Application Note

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Satellite Systems RF & µW Measurements Using a Microwave System Analyzer

Measurement of Group Delay and Amplitude response of RF and Microwave components and assemblies of satellite systems including frequency converters, using the 6840 Series Microwave System Analyzer.

This appnote describes the unique capabilities of the Aeroflex 6840 Series Microwave System Analyzer to characterize the different parts of a satellite system, from the Earth Station or Satellite components to the full in orbit satellite link.

Amplitude Response and Group Delay Measurements

Measurement of Group Delay and Amplitude response of RF and Microwave components and assemblies, including frequency converters.

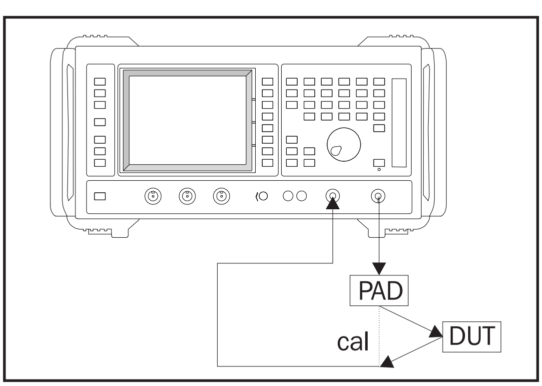
The unique 6840 Series of Microwave System Analyzers (MSA) from Aeroflex offer group delay measurements of components through to complete radios. The MSA's ability to measure frequency converting devices and networks by combining a spectrum analyzer with a fully synthesized source and scalar analyzer has been enhanced by the addition of frequency modulation and group delay options.

An essential feature of a communications link or signal processing device is its ability to convey information without distortion. This requires a flat amplitude response and a linear phase response over the bandwidth of interest. Phase linearity is commonly specified in terms of group delay flatness, which is traditionally measured with a vector network analyzer. While these instruments have high accuracy, there are complications when characterizing frequency converting devices. By using the receiver in the spectrum analyzer as a tuned scalar input, the MSA with group delay option overcomes such problems and provides a more cost-effective solution.

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 recovered low frequency is phase compared with the original modulating signal.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 Aeroflex MSA Series comprises 7 models with source and spectrum analyzer frequency ranges in several combinations from 1 MHz to 46 GHz.

All are available with Group Delay Option 22, which is an additional module that fits into an expansion slot inside the basic unit. All hooks, control and measurement software are provided internally by the MSA, and the group delay functions are accessed via the front panel softkeys as with other measurement parameters.



Connections for Group Delay measurements

Display Modes

Multiple measurements can be displayed simultaneously. Since the group delay measurement is made using the source and spectrum analyzer, the amplitude versus frequency response can also be measured. The extensive marker functions can then be used to investigate the data, including peak to peak ripple across any specified sub-band within the measurement bandwidth, maximum slope (deviation from linear) and maximum rate of change of slope (deviation from parabolic).

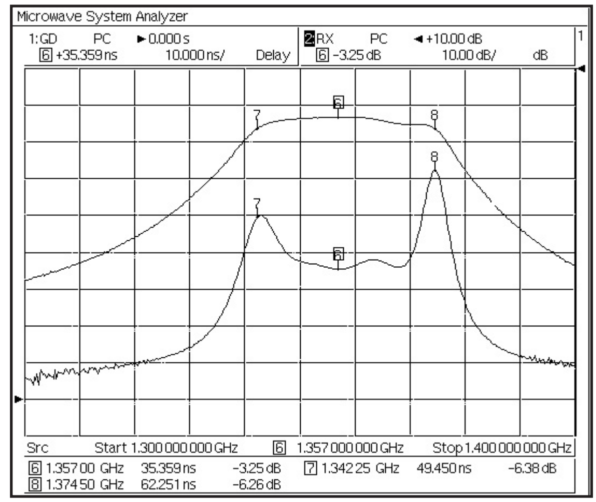


Figure 1 Amplitude and delay response of a band pass filter

Figure 1 shows a screen shot of the 6844 making a group delay and frequency response measurement on a band pass filter. In this instance the marker functions have been used to find the 3 dB bandwidth of the filter using the amplitude response and then display the 3 dB bandwidth on the group delay characteristic. For reasons of clarity, the use of the marker function to display the peak to peak variation within a sub-range has been omitted.

