EIRP OF THE SATCOM CABLE TELEVISION SPACECRAFT

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This paper will describe the field test program undertaken by RCA Americom to establish the EIRP of its F1 Spacecraft now in orbit. This satellite is used primarily for cable television program distribution. The study was performed as a service to the industry in order to provide actual EIRP measurements as opposed to calculated predictions. The results of that exercise will be presented and suggestions for prudent system designs for users of the Satcom Spacecraft will be put forth. This paper will also address the design of the Americom F3 Spacecraft to be launched in the fourth quarter of 1979. Enhancements incorporated for the benefits of the cable television community will be presented and projected contours will be shown. RCA Americom plans to provide actual EIRP measurement results for future satellites used by this industry.

Background

Until June of 1978 all programming for the cable television industry's receive only video services had been provided on the RCA F2 spacecraft located at 119^{o} West Longitude. However, because of the phenomenal growth being experienced by the industry and the even greater progress anticipated for its future, it became obvious that greater space segment capacity was required. A decision to move the cable traffic from the F2 to the F1 spacecraft located at 135^{o} West Longitude was made early in the first quarter of 1978. The purpose of this decision was to make available a greater number of transponders for program material since 12 of the 24 transponders on F2 were dedicated to Alaskan service.

The transfer of the cable traffic was successfully completed by June, 1978. As expected, difficulties were encountered by some cable systems, particularly in the southeastern states, where the signal level from F1 is lower than from F2. In a number of these locations, the measured F1 signal levels appeared to be lower than the calculated values which had been published.

These difficulties led to a decision to undertake a systematic measurement program which would result in a set of measured EIRP contours. These contours would provide cable operators, consultants, and earth station manufacturers more precise data upon which to base the specification of earth station G/T performance at specific locations. This is a useful service to the cable industry, and RCA Americom plans to continue it as future satellites are launched which will serve cable systems.

This paper describes the F1 and F2 measurement program, but before providing the details of that effort it is worthwhile to consider what EIRP is and the reason for its importance.

EIRP

EIRP is an acronym for Effective Isotropic Radiated Power. An isotropic radiator is one which radiates its power equally in all directions. However, a communications satellite's energy is concentrated by a parabolic antenna so that illumination is restricted to a specific desired portion of the earth's surface. EIRP is computed by adding the output power of the final amplifier (Traveling Wave Tube) of the transponder less any losses due to waveguide, coax, and switches, etc. to the gain of the satellite antenna in a particular direction. Thus, EIRP is the power that would have to be radiated by an isotropic radiator to provide the same illumination in a given direction as is accomplished by the spacecraft. The line connecting all points of equal EIRP in a projection is called a contour. It is not the power at the surface of the earth, which will vary due to path loss differences, atmospheric absorption, weather conditions, pointing accuracy of the antenna, and other factors. Received signal strength must be calculated for each location taking such factors as may be required into account. Additionally, certain locations may suffer from blockage due to trees, multipath effects, terrestrial interference, and increased antenna noise temperature, all of which become worse as the elevation angle of the receiving antenna is reduced. Each receiving earth station and system must be responsibly engineered with its unique requirements in mind. The prudent business man will insure that his system is designed to operate satisfactorily (i.e., with adequate margins) not only with a specific desired spacecraft but with all spacecraft it is potentially likely to access. Using approximations and rules of thumb is done at the system owner's peril.

Now that we know what EIRP is, why is it so important?

When reduced to its essence, communications systems engineering consists of using power and bandwidth to provide a desired signal quality to an end user. The spectrum available for the cable broadcasting services considered in this paper is well known and determined by the transponder bandwidth (nominally 36 MHz).

Parameters such as top modulating frequency and peak deviation have been standardized. Thus, the Modulation Improvement, that contribution to signal quality provided by factors of deviation and bandwidth, is essentially fixed. The other contributor to signal quality is the signal strength or power in the communication channel and this is directly related to the <u>sum</u> of EIRP from the spacecraft and the G/T of the earth station.

G/T is a figure of merit for satellite earth stations and refers to the receive gain of the earth station antenna at a given frequency less the total system noise temperature both expressed in dB.

Assuming a given modulation (FM) improvement to achieve a target signal quality (signal to noise ratio) the EIRP and G/T will vary inversely, i.e, if the EIRP is increased by 1.0 dB the earth station G/T may be decreased by 1.0 dB to maintain the same performance. Conversely a lower EIRP requires a corresponding increase in G/T. This is the pivotal reason for EIRP's importance; because G/T is improved in one or both of two ways. Either through an antenna with higher gain (a larger aperture), or a receiver with a lower noise temperature. Both of these options cost money. Thus, EIRP is inversely related to the cost of receive only earth stations; if it goes down the cost to maintain the same level of signal quality goes up, and vice versa.

