Engineering Notes

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Improved Satellite Repeater Amplitude-Frequency Measurement

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Introduction

AFTER the launch into geostationary orbit of a communications satellite, a series of in-orbit tests[1-3] are carried out to confirm that the satellite performance meets specifications and is consistent with prelaunch measurements. Among the most important of these tests is the measurement of the amplitude-frequency response (in-band and out-of-band) of each satellite transponder. In view of the desirability of using frequency space most efficiently, the channels are placed as closely as possible to one another. Most communication satellite transponders are of this nature, e.g., the European Communications Satellite (ECS), the Intelsat series, and the Satellite Business Systems (SBS) all-digital system.[4] In this situation, the out-of-band amplitude-frequency response of the different channels is an important parameter with regard to predicting interference from neighboring channels. Furthermore, the in-band ripple and gain slope are often subject to very tight specifications.[5] In consequence, the in-band amplitude-frequency measurement has to be performed very accurately. It is also a requirement that all in-orbit tests are to be carried out speedily since they are part of a comprehensive series of tests to be performed in limited time.

The subject matter of this Note is the description of a novel satellite in-orbit amplitude-frequency measurement scheme, and the presentation of some results obtained during tests on the Orbital Test Satellite (OTS) in November 1981 using the European Space Agency satellite station at the European Space Research and Technology Centre (ESTEC) in Noordwijk, the Netherlands.

The tests are carried out automatically under GPIB bus control, and some of the advantages are: 1) compensation for propagation effects; 2) compensation for satellite movement such as nutation (important when a transponder has to be measured at beam edge); and 3) automatic system calibration.

Background

In measuring the amplitude-frequency characteristics of a satellite channel, three elements in the chain must be considered: the station transmit chain, satellite loop, and station receive chain. A classical setup for such a measurement is shown in Fig. 1. The sweep generator produces a signal at the desired sweep speed and bandwidth at intermediate frequency (i.f.). This signal is converted to the up-link frequency and transmitted to the satellite. Onboard the satellite, the carrier frequency is changed before retransmission to Earth. On the station receive side, the down-link signal is converted again to (the same) i.f. frequency and detected by a tracking receiver. The tracking output of the sweep generator controls the receiver tuning and also provides the horizontal input to the x-y recorder. The vertical input to this recorder is fed by the receiver output. Because of the round-trip delay (~250 ms), the tracking has to be offset. In most practical situations, a maximum offset of some megahertz is achievable. As a result the sweep speed is limited and a full sweep may last up to several minutes, depending on the bandwidth of the repeater to be measured. Any change in signal level due to changing propagation conditions or satellite motion during the sweep will distort the final result.

It is obvious that, for the configuration shown in Fig. 1, two separate amplitude-frequency responses are required: 1) the Earth station transmit and receive chain response and 2) the satellite/Earth-station loop response. The true satellite repeater response can only be obtained after subtraction of the station transmit and receive system responses from the overall loop response. For this purpose several methods may be adopted.

Method 1

First of all, a test translator may be used which is either perfectly flat in frequency response or has a calibrated response which can be compensated for. In practice, not many stations will be equipped with such a device.

Method 2

A second method involves point by point subtraction of the separately measured transmit and receive chain responses from the overall response.[6] One of the difficulties with this method is that the transmit system response has to be compressed according to the operating point of the satellite. Clearly, the method is inflexible and requires accurate knowledge of each transponder power transfer characteristic.

Method 3

A third method is based on power leveling techniques in combination with a simple (uncalibrated) test translator. Power leveling is usually obtained using a radio frequency (rf) detector whose output after filtering is used to control a variable attenuator in the i.f. chain. The dynamics of this control loop have to be matched to the sweep speed used in the system. Referring to Fig. 1 again, a first sweep is made over the satellite with power leveling at point A [after the high-power amplifier (HPA)], which effectively means that a power constant with frequency is transmitted to the satellite. A second sweep is then made through the test translator with power leveling applied at point B, which means a constant power input into the station receive system. Point by point subtraction of the two results, stored digitally during the two separate sweeps, yields the satellite's amplitude-frequency response.

