Antenna Arrays:

To achieve a more directive characteristics, one method is to enlarge the dimensions of single element antennas. Another way to enlarge the dimensions of the antenna, without necessarily increasing the size of the individual elements, is to form an assembly of radiating elements in an electrical and geometrical configuration. This new antenna, formed by multielement, is referred to as an array.

The total field of the array is determined by the vector addition of the fields radiated by individual elements. To provide very directive patterns, it is necessary that the fields from the elements of the array interfere constructively (add) in the desired directions and interfere destructively (cancel each other) in the remaining space. In an array of identical elements, there are at least five controls that can be used to shape the overall pattern of the antenna. These are:

1. The geometrical configuration of the overall array (linear, circular, rectangular, spherical etc.)
2. The relative displacement between the elements
3. The excitation amplitude of the individual elements
4. The excitation phase of the individual elements
5. The relative pattern of the individual elements

Two element Array:

The total field radiated by the two elements, assuming no coupling between the elements, is equal to the sum of the two and in is given by

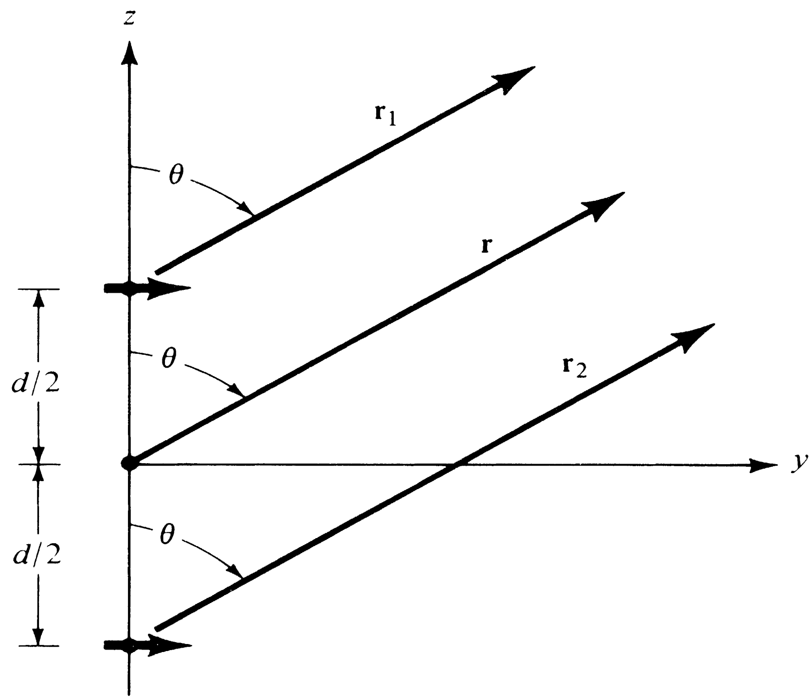
$$E_t = E_1 + E_2 = j\eta \frac{kI_0 l}{4\pi} \left\{ \frac{e^{-j[kr_1 - (\beta/2)]}}{r_1} \cos\theta_1 + \frac{e^{-j[kr_2 - (\beta/2)]}}{r_2} \cos\theta_2 \right\} \hat{a}_\theta$$

Where β is the difference in phase excitation between the elements. The magnitude excitation of the radiators is identical. Assuming far-field observations and referring to fig below

$$\theta_1 \simeq \theta_2 \simeq \theta$$

$$\left.\begin{aligned} r_1 &\simeq r - \frac{d}{2}\cos\theta \\ r_2 &\simeq r + \frac{d}{2}\cos\theta \end{aligned}\right\} \text{For phase variations}$$

