BUTLER MATRIX BEAM FORMING NETWORK COMBINED WITH PHASE SHIFTERS FOR CLUSTER FEEDING OF SCANNING ANTENNA

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1. Introduction

There are roughly two ways of feeding electric beam scanning reflector antennas. One way is array feeding, which feeds power from an off-focal position; the other is cluster feeding, which feeds power from the focal plane. The former is suitable for making shaped-beams, but its antenna efficiency is, in general, not high [1]. Varying the phase relationship between the reflector and the feeding array is possible by using a large number of element antennas. Cluster feeding can reduce the number of elements. It uses a beam-forming network (BFN) consisting of many switches; different antenna elements must be excited depending on the beam orientation. Moreover, phase/amplitude correction demands extremely complex circuits. To increase aperture efficiency, the reflector must be uniformly illuminated, but this increases spillover, which degrades antenna efficiency.

This paper propose a new BFN configuration for cluster feeding that eliminates the switches in the BFN; it can easily form a flat beam that uniformly radiates only the reflector. This BFN consists of several variable phase shifters, a power divider, and a Butler matrix (FFT circuit) [2], which is a multi-beam matrix network; its primary beam pattern by generated using the Fourier transform. This paper first describes its configuration and operation principle. Next, the proposed BFN is used to generate a Gaussian beam and a flat beam that uniformly illuminates the reflector. The effectiveness of the proposed BFN is evaluated by numerical analyses.

2. Configuration and operation principle of proposed BFN

Figure 1 shows the basic configuration of the proposed BFN. Signals are divided by the power divider and are input to the beam port of the Butler matrix through variable phase shifters. Each signal sent to a beam port is distributed and output to all element ports with phase differences depending on the position of the input beam port. The number of the excited beam ports is less than the total number of beam ports. The rest of the ports are terminated. The input signal distribution, $f(x)$, and the output signal distribution, $F(\omega)$, of the Butler matrix are related through the Fourier transform [3]. Here x and ω represent beam port position and

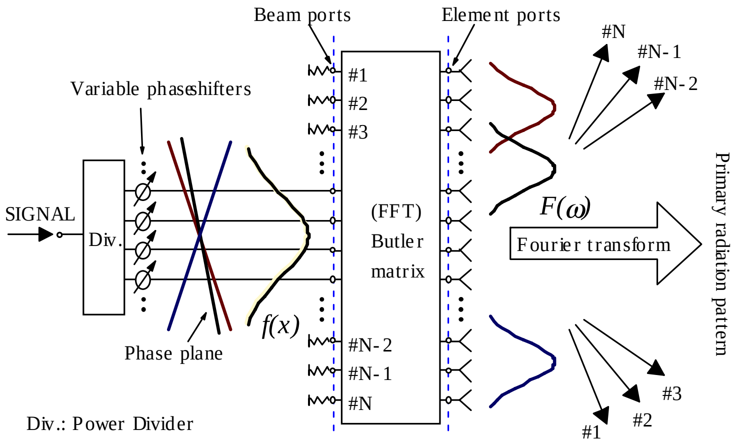

Fig. 1 Proposed BFN configuration

element port position, respectively.

From the time-shifting property of the Fourier transform, the changes in position, $\Delta\ \omega$, of the output signal distribution, $F(\omega)$, can be given as the relation between $f(x)\ e^{-j\omega\Delta x}$ and $F(\omega + \Delta\ \omega)$ [4]. Therefore, by feeding signals with phase differences to the multiple beam ports of the Butler matrix, it is possible to excite the antenna elements required without using switches to change the beam paths. It is a well-known fact that output signal distribution $F(\omega)$ and the primary radiation pattern are related through the Fourier transform. Thus, it is expected that input signal distribution $f(x)$ and the primary radiation pattern will have very similar forms.