Frequency Converting Networks

In the MSA the source and receiver can be made independent of each other so that the stimulus can be set to one frequency while the receiver receives at another. As the group delay measurement is derived from the modulation envelope and the modulation is preserved through a frequency translation, direct characterization with no extra mixers is possible.

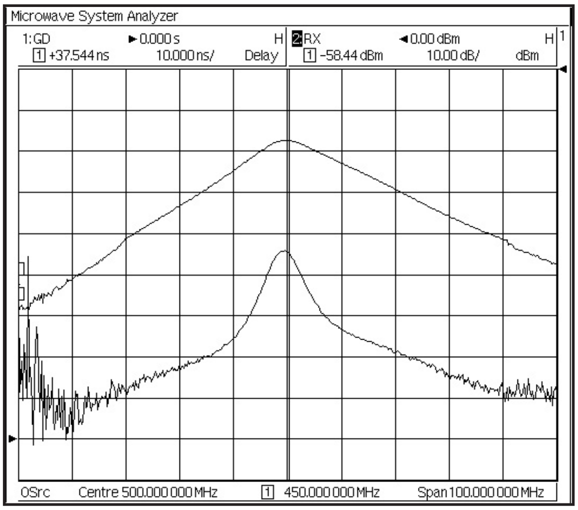


Figure 2 Amplitude and delay response of a downconverter

Figure 2 shows a screen shot of the amplitude and delay response of a 2.2 GHz to 500 MHz down converter. This measurement was calibrated using a through connection at the source frequency range, although "golden standard" techniques could be used for better flatness.

Through Pass Calibration

The 6840 source contains many delay changes due to band switching and the frequency modulation hardware. When measuring a frequency converter, this variation can be normalized by performing a through path calibration over the source frequency range. The calibration will be valid if the spectrum analyzer delay is the same over the source and receiver frequency ranges.

The basic architecture of the spectrum analyzer front end is shown in Figure 3. There are two major frequency bands, above and below 4.2 GHz. If the source and receiver frequency ranges are both in one of these bands, there will be no step due to this band change. If the source range lies in one band and the receiver in the other, there will be an offset on the measured delay but the delay flatness can still be measured. If the receiver frequency range straddles the band change, there will be a step in the measured delay.

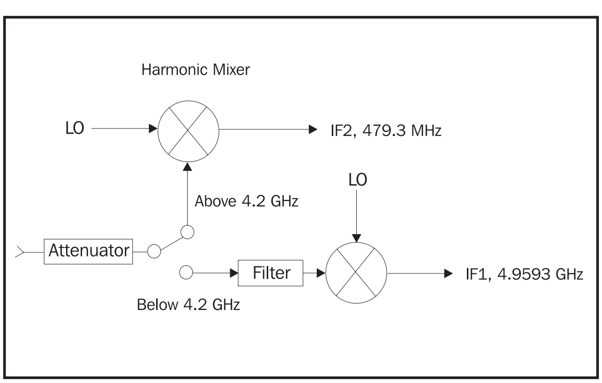


Figure. 3 Simplified block diagram of 6840 spectrum analyzer front end

The group delay flatness of each band is typically +/- 2ns. If you need better accuracy than this, consider a golden standard calibration.

Golden Standard Calibration

In some cases, the through path calibration described above may not give sufficient accuracy. An alternative method uses a golden standard device with known or assumed delay performance. The instrument is calibrated using this device, which is replaced by the DUT for the measurement. This method also removes any band change steps.

A suitable golden standard device is a well matched broadband mixer with external LO - the connectorized devices from Mini-Circuits may be suitable. Another option is to use a modified DUT with the group delay critical components bypassed (usually the filters).