Field Test Program

In response to the numerous questions raised about in-orbit performance of the Satcom spacecraft and because our internal test effort showed some cause for concern, RCA decided to undertake an EIRP field measurement program. The objectives of this program were:

- Establish the EIRP contours by actual field measurement.
- Establish procedures and techniques for measuring EIRP of future RCA spacecraft as an aid in verifying that in-orbit performance meets specifications.

To assure a stringent test effort, we secured the services of an established consulting firm, Compucon, which is well known to the cable community.

Discussions were initiated with them to secure a test concept and procedures and it quickly became apparent that nothing of this kind had ever been attempted in the commercial satellite business. While field test programs had been done, none had been performed to the level of accuracy required to assure that this effort would be meaningful. Initial studies indicated that the accuracies achievable were on the same order of magnitude as the difference between actual and predicted that we were looking for. When we began, achievable accuracy was $\pm$1.6 dB. This was successfully reduced so that the overall accuracy of the Phase I portion of the test was $\pm$0.7 dB and for Phases II and III the corresponding figure is $\pm$0.6 dB.

The services of Home Box Office (HBO) were enlisted to act as industry representatives and HBO personnel were invited to participate as witnesses at all test sites throughout this exercise.

Methodology

The program is to be accomplished in three phases as shown in Figure 1.

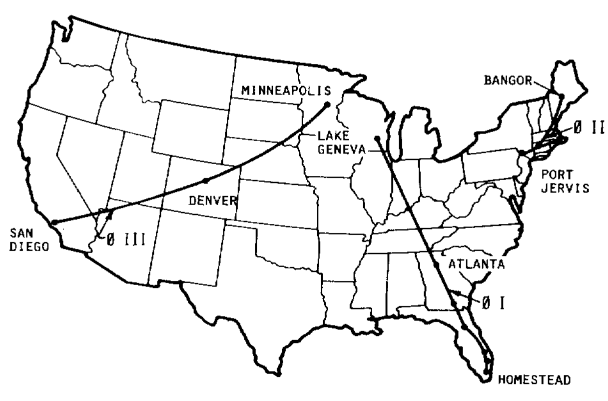

Figure 1. EIRP Test Locations

Phase I consisted of measurements along a radial beginning at the RCA earth station at Lake Geneva, Wisconsin (slightly north and west of Chicago) and extending down to the tip of Florida. The locations at which measurements were taken or are contemplated can be found in Table 1.

Table 1. EIRP Test Locations

Phase I
Lake Geneva, Wisconsin
Glasgow, Kentucky
Atlanta, Georgia
Valdosta, Georgia
Orlando, Florida
Fort Pierce, Florida
Fort Lauderdale, Florida
Homestead, Florida
Phase II
Port Jervis, New York
Plainville, Connecticut
Hyannis, Massachusetts
Bangor, Maine
Phase III (Proposed)
Minneapolis, Minnesota
Omaha, Nebraska
Denver, Colorado
Flagstaff, Arizona
San Diego, California

Chronology

The first discussions were initiated with both Compucon and HBO in July, 1978 with a view toward accomplishing an expeditious test program. A test procedure was established and agreed to by all parties and efforts commenced to obtain the necessary equipment with the required calibration accuracies. To say that considerable difficulty was encountered at this step would be an understatement.

The tight tolerances necessary to assure a valid test, together with the fact that field tests in the past had not been accomplished to such rigid specifications, combined to cause several delays to the project. Problems were experienced in acquiring microwave test equipment because of the demands placed upon manufacturers by a booming industry and in accomplishing the required calibration in a timely manner. Eventually, a test bed was established in Dallas in September of 1978 and a week of dry runs were accomplished to prove-in performance and calibration accuracy.

The first phase of the field test effort was completed in November with Compucon's report submitted in late December and the field test portion of Phase II was finished in mid-March. It was unfortunately delayed because a modification to the test setup resulting from wearout of certain RF components necessitated calibration of the replacement item. At this writing (March, 1979) we are in the process of preparing the Phase III test to obtain data on a radial from Minneapolis to San Diego.

Equipment

The test hardware consisted of a 4 foot parabolic metal antenna, manufactured by Terracom, a low noise amplifier from Scientific Communications Inc., signal generator, power sensor, power meter, spectrum analyzer, and associated couplers, cables and switches from Hewlett-Packard. The antenna was modified to permit rotation of the feed so that vertical and horizontally polarized transponders could be easily measured and so that adjustments could be made for variations in local polarization angle.

The antenna was calibrated at Chu Associates in Massachusetts, while the bulk of the remaining equipment was calibrated by Hewlett-Packard. A block diagram of the test configuration is shown in Figure 2.

