THE ACTIVE PHASED ARRAY ANTENNAS COUPLED THROUGH SLOTLINES

Cheol Mun, Chang Hoon Kang*, Han Kyu Park, and Young Joong Yoon
Department of Radio Communication Engineering Yonsei University
Department of Electronic Engineering Yonsei University*
134 Sinchon-Dong, Seodeamun-Ku, Seoul, 120-749, Korea

ABSTRACT

In this paper, the 5-element active phased array antenna coupled through the slotline in the ground plane between oscillators is designed and fabricated. The proposed slotline coupling structure as a novel coupling structure has several advantages over the transmission line coupling such as the expansion capability in two dimensions and distortion free radiation pattern caused by the coupling network. In experiment, 5-elements active phased array antenna system has 50° scanning range as the free-running frequencies of end elements are controlled.

INTRODUCTION

Phase-shifterless beam scanning techniques in the quasi-optical oscillator arrays have been investigated[1,2,3] recently to overcome the difficulty of implementation and to eliminate the losses from the phase shifters and the quantization errors due to the digital phase shifters in the conventional phased array antenna systems. According to the previous works, a beam from the array of coupled oscillators is scanned by tuning the frequencies of the end elements of the array in the opposite direction[2]. In these arrays, strong coupling networks such as the transmission lines are required to enhance its scanning range. The transmission line can be designed to provide the appropriate coupling strength and coupling phase, but this structure has limitation of expanding in two dimensions for the planar active phased array antennas and distortion of the radiation pattern caused by the coupling networks.

This paper proposes the slotline coupling network in the ground plane to overcome the disadvantages of the transmission line coupling structure, and to provide strong coupling strength. Also the coupling strength and phase can be controlled by adjusting the position, width, and the length of slotline. And the slotline coupling network can be expanded in two dimensions for the planar active phased array antennas because the coupling networks is located on the ground plane. Configuration of slotline coupled active phased array antenna is shown in Figure 1.

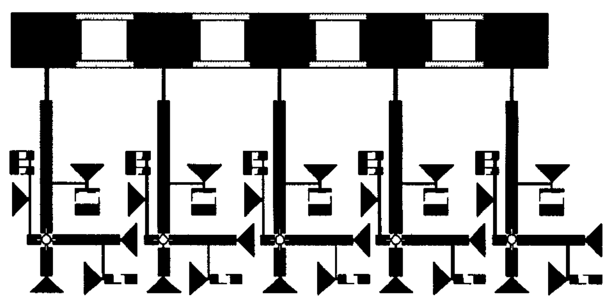

Figure 1 Configuration of slotline coupled active phased array antenna

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SLOTLINE COUPLED OSCILLATOR ARRAY

If the coupling network exhibits broadband characteristics in an array of mutually coupled N oscillators, amplitudes and phase dynamics of N oscillators are the function of the coupling strength and the phase which can be described in terms of Y-parameters of the coupling network[3].

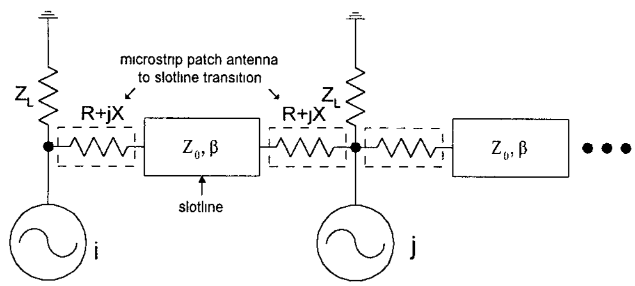

Figure 2 An equivalent circuit of the oscillator array coupled between nearest neighbor through the slotline

An equivalent representation of the oscillator array coupled between nearest neighbors through the slotline are shown in Fig.2. In the part of the microstrip patch antenna to the slotline transition, there are losses in the short end of the slotline due to the propagation of power in surface waves and radiation in the form of space waves. And this losses can be described in terms of an equivalent resistance R. Also reactance due to end inductance of the slotline exists and can be represented as jX. As losses exist and reactance is negligible in the part of microstrip patch antenna to slotline transition, Q-factor of the coupling network is smaller than that of the oscillators. This analysis shows that the slotline coupling network exhibits broadband characteristics and thus the coupling parameter κ_{ij} are written as follow.[3]

$$\kappa_{i,j} = \begin{cases} \dfrac{\eta_i Z_L}{2Z_0} & i = j \\ -\dfrac{Z_L e^{-j\beta L}}{2Z_0} & |i-j| = 1 \\ 0 & otherwise \end{cases} \qquad (1)$$

where $\eta_i=(2-\delta_{i1}-\delta_{iN})$, and N is number of elements.

