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MEMS-Based Communications Systems for Space-Based Applications

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1.0 Introduction

As user demand for higher capacity and flexibility in Communications Satellites increases, new ways to cope with the inherent limitations posed by the prohibitive mass and power consumption, needed to satisfy those requirements, are under investigation [1]. Recent studies suggest that while new satellite architectures are necessary to enable multi-user, multi-data rate, multi-location satellite links [2], these new architectures will inevitably increase power consumption and in turn, spacecraft mass, to such an extent, that their successful implementation will demand novel lightweight/low power hardware approaches.

In this paper, following a brief introduction to the fundamentals of Communications Satellites, we address the impact of MicroElectroMechanical Systems (MEMS) technology, in particular, MEM switches, to mitigate the above mentioned problems and show that low-loss/wide bandwidth MEM switches will go a long way towards enabling higher capacity and flexibility space-based communications systems.

2.0 Fundamentals of Communications Satellites

The fundamental function of a communications satellite is that of providing a communications link between two distant locations on the Earth, namely, a transmitting station and a receiving station [1]. The transmitting station launches a carrier signal, of a certain frequency f_1 , up into space in the direction of the satellite. The receiving station, on the other hand, is equipped to receive a carrier signal of another

frequency f_2 , from the direction where the satellite floats in space. In the simplest case, the satellite receives the carrier signal at the *uplink* frequency f_1 , translates it to the *downlink* frequency f_2 , and transmits it down to the receiving station. In general, the more uplink and downlink frequencies, and the more transmitting and receiving stations the satellite can link, the greater is its capacity and usefulness, but unfortunately, also the bigger is its required physical size (mass) and power consumption. Since mass is the primary driver of satellite costs [1], it becomes tightly coupled to the satellite's performance, ultimately playing a limiting role on it.

The Communications Satellite could be viewed as composed of two main parts [3], namely, a *platform* and a *payload*. The platform includes the following subsystems:

- 1-The physical structure
- 2-The Electric Power Supply
- 3-Temperature Control
- 4-Attitude and Orbit Control
- 5-Propulsion Equipment
- 6-Telemetry, Tracking and Command Equipment.

The payload, on the other hand, includes:

- 1-The receiving antenna
- 2-The transmitting antenna
- 3-All electronic equipment supporting transmission of carriers.

An examination of the mass and power distribution in a conventional geosynchronous satellite [2], reveals that the communications payload accounts for roughly one quarter of the spacecraft's dry mass, and that it consumes the most power of any single subsystem. Furthermore, within the payload, the

transmitters and antennas account for the bulk of the mass and the power consumption. These fractions are bound to increase even more when we consider satellite architectures which are now emerging as solutions to increasing user demands for satellite capacity and flexibility [1].

3.0 Satellite Architectures

An examination of the evolution of satellite architectures [1] shows a steady increase in sophistication, from the conventional single data rate relay satellite, consisting of a simple downconverter, to regenerative satellites with on-board signal processing and routing capabilities. This increased capacity and flexibility comes at the expense of increased hardware, hence, power, mass, and cost.

We believe that MEMS, through their impact on the Antenna System, will be an enabling technology for the realization of the wireless future paradigm, Figure 1, in which space-based systems will become part of a global communications grid. In this grid the satellite will link airborne users, naval/maritime users, home users, remote office users, public phone booths, VSAT terminals, digital cellular, personal communications network microcells, mobile users, etc, as well as be a node for intersatellite communications. The key to this future versatility lies on agile multi-beam, multi-frequency, lightweight antennas. The key antenna technology that will permeate the space-based wireless future is the phased-array antenna. In the next section we discuss how MEMS will impact such an antenna.

4.0 MEMS-Based Phased-Array Antenna

In simple terms, a phased-array antenna consists of a set of phase shifters or true time delay units that control the amplitude and phase of the excitation to an array of antenna elements in order to set the beam phase front in a desired direction. In a typical Ku-band 5-bit state-of-the-art phasor downlink module, Figure 2, each channel consists of a phase shifter, an attenuator, and a solid state power amplifier (SSPA), implemented in Microwave and Millimeter Wave Integrated Circuit (MMIC) technology, driving an array of antenna patches.

