DESIGN OPTIMIZATION OF A SATELLITE COMMUNICATIONS SUBSYSTEM

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ABSTRACT

This paper covers technology and design features used in current satellite communications subsystems to improve weight, size and performance. Low-noise receivers in MIC form, lightweighted multiplexers, solid-state power amplifiers and antennas with beam shaping and capable of polarization frequency reuse are discussed.

Introduction

A simplified block diagram of today's microwave communications subsystem for communications satellites, is shown in Figure 1. It consists of a receive antenna, a wide-band receiver, channelizing (input) multiplexing filters, power amplifiers, recombining (output) multiplexing filters, and a transmit antenna. This general form was established by the Intelsat series of satellites beginning in 1965 and gradually underwent modifications in the number of transponder channels and in overall complexity. With technological advances and design optimizations, there have been significant improvements in total traffic capacity and in efficient useage of the available frequency spectrum. By way of comparison, the initial Intelsat I in 1965 (Early Bird) provided 240 telephone message circuits in two transponder channels within 50 MHz at 6/4 GHz. The Intelsat IV in 1971 provided a capacity of 12,000 circuits in a single carrier/FDM/FM mode of operation in 12 transponder channels within a 500 MHz bandwidth;[1] the RCA Satcom launched at the end of 1975 provided up to 20,000 circuits in 24 transponder channels within the same 500 MHz bandwidth.[2] In addition to these advances within the 6/4 GHz band, the 14/12 GHz band has recently been put to use. Because of fewer flux density restrictions at 14/12 GHz, and taking advantage of smaller antenna sizes, new traffic, such as direct TV broadcast, are becoming realizeable. In addition, there are increased applications for data communications.

This paper will discuss some of the technology and design features used in current satellite communications subsystems to improve weight, size and performance.

Transponder Subsystem

Receiver

In the wideband receiver, the input thermal noise has been reduced through the use of transistor preamplifiers and parametric amplifiers. The required linear output power handling capability has been achieved in solid state form using silicon bipolar and gallium arsenide (GaAs) field effect transistors (FETs). A receiver, for use in a 14/12 GHz transponder and consisting of a 14 GHz paramp, a 14/12 GHz image enhancement mixer, a low noise 12 GHz FETA and a single-ended linear 12 GHz FETA, has a measured gain of 68.5 dB including switch and hybrid losses associated with redundancy. The noise figure controlled by the paramp is 5.1 dB maximum. The linearity is determined by the linear 12 GHz FETA which is shown in Figure 2. Values of third order output intercept point of +28 dBm have been achieved.[3]

Current work is now directed towards increased use of GaAs FETs and towards realizing the entire receiver in microwave integrated circuit (MIC) form which can reduce the weight and volume by a factor of approximately 2.5. Fourteen GHz FETAs using 0.5 micron gate FETs are yielding room temperature noise figures better than 4 dB (see Figure 3). This is very close to uncooled paramp performance and is suitable for most applications.

Multiplexers

In multiplexers, substantial weight reduction has been achieved through the use of ultra lightweight fibre reinforced epoxies, such as graphite fibre epoxy composite (GFEC), as the basic waveguide material. With appropriate processes and material controls, the GFEC has been plated and provides equivalent surface finish loss and temperature stability as plated invar but at less than half the weight. An all-GFEC output sexaplexer built for a 6/4 GHz transponder and consisting of five-pole Chebyshev filters in WR229 waveguide mounted on a common manifold weighs 3.8 lbs. The same sexaplexer using invar with waveguide walls weight-relieved to a thickness of approximately 0.02 inch would weigh 9.5 lbs. Input multiplexers using quasi elliptic function filters in circular waveguide, such as shown in Figure 4, have also been fabricated in GFEC for 6/4 GHz transponder use.[4] The weight of an input triplexer in this form was 1.95 lbs. For a 12-channel transponder, the total saving in weight is at least 10 lbs compared to weight-relieved invar triplexers.

More advanced multiplexer configurations to reduce loss and to implement contiguous channel filtering, are now being developed. Low loss techniques, such as the use of circular TE_{011} mode or multiple half wavelength dominant mode are needed especially for 12 GHz narrowband channels. Typical unloaded Q obtained with the low loss circular TE_{011} mode is 16,000 at 12 GHz while a figure of 12,000 is realizable with dual dominant mode in five half-wavelength cavity filters. Figure 5 shows the isolation characteristic of a 54 MHz six-pole dual mode quasi elliptic filter operating in the TE_{105} mode in square WR90. The midband loss of this filter is around 0.5 dB. This is less than half the loss that would be obtained using conventional rectangular waveguide techniques. This loss could be further reduced by about 0.2 dB if the low loss TE_{011} circular mode is used to realize an elliptic function response.

