ACTIVE ANTENNAS FOR PICOSATELLITE COMMUNICATIONS

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Abstract – The use of active antennas in self-steering arrays and harmonically tuned power amplifiers for picosatellite networks is investigated. The application of these technologies in improving the security, size, and efficiency of picosatellite communications is reviewed, and the current research being performed by our group is presented.

1. Introduction

Internationally, there has been growing interest in the development of small satellites, particularly for a class of satellites known as picosatellites, which have an approximate mass of 1 kg and an approximate volume of 1000 cm^3[1]. Compared to their larger counterparts, small satellites have the advantage of cost-effectiveness and shorter development times, and thus have potential applications in specialist communications, remote sensing, rapid response science and military missions, and technology demonstrators.

Perhaps the most important advantage of small satellites is in their use in networks. Clusters of small satellites are able to share the processing, communication, and mission functions typically associated with single large satellites, without the cost, development time, and possibility for catastrophic single-point failures.

Small satellites and small-satellite networks introduce new challenges and opportunities for research, and call for innovative solutions. One such approach is the use of active antennas. This paper reviews two uses of active antennas for picosatellite communications: (1) retrodirective arrays for picosatellite crosslinks, and (2) harmonically tuned power amplifiers with antenna loads.

2. Retrodirective Arrays for Crosslink Communication

One major obstacle in the use of distributed small satellite networks in space is establishing a communication link between satellites. Since every satellite in the network is subject to constant repositioning, one satellite does not have prior knowledge of another satellite's position, and setting up a communication link can be very difficult. An omnidirectional antenna may seem like an obvious approach to provide a crosslink between satellites, but since the signal is radiated in all directions, this leaves the communication link susceptible to spy satellites. Another problem with the omnidirectional approach is the inefficiency of the antenna, which is a huge detriment on a small satellite with limited power resources.

In response to these security and efficiency issues, the traditional solution has been to establish a direct crosslink using beam-steered directional antennas. However, beam-steering arrays require the use of complex components and digital signal processing algorithms. For a picosatellite with minimal resources, this complexity would negate the advantages of the simple, low cost nature of these small satellites.

A novel solution for small satellite crosslinks are self-steering retrodirective arrays [2], which allow randomly moving satellites to communicate securely with one another. Fig. 1 demonstrates the operation and fabrication of a four-element array based on the heterodyne technique [3]. These types of retrodirective arrays are able to sense the direction of an incoming signal and send a reply in the same direction without the need for complex circuitry and processing algorithms. The high directivity associated with these arrays also improves security and efficiency, and the simplicity of these arrays match well with the simple, low cost nature of small satellites.

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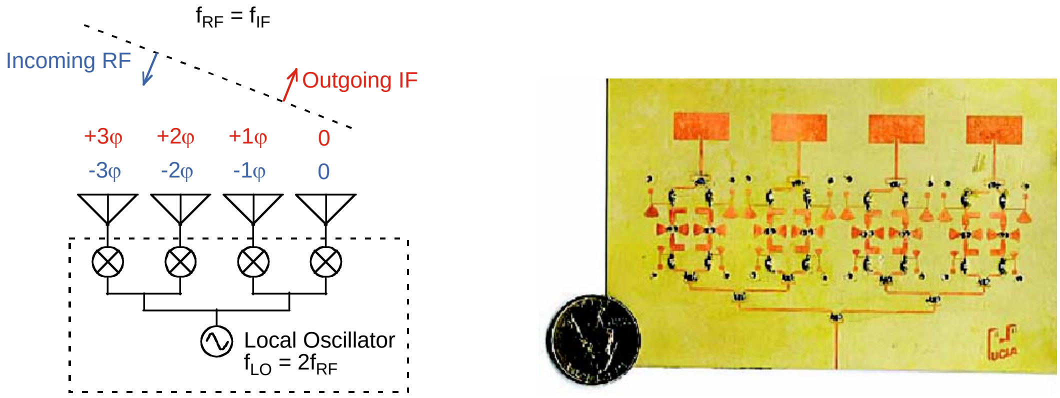

(a) (b)

Fig. 1. (a) Phase-conjugating array based on the heterodyne technique. (b) C-band retrodirective array [3]. An external LO is connected to the phase-conjugating circuitry via a corporate feed network.

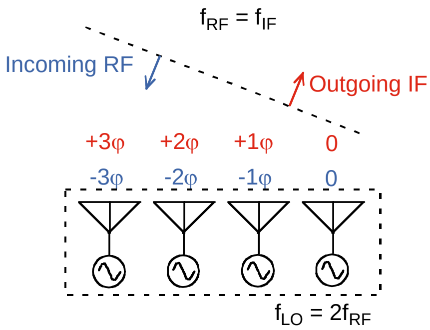

Fig. 2: Phase-conjugating array based on self oscillating mixers [4].

A new retrodirective array based on the use of self oscillating mixers (SOM) [4] has been demonstrated by our group. Fig. 2 shows the architecture of this new design. In this array, the local oscillator, the LO feed network, and the mixers are eliminated and replaced with a set of synchronized self-oscillating mixers. This new design allows for a more compact realization of large retrodirective arrays by eliminating the need for a corporate LO feed structure.