Equation (1) indicates that the coupling phase is the electrical length βL of the slotline and the coupling strength is the ratio of load resistance Z_L to the characteristic impedance Z_0 of the slotline. As the coupling phase is simply the electrical length of the slotline by equation (1), it can be controlled by adjusting the length of the slotline. In this paper, the length of the slotline is determined to one half of the slot wavelength corresponding to 180° coupling phase.

As the slotline approaches the edge of the patch, the coupling strength is stronger, because Z_L, which is a parallel combination of the two radiation resistance, is increased accordingly. Also this reduce degradation of S_{11} characteristics of the patch antenna. Moreover, as the slotline is narrower, the coupling strength is stronger. This fact is due to inproportionality of the coupling strength to Z_0. But considering the reflected wave from the short end of the slotline, too narrow slotline is not efficient[4]. In addition, simulation results indicate that the larger the overlapping area with the patch is, the stronger the coupling strength is. To determine the length, width and position of the slotline providing an appropriate coupling strength and phase, simulation is executed based upon previous analysis. Simulation is carried out using Ensemble simulator in moment method.

As a result of comparison between the transmission line coupling and the proposed slotline coupling by simulation and experiment, respectively, they provide a similar coupling strength of -13dB which is stronger than radiative coupling by 8dB as shown in Fig. 3.

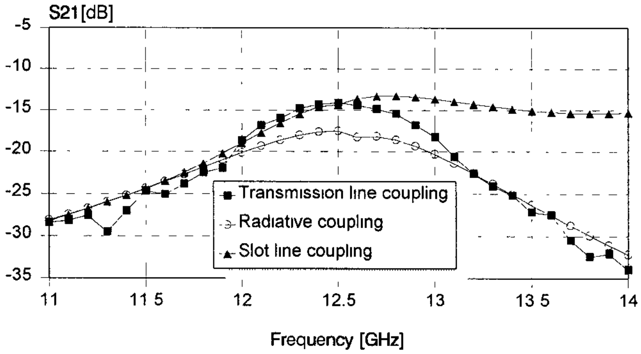

Figure 3 Comparison of coupling strength
Transmission line coupling (measurement)
Radiative coupling (simulation)
Slotline coupling (simulation)

FABRICATION AND EXPERIMENTS

An common-gate inductive feedback topology was used in the design of the oscillator type active antenna. An ATF-13786 MESFET was integrated with rectangular patch antenna on 0.508mm thick Taconic substrate with ε_r=2.5. An oscillator type active antenna is seen as the association of an active circuit with S_{11} as input S parameter and a resonant load (the patch antenna) with Γ as reflection coefficient. In this configuration, the patch antenna acts as both resonant load and radiator. The oscillation conditions are as follow[5].

$$\left|\frac{1}{S_{11}}\right| < |\Gamma|$$
$$ang\left(\frac{1}{S_{11}}\right) = ang(\Gamma) \quad (2)$$

Fig.4 shows simulated $1/S_{11}$ and Γ. This simulation is carried out by rigorous modeling techniques which synthesizes S parameters of linear part by moment method and large signal S parameter of MESFET[6]. In Fig.4, the stable oscillation is expected, because $1/S_{11}$ curves intersect the resonance circle Γ, and inside the intersection the two curves travel in opposite direction with changing frequency. The free oscillation frequency of fabricated active antenna can be tuned linearly from 12.34 GHz to 12.635 GHz when the bias voltage is varied from 3V to 9V.