In practical use, it is important to determine how many beam ports must be used. If the element antennas connected to the Butler matrix have an equal spacing of d, the beam direction of the i-th beam, θ_i, is given by $kd\sin\theta_i = (2i\text{-}N\text{-}1)\ \pi/\mathrm{N}$, where k is the wave number and N is the number of beam ports (or element ports). That is to say, when all beam ports are used, the primary beam can be roughly radiated within the range of $\pm\pi$ in u dimensions ($u = kd\sin\theta$). Moreover, if half the beam ports are used, the range of $\pm\pi/2$ can be covered, which should be sufficient for most antenna configurations.

3. Beam forming characteristics of proposed BFN

3.1. Gaussian beam excitation

Figure 2 shows the signal distribution $F(\omega)$ of the proposed BFN needed to form a Gaussian beam. The Butler matrix used in the BFN is one-dimensional and the number of ports N is 16. Signals are fed to six beam ports, #6 to #11, and the resulting distribution $F(\omega)$ is Gaussian with the half-amplitude of 3.8. 99.3% of the signal power is concentrated on the six beam ports. The amplitudes at the beam ports are 1:5.1:11:11:5.1:1. The phase differences between adjacent beam ports $\Delta\phi$ are 15, 45, 75 and 105 degrees in this case, for the element port shifts of 2/3, 1, 5/3 and 7/3, respectively. Figure 3 shows the output array pattern of the feeding array. As can be seen Fig. 3, the proposed BFN can offer the same beam pattern even during beam scan operation.

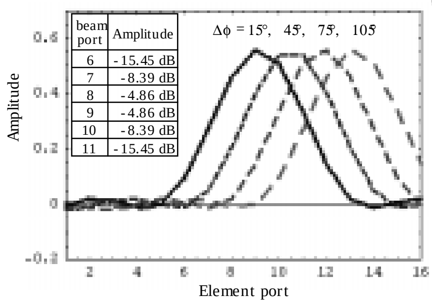

Fig. 2 Amplitude distribution of F(ω) (for Gaussian beam)

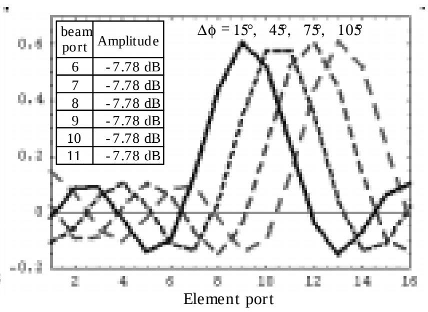

Fig. 4 Amplitude distribution of F(ω) (for Flat beam)

3.2. Flat beam excitation

Figure 4 shows $F(\omega)$ when the same input signals are fed to the six beam ports to obtain a flat beam. Figure 5 shows the output array patterns. As shown in these figures, the proposed BFN can form a fairly flat beam pattern with ripple of less than 2.7 dB. This confirms that the output beam pattern of the proposed BFN is similar to the input signal distribution of the beam

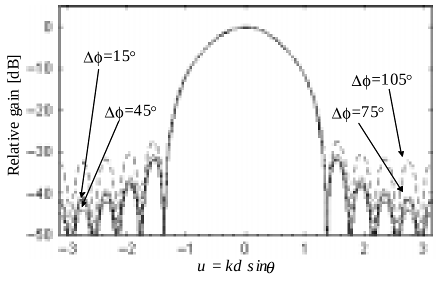

Fig. 3 Array pattern (Gaussian beam)

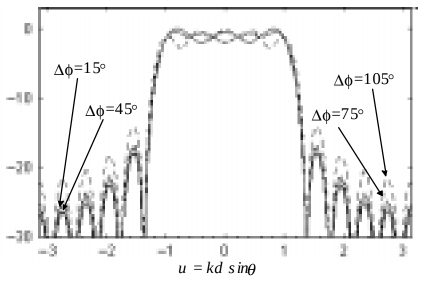

Fig. 5 Array pattern (Flat beam)

port, and no deep consideration of the excitation distribution of the antenna elements is required to obtain the desired pattern.

