The ACTS Multibeam Antenna

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Abstract—The Advanced Communications Technology Satellite (ACTS) to be launched in 1993 introduces several new technologies including a multibeam antenna (MBA) operating at *Ka*-band. The satellite is introduced briefly, and then the MBA, consisting of electrically similar 30 GHz receive and 20 GHz transmit offset Cassegrain systems—both utilizing orthogonal linear polarizations, is described. Dual polarization is achieved by using one feed assembly for each polarization in conjunction with nested front and back subreflectors, the gridded front subreflector acting as a window for one polarization and a reflector for the other. The antennas produce spot beams with approximately 0.3 degree beamwidth and gains of approximately 50 dbi. High surface accuracy and high edge taper produce low sidelobe levels and high cross-polarization isolation. A brief description is given of several *Ka*-band components fabricated for ACTS. These include multiflare antenna feedhorns, beam-forming networks utilizing latching ferrite waveguide switches, a 30 GHz HEMT low-noise amplifier and a 20 GHz TWT power amplifier.

I. INTRODUCTION

THE Advanced Communications Technology Satellite (ACTS), planned for launch in early 1993, will provide a demonstration of several new technologies.

ACTS was conceived in 1979 to help maintain U.S. leadership in satellite communications, and a number of proof-of-concept contracts for critical technologies were awarded in the following years. In 1984 the ACTS prime contract was awarded by NASA to RCA Astro with a major subcontract being awarded to TRW for the Multibeam Communications Package (MCP). In 1987 GE acquired RCA Astro and early in 1988 took the MCP subcontract in-house.

A number of experimenters have expressed an interest in making use of the special features provided by ACTS, and at present a 2-year experiment period following launch has been funded. The satellite carries enough fuel to maintain station-keeping for 4 years, and it is possible that the experiment period will be extended.

It is the purpose of this article to acquaint the reader with the ACTS Multibeam Antenna (MBA) and associated *Ka*-band microwave components. We begin, however, with a general description of the satellite.

II. THE ACTS SATELLITE AND TRANSPONDERS

ACTS is designed to be launched by the space shuttle and has been assigned an orbital slot at 100 degrees W. longitude in geostationary orbit. Fig. 1 is a photograph of
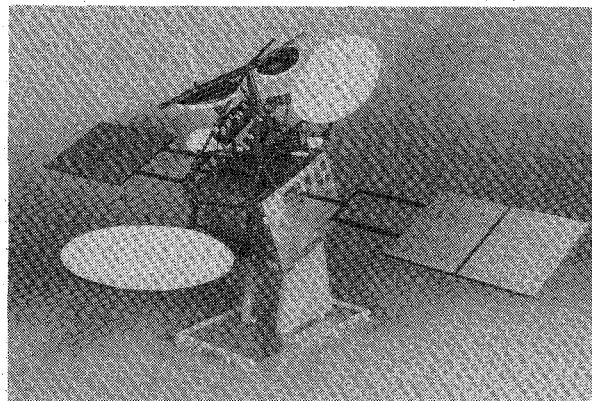
Fig. 1. Photo of accurate model of ACTS—Prominent are the solar panels and the 20 GHz transmit (left or west side) and 30 GHz receive multibeam antennas, including main reflector, nested front and back subreflectors and feed assemblies. Also visible are the steerable beam antenna on the South side and *Ka*-band tracking, telemetry and command antennas on the North side. A *C*-band TT&C omni antenna can also be seen atop the transmit subreflector assembly.

an accurate model of the spacecraft in its deployed, on-orbit, configuration. Prominent on the spacecraft are the receive and transmit MBA's, offset Cassegrain antennas with 2.2 and 3.3 meter diameter main reflectors, respectively. On-orbit the spacecraft is oriented so that the receive reflector is on its east side and the transmit on the west. On the north and south sides are solar panels, which rotate about the spacecraft once each 24 hours so as to keep their surfaces facing the sun.

