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Spatial Fading Emulator using Cavity-Excited Circular Array based on ESPAR Antenna

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1. Introduction

The testing of mobile radio transmission techniques in the field is time-consuming and often inconclusive, due to uncertainty in the statistical signal variations actually encountered. Laboratory testing with signals that duplicate the assumed statistical properties of the signals encountered in the field is an attractive alternative, provided that all of the relevant properties can be simulated[1]. Therefore, we need a standard mobile communication environment, which provides suitable condition for mobile radio transmission experiment.

There are several approaches to generate fading signals. First is a stored channel approach in which actual fading fluctuations are stored in the memory[2]. Second is the so called "Jakes type" fading simulator in which a steady signal is split into several paths, each of which suffers from different Doppler shifts, and they are combined again to generate the fading[1]. Third is the Gaussian amplitude modulation of the in-phase and quadrature components of a steady carrier which can be used to provide uniform phase modulation and Rayleigh envelop fading[3].

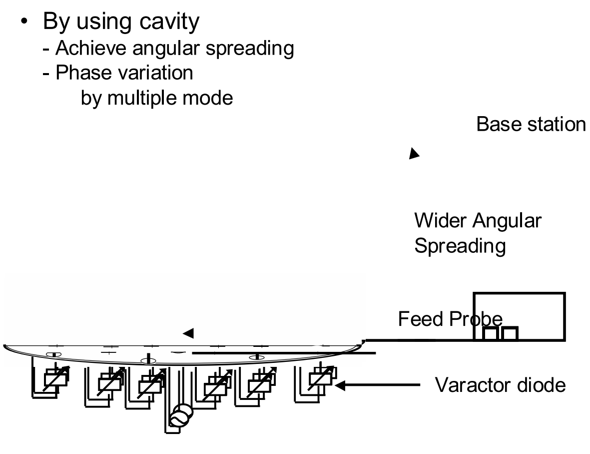

Figure 1: Structure of CECA

The fading simulators can only work in the delay and Doppler domains, and the effect of antennas cannot be considered. To overcome this problem, a fading emulator called a field simulator has been proposed. For mobile terminals, a field simulator composed of a phased array antenna and the shielded box is used[4]. For base stations, another field simulator using the moving metal bars is used to realize the finite angular spread[5]. Yet another field emulator using electronically steerable passive array radiator (ESPAR) antenna has recently been proposed by the authors[6][7]. ESPAR field simulator works well as a spatial fading emulator with low cost and simple structure but only a small anglular spread (AS) could be generated under specific condition. We therefore propose a cavity-exited circular array (CECA) based on ESPAR antenna as a spatial fading emulator to overcome small AS and severe conditions. We call the fabricated CECA fading emulator, not fading simulator, so as not to confuse with electromagnetic field simulators. In the next sections, we show its feature, simulation, and verification by comparing with experiment results and fading simulation results using CECA.

2. Concept and Specification of CECA

Figure 1 shows fundamental structure of CECA. In this example, the array is composed of six inductance-loaded element arranged concentrically for structural symmetry, and one feed pin at the center of the radial cavity. In appearance, the inductance-loaded elements seem to be

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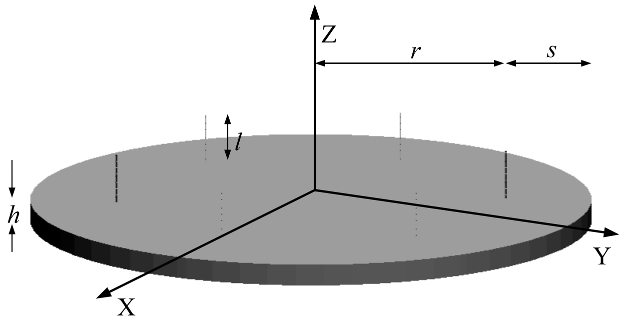
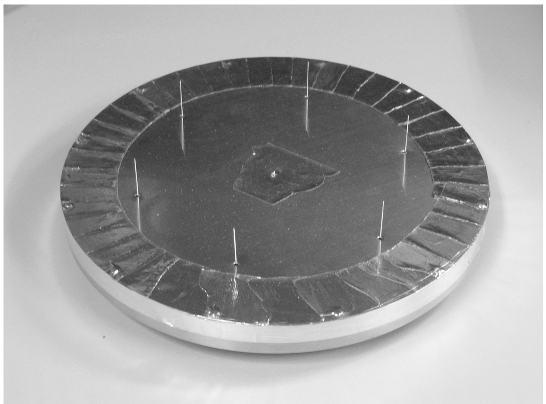


