Design of a low-cost MIC Antenna Array Network at Microwave Frequencies

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Abstract: This project deals with the design and the realization of a low-cost MIC antenna array sub-system at an operating frequency of 9.71 GHz. Applications for this kind of antenna are found in indoor wireless communications systems. Low power radar is also a potential field of application. We present a proposed topology to perform beam switching in many azimuthal directions and in two elevations. Elevation switching is implemented by reflection phase shifters in a phased array, with the constraint of a constant module in both phase states. Loaded line phase shifters are also implemented. Finally, antenna performances are showed and discussed.

Résumé: Ce projet vise à faire la conception et la réalisation d'un réseau d'antennes opérant à 9.71 GHz. Les systèmes de communications sans fil d'intérieur ainsi que les radars sont des domaines d'applications possibles. On présente une topologie d'antennes pouvant commuter le faisceau dans plusieurs directions d'azimut et deux directions d'élévations. Le changement d'élévation du faisceau est réalisé par des déphaseurs utilisant la technique par réflexion. Un soin particulier est apporté au module du coefficient de réflexion dans les deux états de phase. Des déphaseurs à perturbation sont aussi réalisés. Finallement, les performances de l'antenne sont montrées et discutées.

Introduction

Interest towards wireless computer networks at high bit rates (in the order of 150 Mbits/sec) motivates the developpement of indoor wideband radio systems. However, multipath fading, ISI and diffraction constitute a problem, for which many solutions are being studied including anti-multipath modulation, equalization and coding. One of the potential solutions is to use a phased array antenna to reduce ISI and multipath fading. The implementation presented here is at 9.71 GHz, that is one third of an eventual 30 GHz millimeter wave system where such antennas could potentially be implemented by taking proper account of frequency factors rescaling.

In the first section, the geometry of the antenna environment is explained. The topology proposed for beam switching in azimuth and elevation is presented. The second section presents the implementation, simulations and measurements for a sub-system of the complete antenna.

System considerations

The antenna array system proposed for indoor wireless communications applications is illustrated in Figure 1. The antenna can be seen as mounted near the ceiling. A 360 degree coverage is offered by six (or more) antenna sectors tilted at around 30 degrees from the vertical in the direction of the floor. Scanning in the azimuth is achieved by antenna sector switching, while scanning in elevation in two directions separated by 30 degres in realized with phase shifters. An other antenna sector facing towards the bottom is added to insure coverage to the stations located directly below the antenna..

We present in this paper the realization of one of these antenna array sectors of Figure 1, with the capability to switch the antenna beam between two elevation angles separated by 30 degrees, as illustrated in Figure 1(b). To satisfy the radiation pattern specifications in the vertical axis, 3 rows separated by a 0.65 λ spacing are used to produce a vertical beamwidth of approximetly 30 degrees. In the horizontal axis, 4 patches with a 0.65 λ spacing are used to generate a beam of 20 degrees: in this case 18 sectors would be required for a full circular 360 degree coverage, while only 2 patches would be used for a 6 panel configuration. A simple array of 2 one bit phase shifters configuration can generate the desired radiation pattern in elevation. A schematic of the antenna and of the final layout is shown in Figure 2