Also visible are three other antennas. On the south side of the spacecraft is the 1.1 meter diameter steerable beam antenna which, though having lower gain than the MBA, can be directed toward any part of the earth's surface visible from the satellite and beyond the horizon to low-earth-orbit. The maximum slewing rate for this antenna is 1 degree/minute—high enough to track the space shuttle. On the north side are two single-reflector *Ka*-band antennas with beamwidths broad enough to cover the continental U.S. These are used for tracking, telemetry and command (TT&C). Finally, atop the transmit subreflector assembly can be seen the *C*-band omni antenna—also a TT&C antenna, to be used in transfer orbit and also as a backup during normal operation.

During launch the main reflectors, the solar array panels and the *C*-band omni antenna are all stowed in a more compact and rigid configuration.

When the satellite is in operational orbit the attitude control system makes use of momentum wheel assemblies and magnetic torquers to maintain three-axis stabilization

[1]. When the transponders are operational, error signals derived from an autotrack system are supplied to the attitude system processor to meet the 0.025-degree pointing accuracy requirement. At other times an earth-sensor assembly provides error signals to maintain a lower degree of pointing accuracy.

Key features of the ACTS system are: the use of on-board processing and switching, the use of rapidly switched multiple-spot-beam antennas, the use of Ka-band transmission—making possible the utilization of wider bandwidths than are available at lower frequencies but also entailing greater susceptibility to rain-fade attenuation, and the use of rain-fade compensation.

Aside from the MBA and Ka-band components, the ACTS technologies new to a communications spacecraft are: a microwave switch matrix with 900 MHz bandwidth, a baseband processor with memory, and adaptive rain-fade compensation utilizing burst-rate reduction and forward error correction, independently invoked on uplink and downlink.

Fig. 2 is a block diagram of the ACTS Multibeam Communications Package. This package consists of receive and transmit multibeam antennas, which are the subject of the next section, and four transponders. The transponders consist of 29–30 to 3–4 GHz downconverters, either of two types of switching, and 3–4 to 19–20 GHz upconverters with TWT output amplifiers.

No more than three transponders will be used at any time, the fourth constituting a spare.

Either of two switching modes may be used [2]. These are the microwave switch matrix and the baseband processor (BBP). Both normally utilize a time-division multiplexed signal with a 1-millisecond frame interval and serial minimum-shift keying (SMSK). SMSK is spectrally efficient, having a null-to-null bandwidth of 1.5 times the symbol rate. It also has a constant envelope, making possible the use of saturated amplifiers.

The microwave switch matrix normally operates in conjunction with the three trunking beams—Cleveland, Atlanta and Tampa. The system is designed to operate at 220 Mbps SMSK, but other rates are also possible. This mode involves no storage or regeneration of signals, so the transponders may handle other types of modulation as well.

In the alternate mode, the baseband processor demodulates and stores received signals from each of two hopping beams. A baseband switch within the BBP interconnects two uplink with two downlink beams by routing data from input to output storage locations. The data is subsequently read out of storage, modulated, and transmitted on a downlink beam. The data rate is typically 110 Mbps.

Although BBP switching is more complex than IF switching, it offers several advantages [3]. Its ability to reconfigure message routing makes it more efficient in using system capacity in situations with many isolated terminals, and it also makes possible the use of forward error-correction and burst-rate reduction to compensate for rain-fade on particular paths.
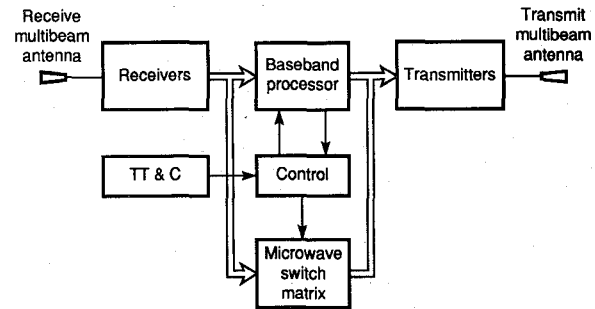

Fig. 2. Block diagram of the ACTS Multibeam Communications Package.

