Microstrip Comb-Line Antenna with Inversely Tapered Mode Transition and Slotted Stubs on Liquid Crystal Polymer Substrates

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***Abstract*-In recent years, millimeter-wave technology has attracted much attention in high-speed wireless communications, imaging and radar applications. Low-cost devices are very important for prevalence of the technology in consumer applications. Antennas for such applications are required to have high gain and low loss due to the high absorption in air-propagation and the high operation frequency. In this paper, a microstrip comb-line antenna constructed on liquid crystal polymer substrates is proposed. The antenna consists of 10 radiation elements and a termination element lined up like a comb and a waveguide-to-microstrip mode transition. Each radiation element has a slot and the mode transition has an inversely tapered section. The antenna realized a return loss less than -15 dB and a radiation with a maximum gain of 13 dBi and a side lobe level less than -10 dB at 60GHz. Radiation efficiency reached to about 90%.**

I. Introduction

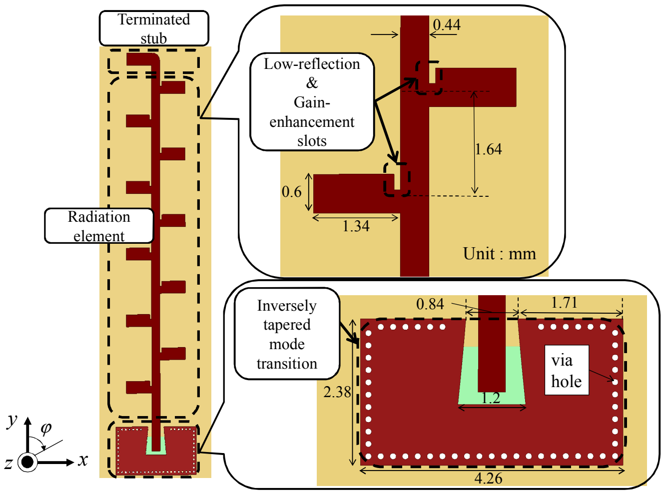
In recent years, microwave wireless network is almost reaching its limitation of capability for quickly increased network traffics. Millimeter-wave communication is one of effective solution for solving this problem because of its large spectrum. Millimeter-wave technology has attracted much attention not only on communications but also on imaging and radar applications. Low-cost devices are very important for prevalence of the technology in consumer applications.

Antennas for such applications are required to have high gain and low loss due to the high absorption in air-propagation and the high operation frequency. Several types of antennas with high gain and low side-lobe level have been proposed [1]. Among them, microstrip-line antenna has low profile and simple structure and can be cost-effectively fabricated.

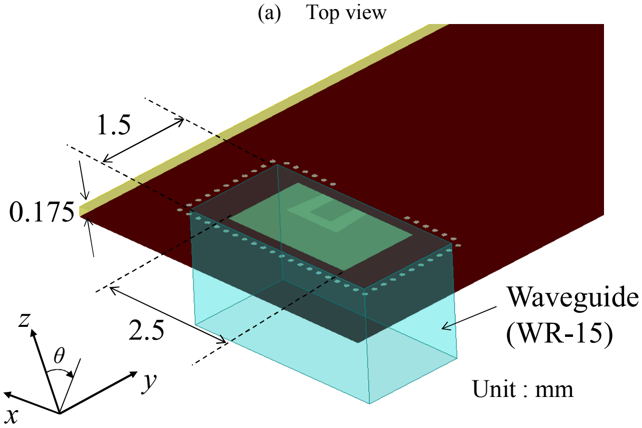
In this paper, microstrip comb line antenna is fabricated on Liquid Crystal Polymer (LCP) substrate and new configurations for realizing reflection cancelation and high gain in spite of keeping low side lob level are proposed. LCP substrate has advantages of its lower permittivity rather than LTCC (Low Temperature Co-fired Ceramic) substrate and loss tangent, similarity to thin filmed polyimide (PI) substrate with respect to the fabrication process easier and cheaper than teflon substrate such as polytetrafluoroethylene (PTFE). As the substrate thickness less than one tenth of a wavelength is preferable for suppressing dispersion depicted in [2], it equals to the thickness less than 0.5 mm at 60 GHz, thin film such as flexible printed circuit (FPC) technology is applicable. By using this technology, proposed antenna which has slotted stubs for reflection cancelation and high gain and mode transition between rectangular waveguide and microstrip line with inverse tapered shape is fabricated precisely. Good agreement is obtained between electromagnetic simulation results and those of measurement. Low reflection less than 15 dB and high gain greater than 13 dBi with maximum side-lobe level around 10 dB are obtained at 60 GHz in measured results so it is demonstrated that proposed antenna is consistent with high gain and low side-lobe level keeping with low reflection. In addition, radiation efficiency greater than 90% at 60 GHz is also realized.

