TRANSIENT RADIATION CHARACTERISTICS OF CLUSTER-FED SCANNING-BEAM ANTENNA

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INTRODUCTION

In multibeam satellite systems, a combination of fixed and scanning beams can improve utilizing efficiency of transponder and therefore increase the satellite communication capacity. Further increase in the capacity can be achieved if fixed and scanning beams use the same frequency simultaneously. In such systems, both fixed and scanning beams must have low-sidelobe patterns. Low-sidelobe patterns are achieved by use of cluster feed (Chen et al., 1980).

Requirements for scanning beams in frequency-reuse with fixed beams are: (1) low sidelobe during both steady-state and transition, and (2) short transition time. The steady-state characteristics are easily inferred from those of fixed beams, but no works have been done on the transient characteristics. This paper discusses the transient characteristics of cluster-fed scanning-beam antenna excited by a beam forming network. The optimal trigger timing to the beam forming network to best fulfill the requirements is presented.

BEAM FORMING NETWORK OF CLUSTER-FED ANTENNA

A cluster-fed antenna consists of a reflector system, a horn array, and a beam forming network (BFN), as shown in Fig. 1. Each beam is synthesized by a cluster which contains n horns. Figure 2 shows a type of BFN comprising n of single-pole multi-throw switches and an $1:n$ variable power divider (VPD). This BFN selects a position of cluster to be excited by setting the switch network appropriately, and excites the cluster by adjusting the VPD to shape the radiation pattern. Even 1:2 VPDs, which are elements of a $1:n$ VPD, are more complicated devices than the simple switches, and have higher insertion loss and increased size and weight. The BFN of Fig. 2 can minimize the number of 1:2 VPDs without losing flexibility in pattern shaping (Sharon, 1983). The advantage leads this BFN to be the subject of study.

Both the VPD and the switches have a finite switching time. During the transient period, not n but, $n+1$, or more, horns are simultaneously excited; the transient power distribution within the horns deviates from the optimal one, and varies with the trigger timing to the VPD and the switches. The transient radiation pattern therefore deteriorates and varies with the trigger timing.

NUMERICAL CALCULATION MODEL

A one-dimensional beam configuration and the three-horn clusters in Fig. 3(a) are assumed. One-dimensional sidelobe suppression by use of the three-horn cluster can easily be extended to the two-dimensional case. Let a beam hop from the base position, No.1, to another position, No.2, and its frequency be the same as that of a fixed beam pointing the position No.3. An element radiation pattern excited by a single horn is assumed as:

$$f(u) = 0.5\,\frac{J_1(u)}{u} + \frac{J_2(u)}{u^2}\,, \qquad (1)$$

where $u = (\pi D/\lambda)\sin\theta$, D is the antenna diameter. λ is the wavelength, θ is the angle from the element pattern boresight, and J_1 and J_2 are the first- and the second-order Bessel functions. The spatial separation of adjacent-horn patterns is obtained by substituting $u \pm \pi$ for u. Within a cluster, the centered horn is excited 8.5 dB (i.e., 0.78/0.11) stronger than the outer two horns in steady-state; this excitation-distribution produces a 45-dB desired- and undesired-signal ratio (D/U) within the No.3 beam zone (see Fig. 4(a)).

The calculation model employs a beam forming network in Fig. 3(b), consisting of a single-pole double-throw switch and an 1:3 VPD. Suppose lossless switch and VPD, and no change in their output phase. Waveforms can be approximated, without losing generality, which show that the transient output powers of these two devices vary linearly with time t (Fig. 3(c)), and that the VPD switching time (T_v) is 3/2 times that of the switch (T_s). When t = 0 the VPD begins a change of state, and when $t = T_1$ the switch begins switching. The time when the output power of port B is equal to that of port C is denoted as t_v for the VPD. In the same manner, t_s denotes that for the switch.

NUMERICAL RESULTS

Figure 4(a) illustrates the steady-state patterns pointing at the base positions No.1 and No.2. Both of the patterns have a D/U of 45 dB within the fixed beam at No.3, resulting from sidelobe suppression by cluster feed. Figure 4(b) shows an example of transient pattern at t = 0 on the condition that $T_1 = -0.5\ T_s$ (i.e., $t_v - t_s = 0.75\ T_s$); the sidelobes are so raised that the D/U with the fixed beam at No.3 is degraded to 30 dB.

The transient variations of D/U are presented in Fig. 5 in terms of the trigger timing ($t_v - t_s$). When $t_v - t_s = 1.25\ T_s$, the VPD begins a change of state after the switch has been completely switched. And when $t_v - t_s = -1.25\ T_s$, the VPD has completed the change of state before the switch begins switching. The period denoted as T_v in left-lower Fig. 5 indicates the period when the VPD is changing its state. In Fig. 5, the minimum D/Us within No.3 zone are plotted. The upper limit of 45 dB shows the ideal transition. Figure 5 shows (1) that the optimal timing of ($t_v - t_s$) = 0 gives the least D/U degradation of 40 dB, and (2) that, in the case where the timing ($t_v - t_s$) deviates from the optimal one, both the degradation of D/U and its duration increase.

