Simultaneous Measurement of Frequency and DOA by Frequency Scanning Array

Nazlı Candan[1], Altunkan Hızal[2], Sencer Koç[3]

Abstract – **A wide band frequency scanning array is implemented for measuring the frequency and DOA of an RF signal. A novel low-profile type of antenna, TaCuRaS has been developed to be utilized in the array. A look-up table comprising the array response is prepared for the estimation procedure. Despite of discrete data, the approach of 2-D inverse interpolation associated with the error norm minimization yields a considerable resolution in the estimates.**

Keywords – **Direction finding, low-profile antenna, frequency scanning.**

I. INTRODUCTION

Estimating the direction of arrival (DOA) of RF signals finds a vast area of interest and application such as electronic warfare systems (e.g.monopulse radars), astronomy etc. For this purpose sensor arrays are usually involved due to their pattern response in many estimation procedures, as can be found in literature, [1],[2],[3].

Our research which is a practical extension of [4] describes a distinct means of finding DOA together with the frequency of an incoming single RF signal, simply based on the usage of a look-up table. We have especially dealt with the design of the array and the associated antenna elements rather than justifying that the method is comparably well with the others. Still an optimum design is not our concern but only it is a proof of concept.

The problem is handled in 2-D, namely the azimuth plane:xz-plane. A multilayer stacked configuration of identical arrays, each oriented along a different angle sector with equal spacing is the topology of the system in Fig. 1.

Therefore the aim for covering the whole azimuth is achieved so as to capture the incident signal from any direction.

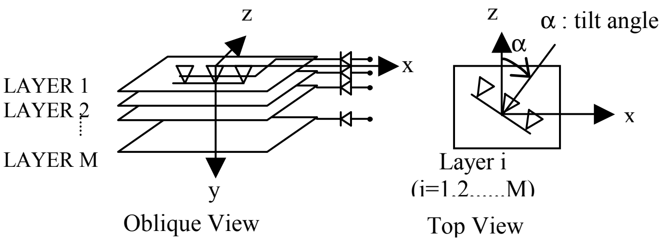

Fig. 1 Stack of multilayer oriented arrays

II. THE RECEIVING ARRAY

A wide band frequency scanning array is aimed in the design. This makes the array pattern more sensitive to frequency. For its simplicity a linear configuration is preferred. The specifications to be satisfied by the array are mainly:

- The array pattern mainly lies on the azimuth plane, hence end-fire radiation is required.
- The beam steering is accomplished by delay line feed-circuitry. Changing frequency inserts phase variation.
- No grating lobe is present within the **single-scanned angle sector (ssas)**.(See Fiq. 5, Section IV)
- Narrow beams are avoided, particularly at the upper frequency limit.
- The pattern is clear of any ripples, exhibiting a smooth variation within the dynamic range.

The expression for the radiation pattern of a frequency scanning linear array:

$$F_{arr}(\theta, f) = \sum_{i=1}^{N} C_i f_{a,i}(\theta, f) e^{j(i-1)[kd\sin\theta - \beta l]} \qquad (1)$$

θ:angle measured from z axis with $\alpha = 0$
f:frequency
C_i:excitation coefficient of the i'th element
$f_{a,i}$:i'th antenna element factor over azimuth plane
k:wavenumber
d:inter-element spacing
β:propagation constant of the delay line
l:length of the delay line

One can obtain the equation of beam steering as:

$$\sin\theta_o = \frac{1}{kd}(2\pi m + \beta l) = m\frac{\lambda}{d} + \sqrt{\varepsilon_{eff}}\,\frac{l}{d} \qquad (2)$$

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$\sqrt{\varepsilon_{eff}}\,\frac{l}{d}$:wrap-up factor

m: 0, ±1, ±2..integer multiples

The wrap-up factor is a measure of how fast the beam is scanned. From the initial frequency f_{in} to final frequency f_{fin} the beam moves from θ_{in} to θ_{fin}.

The selection for the array parameters have come out to be:

$N=4$

$C_1=C_4=0.708,\ C_2=C_3=1$

$\frac{l}{d}=1.1,\ \frac{d}{\lambda_{min}}:0.55$

$f_{fin}:f_{in}=1.55$

III. THE ANTENNA ELEMENT

An original low-profile antenna, TaCuRaS is devised on TAROS [5] and inspired from a ramp-antenna form:an upward curving strip while its width is expanding. It is easily integrated to microstrip devices. As for the radiation mechanism, the waves are launched from the curving open end of the structure showing an end-fire characteristics.(Fig.2)

