A NULL FORMING METHOD FOR AN OFF-FOCUS RF SENSOR

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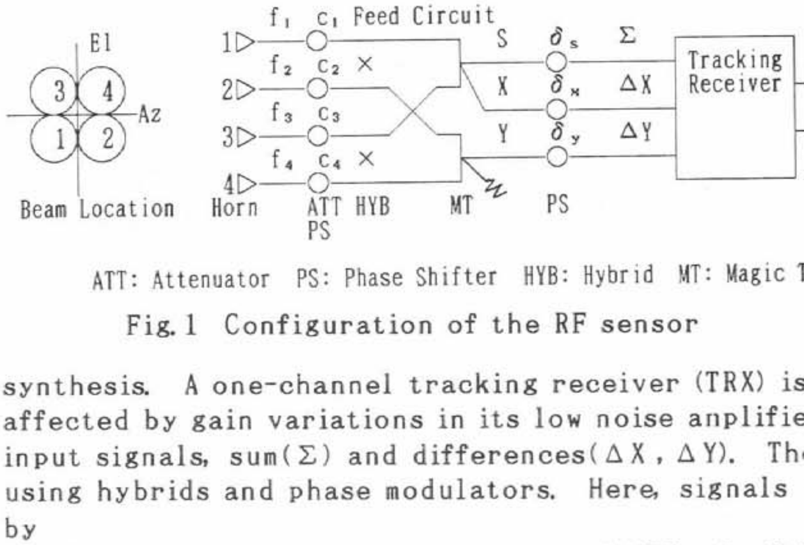
1. Introduction

The development of satellite borne multi-beam antennas has increased the significance of antenna pointing accuracy for much narrower antenna beamwidths. In such antennas, RF sensor feeds to detect pointing direction tend to be located off-focus to avoid interference with the densely placed feed horns for frequency or polarization reuse [1]. This paper describes a design procedure for the pattern synthesis of an off-focus multi-horn type RF sensor.

The radiation pattern excited by a feed horn far from the focus is usually distorted due to the antenna's aberrations. In this situation, a serious problem occurs if the null of the RF sensor's difference pattern is formed in only one direction, as with an on-focus RF sensor. To overcome these difficulties, a new design procedure utilizing the least square method is proposed over the two-dimensional field region. The newly synthesized patterns are shown to work well in a one-channel tracking receiver.

2. Configuration of RF sensor



ATT: Attenuator PS: Phase Shifter HYB: Hybrid MT: Magic T

Fig. 1 Configuration of the RF sensor

The RF sensor considered here is shown in Fig. 1. It consists of a reflector, four horns, a feed circuit and a tracking receiver. Adjusting posts are attached to each horn to control the complex excitation coefficient required for pattern synthesis. A one-channel tracking receiver (TRX) is used because it is not affected by gain variations in its low noise anplifier. The TRX has three RF input signals, sum(Σ) and differences(ΔX, ΔY). These signals are summed by using hybrids and phase modulators. Here, signals Σ and Δ can be represented by

$$\Sigma = As \exp(j(\omega t - \psi + s)) \quad \text{and} \quad \Delta = (1/\sqrt{2})\,\Delta X + (1/\sqrt{2})\,\Delta Y \exp(-j\pi/2) = (1/\sqrt{2})\,Ap \exp(j(\omega t + p)) \qquad (1)$$

where As is a real value indicating amplitude and s is a real value indicating the phase of sum signal, Ap and p are the amplitude and phase of the synthesized difference signals, ω is the angular frequency of the RF beacon and ψ is a phase compensation between coordinate systems for angular detection and a beam drive. The outputs of the TRX are given theoretically [2] by

$$E_1 = E_0 \frac{Ap/As}{4+(Ap/As)^2} \cos(-\psi + s - p) \quad \text{and} \quad E_2 = -E_0 \frac{Ap/As}{4+(Ap/As)^2} \sin(-\psi + s - p) \qquad (2)$$

where E_0 is a constant coefficient.

