HISTORICAL PERSPECTIVES ON COMMERCIAL AND NON-MILITARY GOVERNMENT SPACE APPLICATIONS OF MICROWAVE SYSTEMS IN THE BALTIMORE/WASHINGTON AREA

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ABSTRACT

The Baltimore/Washington area has made significant contributions to commercial and non-military government space applications of microwaves. These include especially (both for experimental/proof-of-concept and for operation), design of communications satellite systems, satellites, payloads and hardware, and satellites for remote sensing, their payload and some hardware, and radiowave propagation on the slant (earth-satellite) path. Unique contributions include the ATS-6 satellite, the discovery and characterization of Gigahertz ionospheric scintillation, possibly the first electronically steerable phased array and the invention and implementation of the waveguide multimode filter.

INTRODUCTION

The non-military application of microwaves to space began in the Baltimore/Washington area with the onset of the space age, with the establishment first of NASA HQ in Washington DC, and Goddard Space Flight Center (GSFC) at Greenbelt, MD and then of Comsat in DC and Comsat Labs, first in DC and then at Clarksburg, MD. The Johns Hopkins University Applied Physics Laboratory (APL) in Columbia, MD, while initially concerned with military endeavors, has also contributed to the non-military side. Subsequently, other companies, such as INTELSAT, Hughes Network Systems, AMSC and Orion have arisen and played a significant role, while companies like Fairchild in Germantown, MD have contributed significantly. There are many entities, small and large in this area active in satellite-related microwave work, making the Baltimore/ Washington area second only to the Los Angeles in the USA and possibly the world.

* Addresses listed below

HISTORIC CONTRIBUTIONS

NASA HQ

The contributions of NASA HQ have been critical in moving microwave systems and hardware into space. While almost all of the implementation has taken place at the Centers, at the JPL and at contractors, many of the concepts, some of the preliminary design work and the force behind the programs have come from HQ. This is especially true of the experimental satellites such as the ATS series, and some of the critical microwave technology, such as radiowave propagation on the slant path. Another major contribution was their efforts with regard to frequency allocations, Reports and Recommendations at the ITU (at the CCIR [later ITU-R] and WARC meetings).

The ATS series of satellites first ventured into microwaves with the ATS 5 propagation experiment at Ku band. The ATS 6 satellite was a major success [1]. A portrayal is shown in Figure 1. The program was managed from GSFC. The satellite was built at Fairchild, in Gaithersburg, MD. One on-board microwave experiment designed at and managed from GSFC was measurement of rain- and cloud-induced attenuation at 20/30 Ghz using an on-

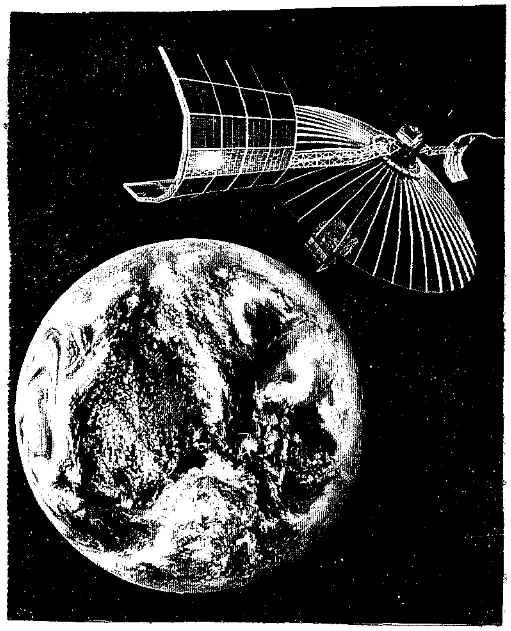

Figure 1. The ATS 6 Satellite

board beacon. Another such experiment employed a 13/18/4 Ghz transponder designed and built at Comsat Labs. The results of these measurements were used to develop rain attenuation models for locations in CONUS for frequencies above 10 Ghz. At L-band, the Position Location and Communicatons Experiment (PLACE) followed the UHF Transit satellite of APL in establishing the technology which led to the GPS (Global Positioning System) currently in world-wide use. At S-band, the ATS 6 deployed a 9 meter reflector that allowed 2-way video and voice for such applications as connecting remote sites in Alaska and Montana with the University of Washington for medical consultation.

