Use of a Transparent Conductive Thin-film on a Glass Substrate in Active Integrated Antenna Arrays with Double Strong Coupling

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Abstract — **Active Integrated Antenna (AIA) arrays were fabricated on a glass substrate using a conductive thin film, which was thin enough to be transparent to realize a transparent RF component. It can be attached to a window glass keeping its visibility. This means a potential to develop to new applications in microwave communication. The AIA arrays, here, consist of CPW, double strong coupling and 2-element array. For the oscillation using the lossy transmission line, a backing conductor and a Partly Thickened Conductor (PTC) were used. It operated at 8.54GHz with the in-phase mode and EIRP was 14.3dBm.**

I. Introduction

The wireless communication system in the microwave engineering will be spread into several application fields in the near future[1]. There are significant needs especially for the systems which have merits both convenience (like mobile communication) and high speed (like wireless LAN). Seamless communication environments have been investigated such that we use a PDA as a wireless indoor LAN, and as an outdoor access terminal. In that case, use of window glass enables a communication engineer to develop new application fields. For example, if there is a window glass embedded at an access point or a repeater, communication systems without disturbance for visibility can be achieved.

In this study, we introduce an optically transparent AIA which have merits of attachability to window glass as well as to hold transparency[2]. In this AIA, a circuit configuration consists of series feedback FET oscillation circuit, strong coupling and 2-element antenna array[3],[4]. We fabricated the circuit pattern by etching of optically transparent conductive film on a glass substrate. Since the conductive thin film has significant loss in the use of transmission line at high frequencies, a Partly Thickened Conductor (PTC) was used to minimize the loss. In order to increase the circuit Q, a double strong coupling configuration was adopted. It consists of not only drain strong coupling line but gate coupling line[5]. In this paper, the design method and the experimental results are shown. Investigation for good operation of the transparent AIA is discussed in the text.

II. Material Conditions

In order to achieve the optical transparency, the oscillator circuit was fabricated on a glass substrate using a transparent conductive thin film[2]. The glass substrate has a relative dielectric constant εr=6.8, a dielectric loss tangent =0.02 and a thickness t=0.76mm. The substrate was metallized on one side by sputtering Ag with thickness of 26nm and overcoating ZnO with thickness of 40nm. The sheet resistance was 1.9 [ohm/square] measured by 4-contact resistance tester. The measured optical transmissivity was 47%. The CPW pattern was formed by the photoresist etching technique. On a part of the CPW strip, the Ag layer was overcoated by the thick film screen-printing process.

III. Design

a. Configuration of AIA

Since it's hard to make a via-hole in a glass, the CPW architecture instead of the MSL was selected. The circuit outline is shown in Fig. 1. The active device in the oscillator is a package type FET, MGF4951A. The source and the gate of the FET used here were connected to each short stub. Two active integrated antennas were connected using the double strong coupling lines. One coupling line is the drain coupling and the other is for the gate one. Due to the double strong coupling line, it's expected to increase the circuit Q, hence the stable mutual synchronization of oscillations.

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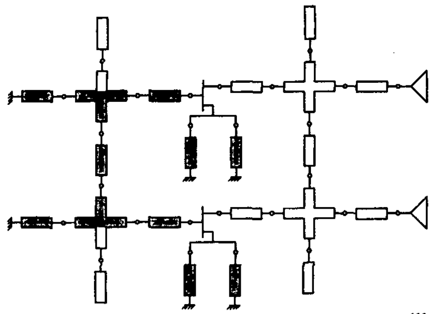

Fig. 1. The circuit outline of 2-element oscillator array. Grayed parts correspond to the parts of the PTC.

According to array antenna theory, the distance between the centers of each antenna should be less than $0.7\lambda_0$ to prevent the grating lobes. This distance corresponds to $1.25\lambda g$ in this glass substrate. Though a CPW-fed slot antenna is popular, each of antennas almost comes in contact with the other when the slot length is λg which is easy to match the impedance. Therefore, in this paper, a folded slot antenna was applied because of the easy matching nature in shorter distance. Further the oscillator was designed under the condition that the length of the strong coupling line is less than $1.25\lambda g$. The return loss and the radiation pattern of the folded slot antenna are depicted in Fig. 2.

