Adaptive Micro-Antenna on Silicon Substrate

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Abstract

Adaptive antenna technology represents the most advanced smart antenna approach to date. Using a variety of new signal-processing algorithms, the adaptive system takes advantage of its ability to effectively locate and track various types of signals to dynamically minimize interference and maximize intended signal reception. This paper presents the design and development of a Micro Antenna for SoC, working at 43.763 GHz and controlled by independent MEMS based DMTL Phase Shifters which are low power in nature. We have also explored other required low power SoC devices which would also have the ability to reconfigure to the demands of our communication device. This in turn will enhance the desirability of our adaptive antenna for future low power mobile devices. The criteria for such a device must be its small size, a functionality that must make it possible to use over a wide variety of applications and similar fabrication techniques as with the rest of the SoC design. Our MEMS based design allows us to have all the communication and control circuitry on a single silicon substrate; enabling easy fabrication.

1. Introduction

Communication has expanded much rapidly in the past couple of decades, and the ever expanding need of communication bandwidth defines new communication protocols which in turn expect better technology to fill in the gap. It would be ideal to have the entire communication module on a single substrate which makes it easier to reuse in a SoC scenario. An antenna is an important part of the communication module which if reduced in size would help reduce the overall system, it would also be ideal to make it reconfigurable to help use the same design for a wide variety of devices and applications.

However, in an adaptive design it is not the antenna that is smart but the accompanying digital signal processing system which allows it to reconfigure to the environment and signal conditions. In this design, we have developed an electrically small antenna, which can be reconfigured in terms of frequency and may also increase or decrease its Directivity, which is a measure of the gain of an antenna in a particular direction. Depending on the application the antenna can pick up a faint signal by increasing its gain or overcome interference by creating a null point, enabling smart devices to configure themselves to any given network or environment.

The design of the Adaptive Micro Antenna comprises of the following parts; a reconfigurable patch antenna along with the analog hardware, which would be the front end of the system, while in the back end, would be the controlling digital hardware.

In earlier adaptive antenna systems these parts would usually be in totally different parts of the device where the antenna had no capability to reconfigure itself, while the digital radio section would reconfigure in order to adapt the entire system. In our design we have integrated a reconfigurable antenna with the digital radio section on the same silicon substrate, allowing the system to reconfigure on both the front end and back end giving the extra flexibility.

The patch antenna system has a simple layout; a group of micro-strip patch antennas connected by an H-tree fed transmission line, and at the feed point of

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the antenna there are a series of MEMS (Micro Electromechnical System) phase shifters, shown in figure 1. These phase shifters make the design unique, since they are designed to alter the phase of the signal on the transmission line and at the same time can act as perfect switches disconnecting the antenna from the circuit. They are fabricated from the same material as that of the antenna, and are much smaller in physical dimension to any existing DMTL (Distributed MEMS Transmission Line) phase shifter [1]. This was made possible only by employing polymers in the design of the bridge.

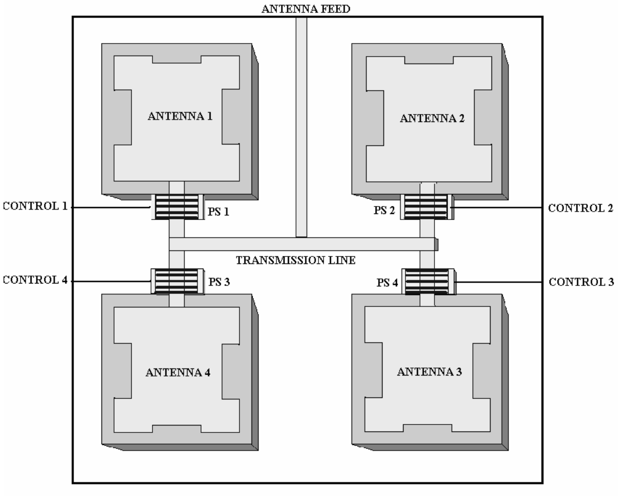

Figure 1 Patch Antennas with their associated MEMS phase shifters.

2. Micro-Strip Patch Antenna

A Microstrip patch antenna is a low profile antenna that has a number of advantages over other antennas, such as being lightweight, inexpensive, and easy to integrate with accompanying electronics [2].