II. Design Concepts

Figure 1 shows a configuration of proposed antenna. Microstrip antenna has comb shape whose radiation elements are partially slotted and with waveguide-to-microstrip mode transition. Antenna is terminated by the stub which is also looks like a tooth of comb. The mode transition is located in base of comb line antenna and it has a conductor with metalized via connected to ground plane to suppress needless radiation and reflection between waveguide and microstrip line. There is gap between mode transition and microstrip line for excitation of mode of microstirp line. The gap width is changed at longitudinal direction and a curve of transition is inversely tapered. Inversely tapered mode transition structure contributes to suppress needless radiation compatible with high gain and low reflection between waveguide and microstrip line. The reason why this structure is effective is because currents which are caused useless reflection and radiation are concentrated on bottom side of microstrip line and the gap between microstrip line and mode transition.



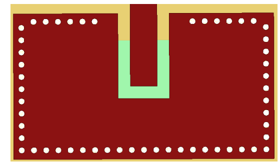
(a) Top view



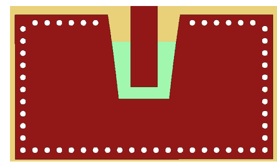
(b) Worm's eye view

Figure 1 Configuration of proposed antenna.

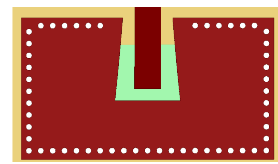
To show the validity of proposed antenna, parametric studies are demonstrated below by using electromagnetic simulation. Simulation is carried out with commercial software HFSS^{TM}. It is assumed that relative permittivity is 3 and loss tangent is 0.003. The thickness of substrate is set to be 0.175 mm for design. First of all, several types of mode transition structures are compared, as shown Fig. 2. Exponential-function-taper is applied for configuration and width of larger and smaller gaps are same in models (b) and (c). Other geometries are optimized for obtaining resonance around 60 GHz. Structure (a) is similar to that of previous reports [3]-[5] so it is regarded as conventional structure in this investigation. As far as I knew previous report, the shape of mode transition between waveguide and microstrip similar to the type of (a) is mainly reported. Figure 3 (a) shows simulated input characteristics and (b) shows simulated radiation pattern in *yz*-plane at 60 GHz for antennas with these structures. $|S_{11}|$<-10 dB around 60 GHz can be achieved in all structures. The result of model (c) has especially $|S_{11}|$<-15 dB around 60 GHz. A bandwidth of $|S_{11}|$<-10 dB which has 1.1 % is obtained and it is wider than that of other structures which have 0.5 % bandwidth of model (a) and 0.8 % bandwidth of model (b), respectively. Maximum gain of models (a)-(c) are 12.8, 13.1 and 13.0 dBi so slight difference is appeared in radiation characteristics in *yz*-plane. Contribution for low reflectance and broadening bandwidth by inverse tapered mode transition between rectangular waveguide and microstrip is successfully demonstrated.