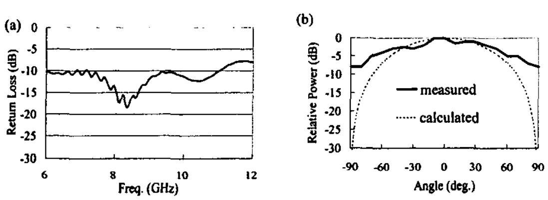

Fig. 2. Measurement of the folded slot antenna made by thin film on the glass substrate (a) return loss, (b) radiation pattern

b. Loop gain improvement

For this AIA with the transparent conductive thin film, backing conductor plays an important role in oscillation. The backing conductor enables the feedback of the RF signal using the microstrip mode in addition to the CPW mode.

In order to strengthen the oscillation, another approach was applied by a Partly Thickened Conductor (PTC). One of the problems using ordinary transparent thin films, such as ITO, is that the transmission line has large loss. And this loss prevents from obtaining oscillation. Therefore, for the purpose of increasing the loop gain, the layer thickness of gate stubs and source stubs was increased in such a way of overlaying the Ag screen-printing. The typical thickness of the print layer is about 6um. The reduce of the parasitic resistance in the source is also expected to prevent the negative feedback, (and excessive self-biasing of the gate) Finally, this strategy (PTC) effected to improve sufficient amount of feedback for the oscillation power and stability. The PTC was also applied to the drain bias circuit to avoid the voltage drop and to the gate strong coupling line to strengthen the synchronization. Since thickening is limited to only these areas, it's minimized to increase an opaque area.

IV. EXPERIMENT and RESULT

The radiated power was measured by an Agilent 8564EC spectrum analyzer and a standard gain horn antenna with the gain of 14.8dB at 8.0GHz. A photograph of this AIA array is shown in Fig. 3.

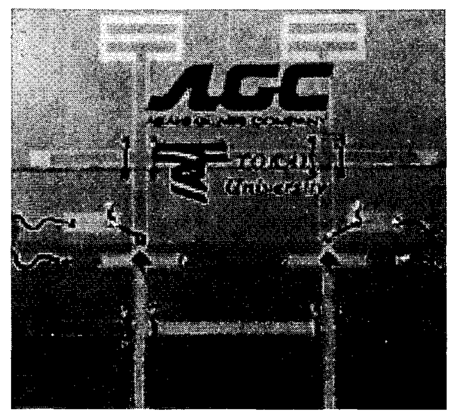

Fig. 3. The photograph of optically transparent AIA array. (Characters placed behind the transparent AIA can be seen clearly.)

a. Oscillator

Figure 4 shows the output power and the frequency of the single element oscillator. Without a backing conductor, no oscillation occurs.

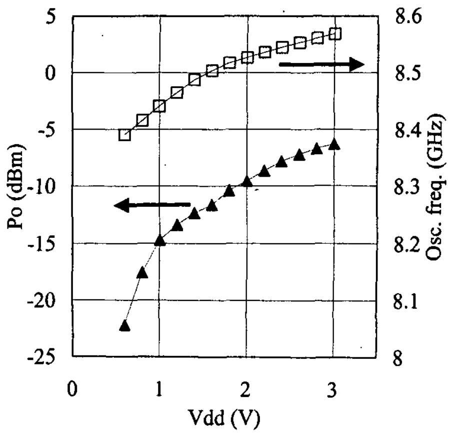

Fig. 4. The output power and the frequency of a transparent oscillator.

b. Backing conductor

To investigate the effect of the backing conductor, one glass substrate metallizing the whole surface of one side was prepared, and this metallized surface was attached on the opposite side to the circuit surface of the antenna array as a backing conductor. By shifting this glass sheet, the area of the backing conductor was changed and the receiving signal was observed at each configuration. These configurations are shown in the Fig. 5. and the measurement result is summarized in Table 1. We tried several samples whose design was slightly different each other, and the oscillation was obtained for all samples only when the backing conductor sheet was attached. The maximum power was observed at the configuration with BC3 and BC4 indicated below.