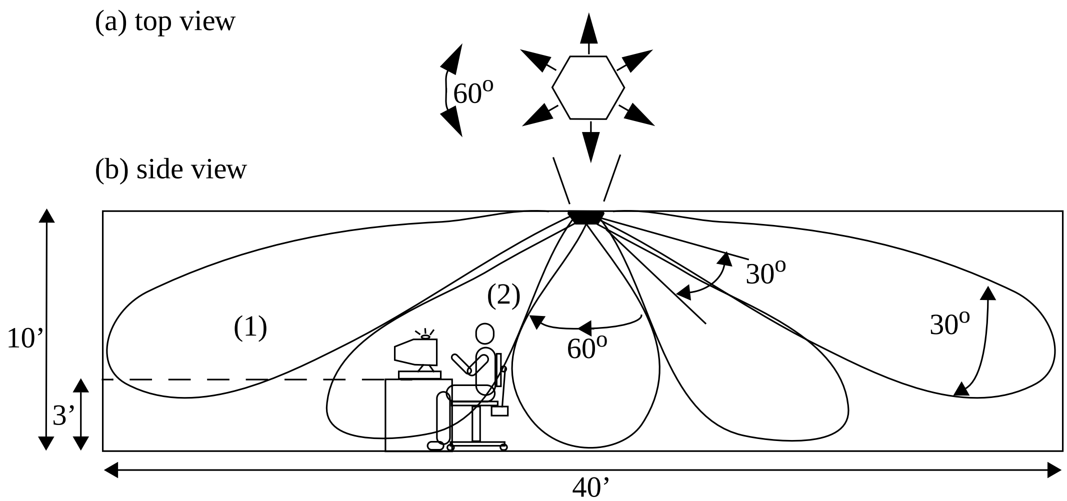

Figure 2. Antenna topology in a typical room

Circuit considerations

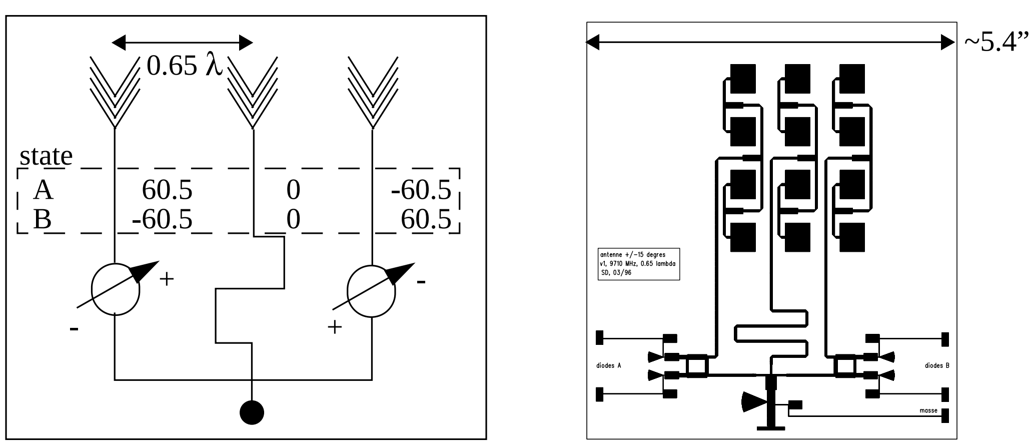

Figure 1. Schematic of the phased array antenna and final layout representation.

The antenna, including phase shifters and power combiners, is implemented on one substrate, as shown in Figure 2. Beam lead diodes are glued on the substrate using Epotek conductive glue. A low loss substrate with a loss tangent of 0.0009, a thickness of 62 mils., a relative permittivity of 2.2, and a 1 oz. copper shield are used. This ensures a good antenna performance and a correct geometry circuitry.

We will divide our discussion in three parts: antenna design, phase shifters simulations and measurements, and antenna measurements.

Antenna design

We use the simple technique described by Munson [1] to model the patch antenna with transmission lines and discrete reactive and conductive elements and to design the patches. The radiation pattern in the H plane of a 4 by 1 array antenna and its reflexion coefficient are show in Figure 3.