(a) Straight

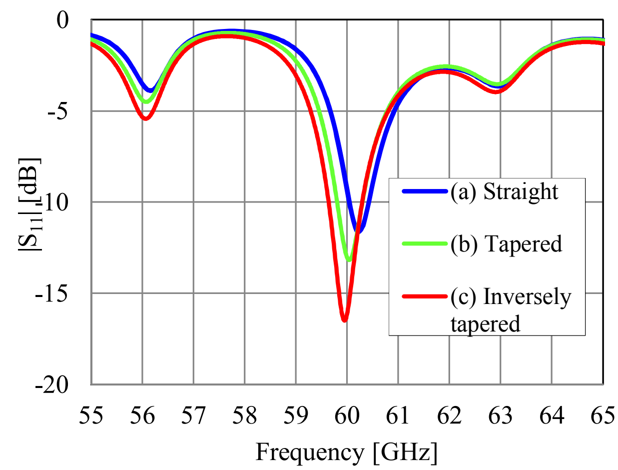


(b) Tapered

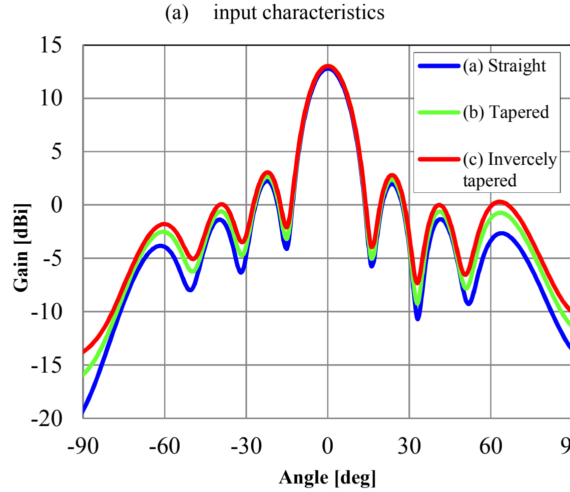


(c) Inversely tapered

Figure 2 Mode transitions for comparison.



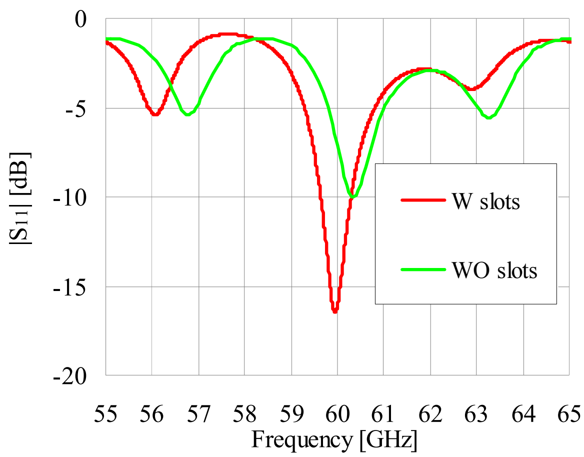
(a) input characteristics



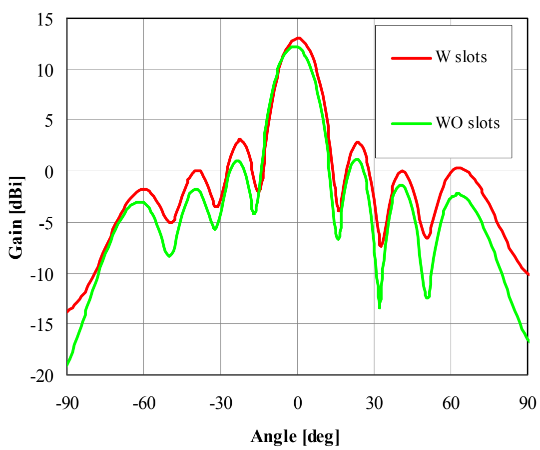
(b) radiation characteristics in *yz*-plane

Figure 3 Simulated input and radiation characteristics for several transitions.

Figure 4 shows the simulated input and radiation characteristics for antennas with and without slots to confirm the effects of low reflection and gain enhancement. The geometry of mode transition is set to be model (c). From input characteristics, reflectance is reduced from -7 dB to -16 dB at 60 GHz by adding slots. From radiation characteristics, maximum gain is increased from 12.3 dB to 13.0 dB at 60 GHz by slots. Additionally, a beam shape of radiation pattern is straightened so radiation to desired direction is achieved by the slots. To explain how it works effectively, Figure 5 shows the current vectors of stubs for two types of antennas. Past papers are reported the effect of slots for microstirp comb line antenna [3]-[4] though they set slots into different position form this investigation. In these past papers, physical phenomena are not sufficiently denoted and parametric studies are mainly reported. It can be explained that slots of stubs generate current pair whose directions are opposite each other. Electric fields by current pair are canceled due to their vicinity and useless radiation and reflection finally reduced.