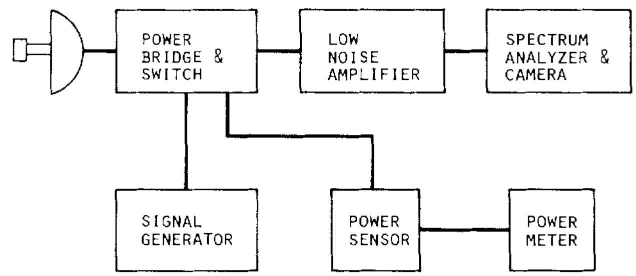

Figure 2. Equipment Block Diagram

The measurement used is a standard one in satellite communications called RF substitution. This method provides excellent accuracy in the detection of unknown low level signals. The parabolic antenna, LNA and spectrum analyzer act as the detection and storage units and the signal generator, power bridge and power meter provide the known source. The unknown saturated (maximum power output) carrier is received from the spacecraft and the system is adjusted to observe peak signal strength. It is then stored on the scope of the spectrum analyzer. A known signal is inserted into the front end of the LNA and adjusted until it is equal in level to the stored image of the carrier received from the satellite. The injected signal is known because the signal generator, power meter, power sensor, bridge, and all cabling have been precisely calibrated. This technique effectively measures the received signal strength at the input to the LNA thereby eliminating it as a source of error. Knowing all losses through the system and the receive gain of the test antenna, one can determine the received signal strength at the input to the antenna. Computation of the path loss and atmospheric absorption losses at the location under consideration permits one to extrapolate back to the EIRP from the spacecraft. The entire test setup was transported from site to site by truck and whenever possible in Phase I the measurements were performed at the headend facilities of a local CATV company or in the parking lot of a local motel.

RFI analyses were performed for each of the test locations to assure that no tests would be taking place in areas of heavy terrestrial interference which might becloud the results. Tests were run from 2:30 AM to 2:30 PM and special emphasis was placed upon measuring HBO transponders 20, 22, and 24 at each location. Four sets of measurements were taken on each transponder throughout the test period with a view toward washing out local atmospheric effects.

A standard gain horn was used for side by side comparison with the 4 foot antenna prior to starting a test run. This was done to check relative gain differentials thereby making sure that the parabolic antenna had not suffered any damage which would have caused its gain to change and invalidate the data. In no instance was any change discovered.

Throughout the test program, personnel from RCA Laboratories provided guidance on techniques for improving accuracy but did not take part in actual test efforts.

Results

Since the test program is not yet concluded, the results presented herein are final only for Phase I.

Phase I: (Chicago to Florida)

- On Spacecraft F1 the measured EIRP (mean of all transponders measured) is 1.6 dB below predicted values.
- On Spacecraft F2 the measured EIRP (mean of all transponders measured) is 1.2 dB below predicted values.
- The measured differences between F1 and F2 agree very closely with calculated differences.
- No other anomalies in spacecraft performance were discovered.

Phase II: (Northeast U.S.)

- The field test portion of this effort was completed on March 19, 1978. Data reduction exercises are, as of this writing, under way at Compucon. These results will be presented as an appendix to this report.

Analysis

The predicted EIRP values provided by RCA to the cable community were calculated analytically from data accumulated during range tests of the spacecraft antenna systems made on the ground prior to launch of the spacecraft. The differences between measured and predicted values thus far discovered during this test effort are believed to arise from errors in the range tests performed by the spacecraft manufacturer as well as the adverse effects of the space environment resulting in some degradation of component performance such as thermal distortion of the antennas.

Future Efforts

The results to date of this program have been taken into account in the design of the F3 spacecraft and some comments about it are apropos. The elevation angle of the antenna platform will be depressed 0.6 degrees from its value on the F1 satellite. This is being done to improve performance to the low signal areas of the southeast.

The contour shown in Figure 3 is a preliminary depiction of the minimum expected performance of the F3 spacecraft at 132°. The F3 will be equipped with four redundant Traveling Wave Tubes (one for each bank of six transponders). In the event of a failure of a primary transponder, the redundant unit would be switched in. This contour represents minimum performance even under the failed condition. It is expected that most transponders will provide performance superior to that shown here. However, until this is conclusively established in range tests this contour should be used for system planning purposes.

Furthermore, we anticipate a program analogous to the one described in this paper as part of a verification of in-orbit performance of the F3 spacecraft after launch and prior to commissioning for service. Revised contours and predictions of EIRP to specific locations will be provided to the cable community and manufacturers once actual RF performance of the satellite has been verified.