4. Offset parabolic antenna using proposed BFN

4.1. One-dimensional BFN

Figure 6 shows the configuration of a circular aperture parabolic antenna using the proposed BFN. The aperture radius is 20λ and f/D = 1. The number of Butler matrix ports N is 16, the beam scanning direction is horizontal. To shape the output beam pattern of the feeding array in the vertical plane, a vertically arranged microstrip antenna array with element spacing of 0.5λ is used for each element. The number of elements is four and the power distribution ratio is 1:2:2:1. The polarization is circular and the element spacing in the horizontal plane is 0.5λ .

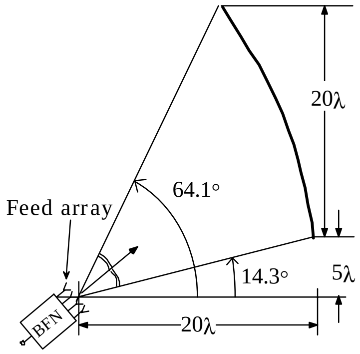

Fig. 6 Antenna configuration

When $F(\omega)$ is a Gaussian distribution with the half-amplitude of 3.8, the output radiation pattern of the feeding array is Gaussian with a -20 dB edge. The aperture angle of the reflector is ±24.9 degrees and the range of the flat beam is calculated as $sin^{-1}\pm 3/16$ = ±22.0 degrees. The distributions corresponding to the above-mentioned beams are shown in Fig. 2 and Fig. 4. Figures 7(a), 7(b), and 7(c) show the variation in the half-power beamwidth (HPBW), relative gain, and the maximum sidelobe level versus phase differences between adjacent beam ports for $\Delta\phi$ = 15, 45, 75 and 105 degrees. Figure 7(a) shows that the variation in HPBW is below 4%, and a narrow beam is obtained with flat beam excitation. Figure 7(b) shows that gain variation is about 0.4 dB. Figure 7(c) shows that a usefully low side-lobe pattern was obtained with Gaussian beam excitation. In the Gaussian case, antenna efficiency is about 69%, the HPBW is about 4.0 degrees, the maximum spillover value is 8%, and the side-lobe levels are below -32 dB. In the flat beam case, antenna efficiency is about 75%, the HPBW is about 3.1 degrees, and the maximum value of the spillover is 14%. When $F(\omega)$ is excited by a Gaussian distribution without using the proposed BFN and the HPBW is 3.2 degrees, the spillover is 20%. When the HPBW is 3.1 degrees, the spillover is 27% and the antenna efficiency is 64%. We must consider the loss of the variable phase shifters which degrades the antenna's efficiency. One solution is to adjust the phase of each beam port against that beam port #8 (or #9), which allows us to eliminate one phase shifter; this reduces the loss by over 17%.