3. Characteristics of an off-focus RF sensor

3.1 Conventional design procedure

An example of a measured radiation pattern excited by an off-focus feed horn, one of the RF sensor feed horns, is shown in Fig. 2. Here, the reflector has a diameter of 350 wavelengths and the horn is 6 beamwidths away from the boresight. The conventional procedure for difference pattern synthesis is to weight each horn so that it has an equal contribution at the crossover point. This leads to the difference pattern of ΔX shown in Fig. 3. ΔY has nearly the same difference pattern. When the three signals are input into the TRX, E_1 or E_2 doubles and the other disappears from the relation in Eqs. (1) and (2). Hence, it is clear that the conventional design procedure is not appropriate for an off-focus RF sensor.

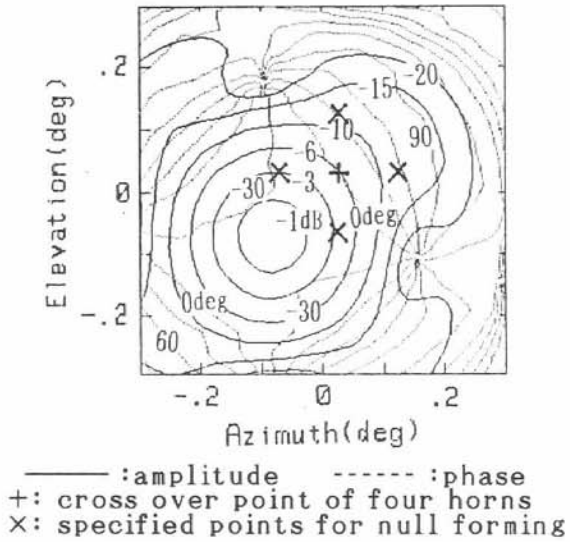


Fig. 2 Component beam pattern measured at horn No. 1, located 6 beamwidths away from the boresight.

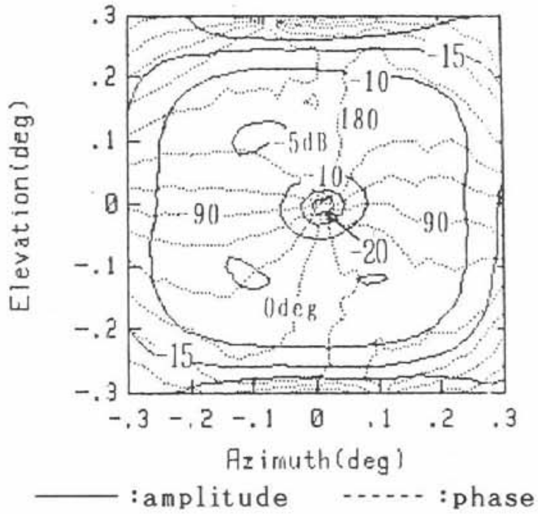


Fig. 3 Difference pattern measured at X port, designed by conventional procedure.

3.2 New design procedure using the least square method

The design goal in difference pattern synthesis is to obtain a wide angular null range along a certain axis, not at a point. Here, the least square method is used for pattern synthesis. However, the procedure is differentiated from the usual method, so that two difference patterns and a sum pattern can be controlled at the same time. Radiation patterns at the feed circuit output ports are given by

$$X(z_j)=\sum_{i=1}^{I} c_i x_i f_i(z_j),\quad Y(z_j)=\sum_{i=1}^{I} c_i y_i f_i(z_j),\quad S(z_j)=\sum_{i=1}^{I} c_i s_i f_i(z_j) \qquad (3)$$

where c_i is the complex weight of the i-th feed horn, x_i, y_i and s_i are the complex transmission coefficients from the i-th input port to output ports X, Y and S, respectively, and $f_i(z_j)$ is the complex field received by the i-th feed