A practical problem with this approach is the enormous difference in power levels involved during the second sweep, leading to uncertainties due to leakage radiation. Although the frequencies at input and output of the test translator are different, leakage radiation from the transmitter still affects the measurement since the (sensitive) detector at the receive side point B is usually a wide-band device. The problem of

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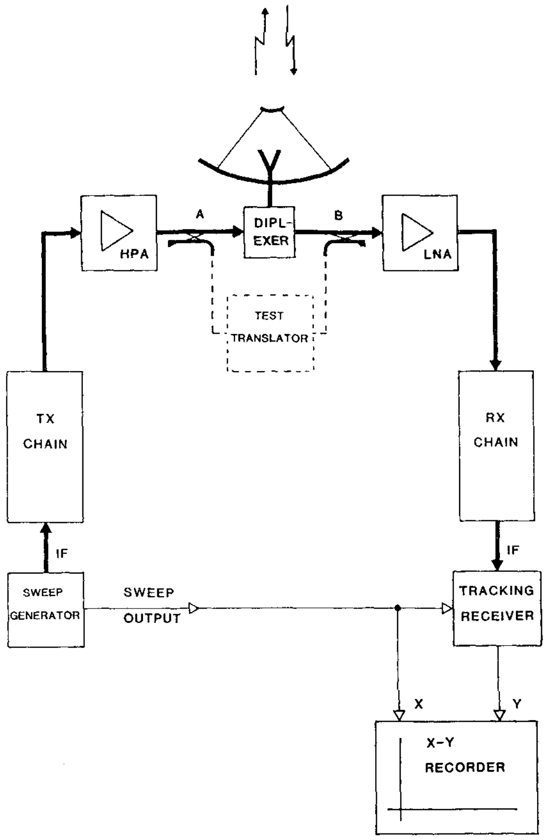

Fig. 1 General outline of measurement setup.

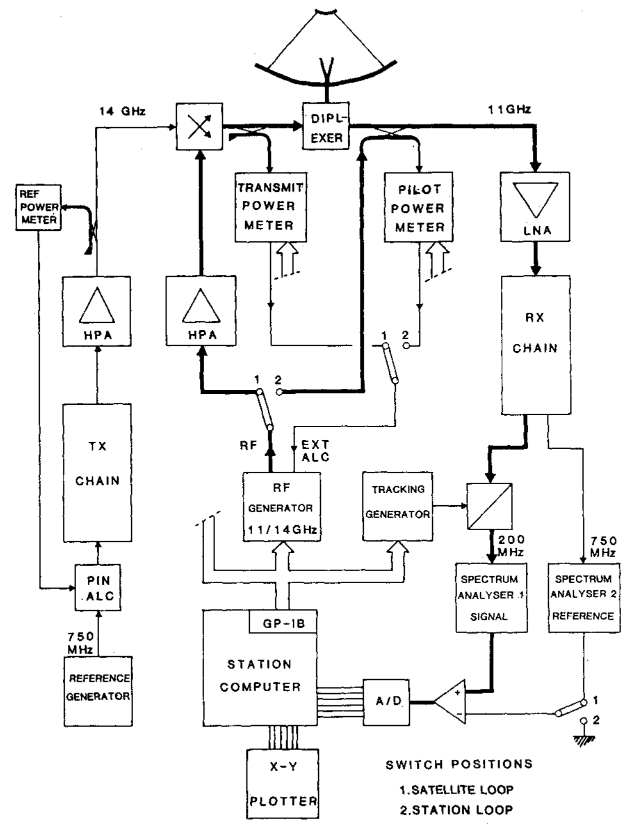

Fig. 2 Amplitude-frequency test configuration.

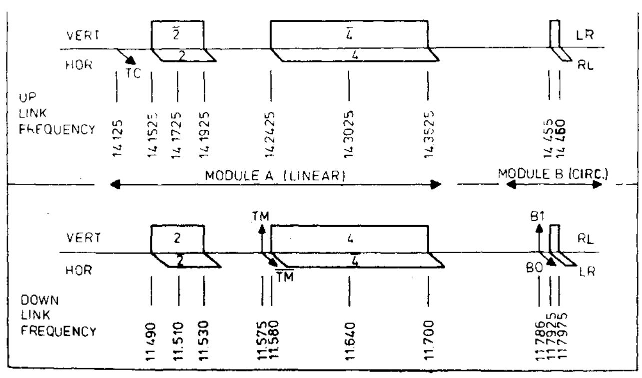

Fig. 3 Orbital Test Satellite frequency plan.

radiation leakage within the antenna cabin from a high-power source (transmitter) to a very sensitive wide-band detector (receiver) is an extremely difficult problem to solve, bearing in mind the approximately 150 dB difference in levels. This particular problem leads to the development of the new method to be described in the next section.