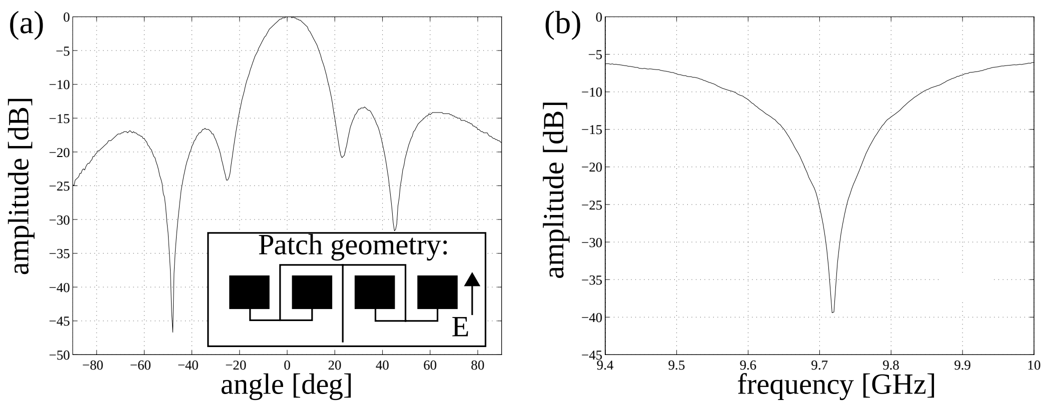

Figure 3. A 4 by 1 antenna measurements: (a) radiation pattern in the H plane; (b) reflexion coefficient.

Phase shifters Design

One bit phase shifters of 121 degrees (2 x 60.5, see Figure 2) have been designed using the reflection technique. We choose an operating impedance of 120 ohms to match the feed network impedance. The circuit used to measure the phase shifters characteristics is shown on Figure 5b, and a quarter wave length transformer is used to adapt to the coaxial transitions. A special stub beetwen the branch line coupler and each diode is placed to provide a constant module in both phase states [2, 3]. Ground is applied to the diodes with standard butterfly ground stubs. Simulated and measured performances are presented on Figures 4 (a and b) and 5(a).

Simulations, with HP-EEsof, and measurements of phase difference are close together in the 5% bandwith of interest around 9.71 GHz, as shown in Figure 4(a), and the phase error is approximetly 10 % at the ends of the band. As shown in Figure 4(b), the insertion loss simulations give a good prediction for the real behaviour of the circuit with a 1 dB loss difference in the band of interest, which is due in particular to the radiated wave. Finally, Figure 5(a) shows the phase measurements in function of frequency for both states.

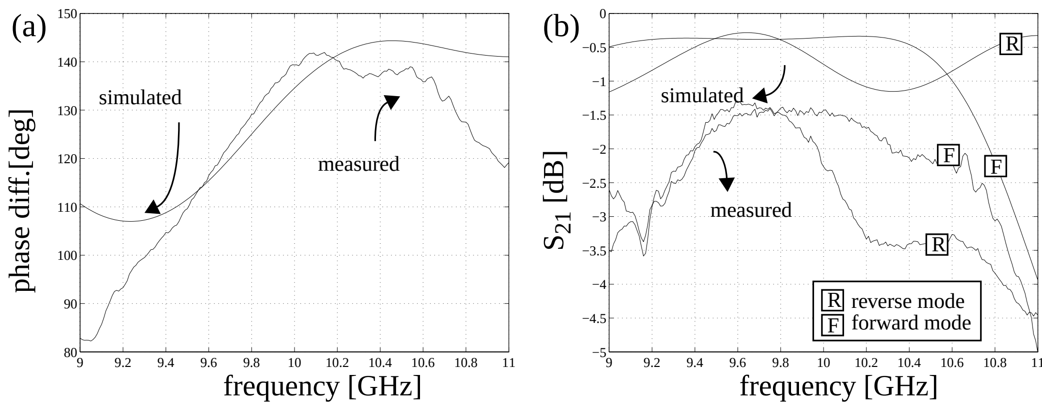

Figure 4. Phase shifter performances: (a) simulation and measurement of phase difference between states; (b) S_{21} simulation and measurement in both states.

We have also designed and implemented a loaded line phase shifter to study the possibility of making complex digital phase shifters on the antenna substrate. A 55 degres loaded line phase shifter has been designed which is considered to be a very high value for this type of phase shifter. We use the complex conjugate technique to design the phase shifter, and a brute force root finding algorithm has been used to find the correct susceptance value considering a series configuration for diodes and stubs. The working impedance is 70 ohms and match to coaxial transitions is realized using a butterfly stub. A photograph of the phase shifter is presented at Figure 7(b) ..