DISCUSSION

1) Parallel shifting of steady-state patterns (for example, from No.1 to No.2 in Fig. 4(a)) would be an ideal beam-scanning. The actual transient radiation pattern is degraded when BFN trigger timing is improperly selected. For example, the lowest D/U is 26 dB when $t_v - t_s = -1.25\ T_s$ and $t = T_v$.

2) There exists an optimal trigger timing which gives the least D/U degradation: ($t_v - t_s$) = 0 is optimal. This optimal timing produces the D/U of 40 dB even at the least desirable time and place. Such timing is achieved with use of delay circuit.

3) Since the transition period of scanning beam to switch its direction is unproductive for communication, it must be minimized, even when time-division multiple access (TDMA) is employed, where no power is transmitted and no interference occurs during the period. Optimal timing minimizes the period to $T_v = 1.5\ T_s$ in this calculation. This optimal timing ($t_v - t_s$ = 0) still requires $1.5\ T_s$ to switch the beam direction entirely. The period can effectively be reduced if we allow a certain value of gain decrease in the zone edge. Allowance of gain decrease of 0.5 dB at the zone edge can

shorten the switching period from 1.5 T_s to T_s; and 2 dB allowance can shorten it to 0.5 T_s.

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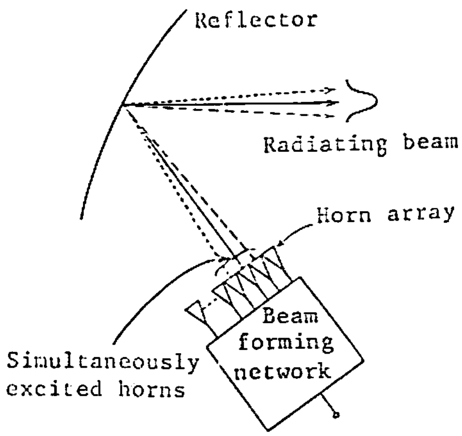


Fig. 1. Cluster-fed reflector antenna.

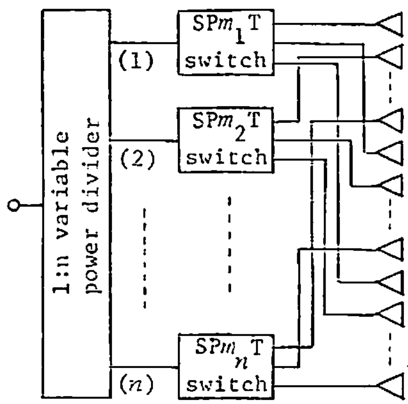


Fig. 2. Beam forming network for scanning antenna.