Principle of the Measurement

A block diagram of the Earth station layout for the amplitude-frequency response measurement, as finally established, is shown in Fig. 2. The measurement is carried out automatically under control of an Institute of Electrical and Electronic Engineers (IEEE) bus controller.

Instead of the usual sweep generator at i.f. frequency, an 11/14 GHz programmable signal generator is employed, which also incorporates an external power leveling facility. The combination of i.f. tracking generator and spectrum analyzer 1, configured as a narrow-band receiver (zero scan mode), replaces the traditional tracking receiver.

A full measurement sequence consists of the following steps: 1) calibration routine and recording of the receive chain response; 2) the recording of the satellite plus station response; and 3) data processing and plotting.

In order to explain the principle of the system, these steps are described in some detail (refer to Fig. 2).

Calibration and Receive Chain Response

To record the receive system response, a signal at the down-link frequency is injected into the front end, using a coupler system at the low noise amplifier (LNA) input. The power meter of this pilot injection circuit is used as the feedback control to the signal generator, thus ensuring a constant signal power at the station receive chain input. The measurement of the receive chain response at down-link frequency with relatively low signal power, rather than the use of a test translator as described in the previous section, eliminates the radiation leakage problem previously mentioned.

While the signal generator is stepped through the desired receive frequency band (with selectable step size and interval), the tracking generator is stepped simultaneously in order to convert the signal at the receive chain out to a fixed i.f. frequency (~200 MHz). Here the signal is detected by spectrum analyzer 1. The vertical output signal is sampled at synchronized intervals, digitized, and the result stored in the controller.

Prior to this receive chain measurement, an automatic calibation is carried out. At band center and at the desired power level, the signal power is brought up and down by approximately 1 dB (+2 and −10 dB for the out-of-band response). The output voltage of the receiver system is measured together with the actual readings of the pilot power meter. In this way, a volts to decibel conversion factor is obtained, which compensates for any dc gain variations in the chain and which is stored for later use. This automatic calibration is particularly important when remeasuring after a lengthy period or when faulty equipment has been replaced. Moreover, this step ensures an automatic calibration of the amplitude-frequency response in decibels relative to the band center.

Recording of Satellite Plus Receive Chain Response

For this part of the measurement, the rf generator is used to drive the high-power amplifier (HPA) at the satellite's up-link frequency. The generator signal is stepped in frequency in a selectable number of steps while power leveling is applied using the transmit power meter. Depending on the number of steps, a full scan through the repeater band will take from several seconds up to some minutes. To compensate for propagation effects and satellite movements during this period, a reference carrier at fixed frequency is sent through a different satellite repeater. On the receive side, this reference carrier is detected by a second spectrum analyzer, in zero scan mode. The stepping signal in the repeater under test is again detected by spectrum analyzer 1 as the tracking generator is stepped simultaneously (delayed, however, by approximately 250 ms, the round-trip delay time). The two analog output signals of the analyzers are subtracted by means of a differential amplifier, and the resulting signal is stored in the controller after digitizing. The advantage of the use of a reference carrier is obvious owing to the fact that it experiences the same fluctuations due to propagation or nutation effects as the swept signal and can therefore be used to eliminate these undesirable effects by subtraction.

Processing and Plotting of Results

Subtraction of the two sets of results, as measured in the manner described above, yields the satellite amplitude-frequency response. The controller executes this subtraction point by point. The final result is plotted, using the calibration factor obtained during the automatic calibration.

The whole measuring sequence is automatic, apart from the tuning of spectrum analyzers and some station switching between the two sweeps. These steps and the input of some essential parameters, e.g., details of the repeaters to be tested, number of frequency steps, and station transmit power, are carried out interactively. The number of frequency steps per full scan is selectable between 10 and 500. The time per measuring point is 1 s (i.e., long with respect to the round-trip delay). Time constants of the leveling loops and video filters of the spectrum analyzers are matched to the measuring interval.

Two spectrum analyzers were used in the development phase of the system. In an operational station, this expensive unit would be replaced by dedicated electronic circuits, basically consisting of a narrow-band i.f. filter followed by a square law detector and low pass filter.

Results

The technique outlined in the previous section is valid for the amplitude-frequency response test of transponders on any geostationary satellite, independent of frequency. During November 1981, measurements were made in the 11/14 GHz frequency bands at the European Space Agency's small Earth station at ESTEC. The satellite under test was the Orbital Test Satellite (OTS) launched in 1978, whose frequency plan is shown in Fig. 3. Excellent results were obtained for all satellite transponders. Figure 4 gives an example of an in-band measurement and shows a channel 2 (linear polarization, 40 MHz bandwidth) response, consisting of 100 connected points. The time required to take this recording was less than 5 min, including all station switching. The reference carrier for this test was fed through the (circularly polarized) channel RL repeater.