The Micro Stripes electromagnetic simulation software [3] was used in the design of the patch antenna. First, a rectangular patch antenna was designed to work around 50 GHz. Next, this design was modified for impedance matching with the transmission line by first adjusting the feed and antenna contact, and then by etching metal from the patch. Simulations were carried out every step of the modification in order to determine if the impedance of the antenna matched that of the transmission line.

The only indication of such a matching point is when there is maximum flow of current into the patch and we observe that the electromagnetic lines completely surround the patch, and the structure radiates from the fringing fields [4] that are exposed above the substrate at the edges of the patch. The resonant length of antenna can be found by the following equation:

$$L = \lambda_g/2 = \frac{c}{2 * f * \sqrt{\varepsilon_r}} \qquad (1)$$

where L is the length of the patch antenna, λ_g is the guide wave length for antenna, f is the frequency of operation for our patch, and ε_r is the dielectric proximity of substrate. The dimension for length L comes close to 1100 µm by equation 1. It was found that for a pure rectangular patch antenna, we still did not establish resonance; hence we further had to improve the design by a number of iterations to a near H-Antenna by etching the material on the sides, as shown in figure 2a and 2b.

The antenna comprises of the following; a silicon based ground, the substrate of silicon nitride which is the insulator that separates the ground from the patch and the patch is made of aluminum. These are also the same materials we have used in the fabrication of the MEMS phase shifters that control the antennas, as shown in figure 3a and 3b.

The height of the substrate and the area of the metal patch form the resonant cavity which defines the fundamental mode for the antenna. The fundamental mode is the largest possible frequency of radiation which the antenna can generate.

In our design the thickness of silicon nitride substrate is 44 µm while that of the aluminum is 0.5 µm, while its length and width are both 1100 µm. The sides have been etched in order to achieve resonance at smaller dimensions.

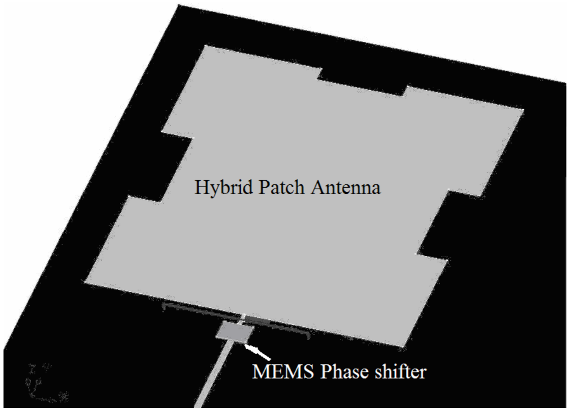

Figure 2 a) Antenna with its MEMS Phase shifter on same substrate

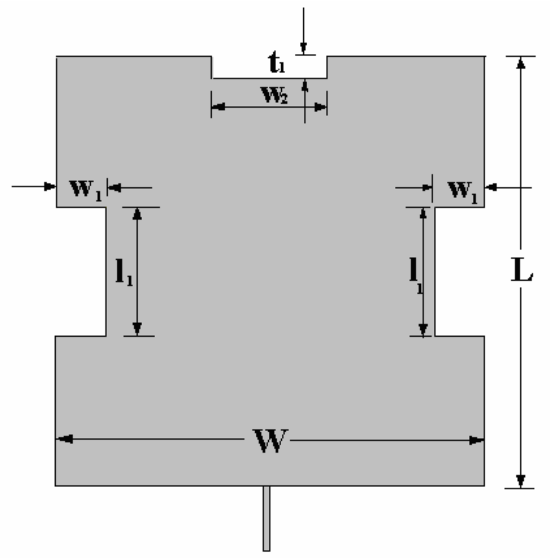

Figure 2 b) Layout of Antenna with dimensions

The final layout of the antenna, shown in Figure 2b, was achieved through a number of simulations with Micro-Stripes. The software gave the output for the return-loss curve for the whole range of frequencies (0-100 GHz). From the return-loss curve we get the resonant frequency for a single antenna. This frequency is the maximum operating frequency of our design and from that multiple frequencies can be generated by electrically connecting more than one patch which would in turn increase the electrical length of the antenna, proportionally reducing the frequency of operation. This allows us to work at multiple frequencies simply by controlling the antenna connectivity to the main transmission line.

