Design of Novel Wiggly Directional Coupler with the Fractal Coupled Sections for Improving Coupling

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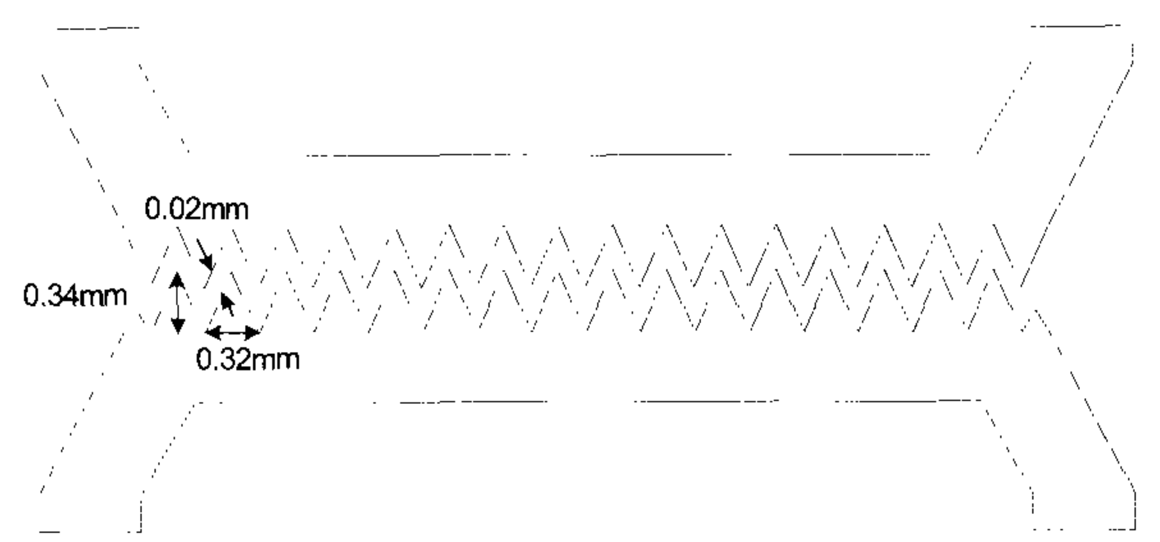
Abstract—In this paper, the new type wiggly directional coupler which uses the fractal coupled shape in coupled sections is presented. A commercial software has been used to analyze this new structure and the simulation results are compared to those of the conventional wiggly directional coupler. To verify the simulation results, the new type wiggly directional coupler was fabricated with the center frequency of 15GHz. The measurement results shows that the coupling of new structure proposed in this paper is more than that of conventional wiggly coupler. The results in this paper also show that the fractal shape coupled lines in wiggling sections can improve the coupling characteristics in wiggly directional coupler.

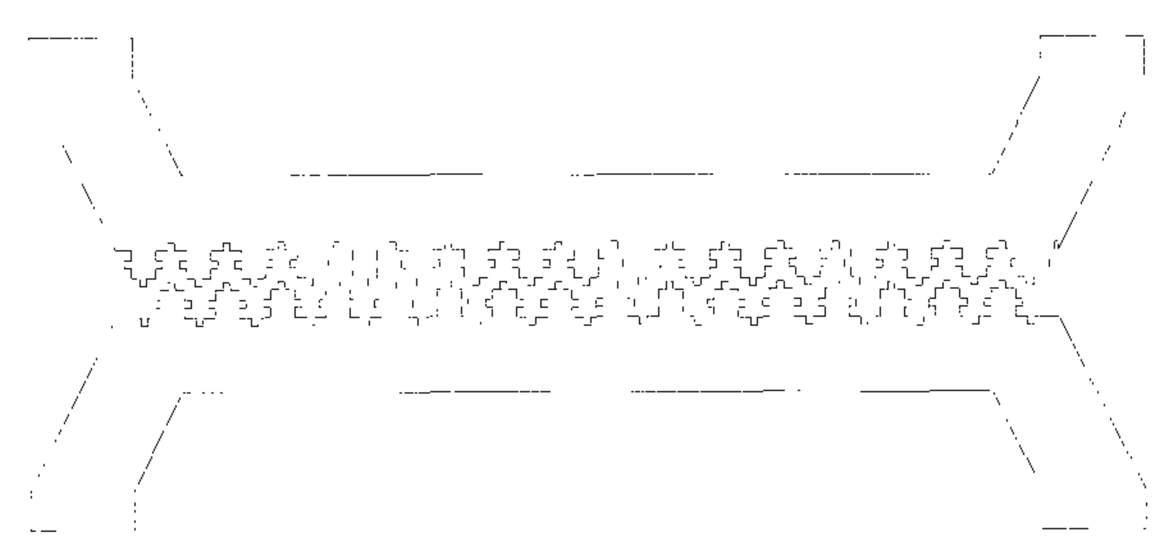
Index Terms—Coupling, Fractal Coupled Section, Wiggly Directional Coupler.