An examination of the measured performance of the individual blocks making up a channel reveals a

number of technology-related limitations, the most prominent of which has to do with the huge insertion loss, e.g. 10.5dB @14.5GHz introduced by a 5-bit phase shifter. The phase shifter, a state-of-the-art FET-based MMIC chip, despite offering wideband performance and small size, dominates the loss of the chain, thus placing an undue burden on the SSPA by demanding a higher gain and power consumption. These, in turn, drive the unit's power supply capability, heat sinking, and weight requirements. When one considers that typical full-scale phased-array antennas contain thousands of channels, it becomes obvious that such losses as exhibited by FET-based phase shifters are prohibitive. The fundamental reason for the high insertion loss associated with FET-based phase shifters lies on the inevitable device channel resistances: both the "open" channel resistance for the case of the low-impedance state, and the residual series resistance in the pinch-off channel, for the high-impedance case [4].

We believe what is needed are switches with ultralow insertion loss to minimize the use of SSPAs; which are capable of broadband operation to achieve versatility for diverse and simultaneous tasks; that possess high electrical isolation to minimize crosstalk effects; that possess ultralight weight (mass) to effect a lower cost per payload; and whose manufacturing is inexpensive. A realization of such a switch is the Deformable Microwave Micromachined Switched [5], Figure 3. The structure consists of a cantilever beam which, with no voltage applied to it, interrupts the path along a transmission line, and that when deflected, closes it. Preliminary results show that, in the DC-45GHz frequency range, the switch possesses an isolation greater than 25dB in the open mode, while keeping the insertion loss below 0.5 dB in the closed mode, Figure 4. Furthermore, a comparison of the performance of MEM and PIN-diode switches shows that MEM switches are far superior both in terms of insertion loss and isolation, as well as bandwidth, Figure 5. Therefore, it appears clear that brought to maturity, MEM switches, of the type shown here, are posed to become a dominant technology, in the not too distant future.

5.0 Conclusion

An example of the impact that MEMS technology can exert on space-based systems, in particular, Communications Satellites, has been presented. One

area where such impact has been illustrated is that of phased-array antennas. The low-insertion loss, high-isolation, and broadband properties of cantilever beam-type deformable microwave micromachined switches will have a tremendous impact on reducing the power consumption, mass, and indeed on the feasibility of future phased-array systems, thus enabling the realization of the wireless future paradigm.

6.0 References

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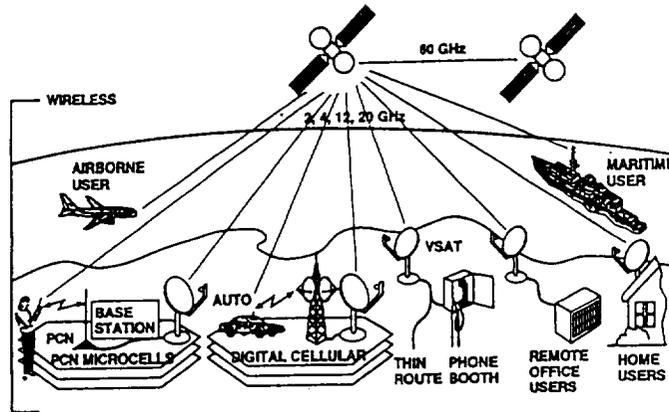


Figure 1. Wireless future paradigm.