The positive effect of this reference carrier is clearly demonstrated in Fig. 5, where the same channel 2 measurement is taken without a reference carrier. It can be seen clearly that the actual in-band channel response is masked completely by residual propagation effects, despite the fact that the weather conditions were almost ideal during this measurement.

Finally, Fig. 6 shows a channel 2 out-of-band response. The measurement technique is similar to that for in-band response except that a different spectrum analyzer setting is required (10 dB/cm instead of 2 dB/cm) and the automatic calibration procedure is adapted for the different measuring range.

Measurement Accuracy

The reproducibility of the curves has proved to be excellent (differences of the order of 0.05 dB), and curves taken at different i.f. frequencies have proved almost identical. This shows that mismatch at the i.f. level has no influence at all on the measurement scheme. The cancellation of propagation effects using a reference carrier is found to be very effective. Even during nonideal propagation conditions (attenuation fading to several decibels), it was possible to produce good results. It is only important to have both the repeater under test as well as the repeater used for the reference carrier at the same operating point. In this way, the attenuation in up- and down-links has the same influence. Proper design of the differential amplifier at the spectrum analyzer outputs ensures that digitizing errors are negligible.

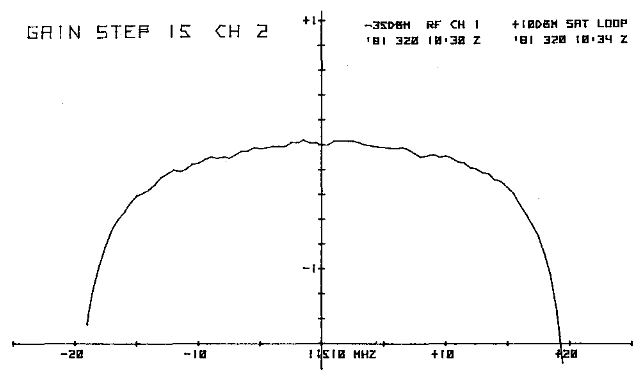

Fig. 4 In-band amplitude-frequency response with reference carrier.

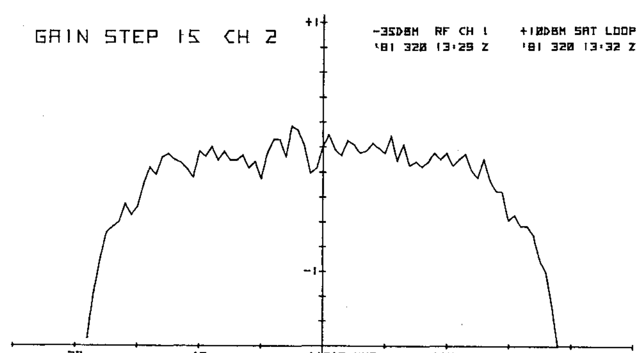

Fig. 5 In-band amplitude-frequency response without reference carrier.

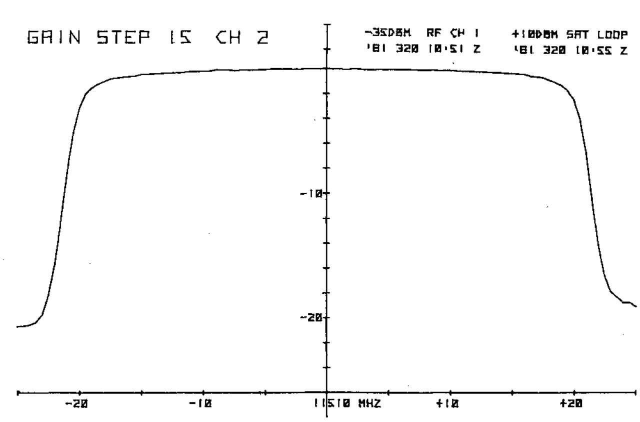

Fig. 6 Out-of-band channel response.

Other sources of error in the system are as follows: 1) fluctuations in coupling factors with frequency both at the output coupler used for power leveling and at the input coupler to the LNA; 2) variation of antenna gain with frequency.