I. INTRODUCTION

Microstrip line is one of the most often used microwave wave guiding structures. It has been used to construct HMIC's and MMIC's for many years. Ones of these circuits are microstrip directional couplers, constructed usually as edge, broad-side or parallel coupled lines[1]. Directional couplers consisting of parallel-coupled microstrip transmission lines are frequently used in balun, filter and various microwave circuits because they are easily to implement in microwave and millimeterwave hybrid or monolithic integrated circuits[2]. It is well known that a coupled transmission line coupler with unequal even- and odd- mode lengths suffers from low directivity and low coupling[3]. Several techniques have been reported to equalize or compensate the unequal modal velocities of the coupled microstrip section. There are mainly two techniques for improving the coupling or directivity of microstrip couplers, by adding lumped capacitances at the ends of the coupled lines and using a dielectric overlay on top of the coupled lines[2]. Although use of lumped capacitances or dielectric overlay structures lead to an improved directivity of microstrip directional couplers, both techniques complicate fabrications and may undermine the advantages of MIC's. Another technique to equalize the phase velocities of even- and odd- mode signals that is compatible with MIC technology is to use wiggly lines instead of straight lines[4]. But the wiggly directional couplers suffer from poor directivity especially when the coupling is decreased or the substrate dielectric permittivity is increased[2].



(a) Typical wiggly coupled directional coupler



(b) Modified coupled directional coupler with fractal coupled sections

Fig. 1. Top view of the wiggly coupled and fractal coupled directional coupler

Fractal structures can be found in many facets of everyday life. For decades, scientists across various disciplines have studied honeycombs, snowflakes, and the human nerve network among others for the fascinating qualities their fractal characteristics bring. In the microwave regime, however, only a modest number of fractal applications have arisen so far. Samavati[5] demonstrated a linear capacitor per unit area while Saleh[6] used self-similar slabs to design microwave filters. Perhaps the most well-known use of fractals is in fractal antennas and arrays, both of which have been studied extensively for their low profile and wideband characteristics[7][8]. In this paper, we introduce a novel structure that can increase the even- mode phase velocity effectively by using the fractal shape meandering in the

Manuscript received February 1, 2008.

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parallel microstrip coupled lines as shown in Figure 1, which can achieve enhanced coupling characteristics because of enlarged electrical length.