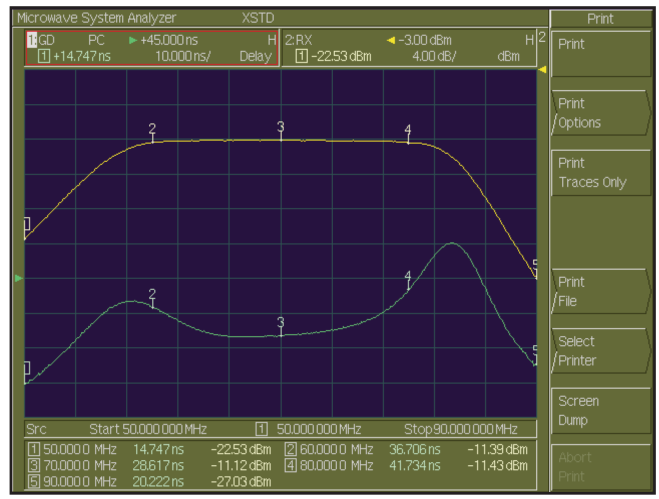


Figure. 4 Amplitude and delay response of a satellite down converter (70 MHz IF output)

Converter LO Accuracy and Drift

The FM envelope delay method used by the 6840 has the advantage that no access to the frequency converter LO is required (as with some VNA methods). However, there are some requirements on LO accuracy.

The 6840 Spectrum Analyzer is fixed to 3 MHz resolution bandwidth for group delay measurements. This, and FM demodulator considerations mean that the 6840 frequency offset must be set within +/-500 kHz of the actual frequency offset for the measurement to work.

Frequency error causes the group delay response of the spectrum analyzer filters to be traced out. This will place an offset on the trace, which won't be a problem if only flatness is of interest. If the converter LO is not very stable, this offset will drift up and down, which may be more of a problem. In this case, auto scaling may help but the only real solution is to stabilize the converter's LO. The magnitude of this effect (measured on one instrument) is 0.1 ns change per 1 kHz frequency error.

Specifications

Group delay range is from 1 nsec to 10 µsec with a resolution of 0.1 nsec and absolute accuracy of 0.5 nsec. When making comparative peak to peak measurements the accuracy is generally better than 0.1 nsec.

Frequency modulation of the source is provided with the group delay option, from 0.1 Hz to 500 kHz.

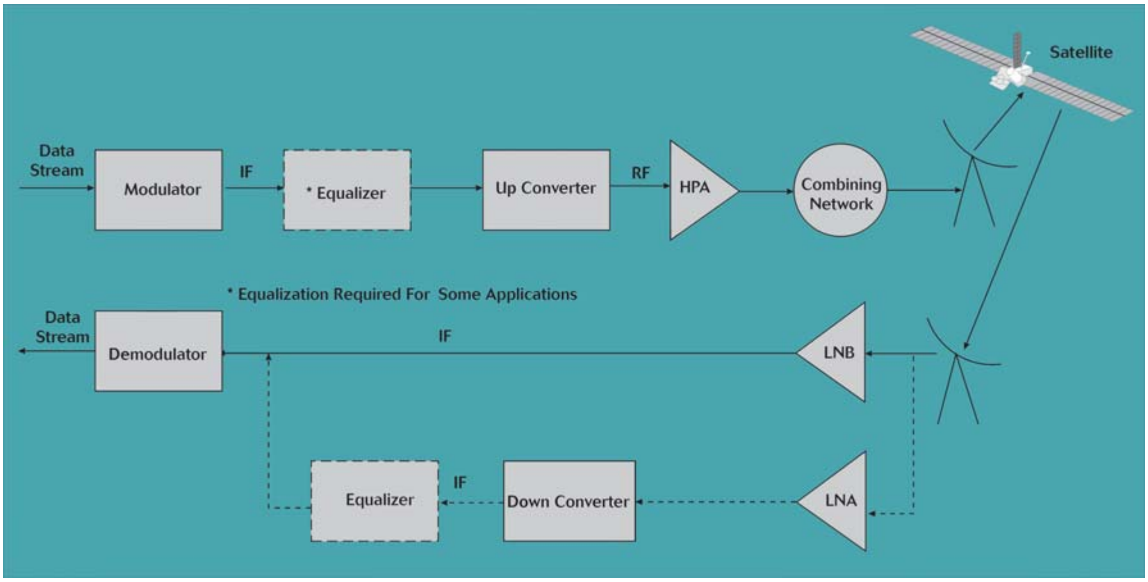


Figure 5 Schematic of a typical satellite link

Satellite In-orbit Group Delay Measurement

Use of 6840 Microwave System Analyzer to measure satellite in-orbit group delay across satellite links.