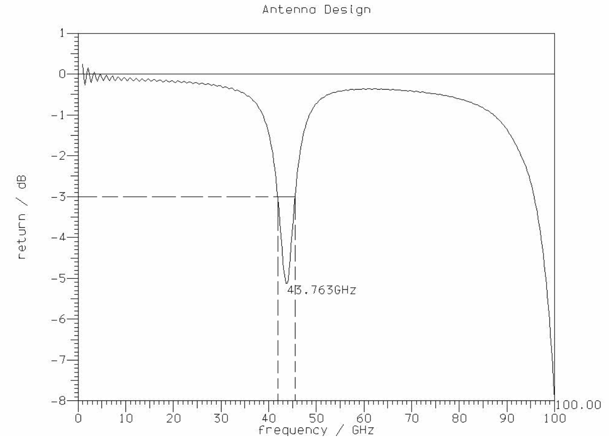

Figure 3 a) Return curve for Antenna

Figures 3a and 3b show the antenna performance from 0-100 GHz range of frequencies and tell us the exact resonant frequency for the antenna, which is also the highest frequency of operation for our device. The resonant frequency was found to be 43.763 GHz, with a bandwidth of 3.5 GHz. These are important figures since they define the characteristics of an antenna.

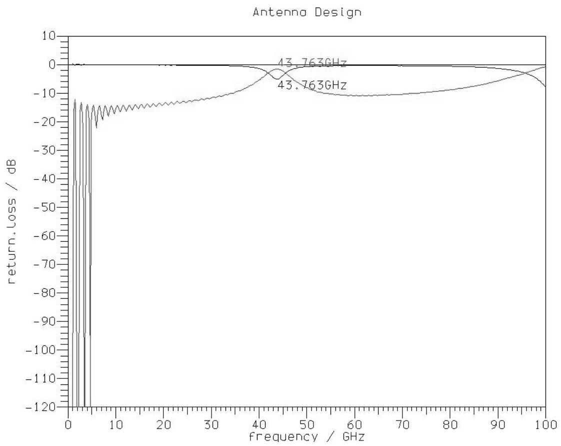

Figure 3 b) Return-Loss curve for Antenna over range 0-100 GHz

For multiple frequency generation we would have to electrically connect two or more antennas, so that the effective wavelength would now increase to λ_{d+}. This would in turn reduce the resonant frequency in an inverse relationship.

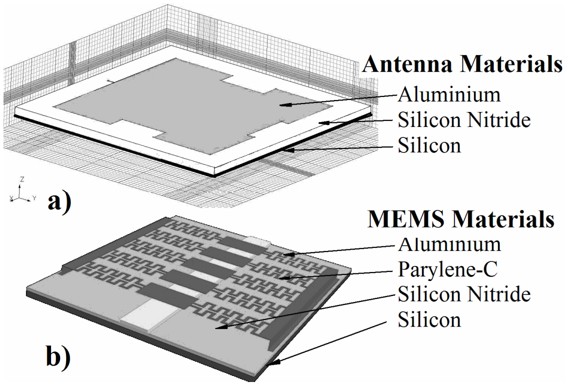

Figure 4 a) Layout of Antenna as in Micro Stripes, b) MEMS phase shifter

3. MEMS Phase Shifters

The MEMS Phase Shifter design, Figure 4b, is based on the DMTL approach, where a series of MEMS capacitive switches are distributed periodically over a transmission line. By applying a bias voltage between the MEMS bridges and ground, we would vary the height of the bridge. This changes the distributed MEMS capacitance on the line, which in turn causes a phase shift in the signal on the transmission line. Therefore, a structure with several MEMS bridges can act as a phase shifter when a bias voltage less than the pull-down is applied [6]. When the bias voltage goes beyond the pull-down voltage for MEMS bridge, the MEMS capacitive switch acts as perfect switch closing the transmission line ahead without any loss in power. Hence by using the MEMS phase shifters we can completely control each individual antenna.

Based on this idea we designed our MEMS phase shifters based on a serpentine bridge made of a polymer Parylene-C. With this design we were able to actuate the bridge at low bias voltages, leading to a low power design.

4. Design Results

For our basic design with the single patch the radiation pattern is shown both in real and polar plots in Figures 5a and 5b.

