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Using a Microwave System Analyzer to Measure Satellite End-to-End Group Delay

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This article explains how accurate group delay measurement near passband edges allows users to determine the maximum usable system bandwidth

There is increasing demand for bandwidth on satellite systems, as with almost all telecoms systems, due to growing levels of Internet traffic, digital TV and other digital services being carried on these links. Consequently satellite operators are being forced to use all of the available bandwidth right up to the band edges, where signal quality can be degraded by components such as filters within the satellite transponder and the ground systems within the transmission path (Fig. 1). Established satellite transponders are typically configured with channel bandwidths in the 36-72 MHz range—depending on the particular satellite system—although it is not unusual for newer systems to be configured with bandwidths of several hundreds of megahertz.

The relative group delay measurement across the bandwidth of these transponder channels is important, in order to determine the amount of distortion or signal degradation that could take place due to increased delay changes at the band edges of these channels. The delay must be measured in order to apply accurate compensation and thus avoid possible data corruption.

To convey information without the risk of corruption requires a flat amplitude response and a linear phase response over the bandwidth of interest. Group delay flatness is a measure of the phase linearity and there are several techniques for measuring this. The two most common are direct phase and envelope delay (modulation delay). Most vector network analyzers traditionally use the direct phase method, and while these instruments offer high accuracy there are complications when characterizing frequency converting devices. A sophisticated microwave system analyzer overcomes these problems by using the receiver in the spectrum analyzer as a tuned scalar input and employing the envelope delay measurement technique.

Figure 1 · To get the best performance out of a satellite link it is necessary to measure and accurately compensate for distortion caused by group delay at the band edges.

The Microwave System Analyzer

A microwave system analyzer (MSA) is typically an instrument that combines a spectrum analyzer with a synthesized source and scalar analyzer, with the addition of frequency modulation and envelope group delay options. This provides the capability to measure frequency converting devices and networks and to perform group delay measurements on components and subsystems.

In the MSA the source and receiver can be made independent of each other so that the stimulus can be set to operate at one frequency while the receiver receives at a different frequency. Because the group delay measurement is derived from the modulation envelope and the modulation is preserved through a frequency translation, direct characterization is possible without the need for access to local oscillators and the use of extra mixers and oscillators in the test set up.

Group Delay Measurement and Calibration Using an MSA

To measure group delay, the source is frequency modulated with a known low frequency and applied to the device under test (DUT). After passing through the DUT, the signal is demodulated and the phase of the recovered low frequency is compared with that of the original modulating signal to measure the group delay. The envelope delay is the average value of group delay over the modulated signal bandwidth. The bandwidth of the modulated signal is known as the measurement aperture and needs to be small in comparison with the group delay variations for accurate measurements. The upper limit of the absolute group delay measurement is plus or minus half the period of the modulation frequency, then it "wraps around" and repeats.

Calibrating out the delays inherent in the MSA can be performed very quickly using a simple through connection, as shown in Figure 2. This will present some compromise in accuracy when testing frequency translation devices, but in most instances this compromise will not be an issue. If greater accuracy is required, then this can be achieved by using a "golden standard" technique, as described in the next section, where a well-characterized component is measured first and compared with the DUT.

Figure 3 shows a screen shot of the amplitude and delay response of a 2.2 GHz to 500 MHz down converter on a MSA that had been calibrated by the through connection method.

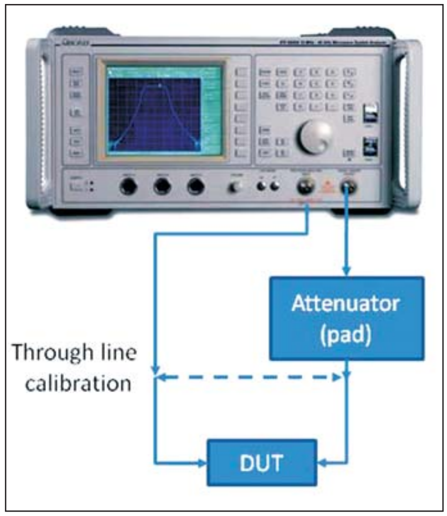

Figure 2 · Through-line calibration of microwave system analyzer.