Typical established satellite transponders are often configured with channel bandwidths of between 36 and 72 MHz depending on the satellite system, although bandwidth over 100 MHz or several hundreds of MHz are not uncommon today. This bandwidth was considered to be more than acceptable when the satellites were launched, but with the increasing demand for Internet traffic, digital TV and other digital services, operators are being forced to fill the available bandwidth to the limit. The consequence of this is that as signals occupy more of the available bandwidth they deteriorate because the transmission path, including the satellite transponder, uplink and downlink, degrades the signal. It becomes necessary to apply compensation for this degradation if the data rate is to be maintained; in order to do this effectively, the impairments must be measured.

Satellite in-orbit testing is carried out for several reasons. In its basic form it is to verify the integrity of the communications payload and the antenna platform following launch and prior to the release of the satellite to the customer. Regular checks are also carried out for the purpose of acceptance testing or anomaly resolution. Measurements can then be compared with forecasted values or previous results.

Group Delay

One parameter that has proved difficult to measure is group delay over frequency, particularly through frequency conversion. Group delay is of prime importance in today's communication systems. The requirement for distortionless transmission through a linear time invariant system is a flat amplitude response and a linear phase response. The components in a typical satellite link, shown in Figure 5, can only approximate these conditions. Group delay is a measure of the phase linearity. Flat group delay versus frequency implies linear phase. Figure 6 shows linear and parabolic group delay, which are typical of delays 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 is flat, a straight line with no slope, so that all frequencies across the carrier bandwidth experience the same time lag through the link. If not, the recovered digits interfere with one another, making them difficult to distinguish and errors occur.

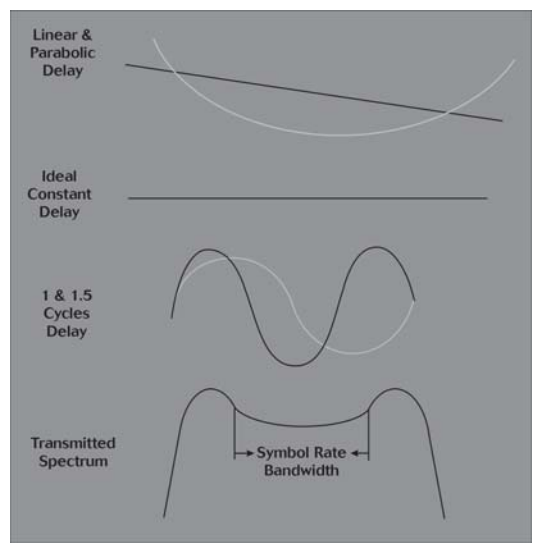


Figure 6 Group delay and the transmitted spectrum

Microwave System Analyzer

The Aeroflex 6840 Series Microwave System Analyzer has become established as the ideal product for the measurement of group delay through frequency conversion components and circuits. It comprises a swept frequency-modulated source and a receiver, as shown in Figure 7, and measures group delay with the envelope or modulation delay technique. Since the group delay is derived from the modulation envelope and not the carrier frequency, the technique can be applied to measure frequency-converting networks. No external frequency converting hardware is needed because the source and receiver frequencies are independent. Figure 8 shows a typical amplitude and group delay response of a downconverter. The MSA can also carry out spectrum analysis, gain compression, third-order intercept, return loss/VSWR and cable fault location.