This was followed by the CTS, a joint US/Canadian project, with 200 watt TWTs on board. The CTS thoroughly proved the feasibility of Ku band DBS in a series of experimental demonstrations starting in 1976.

The latest in this series is the ACTS, a 20/30 Ghz bird. It carries phased-arrray antennas, on-board processing and beam steering, and operates in both channelized and wide band-width modes. It successfully demonstrated the use of the 20/30 GHz bands from space, beam hopping, very high speed (almost gigabit) data rates over the slant path, and a wide variety of hydrometeor attenuation experiments.

COMSAT

Starting in the mid 1960's, Comsat was responsible for the design and operation of the Intelsat 2, 3 4, 4A, (using 4 and 6 GHz) 5 and 5A (using 4, 6, 11 and 14 GHz) satellites and the L-band Marisat satellites and the satellite communications systems rhat used them. These efforts established the fixed and maritime mobile satellite services world-wide. Its activities in the ITU have been critical to the allocations of frequency bands and the Reports and Recommendations required for world-wide operation of these services.

COMSAT LABS

Comsat Labs' microwave contributions have included both proof-of-concept and flight hardware, subsystems and systems as well as earth terminal antennas and feed systems - too numerous to even list. Outstanding contributions include microwave filters for channelization of satelites that minimized guard bands while providing flat response, sharp skirts, etc., etc. with a minimum of loss (very high Q), weight and volume. This work, at 4 GHz, has progressed through Tchebychef filters, with 4 Mhz guard bands and 36 Mhz pass bands in 1968, then to use of dual orthogonal modes per cavity in 1969 [2], to elliptic function filters, to self-equalized filters in dual-mode cavities to 3 and most recently 4 orthogonal modes per cavity, thus reducing weight and volume while maintaining all the other desirable characteristics. These filters have been built and flown at frequencies covering the micowave bands. Figure 2 compares the sizes of a 10-cavity Tchebychef filter used for channelization as noted above with two elliptic funtion dual-mode 8-cavity equivalent filters, each of which performs the same function. (The inventors of the dual-mode cavity filter, Drs. Atia and Williams, were recognized by the IEEE MTT-S with the 1996 Pioneer Award.) Comsat Labs also developed the first high Tc superconductor microwave filter [3]. This filter, built at MIT Lincoln Labs in 1991, uses a YBCO super-conductor on lanthium aluminate, operating at 77K. The advantage of such filters lies in their

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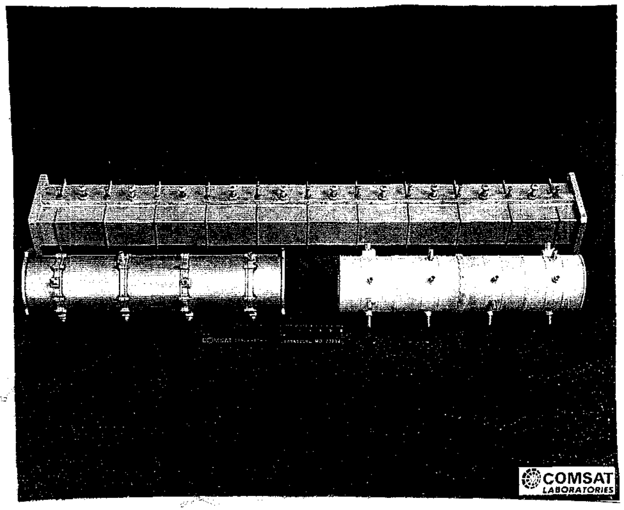

Figure 2. Size comparison of a Tchebychef filter to two dual orthogonal mode elliptic funtion filters

Q's, which are a whole order of magnitude greater than waveguide cavity filters. Advances in space-qualified cooling technology have brought such filters to the brink of deployment in space.