Power Output Stage

In the power output stage, the travelling wave tube amplifier (TWTA) has been used almost exclusively. The major

CH1355-7/78/0000-0251$00.75

TWT development has been the multi-stage depressed collector design which yields tube dc to RF efficiencies greater than 40% compared to less than 30% using conventional designs. A two-stage depressed collector TWTA to be used in a 14/12 GHz transponder provides 20 watts of saturated output power with 57 dB gain, a very low nonlinear distortion AM/PM conversion factor of 1.75 degrees/dB, and an efficiency of better than 31%.[5] The TWT efficiency is better than 40%. TWTs with three-stage collectors are now being designed with even better efficiency. In spite of this very attractive performance, considerable work is being directed towards developing solid-state replacements for the TWTA using primarily high power GaAs FETs in order to achieve lower weight and higher reliability. Four watt and 0.5 watt devices are now available at 4 GHz and 12 GHz respectively.

Antenna Subsystem

In antenna technology, advanced fibre reinforced epoxies have been used extensively to achieve significant lightweighting with the required RF performance and thermal stability. Special techniques have been developed to achieve more efficient use of the available satellite bandwidth through polarization frequency reuse and beam shaping. In a 6/4 GHz 24-channel design, shown in Figure 6, GFEC was used in the feedhorns, waveguide runs and feed support structure.[6] The antenna reflector was fabricated of an all-Kevlar fibre reinforced epoxy sandwich construction. Using a unique 50% overlapped gridded reflector design, it was possible to realize dual polarization frequency reuse of the available bandwidth. The measured polarization isolation was 33 dB minimum. The antenna weight for an assembly which included four reflectors, six feedhorns, all the support structure, waveguide runs and miscellaneous interface hardware was only 52 lbs. In another 6/4 GHz design for an all-Canada coverage application, multiple feedhorns with a single reflector were used with a unique beam-forming network for optimum beam shaping. The measured gain over the coverage area for this antenna was 27.1 dB receive and 28 dB transmit and the antenna weight was 40.6 lbs.

Work is now involved with achieving further antenna optimization through, for example, the use of very large numbers of feedhorns with complex beam-forming networks capable of combining frequency reuse, high polarization isolation techniques with high coverage gains. Typical performance parameters are Canadian coverage receive gain of 33 dB, shaped dual mode transmit spot beams with edge gains of 38.5 dB and isolation between orthogonal polarization of 33 dB, with 100% overlapped gridded reflectors operating in the 14/12 GHz bands.

References

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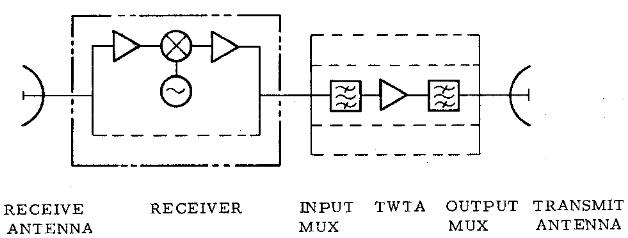