Since both of these effects are broadband in nature, the systematic errors incurred over the relatively small sweep bandwidth are likely to be extremely small (<0.1 dB). These effects can usually be ignored, but may be accounted for if necessary when maximum accuracy is required by prior measurement during the installation phase of an Earth station. The data obtained can then be used in software correction of the measured response. For Earth stations already in operation, practical and economic considerations will determine whether these systematic errors are to be calibrated out.

Conclusions

Results from tests made with the OTS satellite indicate that the technique described for the determination of a satellite repeater amplitude-frequency response gives improved accuracy and reliability as compared with standard procedures. This arises from three factors: pilot injection for receive chain measurement, reference carrier transmission in a neighboring channel, and automatic system calibration in the receive chain. Advantages claimed for the technique described are as follows:

1) The effects of propagation are largely eliminated.
2) The effects of satellite motion are largely eliminated.
3) The measurements are repeatable and precise.
4) A high degree of automation is achievable, resulting in rapid measurement.
5) No prior knowledge of transponder operating point is required.

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HZE Particle Shielding Using Confined Magnetic Fields

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Introduction

In future, long-duration, manned space missions, chronic exposure of flight crews to the high-energy heavy-ion (HZE) component of galactic cosmic radiation appears to be potentially hazardous.[1,2] For galactic heavy ions with energies above 100 MeV/nucleon, typical daily fluences in interplanetary space are approximately 100 nuclei/cm^2. Although not large when compared to proton or electron fluences, their unique damage mechanisms and cumulative adverse effects on nonregenerative tissues (e.g., eyes and the central nervous system) are important considerations for longer missions.[2] Since these particles are charged, shielding may be accomplished either by ionization and nuclear fragmentation (breakup) in passive bulk material shields[3-5] or by active means such as deflection of the incident nuclei by electromagnetic fields. Proposed concepts for the latter include the use of electrostatic fields,[6] plasma,[7] and confined[8,9] or unconfined[10,11] static magnetic fields.

The primary focus of each of these proposed active methods has been to shield against space protons and electrons, especially during periods of intense solar activity. Except for the unconfined magnetic field configuration of Ref. 10, none of the analyses considered HZE particles. For the unconfined field configuration, magnetic shielding offers substantial weight savings over passive shielding for large permanent habitats (colonies), but not for the smaller vehicles likely to be utilized for near-term exploration.[10] Since the HZE particle kinetic energies of interest are on the order of 1 GeV/nucleon, electrostatic shielding can be immediately dismissed as an alternative since the required potentials are in the range of tens of gigavolts. Shielding by plasma will not be considered here since the required potentials and plasma densities are too large to be attainable in the foreseeable future. In this work, attention is focused on examining the suitability of confined magnetic field designs as HZE particle shields. Particular attention will be given to the potential utility of the Mars class design,[9] which displayed substantial weight advantages for shielding against solar protons when compared to equivalent bulk material shields.

HZE Particle Analysis

For a charged particle moving under the influence of a constant magnetic field, the rigidity (momentum per unit charge) is given by[12]

$$R = pc/Ze \tag{1}$$

where p is the particle's momentum, Ze its charge, and c the velocity of light. The rigidity is also related to the radius of curvature (Larmor radius) r and magnetic field intensity through the relation

$$R = 0.003\, Br \tag{2}$$

where B is the component of the magnetic field intensity, T, which is perpendicular to the particle's momentum. The rigidities in Eqs. (1) and (2) are given in gigavolts (GV). From Fig. 1, the most critical trajectory for shielding is grazing incidence. If the "thickness" of the confined magnetic field Δ is greater than or equal to the Larmor diameter $(\Delta > 2r)$, the particle trajectory will not intersect the shielded volume. Since HZE particle motion is usually described in terms of its kinetic energy per nucleon (rather than its total momentum), Eq. (1) can be rewritten as

$$R = A\,(T^2 + 2m_0c^2 T)^{1/2}/Ze \tag{3}$$

where T is the kinetic energy per nucleon (GeV/nucleon), A the number of nucleons (mass number), and m_0 the nucleon rest mass ($m_0c^2 = 0.939$ GeV). Equation (3) is general in that it is valid for any nuclear species (Z,A) at any incident kinetic energy. For simplicity, we now restrict the analysis to iron nuclei ($Z = 26$, $A = 56$), which are among the dominant radiobiologically damaging species in space.[2] For a typical kinetic energy of interest ($T \approx 1$ GeV/nucleon), Eq. (3) yields a rigidity of $R = 3.654$ GV. Present state-of-the-art in continuous magnetic field generation[13] is approximately 25 T.

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