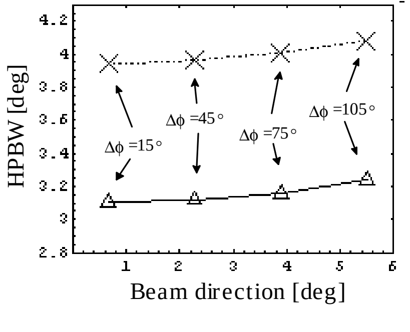

Fig. 7(a) Variation in HPBW versus beam direction

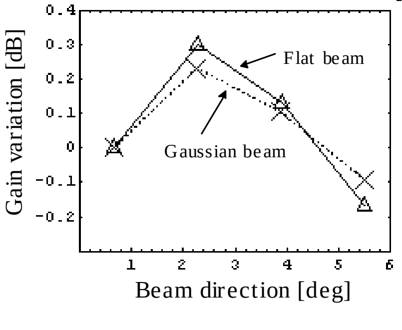

Fig. 7(b) Variation in gain versus beam direction

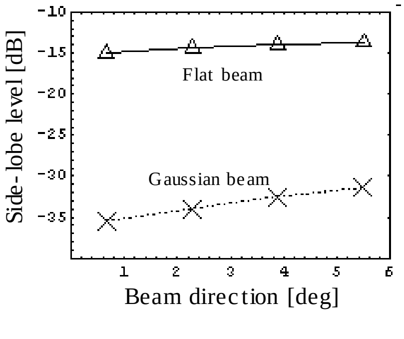

Fig. 7(c) Variation in sidelobe level versus beam direction

4.2. Two-dimensional BFN

Figure 8 shows the relation between the primary radiation beam orientation and beam port position, for the number of the feed array is 16 × 16. The circle represents the reflector edge, and each hatched square shows an active beam port. Figures 9 and 10 show the reflector aperture field and antenna radiation patterns when the same input signals are fed to all 32 ports, respectively. In this case, the phase difference, $\Delta\phi$, is 0 degree. These figures show that the BFN effectively illuminates only the reflector, and that a narrow beam is obtained as the antenna radiation pattern. In this case, antenna efficiency is about 83%, the HPBW is about 3.2 degrees, and the spillover is 5%.

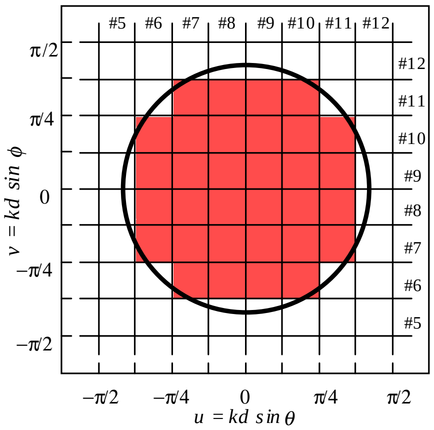

Fig. 8 Relation of radiation beam orientation and beam port position

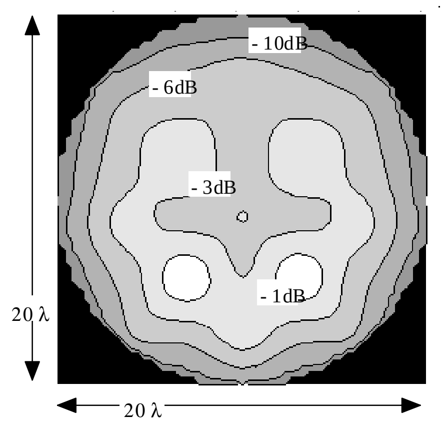

Fig. 9 Aperture field

5. Conclusion

We proposed a BFN configuration suited to cluster feeding by using a Butler matrix, and demonstrated its ability to achieve good pattern characteristics. The BFN provides a beam steering function with fewer variable phase shifters. A low side-lobe pattern and flat beam are easily achieved by changing the power ratio of the power fed to the beam ports. Furthermore, the BFN improves antenna efficiency by reducing spillover.

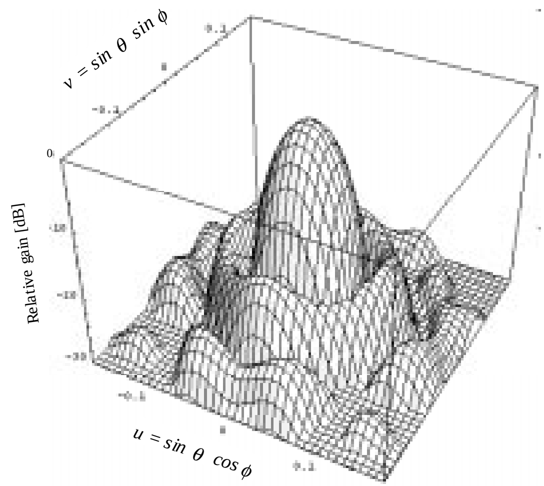

Fig. 10 Antenna radiation pattern

Acknowledgment

The authors thank Dr. Hideki Mizuno for his helpful suggestions and encouragement.

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