Configuration	Frequency (GHz)	EIRP (dBm)
BC1	-	No oscillation
BC2	-	No oscillation
BC3	8.54	14.3
BC4	8.36	14.1
BC5	8.44	0.3

Table 1. EIRP (Equivalent Isotropically Radiated Power) of the 2-element AIA array at five types of the configuration for the backing conductor.

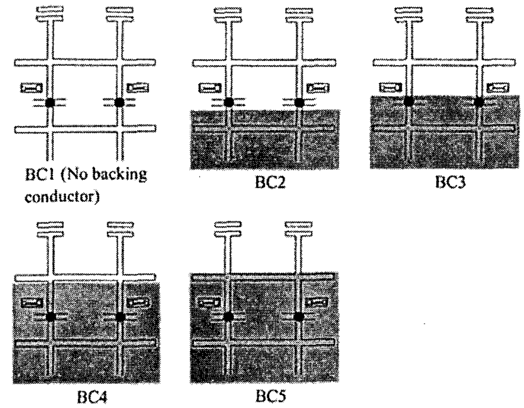

Fig. 5. The configurations of backing conductor. The relative position between the circuit and the backing conductor was changed by shifting the metallized glass sheet as a backing conductor.

c. PTC

Three types of the active integrated antenna arrays were compared. One has the PTC. For the second and the third, the whole conductor plane (including the ground plane) is made of thin film and thick film, respectively. The sample made of only thick film is expected to show the maximum power among the achievable active integrated antennas. All these samples had a backing conductor and its position was adjusted to obtain the maximum power. Measured spectrum is shown in Fig. 6. By applying the PTC, the receiving power increased 2.8dB. The peak power of the array with the PTC corresponds to 14.3dBm for EIRP and its operating frequency was 8.54GHz. The radiation pattern shown in the Fig. 7 indicates that those two oscillators worked in the in-phase mode. An expected radiation from the edge of the glass substrate is suspected to increase the side lobes.

V. Conclusion

The 2-element AIA array operating at 8.54GHz with EIRP=14.3dBm, was demonstrated as an optically transparent transceiver. Though the power of the oscillation is small (and the mutual synchronization among the two elements is not enough) when the whole planar circuit is made of conductive thin film, however, partly thickening the conductor in CPW causes the stable and powerful oscillation. Moreover, it's succeeded to keep the transparency by limiting to minimum thickening area. It's shown that the backing conductor also effects on the oscillation.

Since the synchronization between the two elements was locked in the in-phase mode was realized, it is to be developed to have an additional function, for instance, the beam steering. Moreover, since the optical transparency is still kept, this is the first step to the application as a component mounted on windows which connects between the inside and the outside of the buildings and/or automobiles.

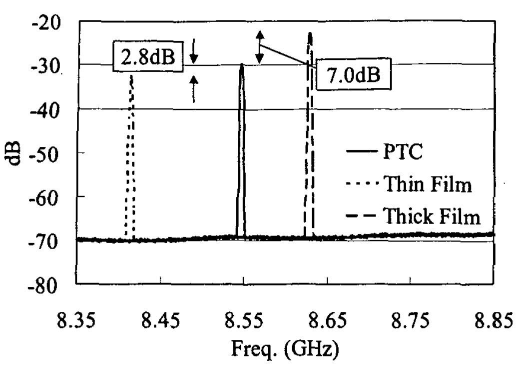

Fig. 6. The spectrum of the receiving signal via a standard gain horn antenna.

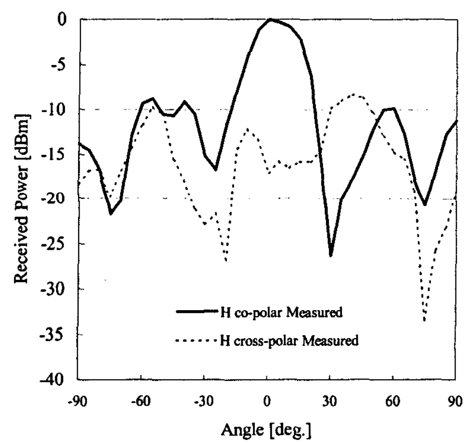

Fig. 7. The radiation pattern of the 2-element AIA array which has PTC construction with a backing conductor.

ACKNOWLEDGEMENT

This work was partially supported by the Asahi Glass Foundation.

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