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THE APPLICATION OF ACTIVE INTEGRATED ANTENNAS TO PHASED ARRAYS

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INTRODUCTION : Presently a fully active phased array may be viewed as an array of passive radiating elements each been driven by an amplifier and phase shifter. For high gain arrays this becomes costly and large in size. An active integrated antenna element has been developed and presented in [1] (Fig. 1). This antenna element utilizes amplifiers within its structure, thus the provided signal gain from a single element is increased. This paper proposes the use of active integrated antenna elements in a phased array in order to reduce cost and size without degrading array performance.

RESULTS : To evaluate an active element phased array performance, a passive element array was studied in parallel for comparison. Each array was required to satisfy the specifications of scan angle $\pm 20^{o}$ with gain $\geq$ 24 dBic, (receive only). Pattern multiplication of the planar array factor in (1) [2] and element pattern in (2) was coded to provide computer simulations of the phased array. The element pattern in (2) is used to describe the radiation properties of both the passive and active elements [1].

$$AF = \sum_{n=1}^{N} I_n \left[\sum_{m=1}^{M} I_m e^{j\,(m-1)\,(k\,dx\,\sin\theta\,\cos\phi\,+\,\beta_x)} \right] e^{j\,(n-1)\,(k\,dy\,\sin\theta\,\sin\phi\,+\,\beta_y)} \tag{1}$$

where $\beta_x = -k\ dx\ \sin\theta_o\ \cos\phi_o$

$\beta_y = -k\ dy\ \sin\theta_o\ \sin\phi_o$

θ_o, ϕ_o define the direction of the main beam

$$E_\theta = f_n(\theta)\ e^{j(n\phi - \frac{\pi}{2})} \tag{2a}$$

$$E_\phi = g_n(\theta)\ e^{jn\phi} \tag{2b}$$

where $$f_n(\theta) = -\frac{\omega\mu a}{4}\frac{e^{-jkr}}{r}j^n\cos\theta\left[J_{n+1}(ka\sin\theta) + J_{n-1}(ka\sin\theta)\right]$$

$$g_n(\theta) = -\frac{\omega\mu a}{4}\frac{e^{-jkr}}{r}j^n\left[J_{n+1}(ka\sin\theta) - J_{n-1}(ka\sin\theta)\right]$$

i) Passive Element Array : Element spacing less than 0.5λ is required for arrays scanning to endfire [3]. The element pattern in (2) is based upon a circular loop and the element size may be varied by the radius "a". Various array and element sizes were simulated. In addition, rectangular and triangular grids were implemented. The low elevation angle scan requirements were satisfied with a triangular grid array. However, approximately 225 elements are needed to satisfy the gain requirements. This yields a fairly large and costly array (Fig. 2). The array device cost estimates in Fig. 2 are based on average price quotations. There are two costs associated with the passive array. The higher cost has a phase shifter and amplifier driving each element. This may be considered as the device cost of a fully active phased array antenna. The lower cost is associated with the array architecture where there is a phase shifter driving each element and only one low noise amplifier (LNA) for the array.

ii) Active Element Array : The proposed antenna element incorporates three LNAs in its design (Fig. 1). The LNA in a standard passive element array configuration has been incorporated in the active element, thus the gain of an active element is composed of amplifier gain and pattern gain. The gain specification must reflect this, thus the specified gain should be referenced at the post-amplifier stage of the passive element array, i.e. $G = 24$ dBic $+ G_{LNA}$. The gain of the active element array is now a function of amplifier gain. This has been calculated for a 7 active element array and plotted in Fig. 3a). As can be seen, under bias conditions for $G_{LNA} = 13$ dB, the gain requirements at lower elevation angles are satisfied (Fig. 3b)). Cost and size projections are given in Fig. 2. The 7 active element array offers a substantial savings in both of these areas.