3. Active Antenna Harmonically Tuned Power Amplifiers for Small Satellite Communications

For picosatellite communications, limited solar/battery power necessitates the need for highly efficient power amplifiers since they typically consume the majority of the available power. In this regard, the usual design approach has been to design for maximum power efficiency coupled with acceptable gain and output power levels. Through the biasing and/or the circuit topology, the design of high-efficiency amplifiers has improved greatly, but at the expense of linearity and the creation of higher order harmonics. The generation of harmonics implies that there is less power available at the fundamental frequency, and thus less efficiency. To minimize this effect, the power from higher order harmonics can be recycled back to the fundamental frequency via harmonic tuning [5]. In the classical harmonic load approach, a short circuit is placed at each even harmonic and an open circuit at each odd harmonic so that the output voltage mimics a square waveform. However, harmonic load simulations and experimental observations have suggested that the optimal load at these higher order harmonics is a finite reactance instead of an open or short [6].

To investigate this phenomenon, simulations have been performed (Fig. 3) to separate the harmonics from the amplifier and optimize the load at each harmonic to achieve maximum power added efficiency (PAE). A Fujitsu FHX35LG HEMT large signal model was biased at 20% of I_{DSS} for class AB operation at 4 GHz. A simple resistor network consisting of a 3-Ω series resistor and a 600-Ω shunt resistor at the gate of the amplifier provided the necessary stabilization. To separate the harmonics coming out of the amplifier, a frequency-dependent splitter is used to direct the power at each harmonic into different channels of the splitter. In this way, complete isolation is achieved between channels, and different loads can be presented at each harmonic.

To find the load yielding the highest efficiency at the fundamental frequency, the higher-order harmonic branches were removed from the circuit using isolators so that they would not interact with the fundamental load. Harmonic balance optimizations were then performed to maximize PAE, with the optimization variables being load impedance and input power. Once the optimal fundamental load was obtained, the second harmonic branch was introduced back into the simulation and this load was optimized for peak efficiency. In the same way, the third and fourth harmonic loads were introduced into the system and optimized for maximum PAE. This harmonic tuning method is ideal because it allows for the separation of each harmonic, which allows us to investigate this phenomenon systematically.

To implement the ideal load at the fundamental and higher order harmonics, active antennas [7] can be used. Traditionally, microwave antennas have been designed to 50-Ω and then combined to the system through an interconnect such as a matching network. Not only does this increase the size of the system, but additional problems can arise from unwanted radiation through the interconnects. In the active antenna approach, active devices and antennas are designed as a single component, which allows the designer to terminate the antenna to the value that optimizes performance. This eliminates the need for tuning or interconnects between the active device and the antenna, which reduces the size and loss of the system [8]. These loads can be implemented through the design of circular sector, slot, leaky mode, or quasi-yagi antenna depending on the characteristics of the load needed. For millimeter-wave space systems, the active antenna approach is particularly attractive because it provides a feasible solution for many of the problems inherent at these high frequencies such as transmission-line loss, limited space and power, and reduced antenna efficiency.

4. Conclusions

The recent interest in small satellite technology stems from the reduction in cost and development time, but problems associated with security, size, and efficiency must be improved upon. The simple and high directivity characteristics of retrodirective antenna arrays provide secure and power-efficient crosslinks between satellites, making them an applicable fit for small satellite networks. Active antenna harmonic tuning of power amplifiers also promises a simple, compact means towards high efficiency small satellite communications.

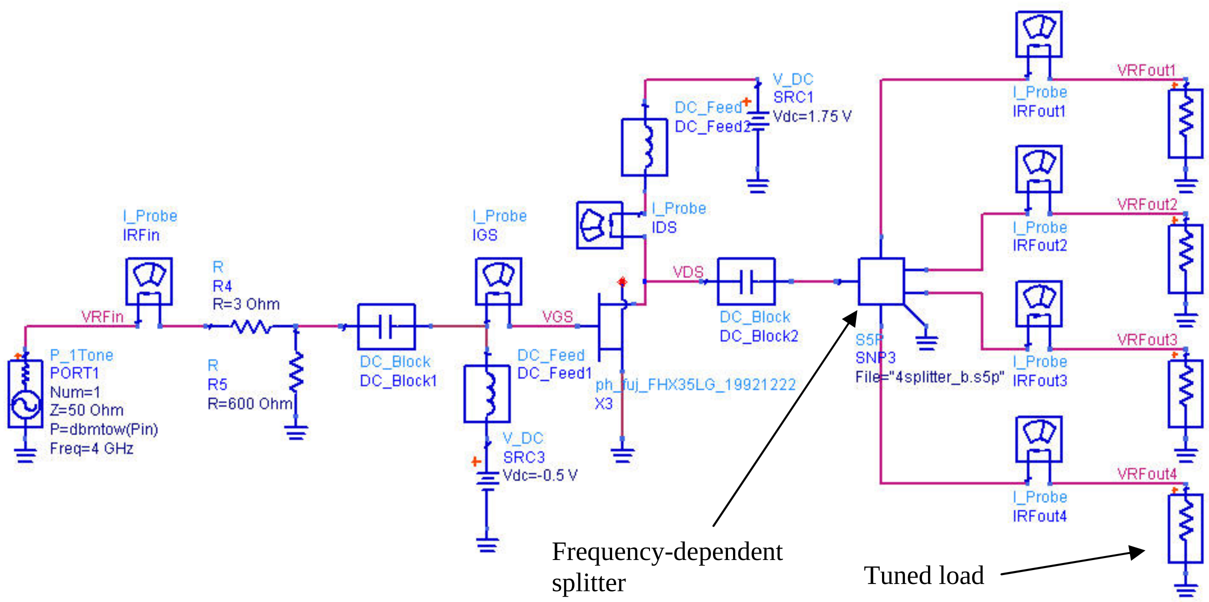

Fig. 3: Harmonic tuning simulation.

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