horn from the direction of z_J, $j=1\sim J+K+L$.
If A_J denotes the desired field value on a sum and two difference patterns in a specified direction z_J, then the squared error ε can be written as

$$\varepsilon=\sum_{j=1}^{J}|A_J-X(z_J)|^2+\sum_{j=J+1}^{J+K}|A_J-Y(z_J)|^2+\sum_{j=J+K+1}^{J+K+L}|A_J-S(z_J)|^2 \tag{4}$$

where directions z_J of $j=1\sim J$, $J+1\sim J+K$ and $J+K+1\sim J+K+L$ specify points on patterns observed in the X, Y and S ports, respectively. To obtain the minimum, ε must be differentiated with respect to the complex conjugate of each feed weight c_I and the resulting expressions set equal to zero [3].

$$\partial\varepsilon/\partial c_I^*=0 \tag{5}$$

where the asterisk denotes a complex conjugate. Substituting Eqs. (3) and (4) into Eq. (5), we have the following matrix expression.

$$[\mathbf{x}^* \vdots \mathbf{y}^* \vdots \mathbf{s}^*]\left[\begin{array}{c:c:c}\tilde{\mathbf{d}}^* & 0 & 0\\ \hdashline 0 & \tilde{\mathbf{e}}^* & 0\\ \hdashline 0 & 0 & \tilde{\mathbf{f}}^*\end{array}\right]\left[\begin{array}{c:c:c}\mathbf{d} & 0 & 0\\ \hdashline 0 & \mathbf{e} & 0\\ \hdashline 0 & 0 & \mathbf{f}\end{array}\right]\left[\begin{array}{c}\mathbf{x}\\ \hdashline \mathbf{y}\\ \hdashline \mathbf{s}\end{array}\right]\mathbf{c}=[\mathbf{x}^* \vdots \mathbf{y}^* \vdots \mathbf{s}^*]\left[\begin{array}{c:c:c}\tilde{\mathbf{d}}^* & 0 & 0\\ \hdashline 0 & \tilde{\mathbf{e}}^* & 0\\ \hdashline 0 & 0 & \tilde{\mathbf{f}}^*\end{array}\right]\mathbf{A} \tag{6}$$

where $\sim$ denotes transpose, $\mathbf{x}$, $\mathbf{y}$ and $\mathbf{s}$ are diagonal submatrices with elements of x_I, y_I, s_I, $i=1\sim I$, and $\mathbf{d}$, $\mathbf{e}$ and $\mathbf{f}$ are submatrices representing feed horn outputs at a specified direction as

$$\mathbf{d}=\begin{bmatrix}f_1(z_1)\dots f_I(z_1)\\ \dots\dots\dots\\ f_1(z_J)\dots f_I(z_J)\end{bmatrix},\quad \mathbf{e}=\begin{bmatrix}f_1(z_{J+1})\dots f_I(z_{J+1})\\ \dots\dots\dots\\ f_1(z_{J+K})\dots f_I(z_{J+K})\end{bmatrix},\quad \mathbf{f}=\begin{bmatrix}f_1(z_{J+K+1})\dots f_I(z_{J+K+1})\\ \dots\dots\dots\\ f_1(z_{J+K+L})\dots f_I(z_{J+K+L})\end{bmatrix} \tag{7}$$

$\mathbf{A}$: vector composed of A_J as $\mathbf{A}=[A_1\ A_2\dots\dots A_{J+K+L}]^T$
where T denotes transpose,

$\mathbf{c}$: vector of complex weight for each horn as $\mathbf{c}=[c_1\ c_2\dots\dots c_I]^T$.
By solving Eq. (6), the set of optimized weights $\mathbf{c}$ is acquired.

3.3 Numerical results

In order to confirm the usefulness of the design procedure, pattern synthesis was carried out. Measured component beam patterns were used for the synthesis. One of them is shown in Fig. 2. Three constraint points for difference patterns were selected at the crossover and the symmetric points separated by half of a 3dB beamwidth, along the azimuth and elevation axes. A_J for these points is set to be equal to zero. In the sum pattern, only the crossover point is selected, and A_J is set at one.