iii) Noise Temperature : With the proposed active elements the noise temperature and G/T must be studied. A preliminary investigation is presented here. For a passive element array, the G/T may be expressed as

$$\frac{G^P}{T} = \frac{G^P_{ARRAY}}{T_S} = \frac{G^P_{ARRAY}}{T_{ANT} + T_{LNA}} \tag{3}$$

where $T_{ANT} = T_{SKY} + T_{LOSSES}$

As a first approximation, the G/T of an active element array, assuming identical amplifiers, may be expressed as

$$\frac{G}{T} = \frac{G'}{T_s'} = \frac{G^{A}_{ARRAY} \frac{\zeta}{4}\left(G^3 + G^2 + G + 1\right)}{T_s\, G^3} \tag{4}$$

where ζ is the radiation efficiency

$$T_S = [\, T_{ARM1} + T_{LNA1} + \frac{T_{LNA2}}{G} + \frac{T_{LNA3}}{G^2}\,]$$

where T_{ARM1} is the temperature of the antenna furthest from the receive point

$T_{ARM1} = T_{SKY} + T_{LOSSES}$

The G/T of a passive element array and several active element arrays are plotted in Fig. 4. As can be seen, although the 7 element array provided sufficient signal gain, the G/T is inferior to the passive array. However, with an increase in directivity , the sky/ground temperature decreases and the array gain increases. Both factors will improve the G/T as defined in (4). This is reflected in Fig. 4 for arrays containing 19 and 37 active elements.

CONCLUSIONS : A comparison between a passive element array and an active element array has been presented. Utilizing active elements satisfies the gain requirements with only seven elements, however, an initial look at G/T shows that the penalty is within the system noise temperature. This may be overcome by increasing the array size. An array of 37 elements has an improved G/T when compared to the passive array. This is the result of a preliminary noise temperature study and an indepth analysis will be presented at the conference. The advantage of the 37 active element array is that it remains less costly and smaller in size when compared to the passive case (Fig. 2). The size is reduced by a factor of 5.5. In terms of performance, the 37 active element array is comparable to the fully active passive element array, thus the cost for equivalent performance arrays has been reduced by a factor of 2.75.

REFERENCES

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[3] Mailloux, R. J., " *Phased Array Theory and Technology* ", Proc. IEEE, Vol. 70, No.3, pp. 246-290, March 1982.