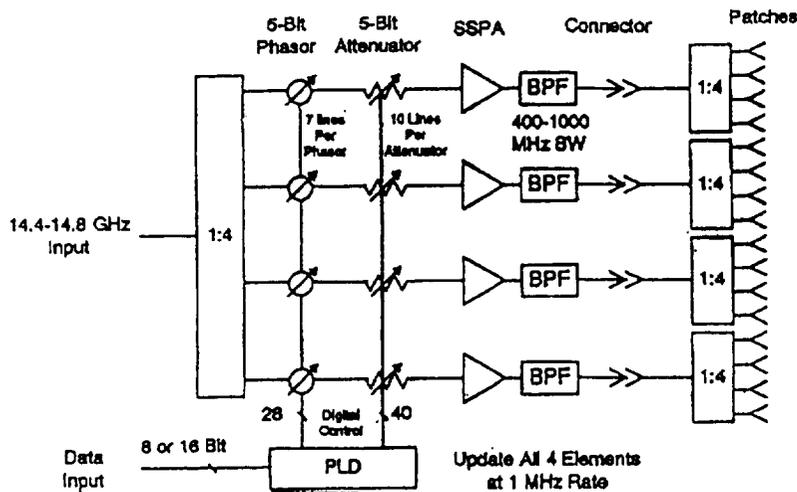


Figure 2. Five-bit phasor downlink module.

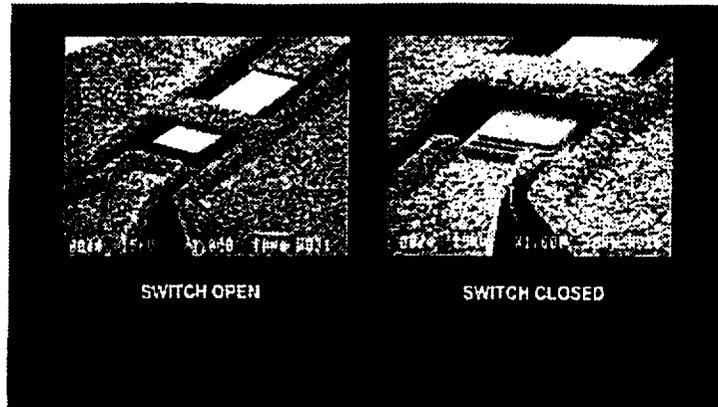


Figure 3. Deformable microwave micromachined switch.

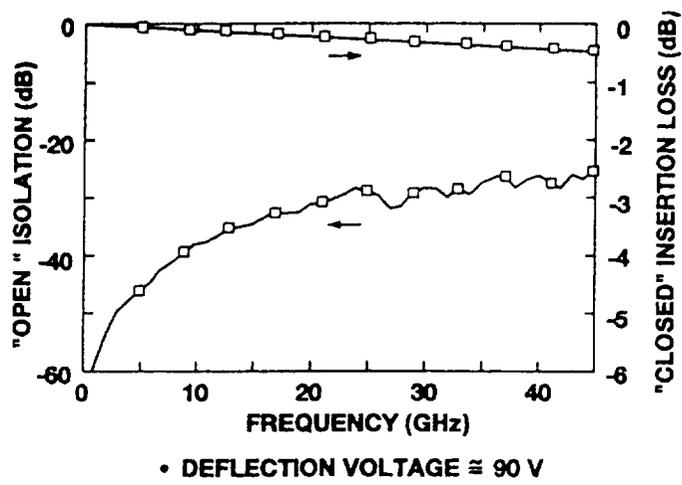


Figure 4. Experimental results of deformable microwave switch.

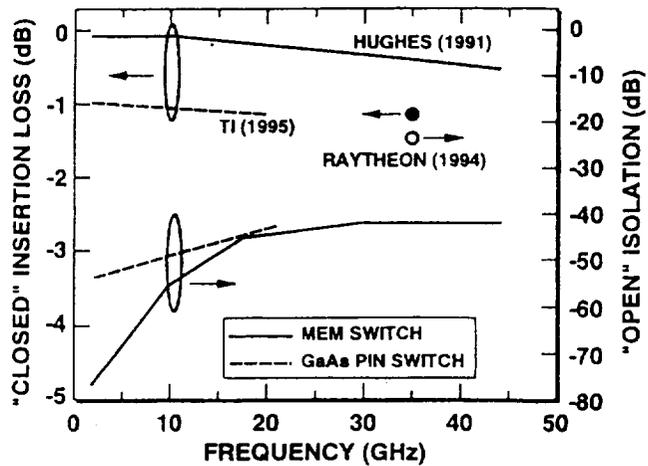


Figure 5. Comparison of insertion loss and isolation of MEM and PIN switches.