Golden Standard Calibration

In some cases, the through connection calibration described above may not give sufficient accuracy. The alternative is to use a "golden standard" device with known or assumed delay performance to calibrate the instrument. A suitable golden standard device could be a well-matched broadband mixer with external LO. Another option is to use a modified DUT in which the group delay critical components (usually the filters) have been bypassed.

Converter LO Accuracy and Drift

The FM envelope delay method used by the Aeroflex 6840 MSA has the advantage that, unlike some VNA methods, it does not require access to the frequency converter LO. However, there are some requirements on LO accuracy.

The maximum resolution (aperture) bandwidth of the 6840 spectrum analyzer is fixed to 3 MHz for group delay measurements. When this resolution bandwidth and FM demodulator considerations are taken into account, this means that the MSA frequency offset must be set within ±500 kHz of the actual frequency offset for the measurement to be valid.

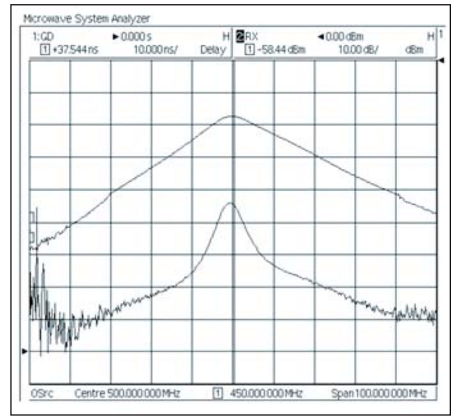

Figure 3 · Amplitude and delay response of a downconverter.

Frequency error causes the group delay response of the spectrum analyzer filters to be offset on the trace, which does not present a problem if only the flatness is of interest. However if the frequency stability of the converter LO is poor, then this offset will drift up and down, which causes more difficulty. Although auto scaling may help in this case, the only real solution is to stabilize the converter LO. The magnitude of this effect has been measured as typically 0.1 ns change in group delay per 1 kHz frequency error.

Satellite In-Orbit Group Delay

Testing group delay flatness on a test bench is fine for components that are relatively portable, but there are many instances where the device under test does not lend itself to this approach. A particular example is when the DUT is a complete satellite link, which clearly cannot be measured by a single instrument in a test lab. There are many reasons why satellite in-orbit testing needs to be carried out. It is generally performed following launch and prior to the release of the satellite to the customer to verify the integrity of the communications payload and the antenna platform. Regular checks may also be carried out in service for the purpose of verifying performance or resolving anomalies.

Group delay over frequency, espe-

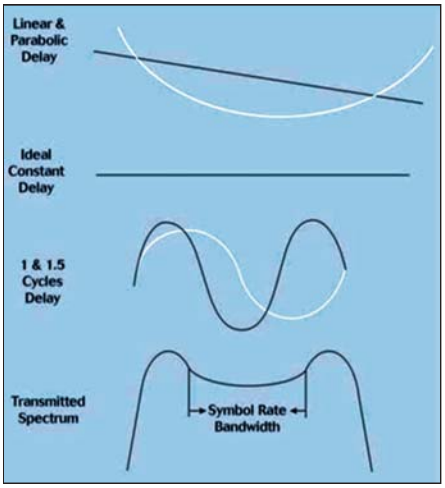

Figure 4 · Group delay and the transmitted spectrum.