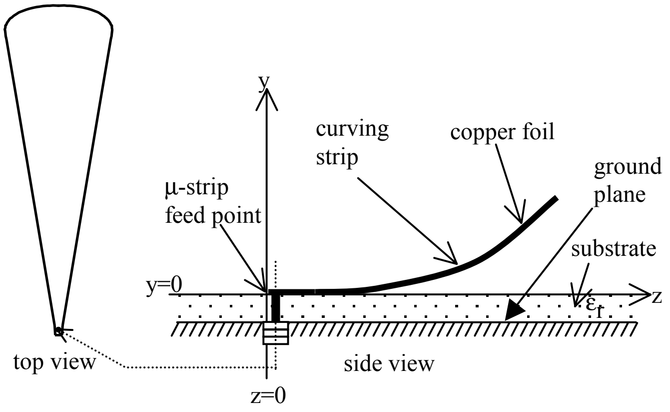

Fig. 2 Top and side view of TaCuRaS

The finite ground plane obstructs the beam maximum to lie completely on the azimuth plane. A beam tilt of almost 30° upward is confronted. Since the beamwidth is almost twice of this value, the azimuth measurements take place within the 3 dB elevation beamwidth.

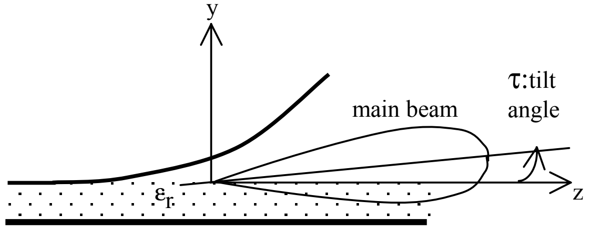

Fig. 3 Beam-tilt on the elevation plane

The return loss measured at the junction point (in Fig. 2) is about -11 dB. The azimuth beamwidth varies from 65°-75° while the elevation beamwidth is almost 30°. Since the back lobe level is less than -15 dB, Kraus' formula [5] is used to calculate the directivity, as to be about 9.5-11 dB within the band of operation.

IV. THE ARRAY ASSEMBLAGE

The array composed of TaCuRaS antenna elements are gathered with the delay line network as shown in Fig. 4 .

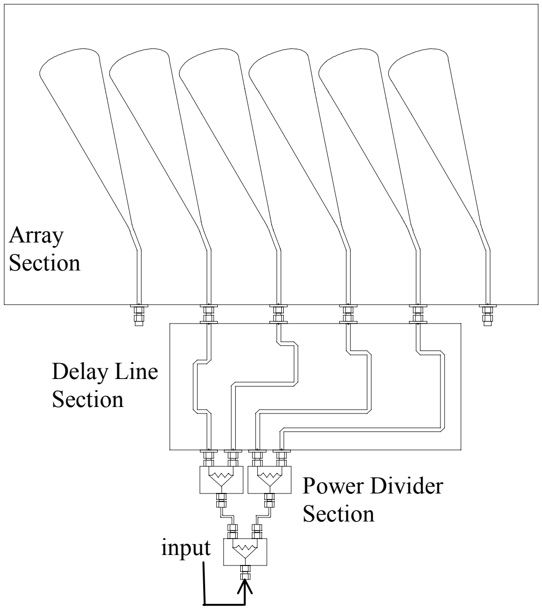

Fig. 4 The whole array assembled

One should note that the insertion of two more inactive dummy elements in the array is because of minimizing the edge effects, thus distributing the radiation evenly. The position of the antenna elements is intentionally left-oriented by an amount of 20° w.r.t. the axis normal z-axis, since the beam scanning takes place around this direction. Therefore the reduction in efficiency is further prevented

The return loss has come out to be not more than -18 dB. This drop when compared to an isolated antenna mainly arises from line losses and 3 dB attenuators along the power dividers. The latter are used for the adjustment of amplitude coefficients.

The pattern parameters are presented in Table I.

TABLE I
AZIMUTH AND ELEVATION PARAMETERS OF THE ARRAY PATTERN

Frequency (f/f_{in})	θ_o	θ_{BW}	τ_o	τ_{BW}
1	-32°	21°	20°	37°
1.275	-17°	19°	20°	77°
1.55	-5°	16	25°	54°

θ_o:beam max. angle over azimuth
θ_{BW}:3 dB beamwidth over azimuth
τ_o:beam max. angle over elevation
τ_{BW}:3 dB beamwidth over elevation

In Table II the gain of the array is obtained from the approximate calculations, similar to those of a single antenna.

TABLE II
GAIN OF THE ARRAY

Frequency (f/f_{in})	τ_{BW}	θ_{BW}	G(dB)
1	37°	21°	15
1.275	77°	19°	14
1.55	54°	16	16

V. THE FREQUENCY AND DIRECTION FINDING PROCEDURE

The amplitude measurement of the stacked array model (see Fig. 1) is simulated by generating the same data obtained form a single array but with the angular position shifted in accordance. The receiving pattern of any two detectors can be given as:

$$V_m(\theta,f)=V_n(\theta-\Delta\theta,f) \qquad (3)$$

$$\Delta\theta = \alpha(m-n) \qquad (4)$$

V_m, V_n : signal level in dB at m’th, n’th detector
α:array tilt angle in azimuth plane

It is easily conceived that there can be M arrays where,

$$M = 360°/\alpha : \text{integer} \qquad (5)$$

and α essentially determines the region lying in between the angles at “overlapping’’ of the pattern of two adjacent arrays. This means within this angle sector only one detector can receive the highest signal level among the others. This will be clearer with the following description.

