24 GHz Active Phased Array Antenna for Microwave Sensors

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Abstract: - Microwave sensors are robust non-contact measurement devices for industrial and vehicular application. Phased array-antenna modules, located in the front-end of the sensor, are often used to enhance the performance of this device. In this paper, a novel 24-GHz microstrip linear array antenna with beam-scanning and signal-amplification properties are presented. The phase shift section is designed using digital and analogue phase control properties, to minimize the requirement of complicated control circuits and large external biasing magnet .

Key-Words: - Microwave, Sensors, Active Array, Antenna, Phase shifter

1 Introduction
Microwave sensors with improved resolution are of recent interest for tank level measurements in petrochemical storage and velocity measurements in automotive radars\cite{1,2}. This class of sensors typically consist of an array-antenna module\cite{3,4} and a digital-signal-processor module. Although most of today's industrial sensors operate at 5.8 or 10 GHz\cite{5} and automotive sensors operate at 77 GHz\cite{6}, recently FCC\cite{7} decided to adopt 24-GHz technology for its next generation of short-range microwave sensors. This can involve a smaller and easy to integrate 24-GHz active phased array antenna to provide beam scanning capabilities to the sensor, which can monitor process control mechanism in petro-chemical storage-tanks and collision-warning in smart vehicles\cite{3-6}.

Phased array antennas require large number of phase shifters to electronically steer the antenna beams in the desired direction\cite{8}. Thus, the cost, size and integration method of the phase shifters are important factors in realizing the phase functions of a phased array antenna. Analogue ferrite phase shifters are widely used in array antennas, where external biasing field is used to control the gyrotropic property of the ferrite material, which in turn controls the phase velocity and, hence, the insertion phase of the propagating electromagnetic signal\cite{8,9}. But often the requirement of large biasing field, generated by big external magnets, considerable add to the dimension of array\cite{10}. Digital switched line phase shifters are also widely used to implement discrete phase control properties, but require complicated control circuitry for producing low resolution beam scan\cite{11}. In this paper, a 24GHz linear phased array antenna with an integrated power amplifier and phase shifter is designed, where the phase control is implemented using both digital and analogue techniques to minimize the requirement of external control circuits. The amplifier is designed to provide gain in addition to offset losses associated with the array feeder and the phase shifters\cite{12}. Professional software is used to optimize the radiation characteristics of the array antenna and demonstrate the beam scanning capabilities.

2 Method of Analysis
Phased array antenna with microstrip ferrite phase shifters are of renewed interest due to its low cost and external phase control properties\cite{4,10}. But to effectively control the differential phase shift, an analogue ferrite phase shifter requires large external magnetizing field, whereas a digital switched line phase shifters require complicated switching circuits for diodes. In this paper, a 2-
2-bit switched line microstrip phase shifter is integrated with a microstrip ferrite phase shifter to achieve the required beam scanning of a 4-element phased array antenna. An amplifier is integrated into the design to provide gain and offset the losses produced by the microstrip array feeder and phase shifters.

The designed 24 GHz 4-element uniform linear phase array antenna is shown in figure 1, which allows the main beam to be scanned by 7.5° from θ=105° or θ=90° (broadside). In this design, switched line technique is used to steer the main beam to θ1=105° and externally biased ferrite substrate is used to scan the steered beam by 7.5° or 105° >θ1>112.5° and 90°<θ2< 97.5°. For this microstrip line feed array, a dielectric-ferrite composite substrate with h=1.27 mm and εr=6 is used for the array feeder and phase shifters and duroid substrate (h=1.2 mm, εr=2.2) is used for the rectangular patches.