II. Design of Wiggly Directional Coupler

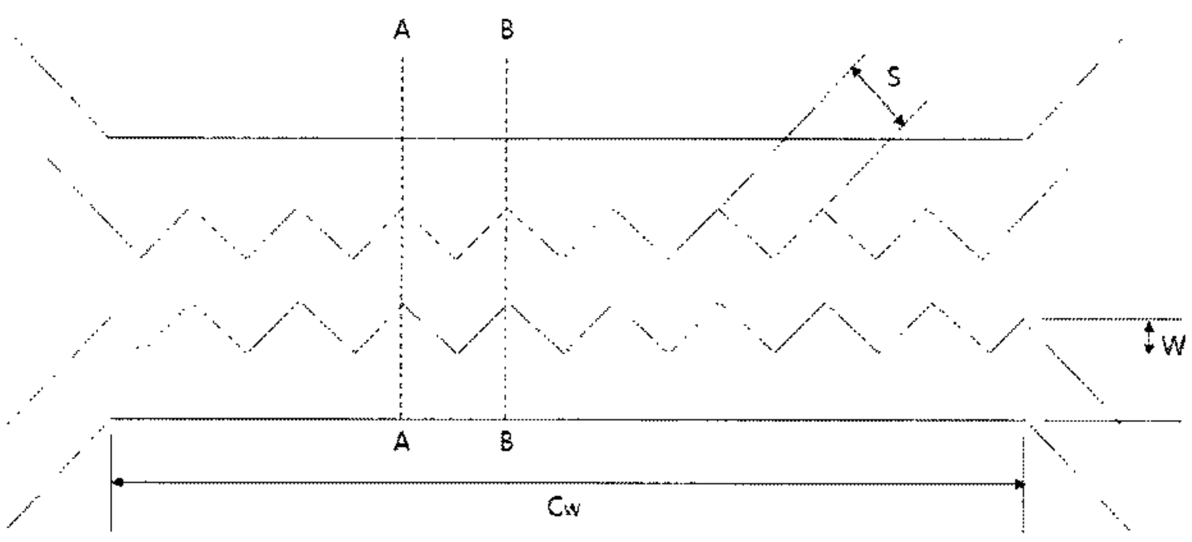
The geometrical parameters of wiggly-coupled lines are defined in Figure 2[4]. If we assume the length between reference plane AA and BB of each lines as ΔL, the odd-mode capacitance of wiggly-coupled lines is given by

$$C_{ow} = (C_f + C_p)\Delta L + C_{fo} \quad (1)$$

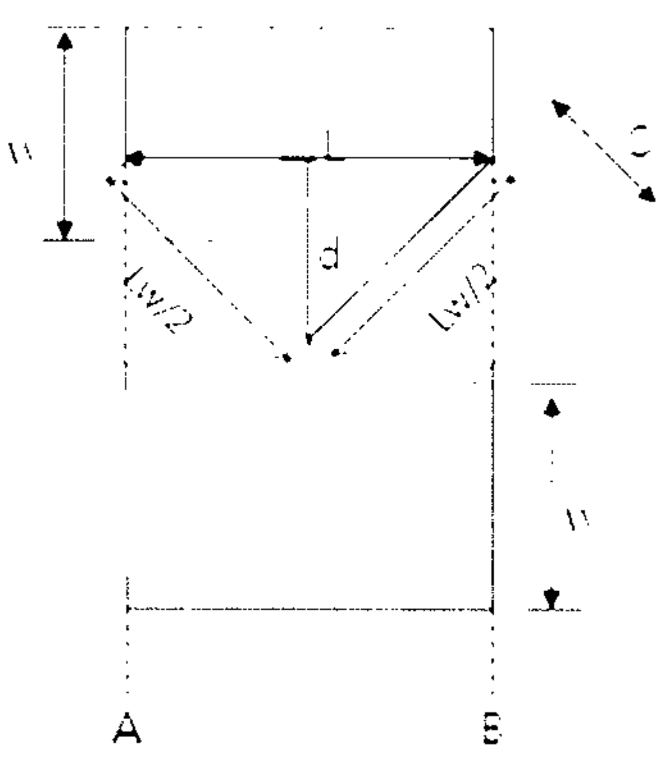
Where, C_f, C_p are fringing capacitance and parallel-plate capacitance , respectively, and C_{fo}, L_w are odd-mode fringing capacitance and effective length in wiggly line. For microstrip lines, the capacitance C_f, C_p can be determined as follows.

$$C_p = \frac{\varepsilon_o \varepsilon_r W}{h} \quad (2)$$

$$2C_f = \frac{\sqrt{\varepsilon_{re}}}{cZ_o} - C_p \quad (3)$$



(a) Wiggly-coupled directional coupler



(b) Design parameters of wiggly-coupled line

Fig. 2 Wiggly Directional Coupler Design Parameters

To equalize the odd and even-mode phase velocities, the following relation should be satisfied.