Certain other enhancements are being included in the F3 design in order to provide superior service. These include bigger (17 amp-hour batteries) which will permit reduced depth of discharge during eclipse operations, thereby prolonging battery life and improving spacecraft reliability and performance. Improvements in the attitude control system are being made in order to have a more stable platform in orbit. Modifications to the thermal design are being incorporated to improve operating characteristics.

Conclusion

RCA Americom and Compucon have attempted in this test program to accurately report the results and characterize performance of the Satcom spacecraft. The lessons learned will be used in the design and implementation of future Satcom systems to insure that the design criteria provided for use by customers will always prove satisfactory in the future.

Our sincere thanks and appreciation to Messrs. Keith Evans, Tom Rea, Don Pidgeon and Helmut Schwarz, whose highly professional efforts contributed to the success of this test program.

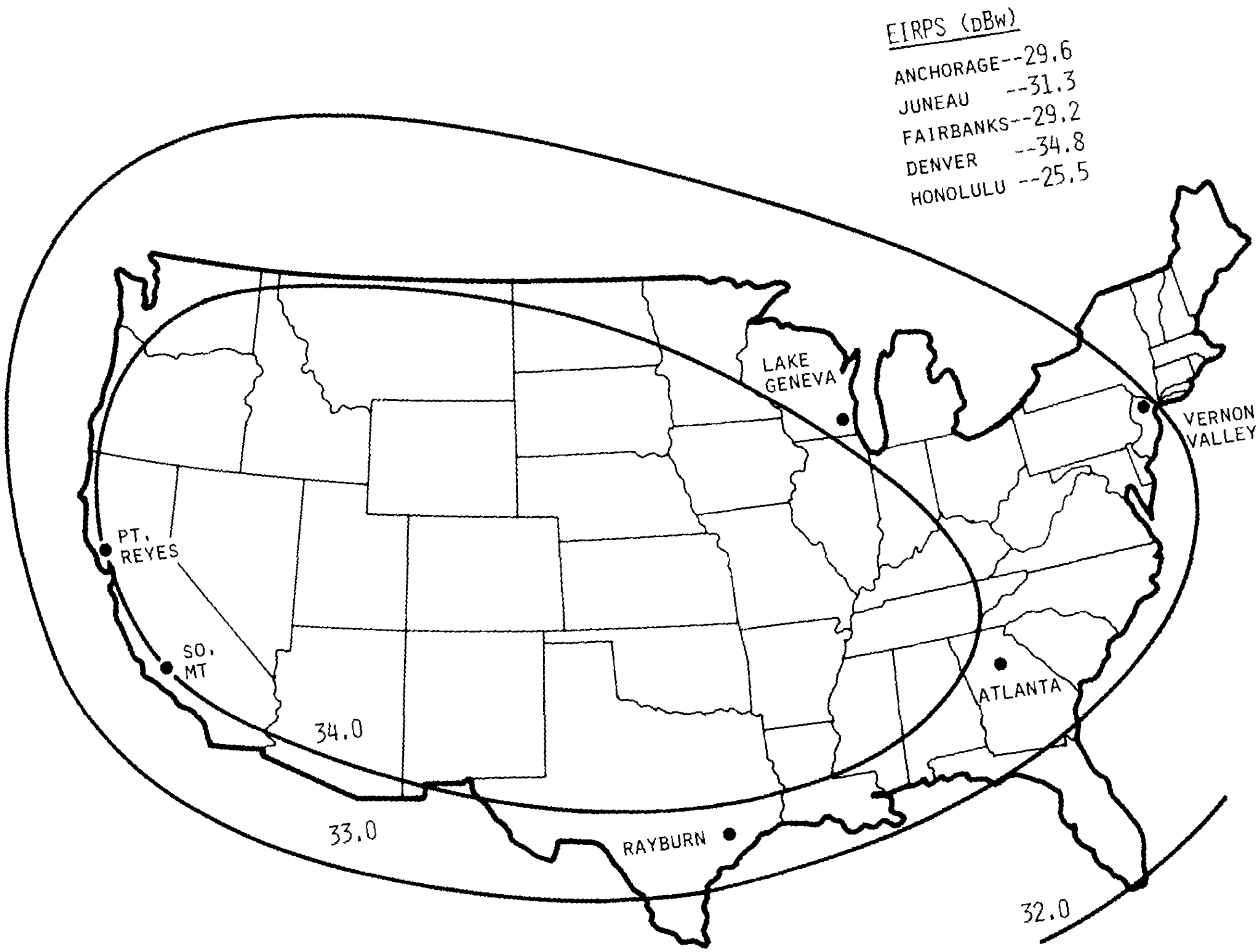

FIGURE 3. F3 SPACECRAFT AT 132° EIRP CONTOURS (PRELIMINARY)