Reconfigurable RF and Antenna Systems

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ABSTRACT — In order for future engineering systems to function in increasingly complex environments in a robust and resilient fashion, they must be able to anticipate threats or opportunities, to discover their state and mode of operation in real time, and to autonomously reconfigure themselves to take advantage of the opportunities or react to impeding threats. These requirements lead us towards engineering systems that are composed of many parts that can assemble themselves at the hardware, software, and logical levels into larger and more capable systems. In this paper we discuss an approach for achieving reconfigurable RF and antenna systems as part of a larger and more complex structure.

Index Terms — Reconfigurable antennas, MEMS switches, RF/Photonics integration.

I. INTRODUCTION

Recently, a number of materials, technologies, and components conducive to implementing reconfigurable systems have emerged, including micro-electromechanical systems (MEMS), field programmable gate arrays (FPGAs), phase change materials (such as certain chalcogenides), and metamaterials to name only a few. Such materials, technologies, and products promise a future where diverse technologies are integrated to create systems that are:

- Far more flexible and capable than those designed and manufactured today, simply because it is possible in many to alter arrangements and properties of configurable elements within a system after it is fielded
- More robust and resilient to defects, due to the possibility of circumlocution, (such as a self-healing wiring harness that re-routes failed connections);
- Implemented far more quickly, since the end product is defined as a set of signals (like a "digital DNA") that rapidly configure pre-built hardware to perform desired functions (such as designing FPGAs with complex circuits instead of building custom integrated circuits or configuring software radios with unique waveforms instead of building a new radio from scratch).

In addition to user-specified configurations, it is possible to create systems that reconfigure themselves autonomously to adapt to environmental changes or operational requirements. The potential for is enormous, but the surface has only just been scratched.

The emergence of reconfigurable elements and components themselves is insufficient to achieve complex and meaningful reconfigurable systems and products. New systems design and engineering tools are required to take full advantage of reconfigurability. Such tools will embrace the full range of reconfigurability becoming possible on the component level, to create systems designs with architectures that morph to maintain system-level performance under widely varying and challenging environments..

This paper deals with one these key reconfigurable components, mainly the RF and antenna systems.

Reconfigurable antenna systems have been introduced in the 1990's and since then many reconfigurable antennas have been developed [1-6]. So far the goal of reconfigurable antennas has been to:

- Radiate on demand at several pre-determined frequencies, or
- Change their polarization, or
- Change their radiation patterns on demand

It is expected that these antennas, can be reconfigured remotely without having to rebuild the antenna or the platform on which the antenna structure is placed on. Some of the challenges that the designer has to face in achieving reconfigurable antennas will be presented and discussed. Next, we present two different approaches for designing reconfigurable antennas.

II. RECONFIGURABLE APERTURES AND SWITCHES

In the first example, a 6-armed star shaped antenna attached to a hexagonal patch antenna substrate, as shown in Figure 1, is presented. . The reconfigurability of the antenna is obtained by controlling the size of an aperture slot distribution inserted in the middle of the antenna. The series of aperture slots follows a Chebyshev distribution and each slot in the distribution can be controlled with a switch. Different switch configurations were investigated and different functionalities of the antenna were obtained. Figure 2 depicts the frequency response of the antenna (S11 performance) for the entire Chebyshev aperture slot distribution. Figure 3 on the other hand is the S11 response when the center slot of the Chebyshev aperture is block by a switch. As one can see by controlling the aperture distribution the antenna is made to resonate at different frequencies.

Although there are many other ways to make this antenna reconfigurable, for example, by connecting or disconnecting each arm from the rest of the antenna here we only present reconfigurability by controlling the aperture feed of the structure. With this particular antenna one can even achieve different linear polarizations by connecting/disconnecting the appropriate arms of the antenna.

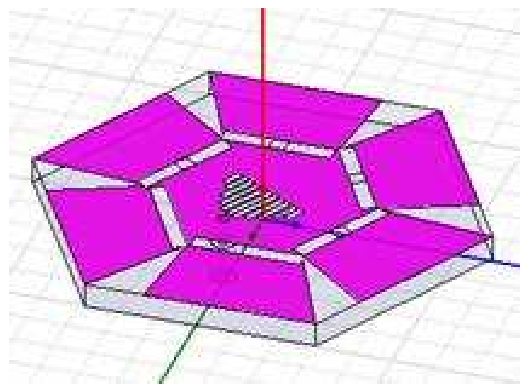


Figure 1. . The 6-arm star antenna with a Chebyshev aperture distribution in the center.

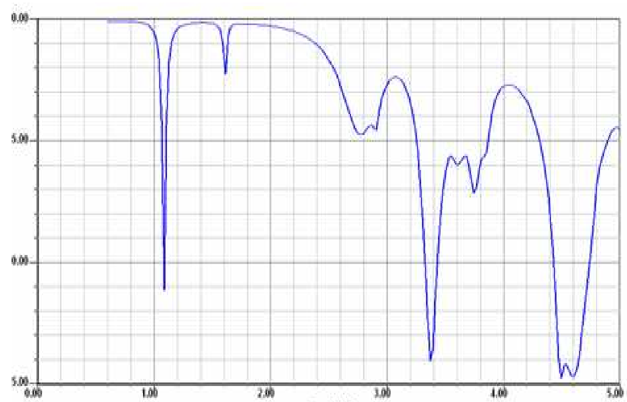


Figure 2. S11 response for the antenna shown in Figure 1.