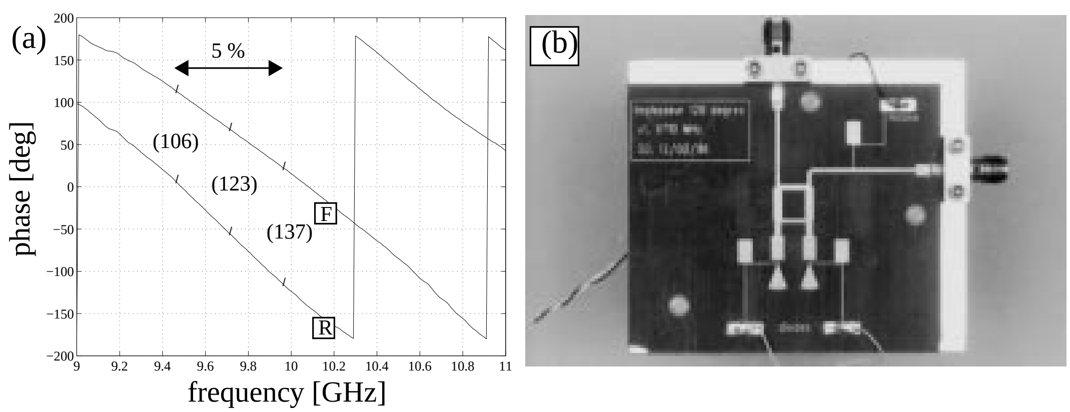

Figure 5. Reflection phase shifter: (a) phase as a function of frequency for both states; (b) photograph of the phase shifter.

For the loaded line phase shifter, simulations and measurements of phase difference are close together (in the 5% bandwidth of interest), as shown in Figure 6(a), and the phase error is 10 % at the lower end of the band and increases up to 20 % at the upper end. As shown in Figure 6(b), the insertion loss simulations predict the general shape of the circuit behaviour except that losses are more important. Finally, Figure 7(a) shows the phase measurements in function of frequency for both states.

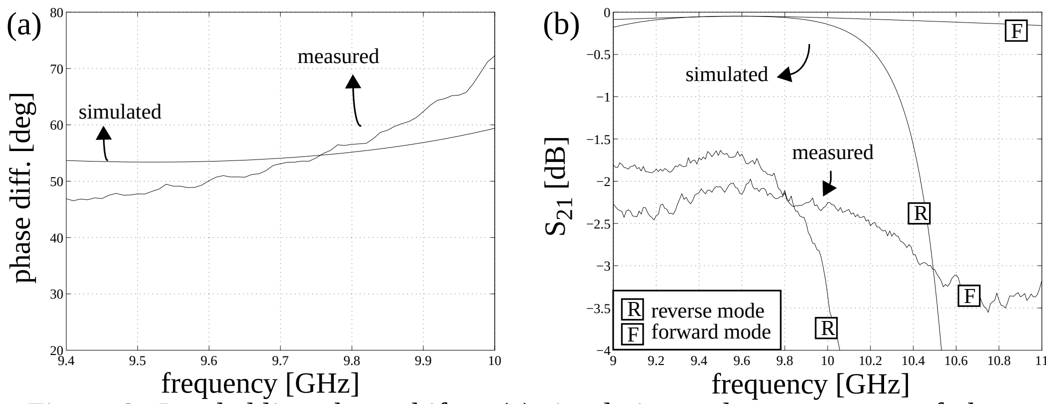

Figure 6. Loaded line phase shifter: (a) simulation and measurement of phase difference between states; (b) S_{21} simulation and measurement in both states.