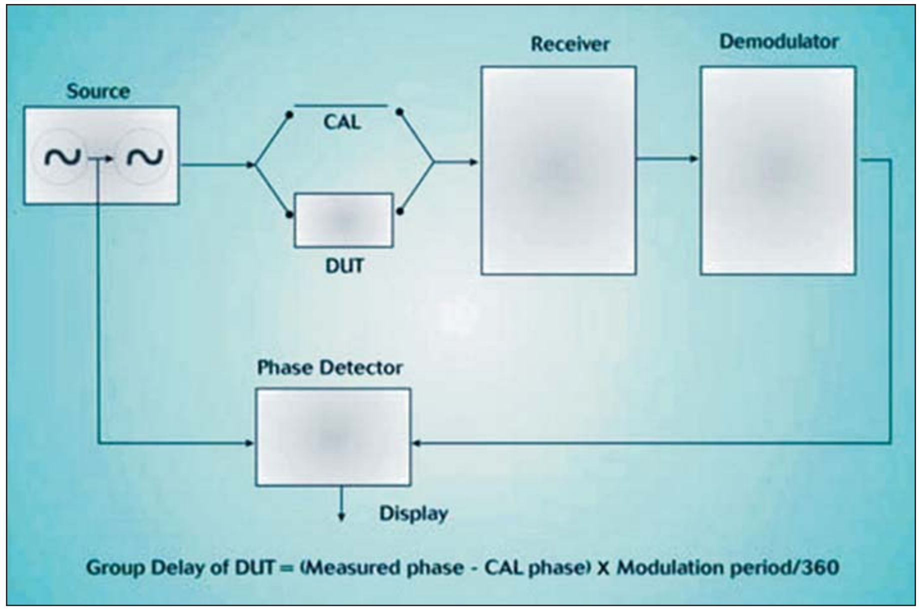

Figure 5 · Set-up screen for satellite link.

cially through frequency conversion, has proved a particularly difficult parameter to measure for satellite links. Figure 4 shows linear and parabolic group delays, which are typical of the types of delay experienced in satellite networks. Parabolic delay is usually associated with bandpass filters found in satellite transponders and communication equipment. The sinusoidal delays are often caused by impedance mismatches in the system. Ideally, the group delay should be flat—a straight line with no slope—so that all frequencies across the carrier bandwidth experience the same time lag through the link. If this is not achieved, then there will be interference between the recovered digits, making them difficult to discriminate between and thus causing errors.

Measurement System

The Aeroflex satellite group delay test system uses two microwave system analyzers fitted with the Group Delay Option 22, coupled with a control PC and serial modems running dedicated software to obtain a relative group delay measurement across the entire link. The test system is configured to generate the test signal to be applied to the uplink, and to analyze the transponded signal received at the downlink to obtain the group delay variation and to perform in-band gain flatness measurements. The two systems are synchronized together across the frequency sweep.

The system can be used for the measurement of group delay and other transfer characteristics of satellite links from ground stations, either co-located or remote, through the in-orbit transponder. A set-up screen (see Figure 5) enables the selection of the input, output and/or conversion frequencies and levels.

Transit Time

The transit time to and from a satellite can be considerable, even for one that is in low earth orbit. For a geostationary satellite it is typically around 250 ms. Because the source and receiver frequencies are synchronized, this can mean in practice that the receiver, which will have an aperture of around 1 MHz, will have moved beyond the received signal, making it necessary to further offset the source and receiver frequencies to compensate for the transit time.

This offset should be calculated as:

$$F_{offset}\ \text{(MHz)} = \text{Sweep (MHz/ms)} \times \text{Transit time (ms)}$$

As an example, if the uplink (source) frequencies are 14-14.5 GHz and the downlink (receive) frequencies are 11.2-11.7 GHz, and the satellite is in a geostationary orbit, the MSA is set to a sweep time of 10 seconds and an aperture (resolution bandwidth) of 1 or 3 MHz.

Then if the transit time is 285 ms and the sweep rate is 0.05 MHz/ms,

$$F_{offset} = 14.25\ \text{MHz}$$

To avoid generating a transmitter alarm, it is preferable for the source frequencies to remain unchanged (i.e., 14-14.5 GHz). The receiver should therefore be set to sweep between 11.18575 and 11.68575 GHz. The instrument will display the receive frequency range, and the received frequency itself will be well within the resolution bandwidth. The predicted offset alone may not be sufficient, as geostationary satellites are not in fact stationary and will also have a Doppler component that needs to be taken into account. The Doppler shift varies throughout the day, on a cycle that repeats daily and reaches zero twice a day. The Doppler frequency is easily measured, and the additional offset must then be applied. Failing to take Doppler shift into account may produce a slope on the group delay characteristic.