$$C_{ow} = \frac{\varepsilon_{ree}}{\varepsilon_{reo}} C_o \quad (4)$$

Where $\varepsilon_{ree}, \varepsilon_{reo}$ are the effective dielectric constants for the even and odd-mode, respectively. From (1) and (4), the length L_w of wiggly-coupled lines can be obtained using (5)

$$L_w = \Delta L \frac{C'_{fo}}{C_{f0}} \quad (5)$$

C'_{fo} is given by (6).

$$C'_{fo} = (C_p + C_f)(\frac{\varepsilon_{ree}}{\varepsilon_{reo}} - 1) + \frac{\varepsilon_{ree}}{\varepsilon_{reo}} C_{fo} \quad (6)$$

To obtain the value of L_w in (5), the wiggle depth d should be defined as

$$d = \frac{\Delta L}{2} \sqrt{(\frac{C'_{fo}}{C_{fo}})^2 - 1} \quad (7)$$

From using (1)-(7), we can obtain the design parameters for wiggly directional coupler.

III. SIMULATIONS & MEASUREMENTS

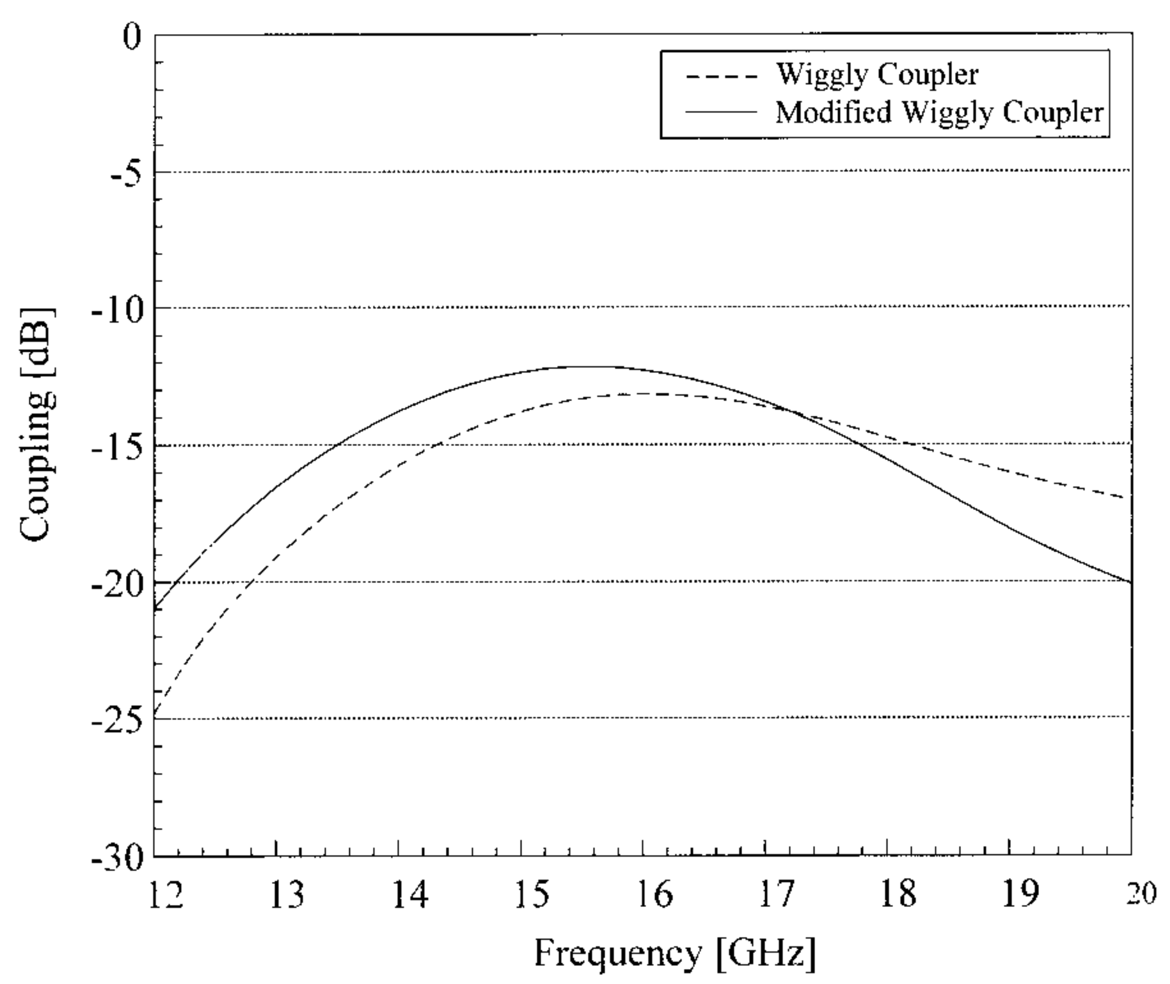
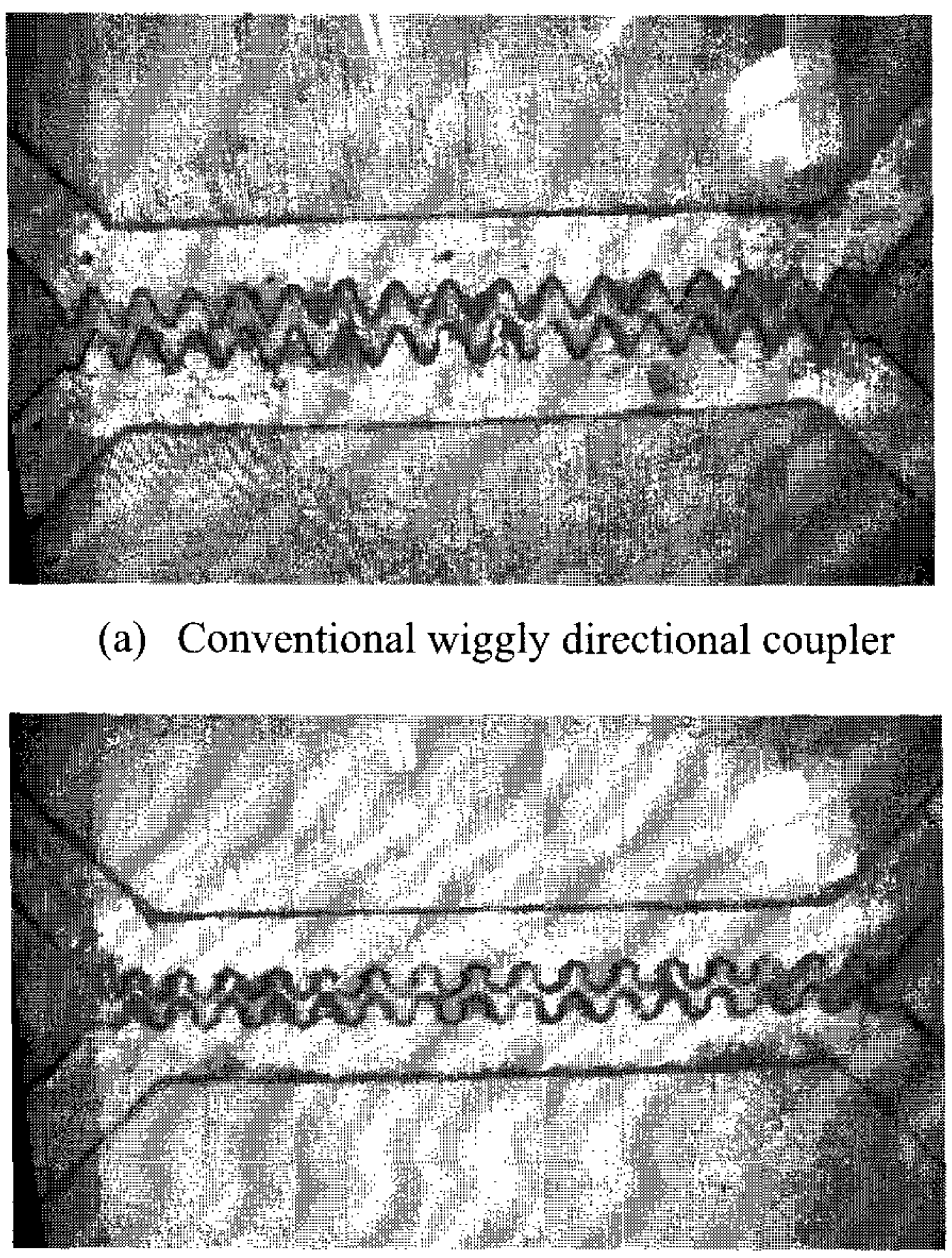