III. THE MULTIBEAM ANTENNA

The ACTS MBA consists of two offset Cassegrain antennas, one transmit and one receive, and an antenna support assembly. The two antennas are nearly identical RF-wise, with the larger 20 GHz transmit main reflector having a diameter of 3.3 meters and the smaller 30 GHz receive reflector a diameter of 2.2 meters. Aside from a common antenna support assembly each antenna consists of three major sections: a main reflector, an assembly consisting of one front and one back subreflector, and a pair of feed assemblies, one having horizontal, and the other vertical, polarization [4].

Because of its high strength, light weight, and low coefficient of thermal expansion, graphite epoxy finds wide use in the MBA. The entire MBA weighs about 900 lb (408 kg) with the antenna support assembly, fabricated from graphite epoxy tubes with titanium fittings, making up about half this weight.

The basic geometry of the two antennas is shown in Fig. 3.

ACTS utilizes the frequency ranges 29.0–30.0 GHz uplink and 19.2–20.2 GHz downlink. Re-use of the same frequency band without interference is made possible, in some cases by spatial separation of low-sidelobe beams, and in other cases, where beams need to be in close proximity, by the use of orthogonal polarizations.

ACTS is an experimental prototype of an operational communications system and incorporates three different types of beam: 3 fixed or trunking beams, 13 switched spot beams, and 34 switched triplet spot beams. The trunking beams, which usually operate in conjunction with the microwave switch matrix, achieve isolation through spatial separation. The triplet and spot beams normally operate in conjunction with the baseband processor and are designed to provide continuous coverage of two adjacent scan areas constituting about 20% of the area of the continental US, as well as additional isolated metropolitan areas. This coverage is shown in Fig. 4, which also shows an example of the larger-area but lower-gain coverage of the separate steerable-beam antenna. The polarization shown is uplink. Downlink polarization is in all cases orthogonal to uplink.

The use of spot beams makes possible antenna gains about 20 db's higher than would be possible for a single beam covering the continental U.S. In the scan areas and

Fig. 3. ACTS Multibeam Antenna geometry.
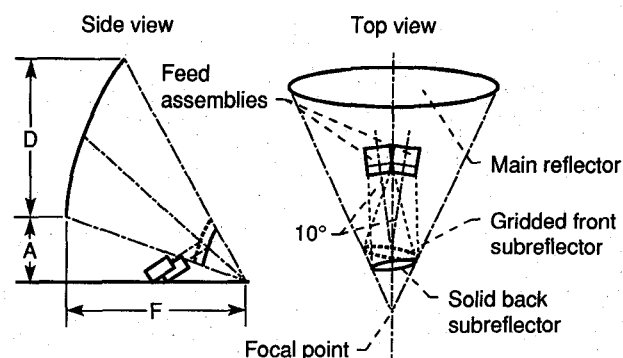
Parameter	20 GHz	30 GHz
D (Main reflector diameter, inches)	129.9	86.6
A (Offset distance, inches)	50.0	44.0
F (Main reflector focal length, inches)	132.0	88.0
Gridded front subreflector		
Focal length, inches	69.0	44.5
Magnification factor	2.0	2.0
Solid back subreflector		
Focal length, inches	52.4	32.4
Magnification factor	2.0	2.0