$$r_1 \simeq r_2 \simeq r \quad \text{for amplitude variations}$$



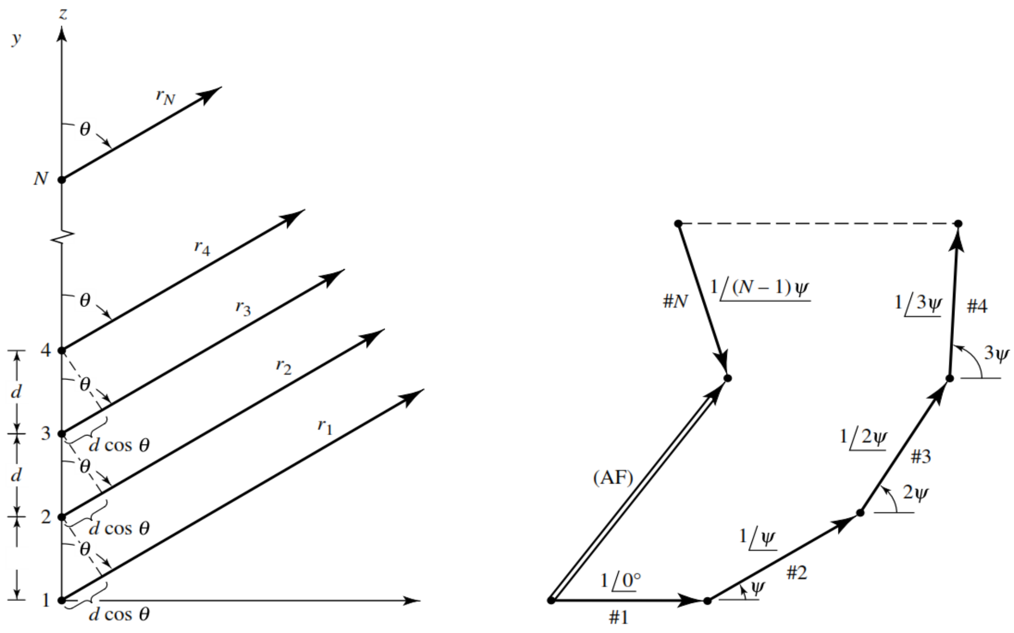
The total electric field equation reduces to

$$E_t = j\eta \frac{kI_0 l e^{-jkr}}{4\pi r}\cos\theta \left\{ 2\cos\left[\frac{1}{2}(kd\cos\theta + \beta)\right]\right\} \hat{a}_\theta$$

It is apparent from the above equation that the total field of the array is equal to the field of a single element positioned at the origin multiplied by a factor which is widely referred to as the array factor. Thus, for the two- element array of constant amplitude, the array factor is given by

$$AF = 2\cos\left[\frac{1}{2}(kd\cos\theta + \beta)\right]$$

N – Element Linear Array: Uniform Amplitude and Spacing:



(a) Geometry (b) Phasor diagram

An array of identical elements all of identical magnitude and each with a progressive phase is referred to as a uniform array. The array factor can be obtained by considering the elements to be point sources.

The array factor is given by

$$AF = 1 + e^{+j(kd\cos\theta+\beta)} + e^{+j2(kd\cos\theta+\beta)} + \ldots + e^{+j(N-1)(kd\cos\theta+\beta)}$$

$$AF = \sum_{n=1}^{N} e^{j(n-1)(kd\cos\theta+\beta)}$$

Which can be written as

$$AF = \sum_{n=1}^{N} e^{j(n-1)\psi}$$

$$\Psi = kd\,cos\theta + \beta$$

After simplification

$$(AF)_n \simeq \frac{\sin\left(\frac{N}{2}\psi\right)}{\left(\frac{N}{2}\psi\right)}$$

Phased (Scanning) Array:

From the above equation, maximum of the Array factor (Field) occurs at

$$\psi = kd \cos \theta + \beta = 0.$$

$$\Rightarrow \beta = -kd \quad \cos\theta$$

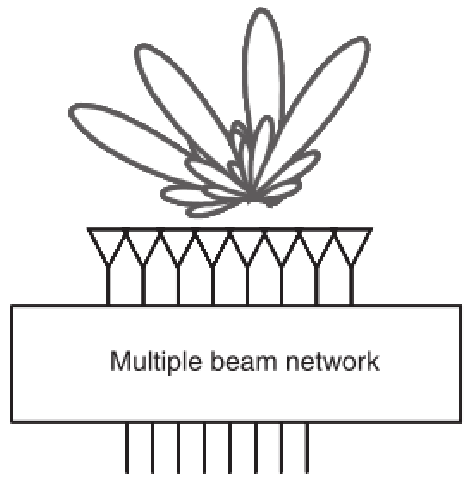
Thus, by controlling the progressive phase difference between the elements, the maximum radiation can be squinted in any desired direction to form a scanning array. This is the basic principle of electronic scanning phased array operation.