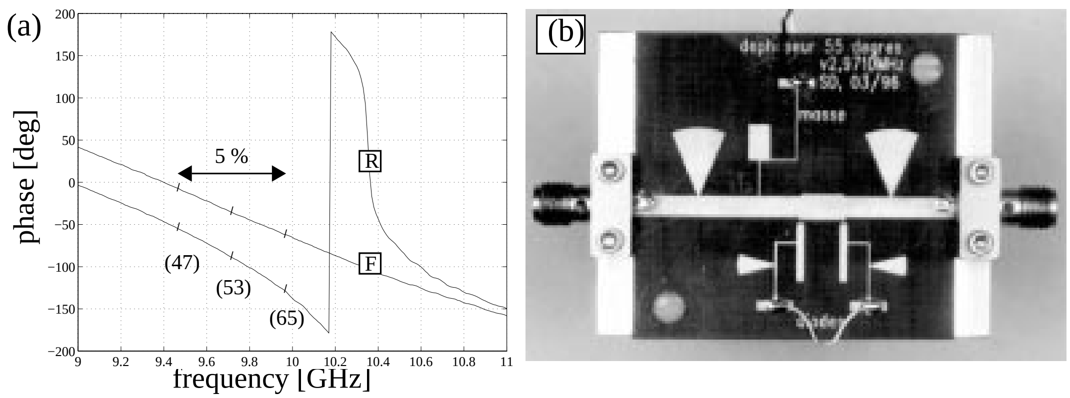

Figure 7. Loaded line phase shifter: (a) phase as a function of frequency for both states; (b) photograph of the phase shifter.

Antenna performance

The characteristics of the antenna shown in Figure 6(b) have been measured. A VSWR lower than 2 has been found for the band of interest, with a gain of approximetly 12.5 dB. The beam switching works very well but side lobes are high, which may be due to coupling beetwen antenna and feed networks.

Conclusion

The design of an indoor communication antenna array system that conjugates antenna switching and phased array switching has been discussed. The design is based on switching between different antenna sectors to achieve coverage in azimuth and on phase shifting to obtain different elevation angles.

For the implementation of a typical antenna sector, a configuration with 4x3 elements spaced by 0.65 λ has been retained. Three horizontal rows of four fixed phase patch networks form the bidimensional array. Equal but opposite sign phase shifts are applied alternatly to the upper and lower rows (1 and 3) to achieve beam switching in the two specified directions, while the center row remains fixed in phase.

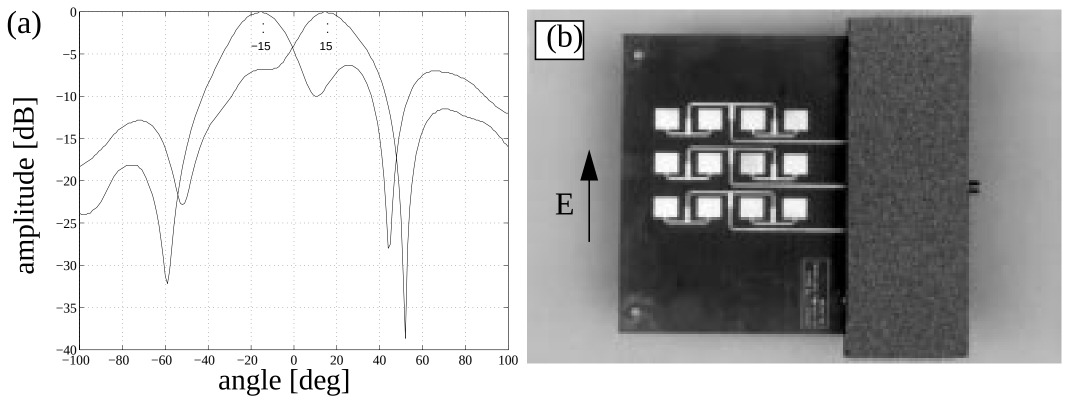

Figure 8. (a) Measured radiation pattern in the E plane for both states; (b) photograph of the measured antenna.

Microstrip phase shifters are implemented on the same microwave substrate as the antenna network. For phase shifts of the order of 90˚ , the technique of reflection phase shifters with the help of branch couplers has been used. Phase shifters producing 121˚ phase shifts have been implemented with this technique. For the reflection, beam lead PIN diodes are used as switching elements and care has been taken to obtain the same module for both phase states.

For finer phase shifts, design and implementation with a loaded-line technique have been achieved with the same substrate and the same beam lead PIN diodes. It is then possible to obtain low-cost digital phase shifters mounted directly on the antenna substrate.

References

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[3] K. Chang, “Handbook of microwave and optical components, Volume 2,” John Wiley & Sons, New York, 1990.