West Hopping Beam
East Hopping Beam
Fixed Beams
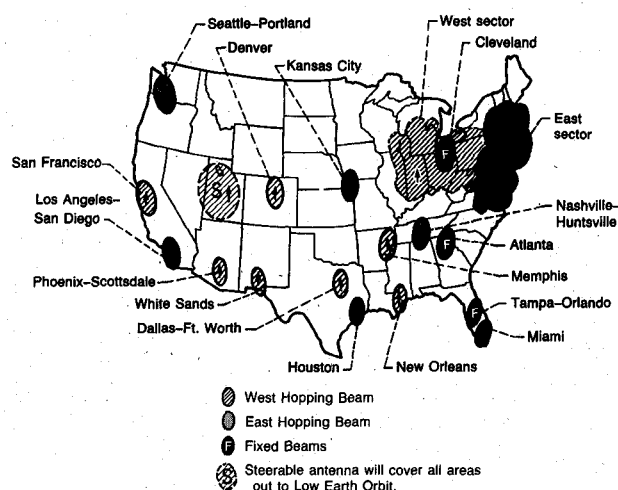Steerable antenna will cover all areas out to Low Earth Orbit.

Fig. 4. Geographical coverage of ACTS Multibeam Antenna—example of steerable antenna beam also shown. Polarizations indicated are uplink. Downlink polarizations are opposite.

between scan spots, beams are switched by switching feed horns—in a manner analogous to switching between high and low beams in an automobile headlight. In the case of continuous scan area coverage, triangular triplets of three feed horns are used, and one horn may at different times be a constituent of more than one beam.

Because the transmit and receive antennas are offset from the spacecraft in opposite senses, the transmit and receive antenna patterns, though similar are not identical. Scanning away from boresight causes some gain loss— about 2 db for West Coast beams.

A. Reflectors and Subreflectors

The ACTS MBA incorporates a total of six main reflectors and subreflectors. High surface accuracy of these reflectors is critical to the RF performance of the MBA.

The largest of these units is the 3.3 meter 20 GHz transmit main reflector. This was formed on a precision mold and consists of 6-ply graphite epoxy front and back facesheets separated by a kevlar honeycomb core. The reflector shell is supported by a backing rib structure of similar construction. This reflector weighs about 80 lb (36.4 kg) and has an rms surface accuracy of 3 mils (0.075 mm). The 30 GHz receive main reflector is similar in construction, weighs about 30 lb (13.6 kg), and has the same surface accuracy. The transmit and receive back subreflectors are also similar in construction but are, of course, hyperboloidal rather than paraboloidal.

The construction of the front subreflectors is very different. Because the front subreflector is required to transmit RF at one polarization and to reflect the orthogonal polarization, it is necessary to make the basic reflector as transparent to RF as is consistent with mechanical rigidity. The front subreflector shells are formed from Astroquartz facesheets and nomex core, each shell having a thickness of approximately three-quarters of a wavelength at the frequency in question. There is no ribbing behind the central section of the subreflector, but a peripheral rib provides rigidity. Each front subreflector has formed copper gridding on its front facesheet to serve as a polarization-selective reflector. The 2-way insertion loss of each front subreflector is below 1 db. Reflection loss is about 1/4 db.

It was at one time planned that the reflecting surfaces of the main reflectors and the back subreflectors should be metallized. However, it has been determined that the conductivity of the bare graphite surface is high enough to ensure adequate performance. To limit temperature excursions the reflecting surfaces of all reflectors and subreflectors are coated with low-insertion-loss thermal paint.

Fig. 5 is a photograph showing a portion of the MBA during testing. Clearly seen are the nested front and back transmit and receive subreflectors, the receive main reflector, and also three of the four feed assemblies. Included in the photo is some non-flight material, such as bubble wrap on the antenna support assembly and tooling balls in the apertures of some of the feed horns.

B. Feed Assemblies and Beam-Forming Networks

The four feed assemblies are basically graphite epoxy boxes containing a number of Ka-band components, including beam-forming networks (BFN's), feed horns, and the latching ferrite switches which are found both in the BFN's and elsewhere in the feed assemblies. Also included are the electronics boxes needed to drive the ferrite switches. Each feed assembly operates with a single polarization. To provide both vertical and horizontal polarization, transmit and receive, requires four feed assemblies.