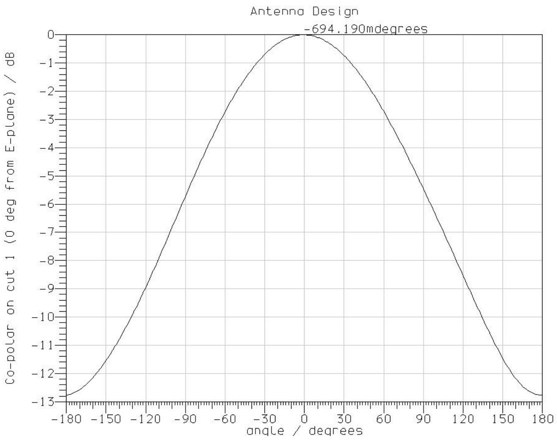

Figure 5 a) Real plot for the Radiation pattern for a single antenna

The directivity for the antenna is found to be 5.10 dBi, see Figures 6a and 6b. The polar plot can help us determine the Half Power Beam Width (HPBW) [5] for the patch antenna which is 128˚. The HPBW of the main lobe of the antenna measures the angle surrounding the direction of maximum radiation across which the antenna drops to half the normalized radiation intensity.

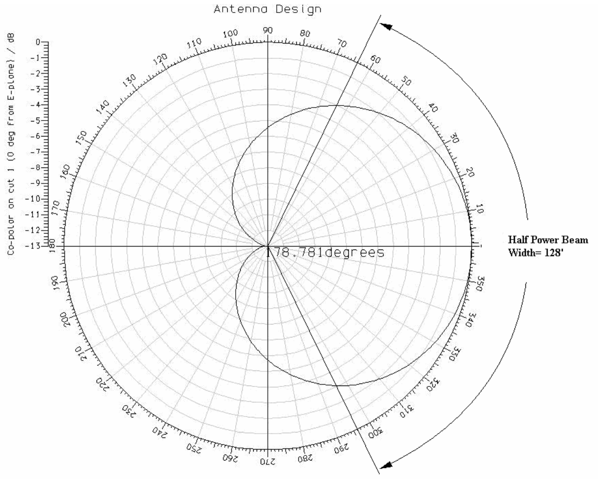

Figure 5 b) Polar plot for the Radiation pattern for a single antenna

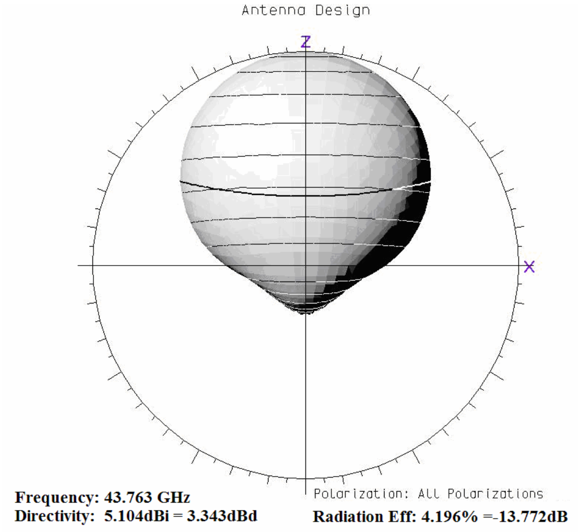

Figure 6 a) 3D radiation pattern for a Single antenna

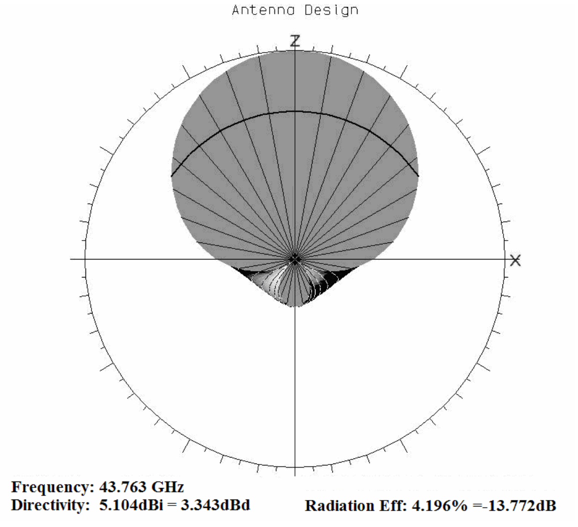

Figure 6 b) Cross section of radiation pattern for a single antenna

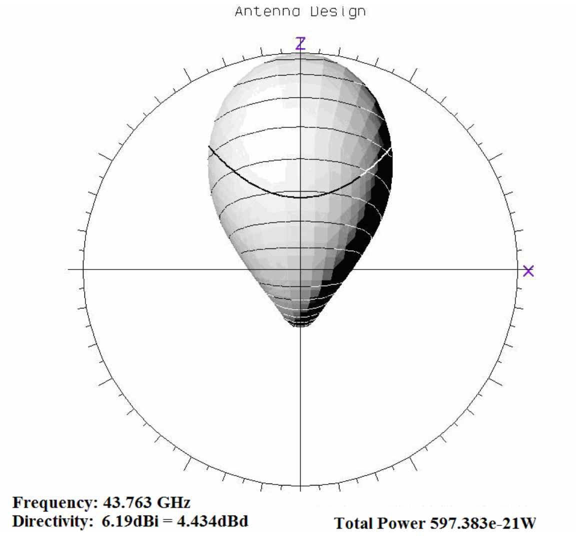

Figure 7a) 3D radiation pattern for Dual antenna

