Wideband circularly-polarized microstrip 1×8 array antenna for TX/RX dual operation at X-band

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Abstract: TX/RX dual microstrip 1×8 sub-array antennas are designed, fabricated, and measured for a wideband array antennas in communications. They have a Right Handed Circular Polarization (RHCP) for TX from 7.9 to 8.4 GHz and Left Handed Circular Polarization (LHCP) for RX from 7.25 to 7.75 GHz. Two stacked patches are used for a wideband characteristics and corner-truncated square patches are adopted for a circular polarization. To enhance bandwidth characteristics of a circular polarization, 1×2 sequential rotation arrays are applied. From the measured results, 1×8 microstrip sub-array antennas have a good agreement with those of the simulation. Therefore the sub-array antennas are applicable to satellite communication antennas, active phased array antennas, and radiators in other antennas.

1. Introduction

In satellite communication, antenna performance plays a important role in the entire communication performance. They must require both considerable gain and beam tracking speed. Therefore physical antenna size is increased and phased array antenna by electrical beam forming is requested more in mobile station. To accommodate the above requirements, antenna has a function to transmit and receive simultaneously for the size restriction in mobile environment. It is designed as a form of sub-arrays suitable for the beam scanning specification and facility to assemble with the active module. In addition to the above, microstrip patch antenna is especially favorable for the low profile structure. However microstrip patch antenna has an inferior feature in terms of the bandwidth characteristics. Especially in the application such as wide angle scanning in elevation and low angle scanning in azimuth, the realization of circular polarization by dual feeding is practically impossible for the size restriction. Therefore circular polarization is realized by the single feeding and corner cutting, its bandwidth is very narrow[1],[2] .

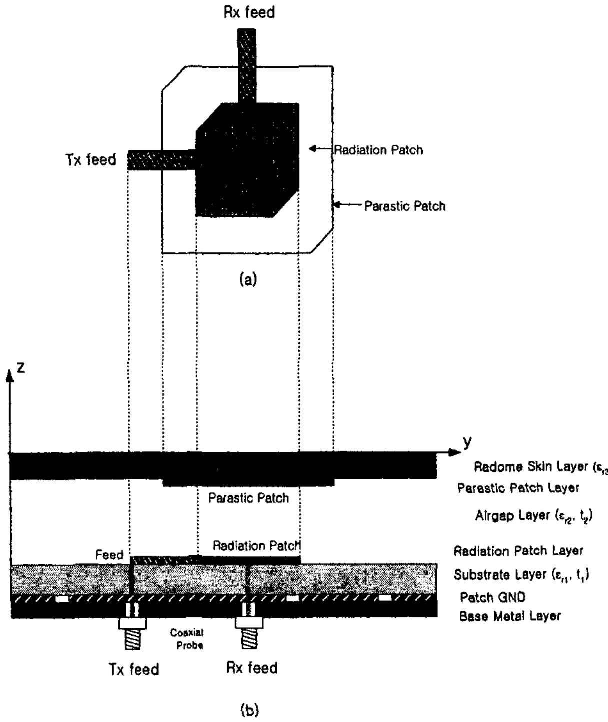
For the compensation of the above, the stacked patch configuration[2],[3] and sequential array technique[4] are adopted. Stack patch is added on the radiation patch spaced by a specific air-gap thickness. A dual resonance by stack and radiation patch enables wide impedance, axial ratio bandwidth and considerable directivity more than conventional single patch. Sequential array by 90° rotation and phase shift also make it possible to obtain wide impedance bandwidth without expense to an increased size or structural complexity.

In this paper, using the above techniques, X-band dual TX/RX 1×8 array antenna was designed, fabricated and measured for the satellite communication.

Specifications for the antennas should be as follows. Frequency ranges are from 7.9 to 8.4 GHz in TX and from 7.25 to 7.75 GHz in RX. Their polarizations are Right Handed Circular Polarization (RHCP) and Left Handed Circular Polarization (LHCP) in TX, RX each. The number of elements in sub-array and their spacings are chosen from the beam scan characteristics for azimuth and elevation each.

2. Design of the dual TX/RX antenna

The dual TX/RX 1×8 array antenna composed of a single truncated square patch radiator is designed. The structure of the radiator used in TX/RX dual array antenna is presented in Figure 1. In this structure the air-gap thickness, two patch sizes and their cutting size are initialized by well-known approximate formular and optimized for the bandwidth, isolation level and its peak locations, TX/RX gain, radiation patterns within its frequency range.