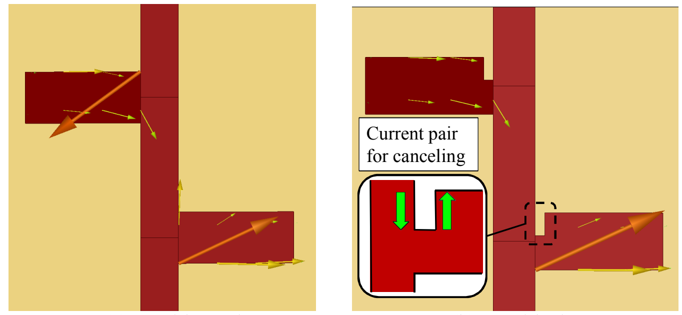


(a) input characteristics



(b) radiation characteristics

Figure 4 Simulated input and radiation characteristics for antennas with and without slots.

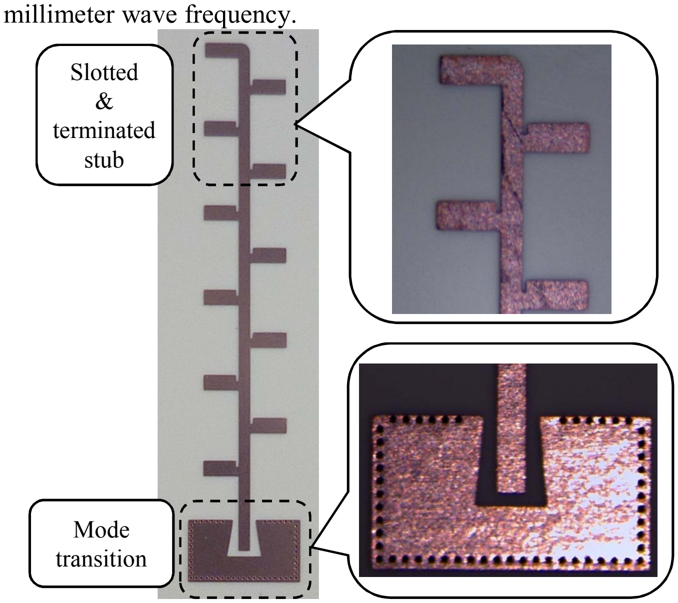


(a) Without slots (b) With slots

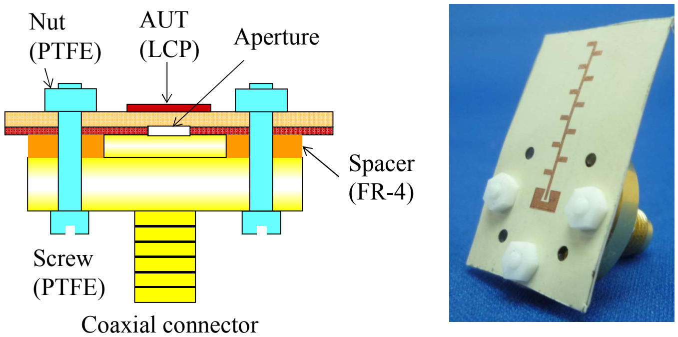
Figure 5 Current vectors of stubs for antennas with and without slots.