(a). Coordinates and Parameters



(b). Prototype

Figure 2: CECA

r	s	l	h	unit
0.675	0.297	0.197	0.096	λ at 2.41GHz
8.4	3.7	2.45	1.2	cm

Table 1: Structural Dimensions of CECA

parasitic elements, but, in this structure, contrary to the ESPAR antenna, these elements are not the parasitic elements in the sense that they are fed via the radial cavity. The radial cavity may be regarded as a feed circuit and the elements above the radial cavity are fed through the radial cavity with pins connected to the reactance elements. A Rayleigh fading channel with AS can be realized as follows. With respect to the fading, each of the fed elements has different phase due to the varied excitation coefficient by controlling the load impedance as well as the generation of higher order modes in the radial cavity. This quasi-random phase generates the Rayleigh fading. In other words, six array elements work as the local scatterer. On the other hand, ESPAR antenna produces Rayleigh fading only under specific condition due to the existance of feed element. Contrary to this, CECA has a lot of flexibility because no direct wave exists. With respect to AS, this structure is advantageous in the sense that the excitation strength is almost independent of the size of the radial cavity, since elements are fed by the radial cavity and not by the proximity coupling. Therefore, this structure may have a wider AS than what an ESPAR antenna can achieve. Selecting the appropriate size of the radial cavity and array would easily control the AS. Figure 2 shows the structure and coordinate of CECA and the fabricated CECA. Table 1 defines dimensions of CECA including distances of antenna element from wall and center r and s, element length l, radial cavity height h.

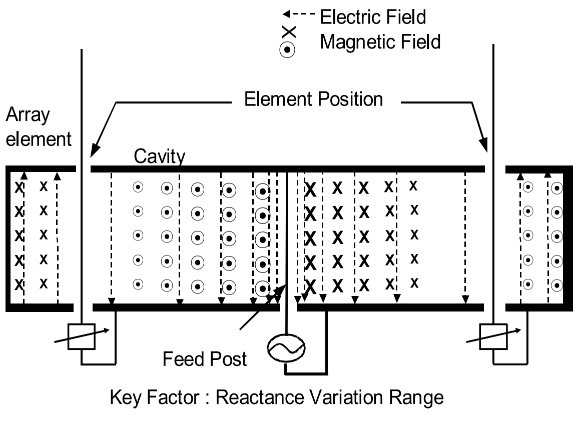
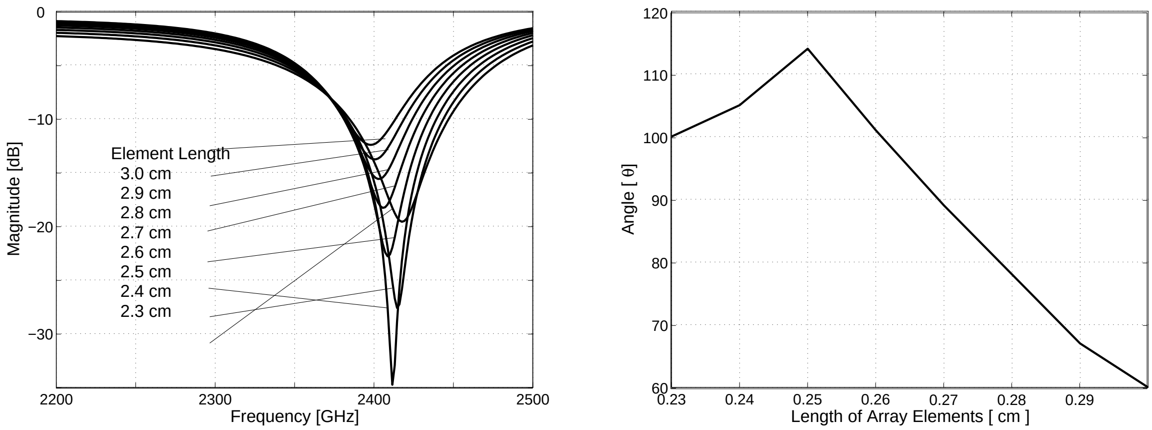


Figure 3: Position of Array Elements

3. Experiment and Simulation of CECA

We have made use of the Method of Moment (MoM) simulator, FEKO[8] as numerical analysis method. We compares the reflection coefficients obtained by the simulation and the experi-



(a).Variation of return loss with element length l on simulation.

