\varphi 2} \quad (2)$$

$$i_3 = A_3.e^{j\varphi 3} \quad (3)$$

$$i_4 = A_4.e^{j\varphi 4} \quad (4)$$

where, A_1 , A_2 , A_3 and A_4 are the amplitudes of the antenna currents and φ_1, φ_2,φ_3 and φ_4 are their phases. These antenna currents flow through the 2-D Feed Network consisting of hybrid rings and fixed phase shifters, which channelizes the antenna signals to a definite output or beam port. Referring to Figure 3, these currents are designated for input ports i_a, i_b, i_c and i_d and for output port as i_e, i_f, i_g and i_h. In particular for the above mentioned incident wavefront, the current gets channelized through the shorter and longer sides of the hybrid rings and then through the phase shifters connected externally for insertion of additional phase.
Current i_g comes out at port beam port 4' and is given by equation,

$$i04' = i_g = A.[e^{j(\varphi 3+ \pi/2)} - e^{j(\varphi 4+ \pi/2)} - e^{j\varphi 1}- e^{j\varphi 2}] \quad (5)$$

Such current calculations can be done for the the other four incident wavefront directions, viz from left, top and bottom. Subsequently these remaining three beams formed can be described on the above basis. Due to space limitation, these calculations are not included in this paper. For the above incident wavefront, beam number 1 RB (Right Beam), the current channelization is summarized in Table 1 below.

Table 1: Beam number: 1 RB

<table>
<tr><th>Input port number</th><th>Phases at input port</th><th>Phases after first column</th><th>Phases after first phase</th><th>Phases after second column</th><th>Output port number</th></tr>
<tr><td>1</td><td>π/2</td><td rowspan="2">π/2 + π/2</td><td rowspan="2">2π/2 + 0</td><td rowspan="4">4π/2 + 3π/2 = 7π/2</td><td rowspan="4">4</td></tr>
<tr><td>2</td><td>π/2</td></tr>
<tr><td>3</td><td>Π</td><td rowspan="2">0 + 3π/2</td><td rowspan="2">3π/2+ π/2</td></tr>
<tr><td>4</td><td>0</td></tr>
</table>

Table 1 shows that beam number 1 RB is formed at a single output port number 4. Simultaneously for this channelized beam, the currents at all other remaining ports are zero. The individual four cases show that an individual beam can be formed at independent ports. There is no ambiguity seen forming either overlap beam or additional beam.

3. Conclusions

The amplitude and phases of the currents for the remaining beam positions can be calculated from their mathematical expressions. It is observed that the incident signal gets channelized towards only one individual port, whereas at other three remaining ports the current value will be zero. It is therefore concluded that simultaneous beams are formed at the output ports for the wavefront incident from different directions on the antenna array and the proposed feed network channelizes these currents towards a specific output port. The antenna array structure being arranged in the two dimensional form, we conclude that the proposed 2-D feed system incorporated could be use to emphasize that the proposed Butler Matrix feed network is a suitable beam former for simultaneous beam formation technique. With all the measured results, the expected radiation pattern can also be computed. This verifies the results from the feed distributions to bring about patterns with acceptable variations with respect to the patterns obtained from the ideal one.

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