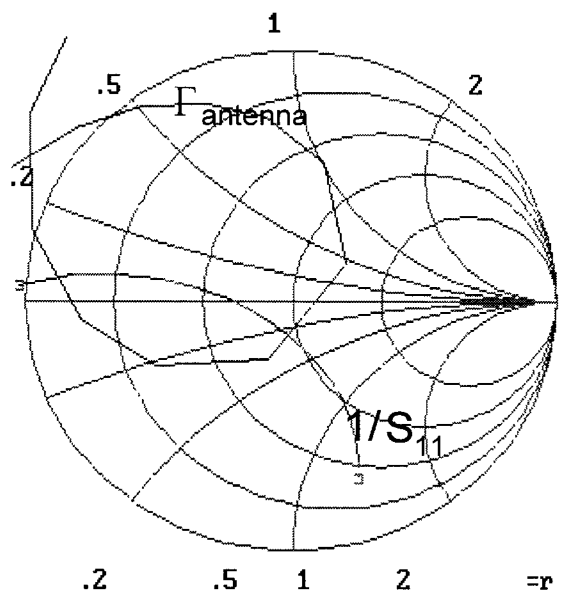

Figure 4 Reflection coefficient of antenna and oscillator (simulation)

The array was composed of five elements, each of which was spaced out 0.6 λ_0. Each element was coupled to its nearest neighbor through two slotlines which are 1mm wide, 10mm long (0.5 slot wavelength) and positioned beneath the edges of the patch. Simulation shows that this structure has -13dB coupling strength and 180° coupling phase. In order to observe the beam steering characteristics of the 5-element active phased array antenna, the free-running frequencies of the end elements are controlled in three ways when the free-running frequencies of inner elements are fixed at 12.5 GHz.

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The fabricated antenna system has a 50 ° steering range from -30 ° to 20 ° off broadside. Fig. 5 shows beam scanning characteristics when the free-running frequencies of end elements are tuned to about 60 MHz in opposite directions from 12.5 GHz, respectively.

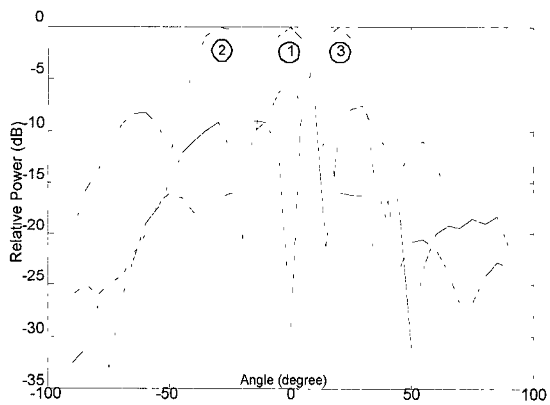

Figure 5 Beam scanning by detunung end elements from -30 ° to 20 ° off broadside

Table 1 Beam direction according to the free-running frequency of each element

	ω_1 (GHz)	$\omega_2=\omega_3=\omega_4$ (GHz)	ω_5 (GHz)	Beam Direction
1	12.5	12.5	12.5	0 °
2	12.443	12.5	12.557	20 °
3	12.557	12.5	12.443	-30 °

CONCLUSION

The overall results show that the proposed active phased array antenna using the slotline coupling structure provides a good scanning characteristics when compared with the system using the conventional coupling structures such as transmission line coupling network. In addition, because the coupling networks are located on the ground plane, the proposed system can eliminate the distortion of the radiation pattern by the spurious radiation of the coupling network and can be expanded easily to a two dimensional coupling network. Now, works on the planar active phased array antenna system is going on, which is coupled two-dimensionally through slotlines between elements.

REFERENCES

[1] S.T.Chew and T.Itoh, "An active phased array with optical input and beam scanning capability", IEEE Microwave Guided Wave Lett., pp.347, Oct., 1994.

[2] P.Liao and R.A.York, "A new phase-shifterless beam-scanning technique using arrays of coupled oscillators," IEEE Trans. Microwave Theory Tech.., vol. MTT-41, pp.1810-1815, Oct., 1993.

[3] Robert A. York, Peter Liao and Jonathan J. Lynch," Oscillator array dynamics with broadband N-port coupling networks," IEEE Trans. Microwave Theory Tech.., vol. MTT-42, no. 11, pp.2040-2045, Nov., 1994.

[4] K.C.Gupta, Ramesh Garg, Microstrip Lines and Slotlines, Artech House, 1996.

[5] John W. Boyles, "The oscillator as a reflection amplifier : an intuitive approach to oscillator design," Microwave Journal, pp 25-30, June, 1986.

[6] R. Gillard, H. Legay, "Rigorous modelling of receiving active microstrip antenna," Electronic Letters, pp 2357-2358, Dec., 1991