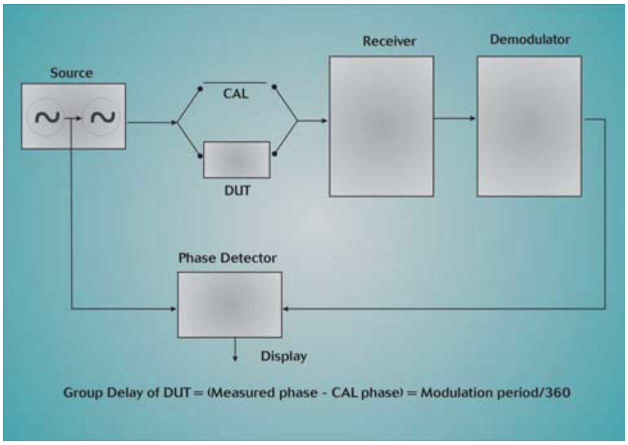


Figure 7 Schematic of the MSA group delay measurement system

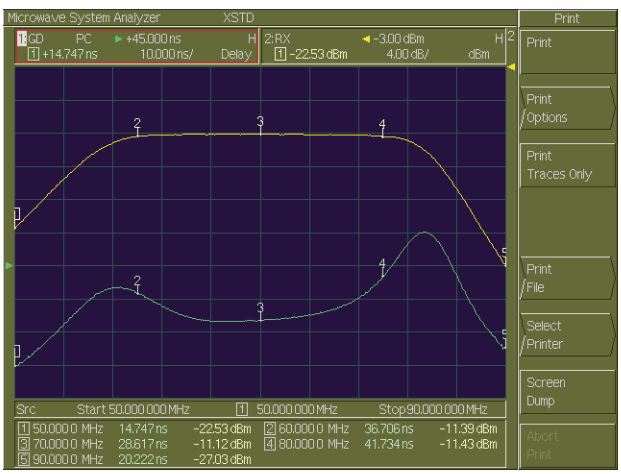


Figure 8 Measured amplitude response and group delay of a downconverter

It is rapidly becoming the instrument of choice in 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 facilitates the selection of the input, output and/or conversion frequencies and levels (see Figure 9).

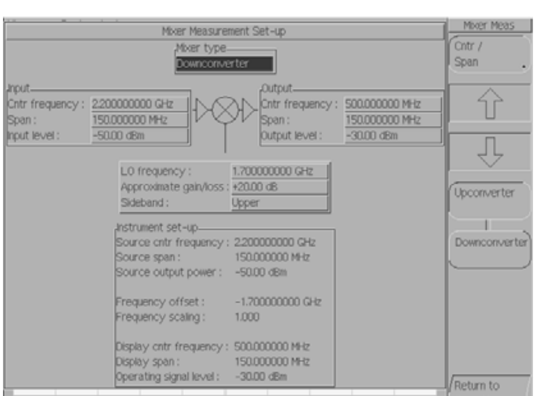


Figure 9 Set-up screen for a downconverter measurement

Transit Time

The transit time to and from a satellite can be considerable even for one in low earth orbit. For a geostationary satellite it is in the region of 250 ms.

In practical terms this can mean that since the source and receiver frequencies are synchronized, the receiver, which will have an aperture of perhaps 1 MHz, has moved beyond the received signal. It is necessary therefore to further offset the source and receiver frequencies to take account of the transit time.

The offset should be increased by:

Foffset (MHz) = Sweep (MHz/ms) × Transit time (ms)

For example, the uplink (source) frequencies are 14,000 to 14,500 MHz and the downlink (receive) frequencies are 11,200 to 11,700 MHz. 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.

Transit time is 285 ms; sweep rate is 0.5 MHz/ms

Foffset = 14.25 MHz

The receiver should therefore be set to sweep between 11,185.75 and 11,685.75 MHz and the source stays to 14,000 and 14,500 MHz to avoid generating any transmitter alarm. The display will show the receive frequency range and the received frequency will be well within the resolution bandwidth. The predicted offset alone may not be enough as geostationary satellites are not stationary and hence also have a Doppler component to be taken into account. The Doppler varies throughout the day, repeats daily and zero twice a day. The Doppler is easily measured and the further offset needs to be applied. If this isn't taken into account then this may produce a slope on the group delay measurements.

In-orbit Measurement

Figure 10 shows the measured group delay characteristic of a satellite in geostationary orbit measured through a single ground station. Input (uplink) frequencies are 14.47 to 14.5 GHz and the output (downlink) frequencies are 12.17 to 12.2 GHz. Calibration was carried out at the input frequencies bypassing the antenna. (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 setting up of the instrument and carrying out of group delay measurements are discussed in detail in the first section of this note. 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.