One of the calculated difference patterns, ΔX, is shown in Fig. 4. It

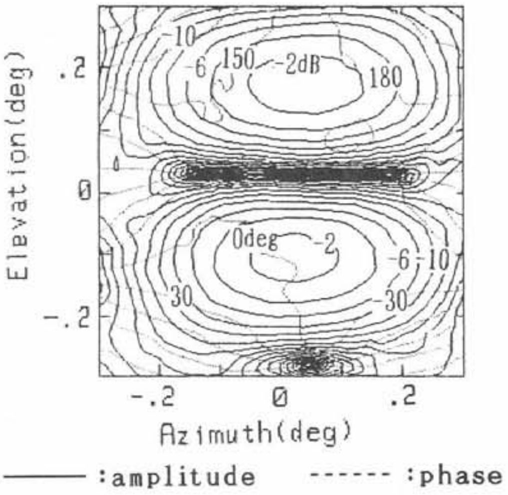
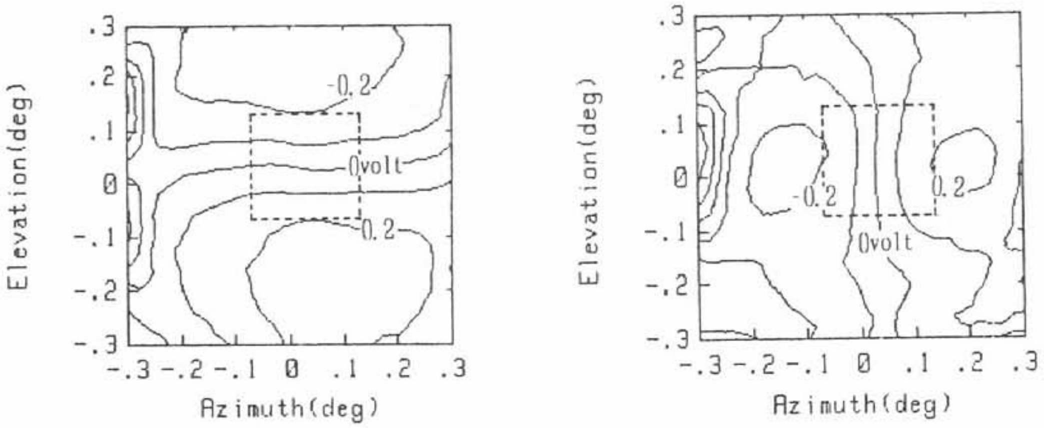


Fig. 4 Difference pattern calculated at X port, designed by least square method.

has a wide angular null range over the 3dB beamwidth. The deviation of c_i, $i=1\sim4$, is about 0.4 dB in amplitude and 50 degrees in phase. Comparing this c_i with that obtained by the conventional approach described in Section 3.1, there is little difference in amplitude (0.3 dB) and considerable difference in phase (40 degrees).

Substituting synthesized patterns into Eqs. (1) and (2), the TRX output patterns are acquired as shown in Figs. 5(a) and (b). These results show that the DC outputs of E_1 and E_2 have orthogonality and almost the same error slope over the 3dB beamwidth of the RF pattern. Thus, the new design procedure has been proven applicable to off-focus RF sensors.



(a) E_1 port output (b) E_2 port output

----------- : square region corresponding to the 3dB beamwidth

Fig.5 Calculated TRX outputs.

4. Conclusion

A design procedure utilizing the least square method is proposed for the pattern synthesis of an off-focus RF sensor. Applying this procedure to four measured component beam patterns, difference patterns with a wide angular null range are obtained. By operating a one-channel TRX with inputs of these RF patterns, it was shown that two DC output patterns have orthogonality and almost the same error slope, showing equivalent properties to an on-focus RF sensor. It can be said that flexibility on locating a RF sensor is much extended.

Acknowledgments

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