Fig. 3 Simulation results of coupling characteristics

The geometrical shapes of wiggly coupled and wiggly coupled lines with fractal shape are defined in Figure 1.

Figure 1 shows a typical wiggly line coupler (a) and a modified wiggly coupler with fractal shape coupled sections (b), respectively. Due to self similarity of fractal coupled shape in Figure 1(b) that results electrical length longer than that of the typical wiggly coupler, so more coupling can be achieved in modified wiggly coupler. A 13 dB wiggly directional coupler with $\varepsilon_r = 10$ high permittivity substrate is designed at the center frequency of 15GHz based on the design parameters of Figure 2. The EM simulations are performed to show the validity of proposed novel structure using the commercial EM software[9]. Figure 3 shows a coupling characteristics versus frequency plot for a typical wiggly coupler and modified wiggly coupler in this paper. It is clearly shown from the data that coupling characteristics of the modified wiggly directional coupler with fractal shape compared to the typical wiggly coupler can be slightly improved. To verify the simulation results, we made the wiggly and modified wiggly directional coupler. The substrate used is CER-10 produced by TACONIC which has $\varepsilon_r = 10$ and the substrate thickness is *0.635mm*.

Because of its small size, we used the microscope to see the coupled section in detail. Total size area of the directional coupler was below *8mm×5mm* because of its high frequency characteristics.



(a) Conventional wiggly directional coupler

(b) Modified wiggly directional coupler

Fig. 4 Manufactured directional coupler

Figure 4 shows manufactured conventional wiggly directional coupler and modified wiggly directional coupler with fractal coupled section. Due to inaccuracy of etching and fabrication, the fractal coupled section has not accurate shapes as designed. Figure 5 represents the coupling characteristics measurement results of each coupler. Compared to simulation results of Figure 3, there are some differences between simulation and measurement results. But, for both case, the coupling characteristics of modified wiggly directional coupler with fractal coupled section are improved, about *2-5dB*, compared to the conventional one around at the designed frequency(15GHz). We can consider that the error in both results due to the inaccuracy fabrication. These results implies that with the fractal shape in wiggly coupled section it is possible to implement directional coupler with improved coupling compared to conventional approaches.