![Fig.1: Schematic diagram of proposed microstrip phased array antenna.](image)

The computed dimensions and impedance of the rectangular patch are; L=3.14mm, W=4.94mm and R_in=301Ω, respectively. A 150Ω quarter wave (λ/4) transformer is used to match the 75Ω feed line with the radiating patches. The reflection response of a patch element is shown in figure 2(a). Note that this 24 GHz antenna exhibits an impedance bandwidth of 8.5%. To minimize surface waves, both dielectric and ferrite substrates are selected with same parameters, where the dielectric substrate hosted the array feeder and the switched line phase shifters and the ferrite substrate hosted the ferrite phase shifters. The reflection and transmission responses of the 1:4 Wilkinson type array feeder are shown in figure 2(b).

![Fig.2: (a) Reflection response of a radiating patch, (b) S-parameters of the 1:4 array feeder](image)

The schematic diagram of the designed microstrip phase shifters are shown in figure 3(a), where the digital 2-bit switched line phase shifter steers the array beam towards θ=105° from θ=90° (broadside) and the ferrite phase shifter scans the steered beam by 7.5°. From the phase function of a 4-element linear phased array antenna with patch separation of 0.5λ, beam steering of θ=90° and 105° requires a progressive phase shift (βp) of 0° and 46.5°, respectively. Thus, the 2-bit switched line phase shifter is required to produce patch excitation phases of 0°, 46.5°, 93° and 139.5°, to achieve βp=46.5° and in turn steer the main beam towards θ=105°. Now to scan the beam by 7.5° from θ1=90° or θ2=105°, magnetized ferrite phase shifters are used to generate the required progressive phase shift of βpf=23°. This is achieved by using progressive microstrip lengths and external magnetizing field, as shown in figure 1. To determine the external phase control characteristics of magnetized...
ferrite based microstrip line, the phase constant ($\beta$) versus external magnetizing field ($H_0$) curve is plotted in figure 3(b). The dotted point of this curve illustrates that changing $H_0$ from 0 to 350 KA/m changes the $\beta$ from 1225 to 1175 rad/m, resulting a phase change of 50 rad/m or 2.87 deg/mm. Thus, if the unbiased ferrite substrate

![Ferrite Substrate Diagram](image)

is magnetized with $H_0=350$ KA/m, a progressive microstrip lengths of 8 mm (in each array arm) is needed to produce the patch excitation phases of $0^\circ$, $23^\circ$, $46^\circ$ and $69^\circ$, which in turn steers the array beam $\theta_1$ from $90^\circ$ to $97.5^\circ$ or $\theta_2$ from $105^\circ$ to $112.5^\circ$. By gradually changing the strength of $H_0$, the array beam can also be scanned in a smaller steps.

An amplifier circuit is designed using a GaAs FET (Fujitsu FLR056XV) and integrated with the array antenna to provide a signal gain and compensate for the losses in the array feeder and phase shifters. Figure 4 illustrates transmission and reflection parameters of the active antenna (of Fig.1), where a signal gain of 5 dB is shown at 24 GHz. Note that the amplifier also compensates additional 12 dB of losses contributed by the array feeder and phase shifters. Figure 4(b) demonstrate the E and H plane radiation response of the array antenna. Note that since both the 2-bit switched line and the magnetized ferrite phase shifters are activated, the net beam squint of $112.5^\circ$ is shown, which requires an external biasing of $H_0=350$ KA/m for the ferrite phase shifter.

![Transmission and Reflection Parameters](image)

Although the required phase control in the designed array antenna can be achieved by using either analogue ferrite or digital switched-line phase shifters, both techniques would have required far more complicated external control mechanism. Also in this design, each technique can be individually selected to implement discrete or continuous beam squint

3 Conclusion

Analogue and digital techniques of array beam scanning is combined to avoid complicated external phase control circuitry. A simple 2-bit microstrip phase shifter is used to steer the main beam, which is later scanned using a relatively low external biasing field of a ferrite phase
shifter. An amplifier is integrated in the design to provide signal amplification and compensation for the losses contributed by the array feeder and phase shifters. S-parameter and radiation responses of the designed array is included to demonstrate beam scanning, where digital, analogue or phase control using both techniques can be individually activated to achieve discrete or continuous beam squint.

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**References:**