For a dual patch antenna the radiation pattern is more convergent compared to that of the single antenna. Even the directivity has increased to 6.19 dBi by the effect of two antennas working together. The main beams would add up increasing the overall strength of the beam while reducing the back radiation, thereby increasing the gain or directivity as observed from Figures 7a and 7b.

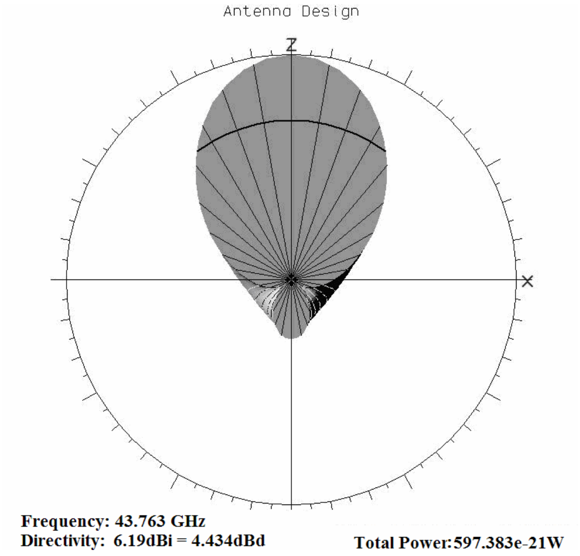

Figure 7 b) Cross section of radiation pattern for Dual antenna

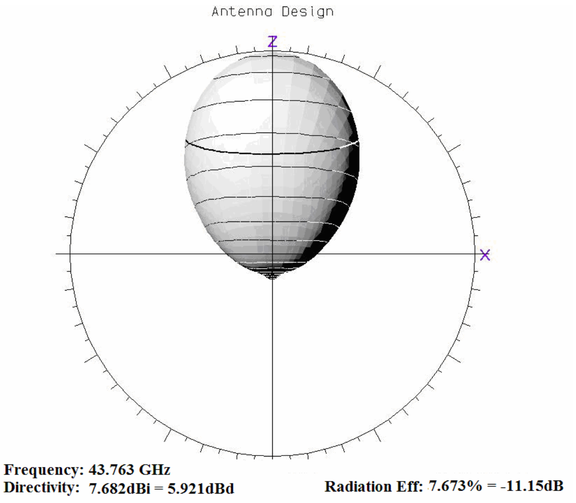

Figure 8 a) 3D radiation pattern for Four antennas

In the case of four antennas working collectively, the back radiation decreases and the overall directivity increases to 7.68 dBi, as can be seen from Figures 8a and 8b. The results for the above simulations are summarised in Table 1. Since we can control each antenna by means of our MEMS phase shifters we can change the phase of each individual antenna thus creating a phased array antenna.