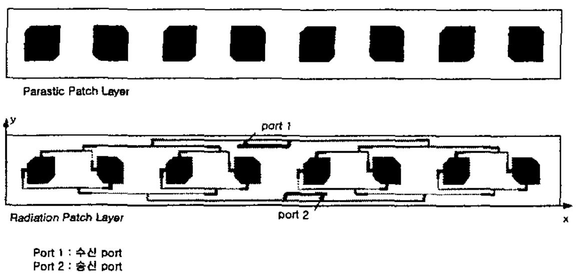


(a) top view (b) side view
Figure 1. The structure of the single radiator

The appropriate air-gap thickness betwenn the radiation patch fed directly by microstrip line and the parastic patch made it possible to obtain wide bandwidth characteristics due to dual resonance effects. The thicker air-gap is used, the more enhanced isolation characteristic is obtained but the narrower its bandwidth is. Especially its radiation patterns are much more influenced due to sequential array of 90° as its frequency is more distant from the center. Therefore 2.5mm($0.067\lambda_0$) of the air-gap thickness is applied for the trade-off. Its patch and cutting sizes are determined to maintain a considerable gain, minimize gain loss at 7.25 GHz, which is the starting frequency of RX and locate its isolation peak at around 7.9 GHz, which is the starting frequency of TX. The bigger parastic patch sizes are used, the more gain is obtainable in RX but they make TX gain lower and isolation peak move toward RX. The more are parastic patches cut, the more are its CP characteristics enhanced but the worse its isolation is.

In the figure 2, the top view of the parastic and radiation patches are represented in the form of the dual TX/RX 1×8 array antenna. The distance between elements was determinced by the following relation not to occur in the visible region when the array antenna is electically scanned.

$$\frac{d}{\lambda} < \frac{1}{1+|\sin\theta_0|} \quad (\theta_0 : \text{max scan angle}) \qquad (1)$$



➔ Port 1 : RX port , Port 2: TX port

Figure 2. 1×8 Truncated square patch array antenna

The layers used in this configuration are as follows in Table1 and its permitivity and thickness are presented. A RF35 substrate (ε_r =3.5, d=0.508mm) is used for the radiation patch layer to integrate the patch antenna and TX/RX dual feeding network.

The 1x2 sequential array technique is adopted by rotating elements and giving phase difference of 90° to improve the impedance and axial ration bandwidth.

Table 1. The dimension for the array antenna

Radome skin permitivity	ε_{r3}	2.5
Radome skin thickness	t_3	0.508mm
Air-gap permitivity	ε_{r2}	1
Air-gap thickness	t_2	2.5mm
Substrate permitivity	ε_{r1}	3.5
Substrate thinkness	t_1	0.508

The simulation result of the return loss and isolation characteristics is shown in Figure3. (a). It is shown that the return loss characteristics below –15dB is obtained over the RX frequency range from 7.25GHz to 7.75GHz and 25% of the impedance bandwidth (< -10 dB) is achieved. For the TX frequency range from 7.9GHz to 8.4GHz, the return loss characteristics below –18dB and 25% of the impedance bandwidth (< -10 dB) is achieved.

The isolation characteristics between TX and RX port is represented in Figure 3. (b). They have the value below –10dB over the bandwidth from 7GHz to 8.7GHz and –15dB for the TX bandwidth. This is because of the 150MHz of the narrow frequency gap between TX and RX, the wide impedance bandwidth and opposite polarity of the circular polarization. The more its impedance bandwidth is, the less its isolation is achieved. It is only achievable to have a narrow isolation peak below –20dB. Therefore, over the trial between design and measurement, it is proper to locate experimentally its isolation peak near the TX starting frequency.

The simulation result of the array gain and axial ratio characteristics are shown in Figure 4. The RX gain is ranging from 15.1 to 16.0dBi, axial ratio is below 1.5dB over its bandwidth and 23% of the axial ratio bandwidth (< 2.0 dB) is obtainable. For the TX bandwidth, it is achieved the gain from 16.2 to 17dB and axial ratio below of 1.5dB and 19% of the axial ratio bandwidth (< 2.0 dB).

