Phased Array Antenna Using Active Device

Chul-Hun Seo†

Abstract - This paper presents a new active antenna consisting of a microstrip patch for the passive radiator, a mixer for frequency conversion, a voltage controlled oscillator (VCO) and a phase detector for phase control. The microwave signal frequency has been converted into intermediate frequency (IF) on the antenna elements by the mixer. The active antenna consists of two ports, the IF port has a transmitted IF signal via power combined to the baseband and the dc control port is under the control of the phase-detector. The input voltage of the VCO is controlled by the phase detector. The scan range of the array is determined by the phase detector and the VCO and is obtained between 30° and – 30°

Keywords: active, mixer, oscillator, phase array antenna

1. Introduction

Active phased array antenna without phase shifter has recently been attracting much attention because it provides a new paradigm designing modern microwave and millimeter wave architecture for both military and commercial applications. Many new mobile communication systems require continuing research in the area of systems and components in order to produce highly integrated and compact designs. Many innovative approaches have been proposed for realizing an efficient quasi-optical power-combing active array [1-3]. It is possible to realize beam-steering arrays without the use of phase shifters, which are considered indispensable in conventional systems. Liao and York used arrays of the coupled oscillator type for phase-shifterless beam-scanning technique [4-5]. Coupled VCO's were used in several elements for power combining and beam scanning array [6]. Phase noise performance and multimode operation were analyzed in beam steering arrays [7]. Retrodirective arrays reflected any incident signal primarily back toward the source without prior knowledge of the source's location [8]. It is possible to adjust coupling parameters between array elements and to increase coupling strength by proper selection circuit parameter in the transmission line coupling, which is used for increasing the coupling strength and compensating the undesired radiative coupling with stubs [9-10].

Now the size of the active phased array antenna needs to be minimized for reducing noise and integrating with other microwave devices. In this paper, a new self-steering phased array antenna controlled by the VCO, the mixer and the phase detector is described. Because the RF signal was converted into an IF signal on the array element, the loss of RF signal was very small and the system size was reduced compared with the conventional system. The phase difference between the incoming signals was set as zero by varying the applied voltage of the phase detector to the VCO. The scan range of the array was controlled by the VCO and the phase detector, which reduced the phase difference between the input signals of the array elements and input signal with frequency f_s

2. Basic Theory

Fig. 1 shows a 1 ×4 beam self-tracking using Intermediate Frequency Processing (IFP). Each active antenna is coupled to the mixer, the VCO, and the phase detector. The reference oscillator is tuned at the intermediate frequency f_o in Fig. 1. The outputs of the mixer and the reference oscillator are connected to the inputs of the phase detector, which compares their phases. This phase difference determines the output voltage of the phase detector, which controls the VCO. The output of the VCO causes zero phase locking. Beam steering is performed by controlling the VCO and the phase detector. Let two elements with λ/2 spacing be operated in the phase, employing the use of broadside beams. If the incidence angle of the signal is 30°, the path difference of two incoming signals becomes 90°. The output voltage of the phase detector is proportional to the phase difference between the phases of the two inputs and is applied to the VCO. The input voltages of two VCO's have the same magnitude but different polarity so that the output signals from both mixers are locked into the phase, as follows:

$$\varnothing_0 = \varnothing_1 = \varnothing_2 \quad (1)$$

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where $\varnothing_0$, $\varnothing_1$, $\varnothing_2$ are phases of the reference oscillator, the first and the second mixer, respectively. This means that the phase difference between the reference oscillator and the mixer becomes zero. If both active mixers are set with equal gain, two inputs of summation have identical amplitude and phase as follows;

$$V(\varnothing_1) = V(\varnothing_2) \qquad (2)$$

After the IFP, the total voltage, $2V(\varnothing_1)$, finally is obtained at the summation and it shows that it is possible to maximize the response of the phased array by steering the beam onto the incoming signals.

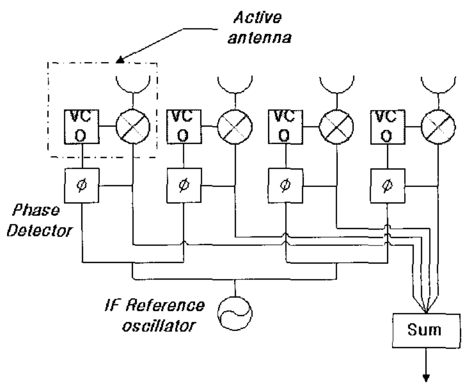

Fig. 1 Block diagram of the proposed phased array antenna system using the intermediate frequency processing

3. Active Antenna for the Beam Tracking Antenna

A configuration of the active array antenna is shown in Fig. 1. The array was sub-sequentially fabricated on 0.76 mil thick GML-1000, which has a relative dielectric constant of 3.25. A microstrip line antenna was employed as a load for each VCO. The antennas were designed to be one-half wavelength long at 2.45 GHz. Each antenna was 33 mm long by 30 mm wide, which provides load impedance of 120Ω . at resonance. A quarterwave transformer was used to match this mismatch. It was 19.17 mm long by 0.84 mm wide. The bandwidth of the antenna was 30MHz (2.42GHz – 2.45 GHz).