III. Experiment Results

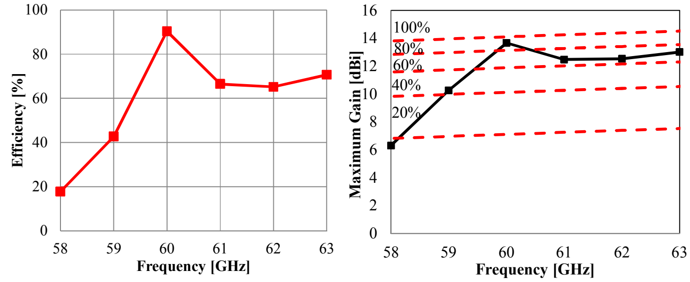
Figure 6 (a) shows the fabricated antenna on LCP substrate for measurement and (b) shows the configuration for radiation measurement. In figure 6 (b), glass-epoxy spacer contributes to avoid useless deformation of antenna under test (AUT) due to its thickness and flexibility and PTFE screw. Nut for alignment can be expected to make AUT free from influence in radiation measurement rather than the configuration composed of nylon screw and fitting pins such as [6]. This configuration is also new proposal in this investigation and it is simpler and expected to be lower losses than previous one which is included in test jig and long microstrip lines for avoiding feeding structure [7]. By using this configuration, measured input and radiation characteristics are shown in Fig. 7 and Fig. 8 comparing with simulated ones. According to these figures, good agreements are obtained in both results. Figure 9 shows radiation efficiency and maximum gain for measured antenna. Maximum value of radiation efficiency is 90 % at 60 GHz and relative bandwidth of efficiency greater than 60 % is 2.4 %. From result of fabricated antenna, low reflection and high gain and efficiency are finally obtained at design frequency so this structure can be applicable at millimeter wave frequency.



(a) Fabricated antenna on LCP substrate.



(b) Configuration for radiation measurement.
Figure 6 Fabricated antenna and configuration for measurement.



(a) Efficiency (b) Maximum gain
Figure 9 Measured radiation efficiency and maximum gain.

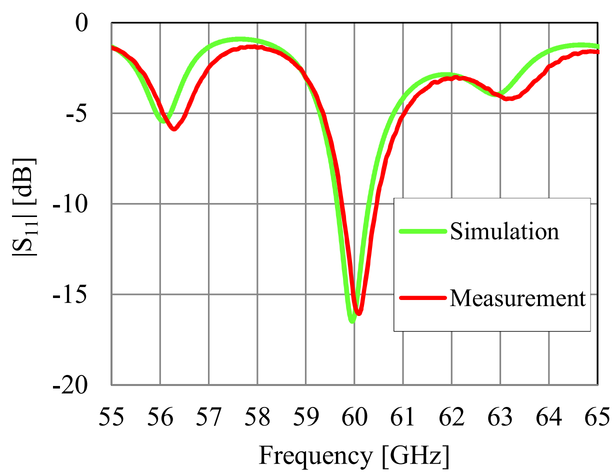


Figure 7 Simulated and measured input characteristics.

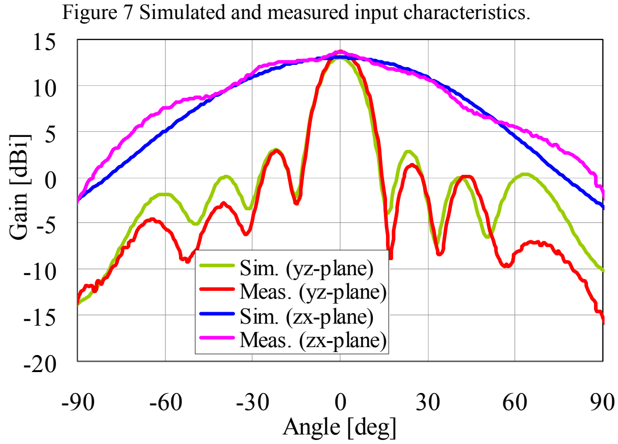


Figure 8 Simulated and measured radiation characteristics at 60 GHz.

IV. CONCLUSION

In this paper, microstrip comb line antenna on liquid crystal polymer substrate is proposed. Mode transition shape and slotted stubs of radiation element play a role for low reflectance, small reflectance bandwidth and gain enhancement keeping low side-lobe levels. Proposed antenna is fabricated by flexible printed circuit technology and it is measured with new measurement configuration suitable for flexible device and avoidance of influence by fixture. Good agreement between simulated and measured results and good operation at millimeter wave frequency is finally confirmed and it is suitable for low cost and mass-product.

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