A transmit BFN is a waveguide network whose function is to receive RF power at a single waveguide junction and deliver it divided 3-ways but in-phase, to a selectable triplet of waveguide flanges.
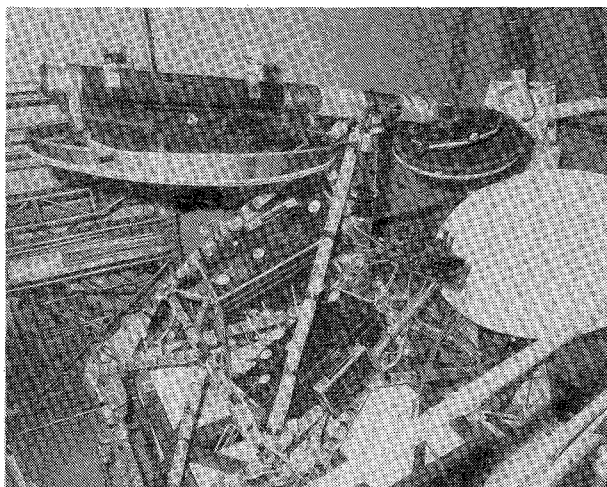
Fig. 5. Photo showing a portion of the ACTS MBA during testing—visible are the 2.2 meter receive main reflector, transmit and receive nested front and back subreflector assemblies and 3 of the 4 feed assemblies. Antenna support assembly tubes are covered with bubble wrap, and there are tooling balls in the apertures of some of the feed horns.

A receive BFN operates in the reverse sense, equally weighing in-phase input signals from a selectable triplet and combining them into a single signal at an output waveguide flange.

Each BFN consists of a 3-way power divider (or combiner), sections of waveguide with bends and step-twists, and ferrite switches. The BFN is designed so that all RF path lengths are accurately matched to insure in-phase operation of all horns in a triplet beam. The West BFN's provide 19 flanges and make possible the selection of 22 triplet beams while the East BFN's use 12 flanges to make possible the selection of 12 beams. The BFN's were fabricated under a subcontract with Electromagnetic Sciences of Norcross, GA.

Fig. 6 is a schematic diagram of the transmit West BFN and spot beam network. The receive West schematic diagram is identical. Fig. 7 is a photo of the engineering model of the receive West BFN. The 3-way power divider, gold-plated electroformed copper waveguide sections, ferrite switches, waveguide loads, and triplet flanges can all be seen. Also visible are the flex cables, low characteristic impedance, parallel flat-conductor transmission lines, used to provide the high-current pulses required to operate the ferrite switches.

The 3-way power dividers are 6-port networks with 2 of the ports being internal resistive loads. This is analogous to the use of a magic-T with a matched resistive load on the series port (a 4-port network) as a 2-way power divider, to provide a better match than is possible with a simple waveguide T. The ferrite switches are latching 3-port waveguide circulator switches whose sense of circulation is established by the polarity of a current pulse through a single latching wire loop. These switches have low insertion loss (about 0.1 db), low mismatch loss, and better than 18 db isolation across a 1 GHz bandwidth. Insertion loss is about 1 db for the 30 GHz receive BFN's and is lower for the 20 GHz transmit units.
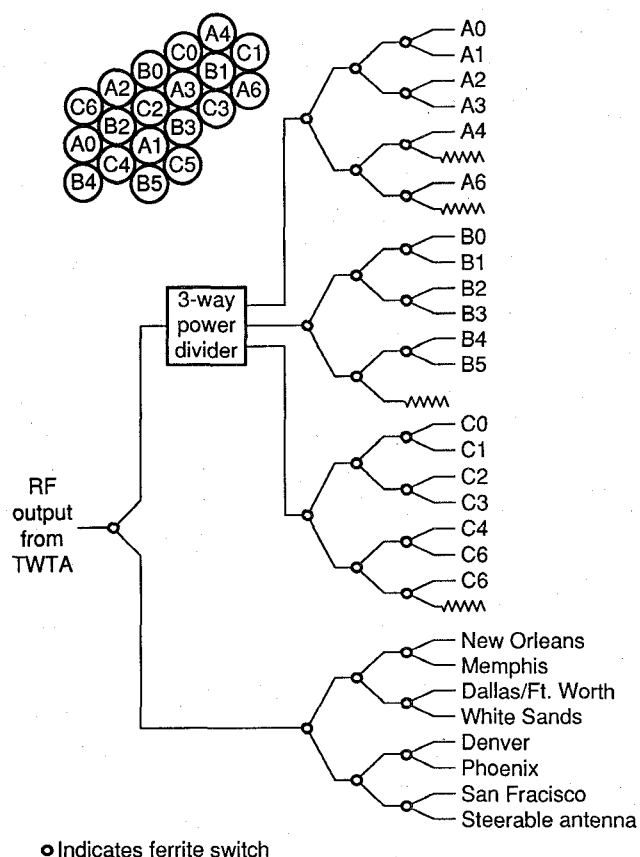