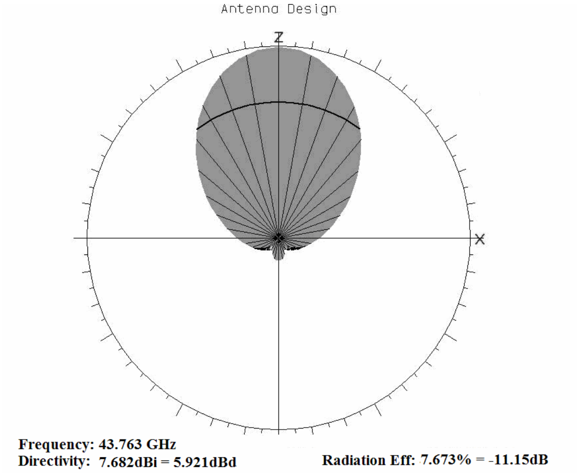

Figure 8 b) Cross section of radiation pattern

We have simulation results where antennas were configured to cancel the main beam thus creating a null as shown in Figure 9a. This can be best used to reject interference signals. We were also able to change the direction of the main beam, as shown in Figure 9b, by changing the phase of any one antenna with respect to the others.

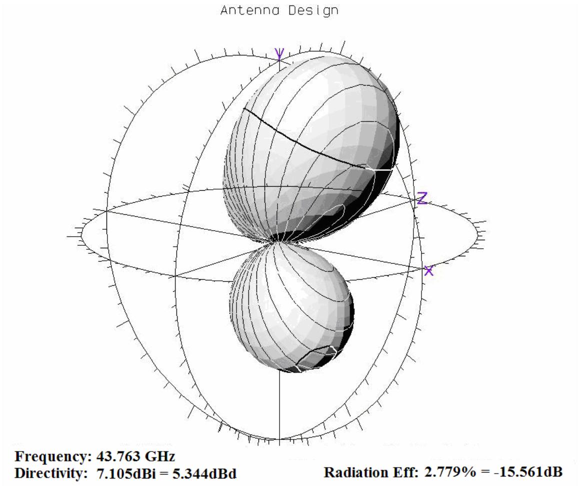

Figure 9 a) Null pattern generation by four antennas

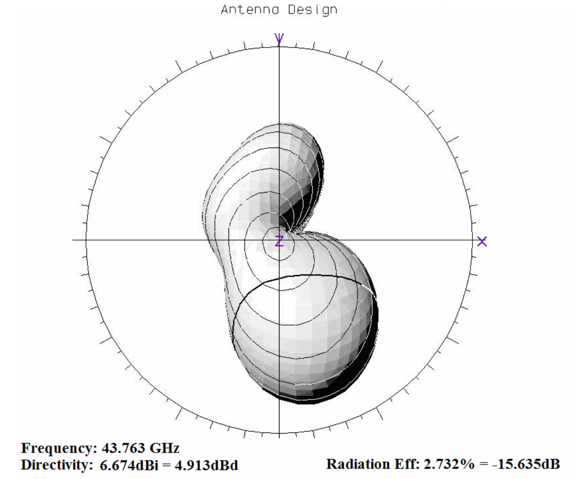

Figure 9 b) Direction of main beam changed

Table 1 Summary of simulation results

Antenna Design	Directivity
Single Antenna	5.10 dBi
Dual Antennas	6.19 dBi
Four Antennas	7.68 dBi

5. Adaptive Antennas

Up till now we have discussed the construction and initial simulation results of our reconfigurable Micro Antenna design. We can now discuss how our design can be easily employed in adaptive antennas and utilised in future wireless devices.

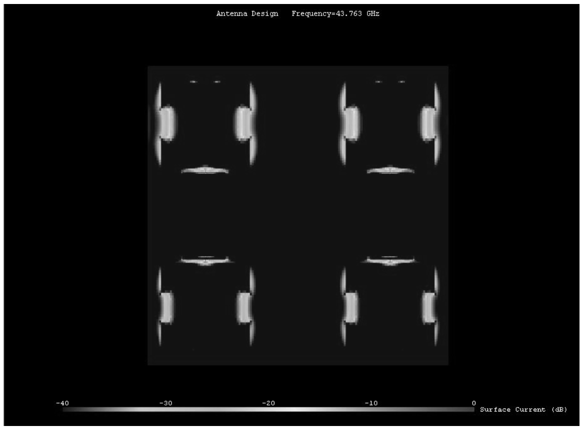

Figure 10- Antennas radiating due to the fringing field, shown in white.