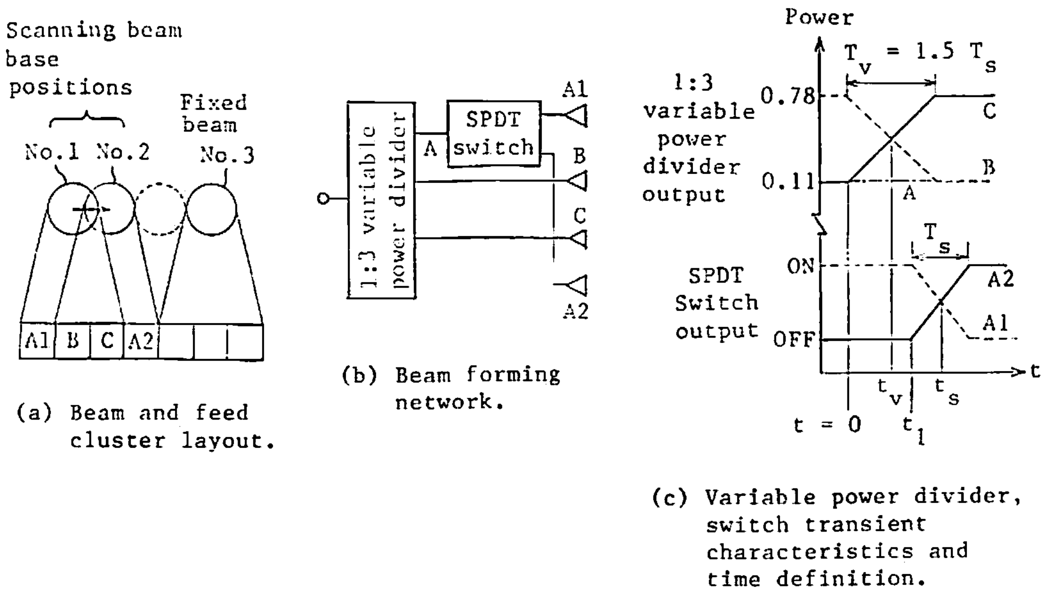
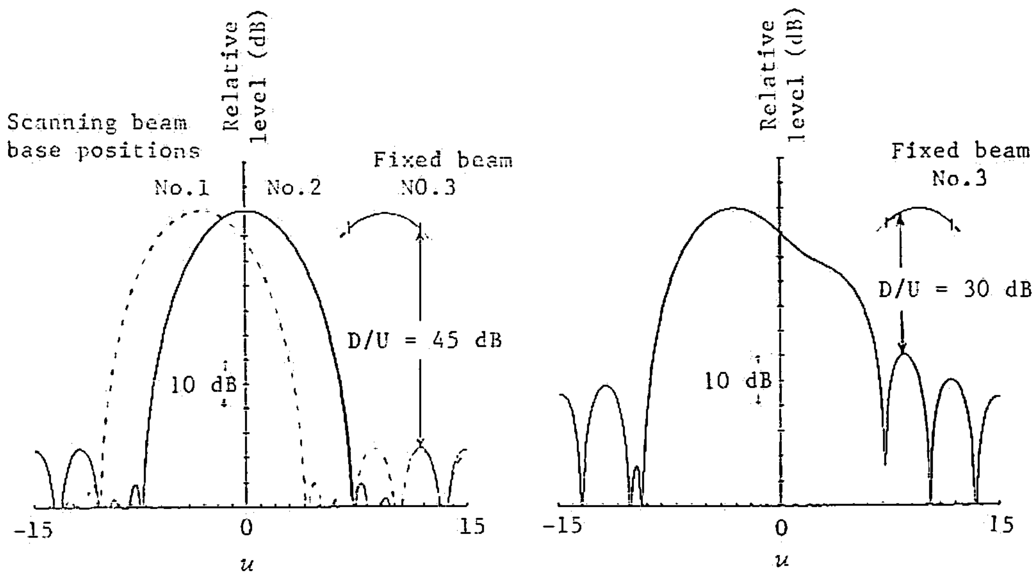


Fig. 3. Numerical calculation model.



(a) Steady-state patterns. (b) Transient pattern.

Fig. 4. Radiation patterns.

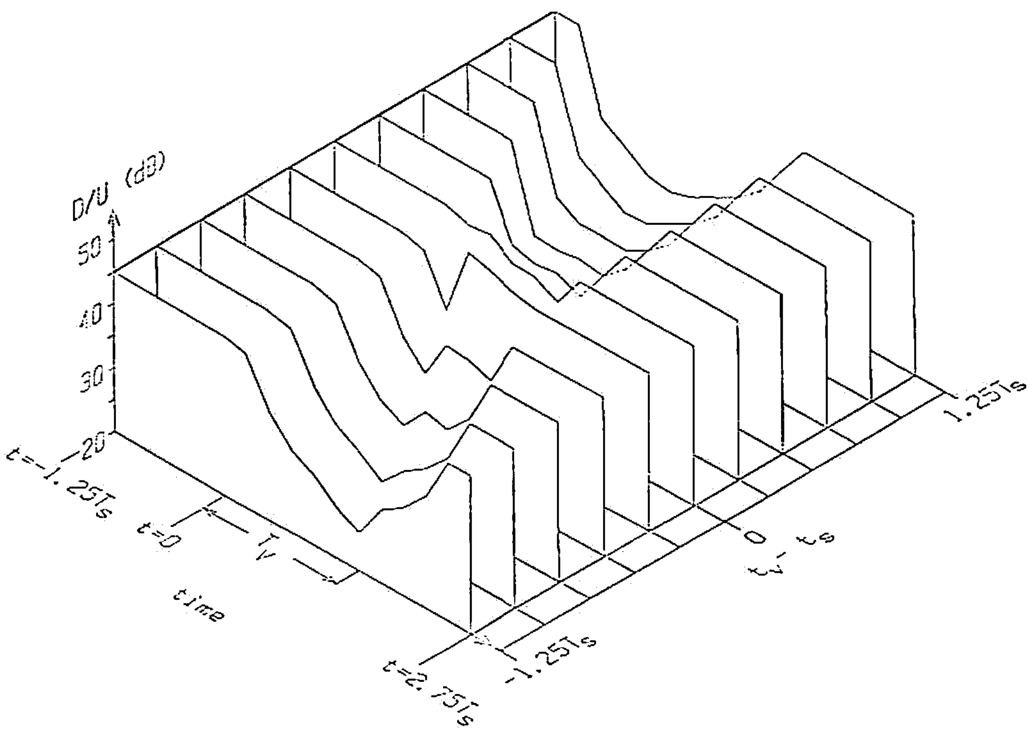


Fig. 5. Transient response of desired and undesired signal ratio (D/U) for $-1.25\ T_s \leqq t_v - t_s \leqq 1.25\ T_s$.