Fig. 6. Schematic diagram of transmit West Beam-Forming Network—receive west is similar.
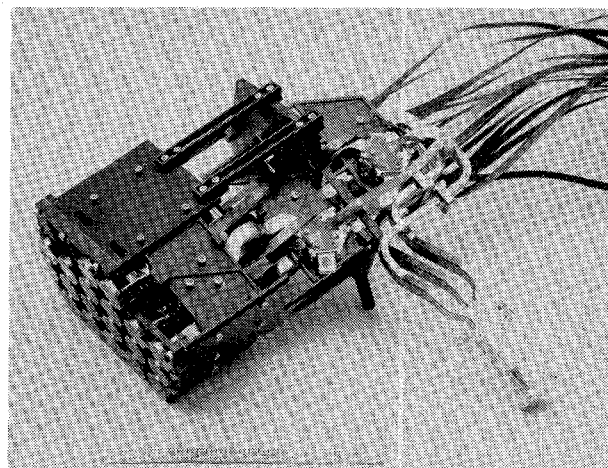

Fig. 7. Photo of engineering model of Receive West Beam-Forming Network—visible are the 3-way power divider, electroformed waveguide sections, ferrite waveguide switches and 19 feed horn flanges. The flex cables used to transmit latching current pulses to the ferrite switches can also be seen.

The feed assemblies incorporate three different types of feed horn [4]. These are illustrated in Fig. 8. Not shown are the transitions from rectangular to circular waveguide. Fig. (8a) shows a multiflare horn designed to provide the circularly symmetrical primary pattern needed to provide efficient illumination of the reflector. This horn is used for the three trunking beams and provides an edge taper of −17 db at ±13 degrees, resulting in very low sidelobe
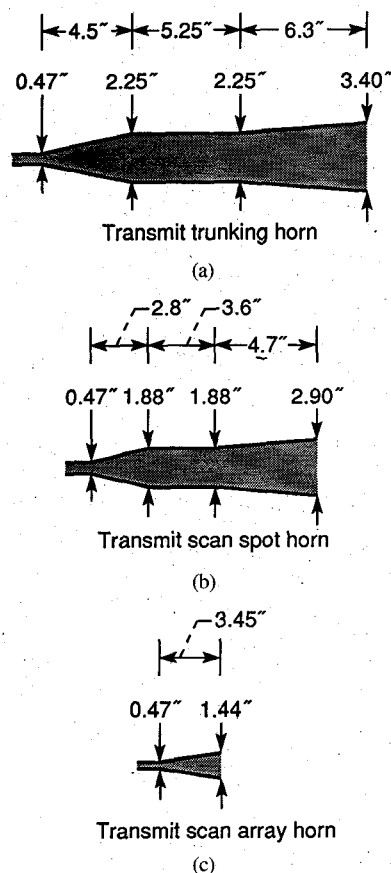
Fig. 8. Diagrams of the three types of Transmit Feed Horns.

levels, more than 30 db below peak at 2 half-power beamwidths from peak. A multiflare horn was chosen in preference to either a dual mode horn or a corrugated horn, both capable of good symmetry, because of the narrow bandwidth of the former and the weight and manufacturing difficulties of the latter.