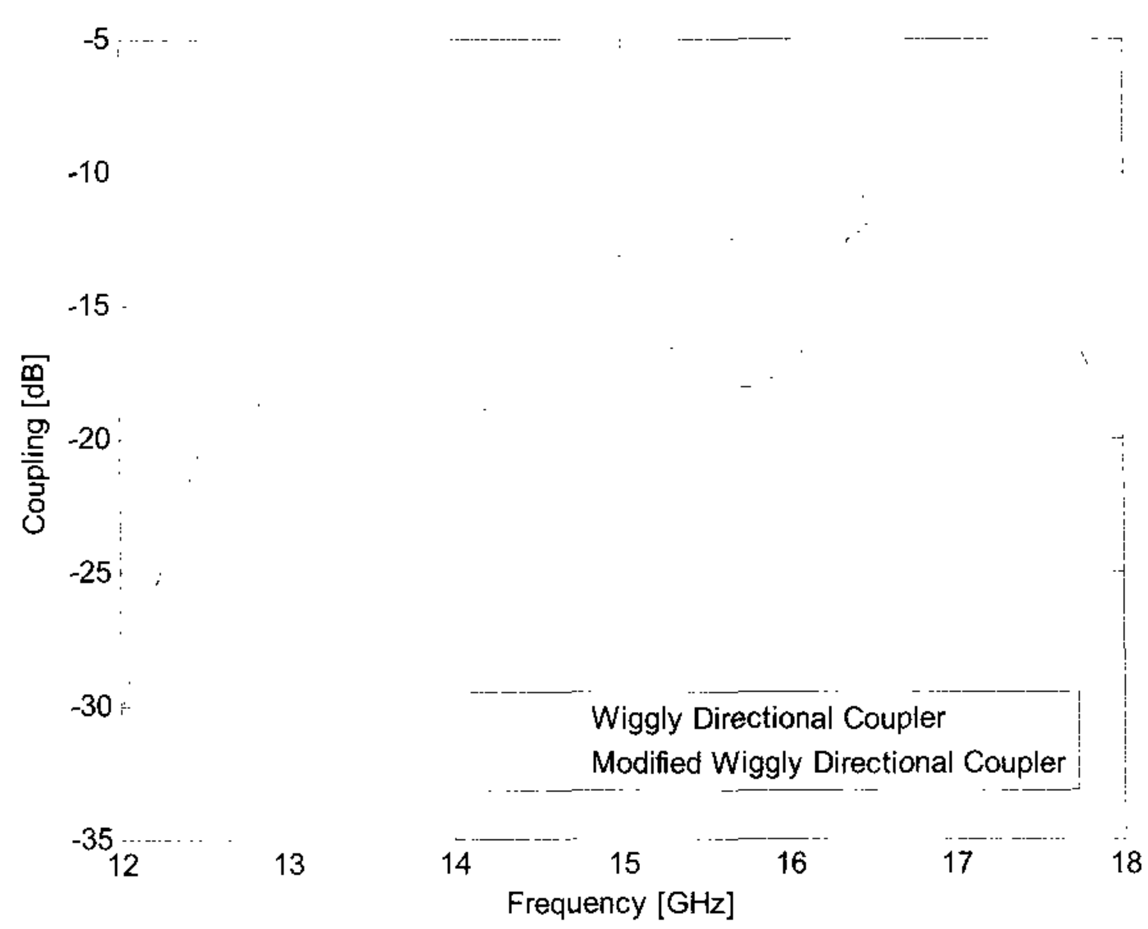


Fig. 5 Measured coupling characteristics

IV. CONCLUSIONS

In this paper, a modified wiggly coupler with fractal coupled structure has been successfully developed to improve the coupling of a typical wiggly directional coupler. It is shown that the loose coupling of the typical wiggly coupled line can be enhanced by use of cascaded interconnecting fractal shape coupled sections. This newly proposed wiggly coupler structure in this paper has possibilities of being attractive component in many microwave circuits and can be applied to other similar applications.

ACKNOWLEDGMENT

This research was supported by the MIC(Ministry of Information and Communication), Korea, Under the NEXT(Nurturing Excellent engineers in informa tion Technology) supervised by the IITA(Institute o f Information Technology Advancement)

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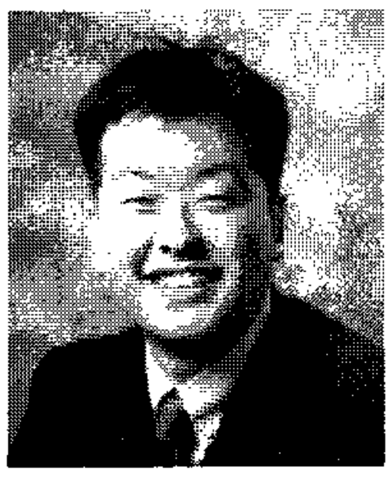

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