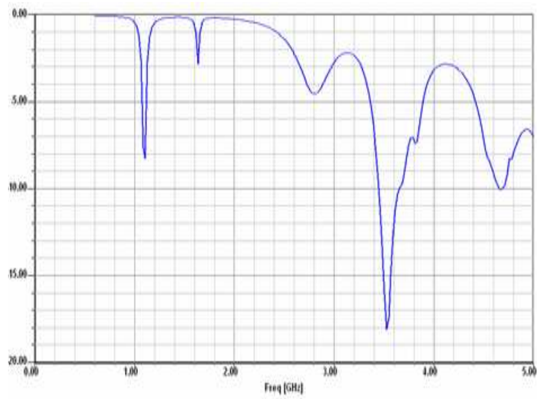


Figure 3. S11 response fro the antenna shown in Figure 1 with its center slot blocked

One can also rotate the aperture and change both the resonating frequencies and the radiation pattern as well, but achieving this is not as simple as changing the aperture slot distribution or connecting and disconnecting the arms of the antenna.

III. INTEGRATING RF/PHOTONICS

The second example, in Figure 4, shows a system where reconfigurability is introduced at two different levels. At the photonic level and at the RF level. The desired scheme here is to convert infrared mode-locked laser pulses into a a source of RF electromagnetic radiation . It is essentially a marriage of microwave and optical techniques. Laser pulses directly generate electrical pulses via a metal-semiconductor-metal photoconductor. These pulses are routed by a coplanar waveguide to a reconfigurable fractal bow-tie antenna. The antenna is re-configured by varying its geometry with MEMS switches. It is tuned to resonate at the quantum dot laser (QDL) mode-lock frequency, whereupon it radiates into free-space.

This set up can serve as a building block of a large aperture THz array. All elements can be coplanar and integrated on a common structure. This device is small, with characteristic dimensions less than 1 cm.

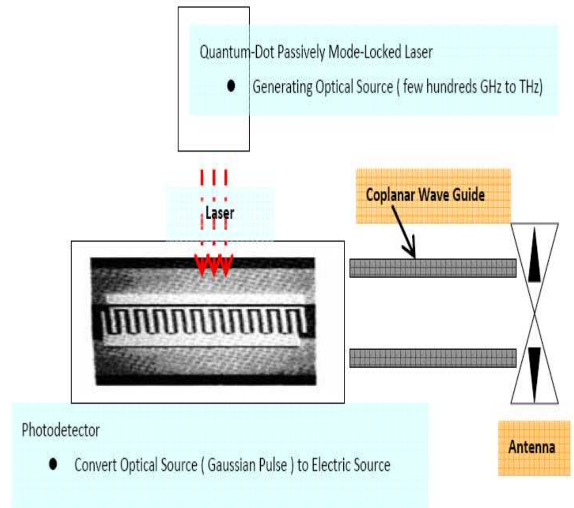
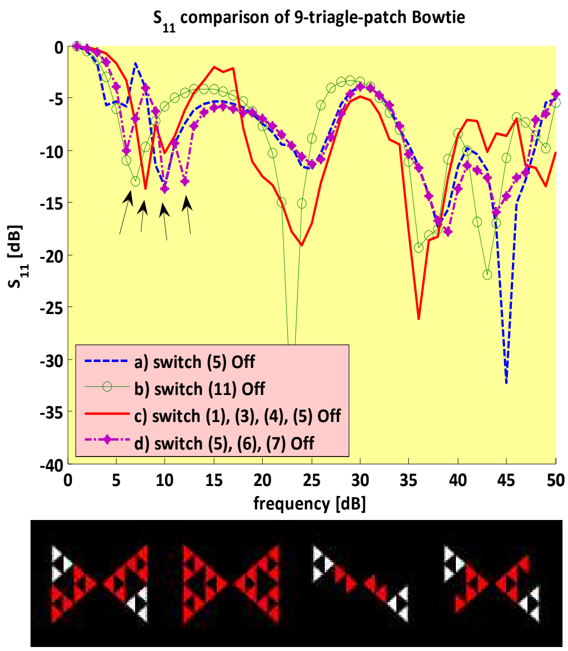


Figure 4. Combining a reconfigurable Quantum Dot Laser and a reconfigurable RF antenna

The challenge here is to minimize the losses due to mismatches between the optical and the RF components and to maximize the efficiency of the transmitting or receiving antenna.

For the reconfigurable laser/reconfigurable antenna, two things need to be considered in advance. First of all, the antenna must be designed to operate up to the THz-frequency domain. Second, the antenna can also realize the quantum dot laser repetition rate. Here an RF-MEMS reconfigurable fractal antenna is used. By controlling the MEMS switches attached to it [4] one can achieve . a multiband capability. Our initial simulation results, shown in Figure 5, indicate that the reconfigurable antenna can operate at various desired resonant frequencies: f_{RES} = 5, 10, 20 ,40 GHz and beyond.



(a) (b) (c) (d)

Fig5. S_{11}-value comparison: (a) $switch_5$ Off, (b) $switch_{11}$ Off, (c) $switch_{1,3,4,5}$ Off, (d) $switch_{5,6,7}$ Off

IV. SELF RECONFIGURABILITY

Another goal is to make the antennas self reconfigurable and intelligent so that the antenna can predict what switches should be on or off in order to achieve the appropriate response. In this context, one can use machine learning, neural networks [7-9], or any other optimization technique such as PSO, GA etc. to be programmed on FPGAs (Field Programmable Gates) to achieve this goal. The FPGA can be then part of the antenna that makes it self reconfigurable.

V. CONCLUSIONS

The promise of true reconfigurable systems will transform the way products are designed, manufactured, and used. Here, several reconfigurable antennas have been presented and discussed including a new RF/Photonic interface that consists of a reconfigurable antenna and a reconfigurable quantum dot laser.

Reconfigurable antennas can be constructed to take various shapes and sizes, including electrically small antennas.

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