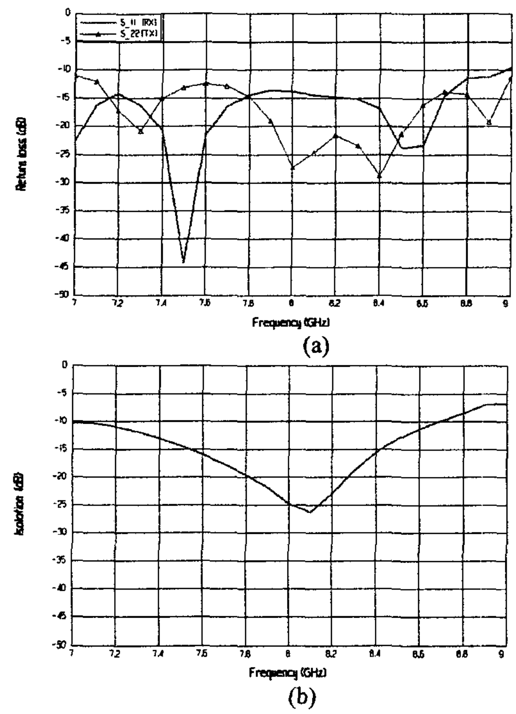
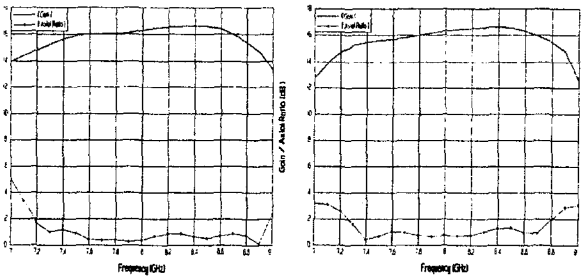


Figure 3. The simulation result of the 1×8 array antenna returen loss and isolation
(a)Return loss (b) Isolation between TX/RX

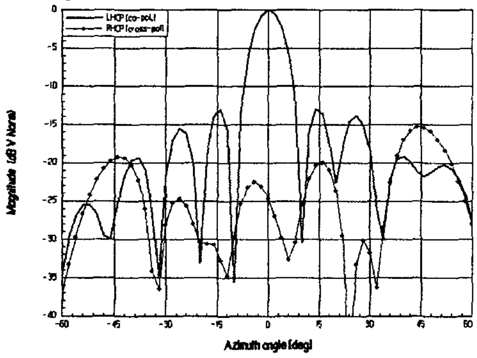


(a) (b)

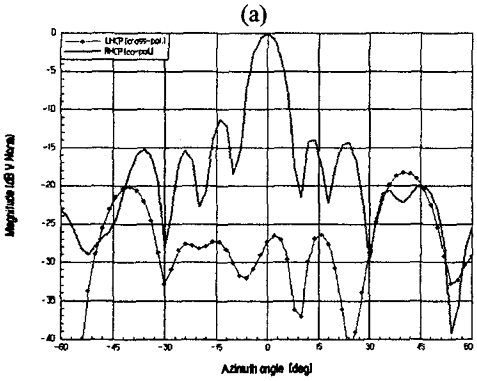
Figure 4. 1×8 array antenna gain and axial ratio simulation result
(a) port1 (RX port) (b) port2 (TX port)

The TX and RX radiation pattern by simulation is presented in Figure 5. It is presented in (a) and (b) respectively that left-handed circular polarization pattern at 7.5GHz and right-handed circular polarization pattern at 8.15GHz on azimuth plane pattern with their cross-polarization.

The side-lobe value below –12dB is obtained for 7.5GHz and 8.15GHz and their 3dB beam-width is 8.6 and 8° respectively.



(a)



(b)

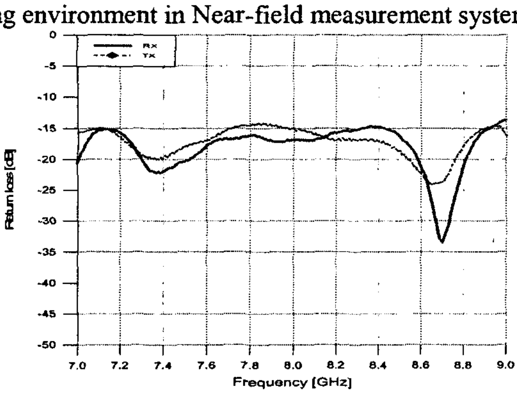
Figure 5. The simulation result of 1×8 array antenna radiation pattern
(a) f_r=7.5GHz (b) f_r=8.15GHz