Array Feeds:

General antenna array feeds are series, and corporate feeding networks. The corporate feed network is used to provide the power splits of 2^n. This is accomplished by using either tapered line, to match 100-ohm patch elements to a 50-ohm input or using quarter-wavelength impedance transformers. Series fed antenna arrays technique is limited with a fixed beam or those which are scanned by varying the frequency, but it can be applied to linear and planar arrays with single or dual polarization.

Multiple Beam Array Feeds:

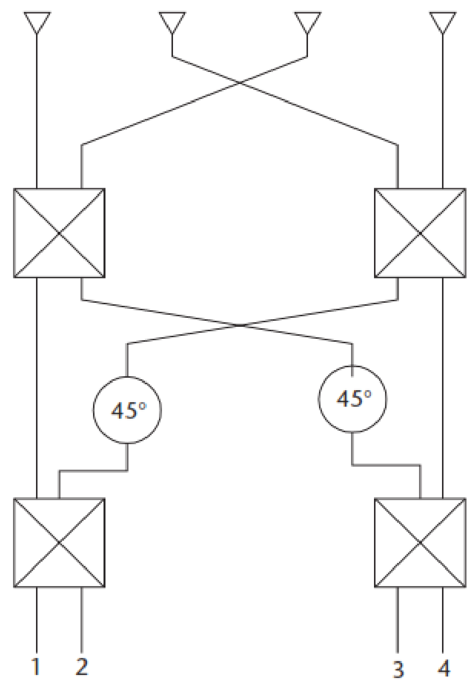
A special category of array feed is the multiple beam array is shown below, where each input port excites an independent beam in space. These can be produced with a digital beamformer, but in addition there are a variety of antenna hardware concepts that produce multiple beams.



Butler matrices are a circuit implementation of the fast Fourier transform and radiate orthogonal sets of beams with uniform aperture illumination. Because the beams of a matrix fed array area phase are scanned, they are inherently modest bandwidth systems. Multiple beam lens and reflector systems have the advantage of being wide band scanners, as their beam locations do not vary with frequency.

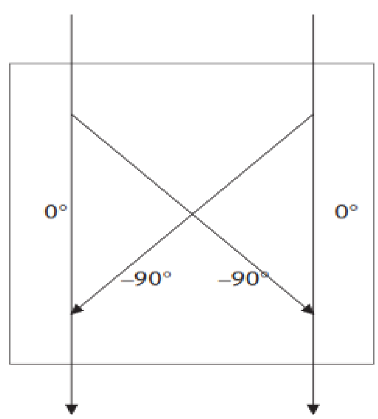
Butler Matrix:

The Butler matrix is the most commonly used beamforming network that, in conventional form, is capable of producing M beams, where M is any integral power of 2. The butler matrix uses passive hybrid power dividers and fixed phase shifters to produce the desired progressive phase shifts at the elements of an antenna array necessary to form simultaneous multiple beams. A four element Butler matrix is shown in figure below, where phase lag directional couplers and phase shifters are used to produce four orthogonal teams.



4x4 Butler Matrix beamformer

The directional coupler has outputs that are equal in power but ate 90˚ out of phase, as shown in figure below. Then, from figure 4x4 butler matrix beamformer, we can see that when the input signal e^{j0} is applied at each of the matrix ports, the resulting phases at the array elements are given in table 1.



Hybrid coupler

Now let a four-element array be connected to the input ports of the 4x4 Butler matrix. Then for a symmetric beam former, the locations of the four beams and the corresponding adjacent element phase shifts would be given in table 2.

	Input Port			
Output Port	A_1	A_2	A_3	A_4
P_1	0°	–45°	–90°	–135°
P_2	–90°	45°	–180°	–45°
P_3	–45°	–180°	45°	–90°
P_4	–135°	–90°	-45°	0°

Table 1. Phases at Array Elements in a 4x4 Butler matrix

Beam Index b	Phase Shift β_b	Beam Location θ_b
–2	–135°	138.6°
–1	–45°	104.5°
1	45°	75.6°
2	135°	41.4°

Table 2. Beam locations