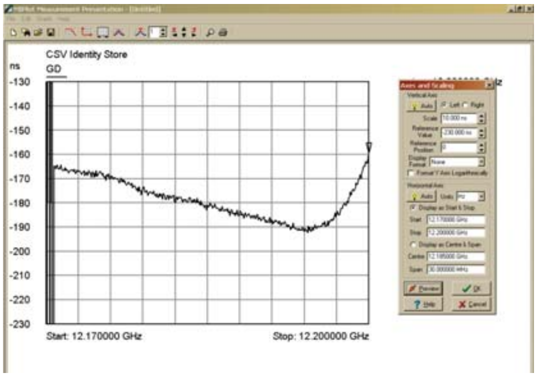


Figure 10 Relative group delay of an in-orbit satellite transporter displayed using MiPLOTTM (courtesy of Loral Skynet®)

Remote Ground Stations

This group delay test can be carried out across links where the ground stations are not co-located. The MSA acting as the source is located with a controlling PC running dedicated software at the link provider's main station. A second MSA acting as the receiver is installed at the receiving end that could be anywhere in the world where the satellite has a transmission footprint. Using one of the control interfaces 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 over the frequency sweep. Measurement data is then returned from the remote end to the local PC for review and storage of the results. See next the section of this note for further details.

Conclusion

The Aeroflex 6840 Series Microwave System Analyzer is the ideal single box solution for in-orbit measurement of group delay across satellite links because all units will readily cover all of the currently required bandwidths and any future increased bandwidths within a single unit. Models cover 10 MHz to 20, 24 and 46 GHz.

Microwave Satellite End to End Group Delay Measurement System

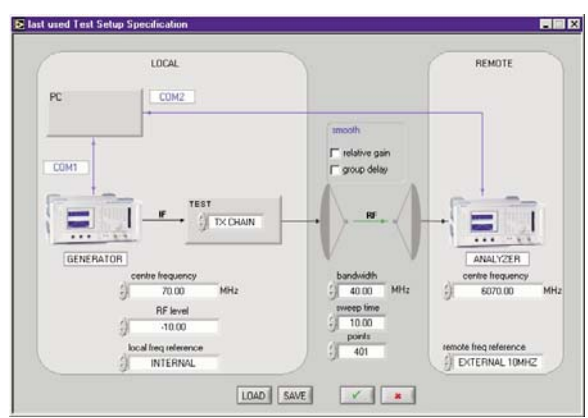
A unique measurement system designed to evaluate the group delay and in band performance over a satellite telecommunications link

The Aeroflex group delay test system is a unique product ideal for engineers working in the microwave and satellite communications industries. The system comprises the Aeroflex 6840 Series microwave analyzers and dedicated software for the collection and processing of measurements. The system is ideal for use by today's microwave and satellite link service providers, and for the maintenance of satellite 'teleport' ground-stations. mTypical established satellite transponders are often configured with channel bandwidths of between 36 and 72 MHz depending on the satellite system, although bandwidth over 100 MHz or several hundreds of MHz are not uncommon today. This bandwidth was considered to be more than acceptable when the satellites were launched, but with the introduction of high bandwidth IP and communications signals, the satellite transponder bandwidths are being used to their limit. The relative group delay measurement across the bandwidth of these channels is important to determine the amount of distortion or signal degradation that could take place due to increased delay changes at the band edges of these transponder channels.

The Aeroflex group delay test system uses microwave analyzers coupled with serial modems and a control PC running dedicated software. Using one of the control interfaces to the local Analyzer, LAN or GPIB, to the local analyzer and a serial connection to a remote analyzer, the instruments are configured to obtain a relative group delay measurement across the section of link to be analyzed. The instruments used as source or analyzer will depend on the direction of the measurement required. The two instruments are synchronized together over the frequency sweep. A Rubidium standard or a local high stability frequency reference must be used at either end of the system to obtain an accurate synchronization. Measurement data is then returned from the remote end to the local control PC allowing for review and storage of the results.