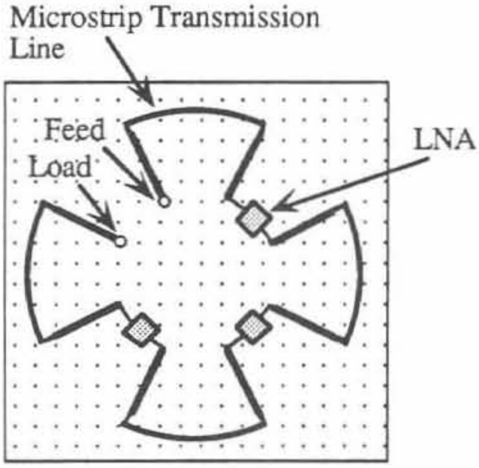

Fig. 1 Active integrated antenna element

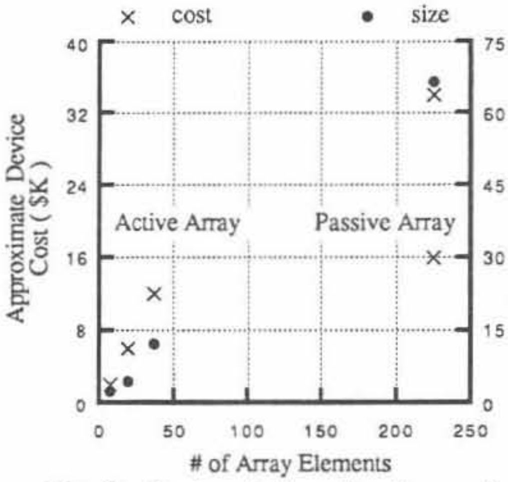

Fig. 2 : Cost and size of active and passive element arrays

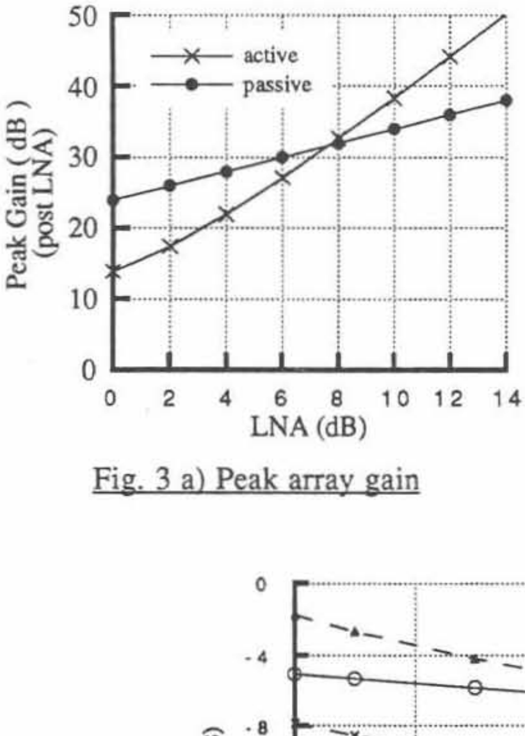

Fig. 3 a) Peak array gain

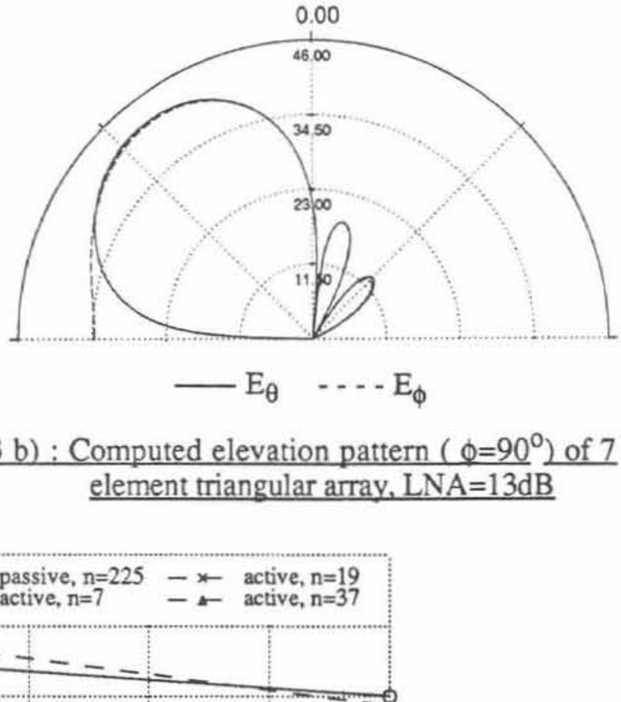

Fig. 3 b) : Computed elevation pattern ($\phi=90^0$) of 7 element triangular array, LNA=13dB

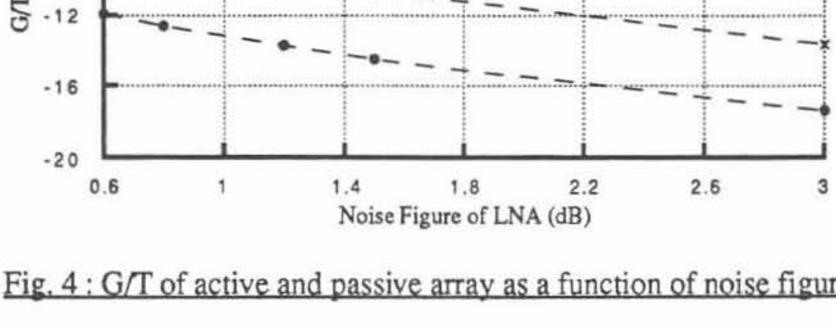

Fig. 4 : G/T of active and passive array as a function of noise figure