FIGURE 1: COMMUNICATIONS SUBSYSTEM BLOCK BLOCK DIAGRAM

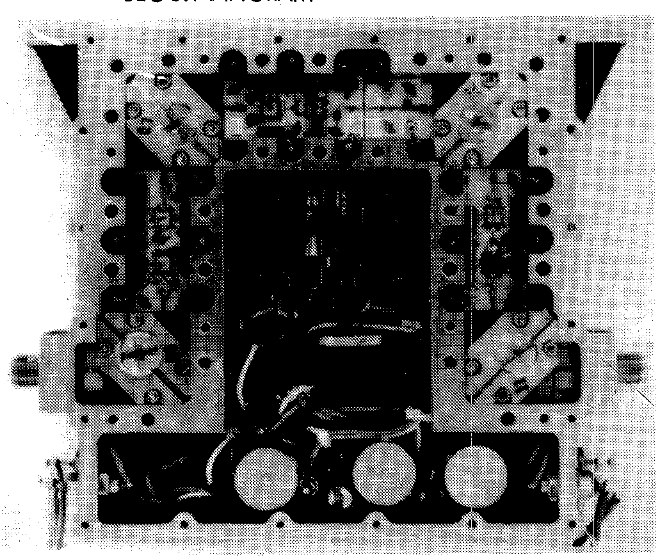

FIGURE 2: 12 GHz FET AMPLIFIER

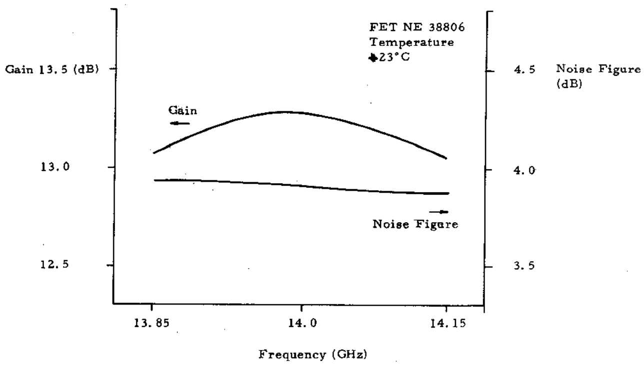

FIGURE 3: GAIN, NOISE FIGURE OF TWO-STAGE 14 GHz FET AMPLIFIER

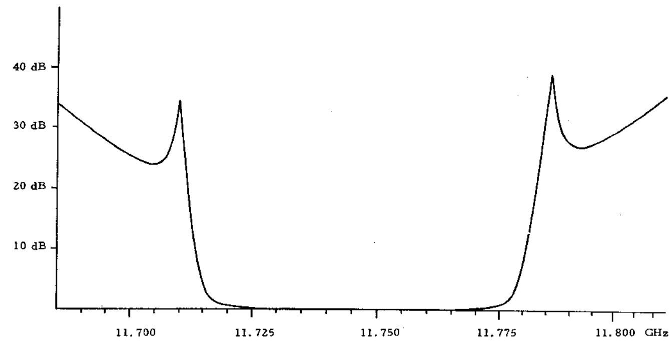

FIGURE 5: MEASURED OUT-OF-BAND RESPONSE OF SIX-POLE DMQE TE_{105} FILTER IN SQ WR90

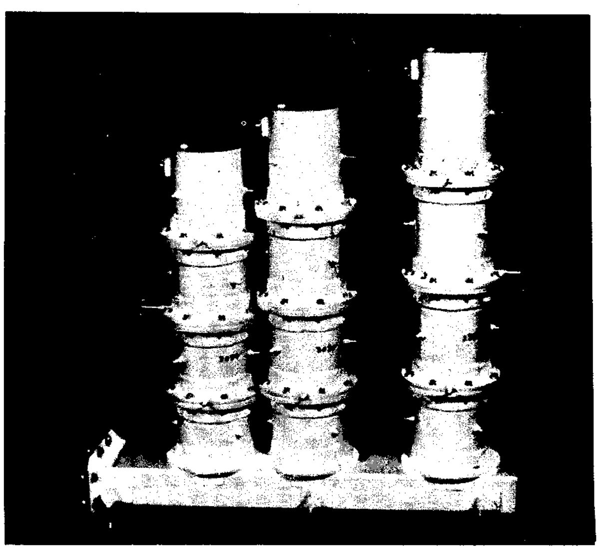

FIGURE 4: 4 GHz DMQE TRIPLEXER IN GFEC

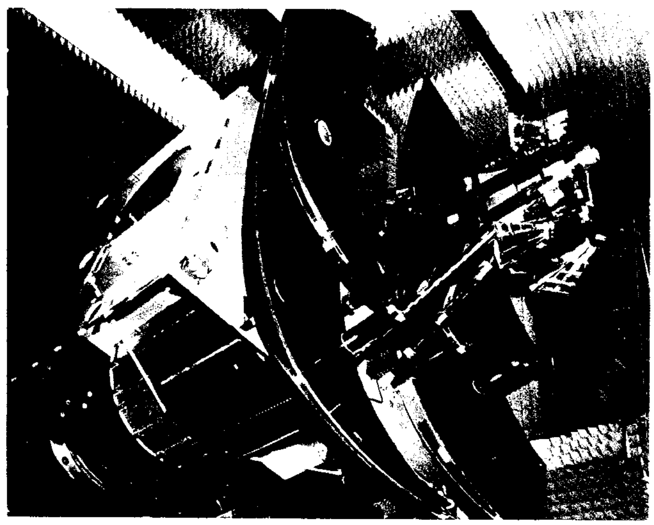

FIGURE 6: 6/4 GHz SATELLITE ANTENNA