The pattern of three successive arrays is observed at three different frequencies f_{in} , f_{mid} and f_{fin} (shown in Fig. 5). For each detector the **single-scanned angle sector (ssas)** looks toward a different direction. For a signal incident on one of the **ssas** the corresponding detector reads the highest of all the detectors.

In our problem, since the dynamic range is a limiting factor (about 20 dB) the signal levels lower than a certain value can not be meaningful. The pattern values of only other two neighbor detectors lying in the **ssas** can comply with this restriction. So the simultaneous reading of three successive arrays is selected delibaretly.

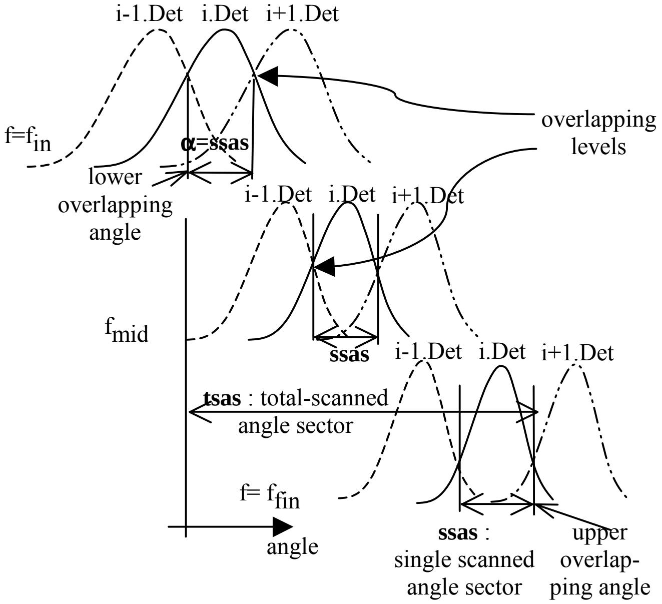

Fig. 5 Related scanned sectors for 3 consecutive detector patterns

Moreover the **ssas** for a detector shifts with the frequency as seen in Fig. 5. Thus within the band of operation what is required to measure is the amplitude data lying in the **total-scanned angle sector (tsas)**. As the measurements were realized by a network analyzer, discrete samples of the pattern could be obtained. This helps in the preparation of the look-up table.

A difference vector (in dB sense) is arranged from the reading of three adjacent detectors:

$$\overline{R} = \begin{bmatrix} V_i - V_{i-1} \\ V_{i+1} - V_i \end{bmatrix} = \begin{bmatrix} R_1(\theta,f) \\ R_2(\theta,f) \end{bmatrix}, \ i:1,2,..M \qquad (6)$$

The usage of index takes place in cylic order:

$$i = \begin{cases} M, & i+1=1 \\ 1, & i-1=M \end{cases} \qquad (7)$$

Actually the variation of the difference vector due to the angle and the frequency is sampled as indicated in Eqn. (8)

$$\overline{R} = \begin{bmatrix} R_1(\theta_m, f_n) \\ R_2(\theta_m, f_n) \end{bmatrix} \qquad (8)$$

The prepared table is clear of noise because of the instruments and devices used. However the performance of the system is to be evaluated in a noisy environment. For a predefined SNR (Signal to Noise Ratio) a set of noisy signals are generated from the clear measured signal.

The measurement of noisy signal is simulated over 3-detectors in which the middle one reads the highest. Thereafter the noisy difference vector is simply compared with the entries of the look-up table norm-wise. The estimates will be the pair minimizing this error norm.

$$(\hat{\theta},\hat{f}) = \underset{\theta\in[0,360°],\, f\in[f_{in},\, f_{fin}]}{\arg\min} \left\| \overline{R}(\theta_m, f_n) - \overline{\tilde{R}}(\theta, f) \right\| \quad (9)$$

$\overline{\tilde{R}}$: difference vector for the measured noisy signal.

A simple norm comparison does not suffice since the actual value may lie somewhere in between the sampled data. The approach to solve this problem is to apply 2-D inverse interpolation which has worked well in our case, with the rms errors:

min. rms angle err = 0.04°
min. rms. frequency err. = 0.006 GHz

These are calculated for SNR=50 dB.

The ambiguity problem arises specific to the array manifold. This means one can confront multiple solutions during the computations. The reason is that the $\overline{R}$ function is not monotonic over θ-f domain.

V. CONCLUSION

In this work our aim for the simultaneous estimation of frequency and DOA of a signal is achieved as a proof of concept. The frequency scanning array system constructed with the novel antenna elements TaCuRaS has performed the desired response but not the optimum. The new antenna has shown that it is useful for microstrip end-fire array applications.

As a continuation of this search, the array manifold can be arranged with another design so as to minimize the ambiguity problem challenged during the estimation.

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