The mixer's in the array were designed to convert the RF signal into the IF signal at the design frequency of 2.45 GHz. This research chose the single type mixer with low noise characteristics. The local oscillator (LO) and the RF ports were simultaneously connected to the gate of the FET. LO had high level power for inducing the nonlinearity of the FET. Fig. 2 indicates the layout of the active antenna element with the mixer and the VCO. 2.4 GHz to 2.5 GHz and 100 MHz to 200 MHz were the RF passband and the IF passband, respectively. The mixer's of this design used an NE32484 GaAs FET and were constructed using equivalent substrates in the antenna design. The VCO's in the array were designed to provide maximum power at the design frequency of 2.45 GHz. The VCO's of this design used an NE32484 GaAs FET and were constructed using identical substrates in the antenna design. The FET had two source leads; one was directly connected to the microstrip patch and the other was shortened to prevent RF signal. The bias circuit was simplified by only applying voltage on the drain and VGS = 0.

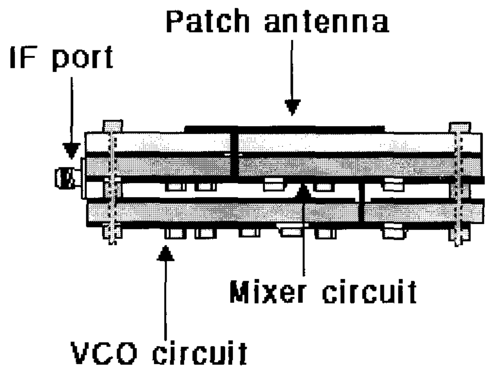

Fig. 2 Layout of the active antenna element coupled to the mixer and the VCO

4. Measurements

The conversion gain of the mixer was 10.0 dB in the passband in which the bias conditions were V_{ds}=3.5V, I_{ds}=12mA and V_{gs}=0.90V. The LNA was placed before the mixer to obtain low noise characteristics and the radiation stub was used to isolate the RF circuit from the bias circuit. The isolations of RF to IF port and LO to IF were 35dB and 50 dB, respectively.

The output power of the oscillator was 10 dBm at 2.44 GHz and the phase noise was 90dBc/Hz with 10 kHz in which the bias condition was V_{DS}=2V, I_{DS}=10mA. We have chosen element separation to be $\lambda_g/2$ to avoid the grating lobe. The locking range and the tuning range were obtained at 191 MHz and 240 MHz at a center frequency of 2.44 GHz, respectively, within 1.5dB power variation by changing the applied varactor diode voltage from 1 V to 4 V.

The chip resistors and the transmission lines connected the oscillator units to each other. The oscillation frequencies and the far-field radiation patterns were measured. The chip resistors suppressed the undesired modes, since the current distributions at the junction are all zero for the in-phase mode but are not zero for all the undesired modes.

For the 4-element linear array, the use of chip resistors was able to achieve the stable in-phase mode oscillation. The stable in-phase mode oscillation at 2.44 GHz was observed, which was only 0.4% deviated from the designed frequency of 2.45 GHz.

The measurement of array elements with the stub had good agreements with the theoretical results compared with those of the array elements without the stub. They show that the stub and the varactor diode are important parameters used to extend the scan range. The beam scan angle was 0° at the 2.99 V applied varactor diode voltage and it increased according to voltage variation. The directivity of the array antenna was greatest at 0.9 λ_g element separation but the sidelobe level was high compared with other element separation. As the element separation was increased, the scan range was decreased. We have chosen element separation to be 0.45 λ_g after considering the directivity, the sidelobe level, and the scan range. –30° to 30° was the theoretical scan range and the measurement with 0.45 λ_g element separation in Fig. 3. If the bandwidth of the array antenna is wide and the current of the phase detector is large, the measurements will be close to the theoretical ones.

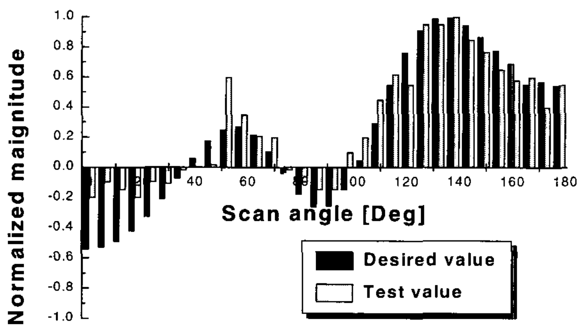

Fig. 3 Comparisons of the theoretical and the measured results

5. Conclusion

The new active antenna in this paper consists of a microstrip patch for the passive radiator, mixer for frequency conversion, voltage controlled oscillator (VCO) and phase detector for phase control. The voltage of the phase detector was applied to the input of the VCO according to the phase difference between incoming signals. The microwave signal frequency has been converted into the intermediate frequency (IF) on the antenna elements by the mixer. The active antenna has two ports, the IF port transmits the IF signal via the power combiner to the baseband and the dc control port is controlled by the phase-detector. This converted IF signal has been used for beam tracking in this phase array antenna. The input voltage of the VCO is controlled by the phase detector. The scan range of the array has been determined by the phase detector and the VCO and was obtained between -30° and 30°.

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