3. Measured result of the array

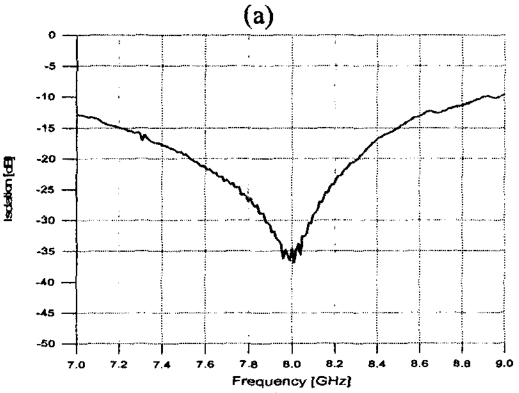
To verify its validity of the simulation result, dual TX/RX 1×8 array antenna was fabricated, measured. The measured return loss, isolation characteristics and its radiation pattern on azimuth plane are presented in Figure 6 and 7 respectively. The measured return loss generally have a similar result compared to the simulation. Though the performace is degraded aboutby 5dB over the frequency ranges of the TX, it has a satisfying result below –14dB (VSWR=1.5). The isolation characteristics betweeen TX and RX port has its peak value at 7.98GHz in measurement and 8.15GHz in simulation. However the measured isolation peak is shifted by 200MHz, its difference was already considered in the simulation and as a result its peak is very close to 7.9GHz which is the starting frequency of the TX. The fabricated sub-array antennas compenstate the imperfections of RX filter by obtaining their brilliant isloation level under –30 dB at 7.9GHz. The gain degradation level due to its imperfect isoltion is under 0.2dB because the isolation level is maintained below –15dB over the all frequcy ranges of TX and RX

From the measurement result in Figure 7, the radiation paterns at 7.5GHz in RX and 8.15GHz in TX are similar to the simulation except that its side lobe level and cross-polarizatin level are relatively high. The measured gain is relatively low compared to that of simulation. TX gain have a value from 14.0 to 14.5 dBi and RX gain have a value from 13.3 to 14.5 dBi. This is due to the insufficient consideration by a simulation tool especially in unnecessary radiation from a bending or stepped width of microstrip line and coupling in feeding line.

The measurement results generally have a good agreement with those of the simulation. However their differences are due to the relatively non-uniform electrical characteristics used in the layer, the error in microstrip line width realized by high-impedance and non-perfect shielding environment in Near-field measurement system.



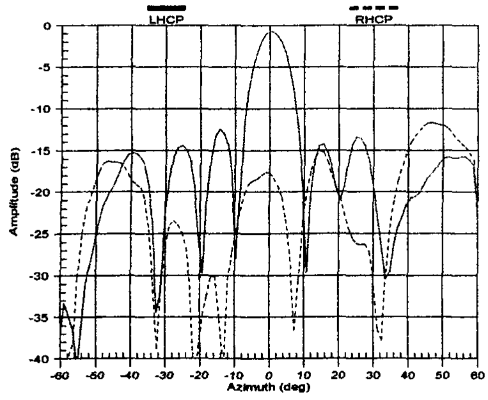
(a)



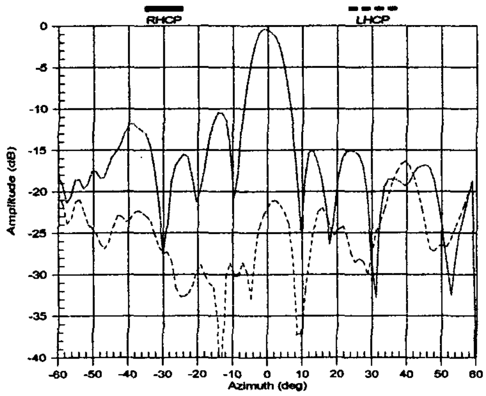
(b)

(a) return loss (b) isolation characteristics

Figure 6. The measured 1×8 array antenna return loss and isolation characteristics



(a)



(b)

Figure 7. The meausred 1×8 array antenna azimuth radiation pattern
(a) f_r=7.5GHz (b) f_r=8.15GHz

4. Conclusion

In this paper, X-band dual TX/RX 1×8 array antenna was presented for the satellite communication. The corner-truncated square patch radiator as a single antenna is fed directly from the two orthogonal edges to implement TX/RX dual circular polarization antenna. An electromagnetic coupling between active and stack patches and 1×2 sequential rotation arrays by 90° are used for the wide impedance and CP bandwidths.

The 1×8 array structures separated by 0.75 λ_0 at 8 GHz is applied to satisfy the beam scan requirements when used as active phased arrays . A direct feeding by microstrip line is applied for its simplicity in assembling and a minimum number of layers.

The sub-array antennas are applicable to satellite communication antennas, active phased array antennas, and radiators in other antenna.

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