Smart antenna systems combine an antenna array with a digital signal processing (DSP) capability to transmit and receive in an adaptive, spatially sensitive manner. In other words, such a system can automatically change the directionality of its radiation patterns in response to its signal environment [11]. We have already provided the mechanism for the antenna system to control each individual antenna in order to modify the direction and gain of the overall signal.

With our existing 4 element array we can create and steer nulls at various points surrounding the antenna. This means that we can suppress multipath signals coming from different directions and receive the desired signal alone. But when posed with multipath signals coming from the same direction, we would need to employ larger arrays, so that we can create groups of multiple directive antennas. Each can then receive the best signal through the method of equal gain combining.

We have designed our antenna for highly directional and not for omni directional signals. This was done in order to utilise the whole power of the transmitted signal in enhancing its strength in a desired path of communication rather than waste it in free space.

In the digital part we would require low power and reconfigurable logic that would help our antenna adapt to its environment. If the received signal power reduces in strength or changes its direction compared to the main lobe of the antenna, the digital logic would have to sense the loss in signal strength and then employ a reconfigurable Viterbi decoder [12] for forward error correction to tackle multipath fading and adapt the system. The digital logic would then change the direction of the main lobe until acceptable levels of signal is received. Such systems are already in use in 3G and 802.11 LAN networks but having them to reconfigure would allow us to cater for multiple applications and networks at the same time.

It would be also ideal to have low power digital cores such as a high throughput and low power FIR Filter [13]. This would allow our device to communicate at higher data rates without the expense of power. We can have a low power FPGA core that would be able to update the algorithms as new and improved versions come in. This would keep the cost of the whole device low and would allow a longer product life.

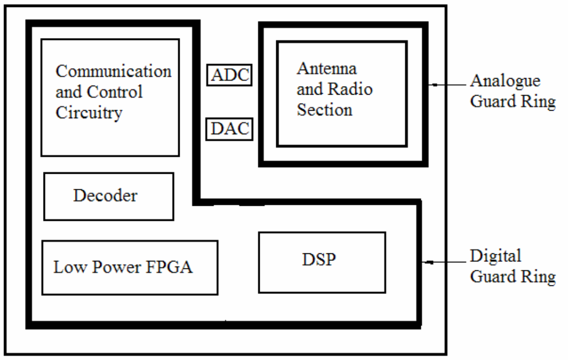

Figure 11 - Floor plan for Digital and Analogue blocks

Adaptive arrays utilize sophisticated signal-processing algorithms to continuously distinguish between desired signals, multipath, and interfering signals as well as calculate their directions of arrival [11]. These real time calculations can be effectively carried out in the accompanying control circuitry present on the same chip. All the necessary systems can be effectively fabricated onto a single silicon substrate. We can allow for island partitioning of the digital communication and control backend circuits from the analogue radio front end circuits on the same chip. This is required since the noisy digital circuits running on a clock must not affect the analogue radio circuits like the modulator, low noise amplifier or power amplifier. Even the MEMS control lines are DC signals and will be well integrated into the analogue section. Since these control signals are exponential in nature, any deviance in the higher range would affect the phase of the antenna changing the desired shape of antenna pattern. Even tough the requirements for partitioning are strict, effective floor planning and utilisation of analogue and digital guard rings in the design, as shown in figure 11, will allow us to fabricate adaptive array antennas on a single chip.

6. Conclusion

We have explored the design of an Adaptive Micro Antenna, presenting results with a single, dual and four antennas. We have also shown how the overall radiation pattern can be changed by controlling each individual antenna by its associated phase shifter. Effective use of digital IP cores and possibly evolvable algorithms, to allow the device to learn faster will make this design a truly smart antenna which can be employed in a number of future low power wireless devices.

At present we have successfully tested the MEMS Phase Shifters and the Patch Antennas. We will soon fabricate these on a single chip at facilities based within the University of Edinburgh. The success of the model will lead to an on chip adaptive antenna. This will be a versatile device, which would find use in almost every communication device, ranging from future mobile devices to satellite sensors.

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