Fig. 8(b) shows the multiflare horn designed for the scan spot beams. It is similar to the trunking horn, except for an edge taper of -10 db at ± 13 degrees. The scan array horns, Fig. 8(c), are simpler single flare horns with an edge taper of about 3 db.

C. Gain and Efficiency

The expected peak gains of the transmit and receive spot and trunking beams range from 48 to 54 dbi, with the lower gains being for West Coast beams, where the scanning loss is greater. The minimum gain, transmit and receive, over the entire East and West scan sector areas is expected to be about 47 dbi.

The expected efficiency of the antenna is of the order of 50%.

IV. OTHER Ka-BAND COMPONENTS

A number of new 20 and 30 GHz components have been developed specifically for ACTS. In addition to those already described in conjunction with the MBA, these are: a 30 GHz low-noise amplifier, a 20 GHz travelling-wave

tube power amplifier, and 20 and 30 GHz waveguide filters. These are briefly described below.

A. 30 GHz Low-Noise Amplifier

The ACTS low-noise amplifier contains a 3-stage high-electron-mobility transistor (HEMT) amplifier which, together with a diode-ring mixer and associated units, comprise the downconverter, whose function it is to translate the 29–30 GHz received signal to a 3–4 GHz IF.

The HEMT's are made by GE Electronics Laboratory and are one-quarter micron gate AlGaAs/GaAs units. The individual HEMT's have a noise figure of 1 db maximum and a gain of 11 db minimum. All are from the same lot but the quietest are selected for the first stages.

Each 3-stage amplifier has a rated noise figure of 3.4 db, beginning-of-life, and 3.6 db, end-of-life, and a gain of 20 db.

B. 20 GHz Travelling-Wave Tube Amplifier

The ACTS downlink power amplifiers are Watkins-Johnson WJ3712-4 TWT's. The performance of this tube is optimized for data communication. The tube operates in the saturated mode with a power output of at least 46 W and a gain of over 50 db. This tube has a dual-stage depressed collector and an M-type dispenser cathode capable of a 10-year life. It has an efficiency of greater than 42%.

C. Waveguide Filters

The receive image/beacon reject filter is a cascade of a reduced-width waveguide for image rejection and a 4-pole circular cavity waveguide filter of invar construction to reject the so-called uplink fade beacon—actually a downlink beacon on the spacecraft, used to facilitate ground measurement of uplink frequency propagation conditions. This filter has an insertion loss of less than 0.2 db from 28.9–30.0 GHz and a rejection of greater than 35 db from 21.9–23.0 and at 27.505 GHz.

The transmit waveguide filter is a cascade of a 6-section, electroformed copper waffle-iron band-pass filter and an invar 3-pole circular cavity notch filter. It has an insertion loss of less than 0.5 db from 19.2–20.0 GHz and rejections of greater than 50 db from 0–13 GHz, greater than 40 db at the downlink telemetry and beacon frequencies of 20.185 and 20.195 GHz, and greater than 50 db in the 29.0–30.0 GHz uplink communications band.

V. CONCLUSION

The expected growth in satellite communications in the coming years will require the extension of existing capabilities. ACTS represents an important advancement in these capabilities in several respects, and it is anticipated that ACTS will provide an important impetus to the future use of the Ka-band and multibeam antennas in communication satellites.

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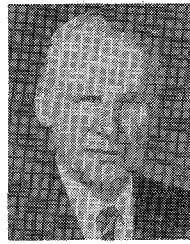
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He worked as an electronics technician at Boeing Airplane Co. in Wichita, KS, and subsequently in the U.S. Army during the Korean War. From 1957 to 1964 and from 1968 to 1984 he was a faculty member in the Department of Electrical Engineering at the American University of Beirut in Lebanon.

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