(b).Phase variation range of elements with array length at 2.41 GHz

Figure 4: Variation with element length – only the length of array elements vary while element position parameters r, s are 8.5 cm, 3.8 cm respectively.

ment in order to clear that the simulation model is valid. The aim of design CECA is to obtain wide reactance variation range of the array elements. After the parametric study of CECA, we found that the size of the cavity shall be chosen so that it is resonant, and the array elements shall be arranged at the peak of electric field of the mode as Fig.3. Specially, we know that the length of array elements take a big effect to reactance variation and reflection coefficients as Fig.4. Therefore, we designed CECA in several modes by simulation. To obtain wider AS, we make r large, which means the use of the higher order mode. The parasitic element in an ESPAR antenna is 0.25λ away from the center. Contrary, array element position r of CECA in TM_{030} mode is 1.1872λ. Therefore, we know intuitively that AS of TM_{030} CECA is about 4.75 times larger than ESPAR's.

4. CECA on Reactance Domain

In this part, we show the characteristics of CECA on the reactance domain[9]. It is necessary to verify the variation of phase on array elements in case of loading varactors at all array elements. We suppose that the capacitance of the varactor has been varied in the range of 0.5pF – 9pF, which correspond to -132.63Ω – -7.37Ω. However, phase on array elements vary in more complicated manner than this value because of mutual coupling between array elements both inside and outside of the cavity. We compare two cases — fixed reactance and random reactance of varactor. We know that all the elements have the same current distribution because CECA has a symmetric structure when all array elements are connected to 4.2pF varactors. Next, we change the reactance of the varactor at random. Figure 5 shows an example of the current distribution of the cavity when 0.5 pF, 9 pF, 4.7 pF, 1 pF, 2.8 pF and 7.3 pF are respectively loaded. From Fig. 5, the phase values on the array elements vary. We will show later that they shall generate the spatial Rayleigh fading.

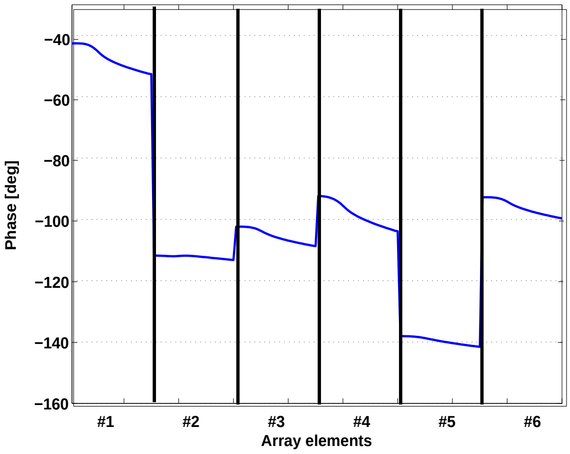


Figure 5: Phase on each array elements - when random varactors are loaded

5. Fading Emulation

We obtain impedance $[Z_c]$ by simulation when varactors have not been loaded.

$$[Z_c][I] = [V] \tag{1}$$

where $[Z_c]$, $[I]$ and $[V]$ denote impedance matrix of CECA defined at the parts at the lower plate of the cavity, current vector defined at the elements inside cavity and voltage vector between the elements and the lower plate of the cavity, respectively. When varactors have been loaded, the impedance Z_{va} is added to impedance $[Z_c]$ and then we obtain the current distribution. When the varactors are connected,

$$[Z_c + Z_{va}][I] = [V_0], \tag{2}$$

where

$$[Z_{va}]_{mm} = -j\frac{1}{2\pi f C_m}, \tag{3}$$

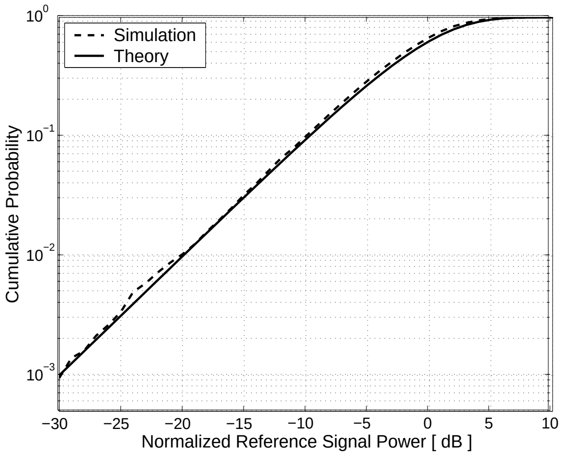


Figure 6: Cumulative Probability of Fading Signal Power

V_0 is the applied voltage from outside, f and C_m denote the frequency and the capacitance of the mth varactor respectively. In simulation, the Monte Carlo method is applied in order to make random local scatterer of array elements by random choice of the varactor reactance. As Fig.6 shows, CECA has generated a channel close to Rayleigh fading.

6. Conclusion

A cavity-excited circular array based on ESPAR antenna used as a spatial fading emulator has been proposed and its features based on simulation by a MoM simulator and measurements on the fabricated CECA are presented. The proposed antenna has worked well as a spatial fading emulator that can simulate the base station environments with about 4.75 times wider AS than ESPAR's.

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