The Comsat Labs 13/18/4 Ghz transponder on ATS 6 was used by Comsat Labs to measure rain attenuation on the slant path from locations throughout the USA east of the Mississippi. Radiometer measurements of attenuation on the slant path at 12 Ghz and at 20/30GHz were conducted at many sites world wide. Comsat Labs built the Comstar 19/28 GHZ beacons. Rain depolarization measurements were conducted at 4/6 Ghz at several sites around the world. Comsat Labs participated in 20/30 GHz slant path rain attenuation measurements using the ATS 6, Comstar beacons and the ACTS. It accumulated a world wide data base on rain-induced impairments on the slant path used to develop models for predicting such impairments based on climate statistics.

In 1969, COMSAT encountered Equatorial GHz Iononspheric scintillation i.e. signal fluctuation[5] and then Comsat Labs measured it world-wide. This characterized it as a function of location vis-a-vis the geomagnetic equator, time of day and year and the solar cycle. Such scintillations occur in signals traversing the ionosphere for a band ± 12° about the geomagnetic equator, i.e. microwave signals on the slant path to geostationary satellites. They usually arise at sunset in the ionosphere, when the ionosphere is beginning to undergo diurnal changes, during the equinoctal seasons, and their frequency of occurrence and maximum amplitude follow the solar cycle. Comsat Labs also conducted measurements of tropospheric signal fluctuations at 4 and 6 Ghz at low elevation angles, world wide. These fluctuations are much slower than ionospheric scintillations.

Microwave antennas and related microwave hardware was another fruitful area of R&D at Comsat Labs. The torus reflector, invented in the late 1940's at the Naval Research Labs (also located in this region) was generalized, optimized and prototyped for use in earth terminals [4]. High polarization purity dual orthoganal polarization wide-band feeds, polarizers and orthomode transducers were developed, as well as multi-band dual orthoganal polarization feed systems. Finally, the first large scale non-military space-qualifiable Kuband phased array using GaAs (Gallium Arsenide) MMICs was developed.

Comsat Labs also embarked on the systematic development of GaAs MMICs for space applications. A first here was the development of an MMIC switch matrix, which could be qualified for space applications.

APL

APL made such contributions as the first large-scale microwave phased-array [6]. This array was developed for the AEGIS program. The earliest development was an 8x6 S-band phased-array which employed an electonically controlled broadband 4-bit latching ferrite phase shifter, shown in Figure 3, which was remarkable for its time, 1966. The AEGIS prototype array had 256 elements. It used a continuously variable S-band phase-shifter, developed in 1967, also very broadband.

APL was and is very active in remote sensing. Early work included the detection of clear air turbulence. Other contributions included the Ku-band radar altimeters for the Seasat,

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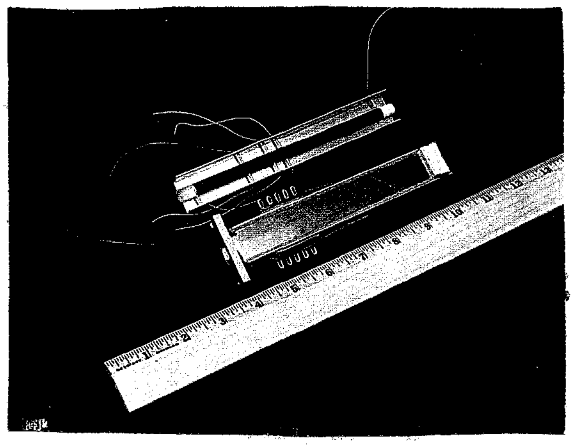

Figure 3 . Electonically controlled broadband 4-bit ferrite phase shifter

Geosat and TOPEX satellites used to measure sea state and elevation. The TOPEX altimeter is state of the art, providing the most precise measurements of sea surface to date.

APL also participated in numerous propagation experiments mentioned above. Further, they have participated in the characterization of the effects of buildings, vegetation and terrain on radio waves. Perhaps their most unique contribution has been to show how radar can be used to characterize rain attenuation on the slant path without use of a satellite. Reflection of radar signals at microwave frequencies by rain has been known from the earliest days of radar. But the use of radar to charaterize rain fall and rain rates is more recent. It entails modeling rain rates in terms of radar reflectivity. APL has contributed significantly to the development of accurate modeling for this phenomenon. This work will be used in the near future, using radar on board the TRIMM satellite as a remote sensor to measure rain from above.

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