Typical Application Examples

Example 1. Satellite Communications System Evaluation and Installation

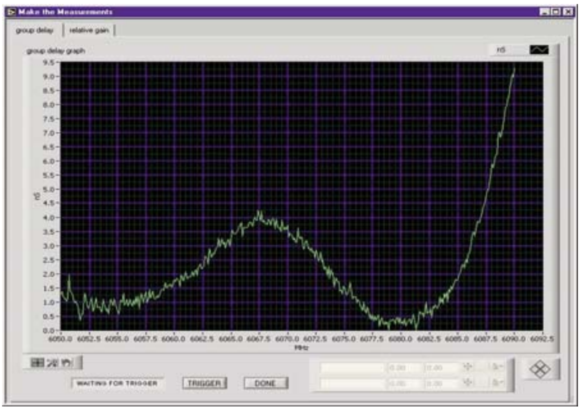


Example 1 Set-up screen for satellite link

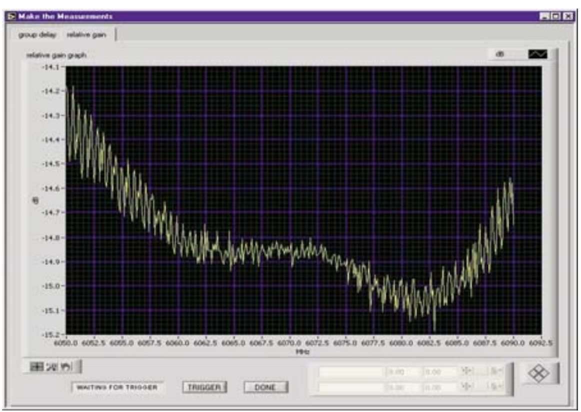
The Aeroflex group delay test system can be used to measure the relative group delay across a newly installed satellite communications link. The PC and microwave analyzer acting as the generator are located at the link provider's main up-link station. The remote end of the system could then be installed at the receiving end, which could be anywhere in the world where the satellite has a transmission footprint. The local system can then control the remote system to measure the relative group delay across the link (either from IF to IF, or various combinations of IF to RF) to determine the performance.

If there are several receiving stations, it is possible to install a remote system at each station allowing measurements from all down-link locations.

Example 2. Ground Station System Evaluation and Installation



Example 2&3 Group delay and relative gain of the link



The test system can also be used for ground system evaluation. Often, in large ground stations, the actual dish antenna can be a long distance from the modem and equipment rack. It is often necessary to perform a measurement of the group delay variation, and gain flatness between the system IF and the RF at the antenna. The Aeroflex group delay test system can be used to measure signals between any two parts of the system. The unique offset measurement facility of the 6840 Series allows easy measurements between IF and RF. If the distance between the modem and the antenna is in the order of a few hundred meters, then the internal instrument reference standard and the serial modems can simply be linked together with appropriate cables.

The measurement speed will depend on several factors and is defined as; sweep time (Gain/Freq) + sweep time (Group Delay) + data retrieval time. For remote operation using a modem, assuming a sweep time of 10 seconds, a 500-point trace and a 10 second data retrieval time, the overall measurement time would be 30 seconds typically. The quality of the modem and telephone link to the remote instrument will affect measurement time. Any jitter introduced by the link will cause the instruments to lose synchronization and will restart the measurement.

System Requirements

1) Two Aeroflex 6840 Series Microwave Analyzers. Both instruments must be fitted with Group Delay (option 022) and the corresponding Step Attenuator for the instrument type chosen. Both instruments must have the same software version installed.

2) A PC is required to run the software. The software licence is supplied on a CD-ROM disc therefore a suitable ROM drive is required in the PC.

Minimum PC requirements are as follows:

750 MHz Pentium

256 Mb RAM

100 Mb free hard drive space

CD-ROM Drive

RS232 and LAN ports

Windows 2000/XP

3) A LAN or a GPIB interface is required in the PC to communicate with the local instrument. Two modems are required to communicate with the remote instrument (one at the PC, the other at the remote instrument). These modems must be external RS232 56K modems with leased line capability and dumb mode operation.

4) If the two instruments are not adjacent (if the reference out from one cannot be connected to the reference in of the other), they must be run from an external 10 MHz clock reference. The matched frequency accuracy of the two clocks is critical to the operation of the system, and must be held to within +1x10-10 Hz. Aeroflex recommends Rubidium frequency standards for both instruments if they cannot be run from the same clock reference.

For more information on the Aeroflex products mentioned in the application note, please visit our web site at: www.aeroflex.com/ats/products/category/General_Purpose_Test/Microwave or contact your local sales office.

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