In-Orbit Measurement

Figure 6 shows the measured group delay characteristic of a satellite in geostationary orbit measured through a single ground station. Input (uplink) frequencies are 14.47-14.5 GHz and the output (downlink) frequencies are 12.17-12.2 GHz. Calibration was carried out at the input frequencies—it is normal to calibrate at the source frequency rather than the receiver frequency to remove the delay changes inside the instrument through band switching and the frequency modulation hardware. The instrument calibration and performance of group delay measurements are the same as for the standalone measurement described earlier. In this case the sweep time was 10 s, and the sweep rate was therefore 3 kHz/ms. The transit time offset is less than 1 MHz, so with an aperture of 3 MHz it can be ignored.

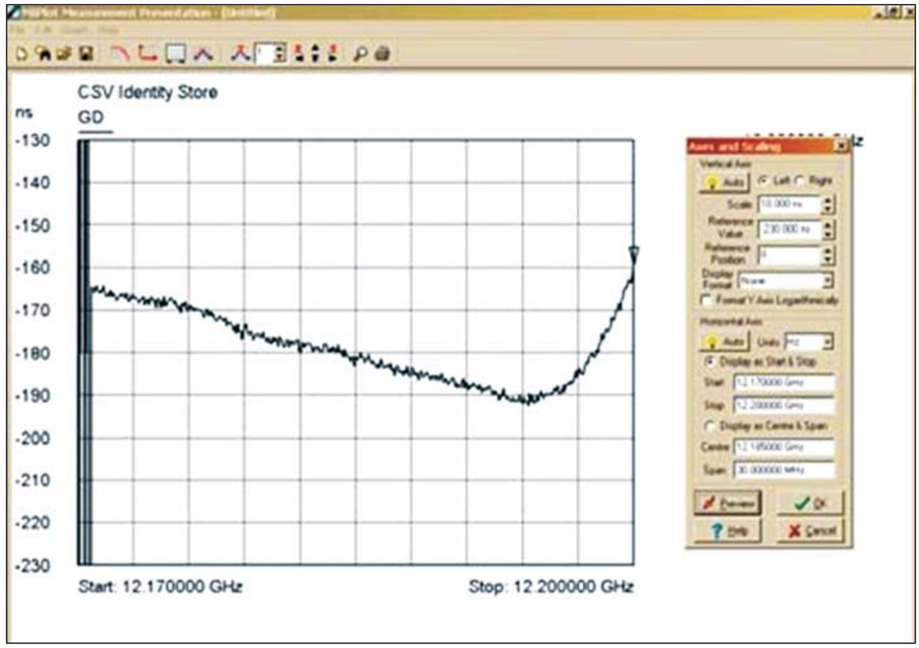

Figure 6 · Measured group delay characteristic of a satellite in geostationary orbit.

Remote Ground Stations

This group delay test can also be carried out across links where the ground stations are not co-located. The MSA acting as the source is co-located with the control PC running dedicated software at the main station of the link provider. The second MSA that acts as the receiver is installed at the receiving end, and this may be located anywhere in the world where the satellite has a transmission footprint. Using a control interface to the local MSA and a serial connection via modems to the remote MSA, the instruments are configured to obtain a relative group delay measurement across the section of the link to be analyzed. The two instruments are synchronized across the frequency sweep using a local high stability frequency reference (typically rubidium) at either end of the system for accurate synchronization, and measurement data are returned from the remote MSA to the local PC for review and storage of the results. Either MSA can be configured as the source or the receiver, so the transmission path can be tested in both directions without the need to move the equipment. If there are several receiving stations, it is possible to install a remote MSA at each station allowing measurements from all remote stations from one location.

Conclusion

A test system for end-to-end measurement of a satellite communications system has been described, based on two microwave system analyzers fitted with dedicated group delay measurement capability and specialist software. The Aeroflex 6840 Series MSA covers all current and future satellite frequency band allocations up to 46 GHz.

The same system is also applicable for ground system evaluation and installation. The measurement of group delay allows distortion across the band to be compensated for, and thus ensures the integrity of the data that is transmitted across the link.

Author Information

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