

Keysight Technologies

Precision Validation, Maintenance and Repair of Satellite Earth Stations

FieldFox Handheld Analyzers

Application Note



To assure maximum system uptime, routine maintenance and occasional troubleshooting and repair must be done quickly, accurately and in a variety of weather conditions. This application note describes breakthrough technologies that have transformed the way systems can be tested in the field while providing higher performance, improved accuracy, capability and frequency coverage to 50 GHz. A single FieldFox handheld analyzer will be shown to be an ideal test solution due to its high performance, broad capabilities, and lightweight portability, replacing traditional methods of having to transport multiple benchtop instruments to the earth station sites.

A satellite communications system is comprised of two segments, one operating in space and one operating on earth. Figure 1 shows a block diagram of the space and ground segments found in a typical satellite communications system. The space segment includes a diverse set of spacecraft technologies varying in operating frequency, coverage area and function. The satellite orbit is typically related to the application. For example, about half of the orbiting satellites operate in a Geostationary Earth Orbit (GEO) that maintains a fixed position above the earth's equator. These GEO satellites provide Fixed Satellite Services (FSS) including broadcast television and radio. The location of GEO satellites result in limited coverage to the polar regions. For navigation systems requiring complete global coverage, constellations of satellites operate in a lower altitude, namely in the Medium Earth Orbit (MEO), that move around the earth in 2-24 hour orbits. At even lower altitudes, namely in the Low Earth Orbit (LEO), satellites provide applications which include remote sensing and mobile communications. The International Space Station and the Hubble Space Telescope also operate in LEO.

System requirements may be very different depending on the orbital location. For example, tracking GEO satellites requires only minor adjustments when pointing the ground segment antenna while LEO satellites require the ground station antennas to follow the satellite's trajectory in orbit. The space segment also includes the earth-based satellite control subsystem that provides the functions of tracking, telemetry and command (TT&C). The TT&C determines the satellite's orbital position and provides commands to adjust its altitude, orientation and trajectory. The TT&C also relays information regarding the health and operational status of the satellite payload [1].

The ground segment, also referred to as the earth segment, contains gateways, hubs and user terminals. Communications, including voice and data, are carried between the gateway and hubs to user terminals through the satellite acting as a relay. Gateways connect the satellite communications to other terrestrial networks such as telephones (PSTN), cellular networks and the internet. Hubs provide connections between different elements of a common system including numerous user terminals and other hubs. Gateways, hubs and user terminals are typically referred as earth stations [1].

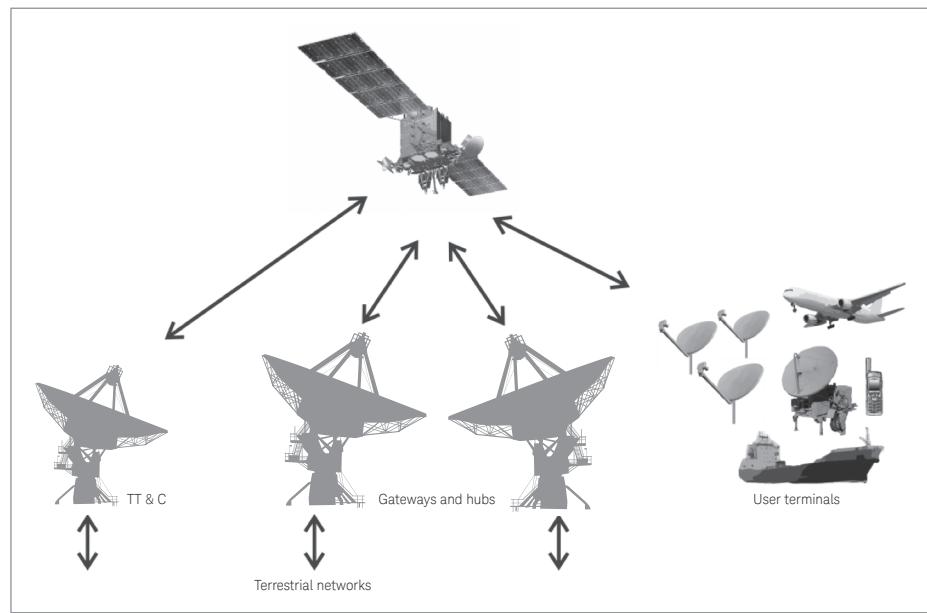


Figure 1. Space and ground segments in a satellite communications system

Connectivity between gateways and hubs to user terminals may operate in a point-to-multipoint fashion or in one of several duplexing modes achieving two-way communications. When the connection is point-to-multipoint, such as in broadcast applications, an earth station transmits the uplink signal to the satellite for wide area distribution to potentially millions of user terminals. During satellite rebroadcast, this content is received by all user terminals located within the beam of the satellite antenna. The origin of the broadcasted content may be delivered from a terrestrial network or from another satellite system such as in Direct-to-Home (DTH) television systems. The user terminals may be homogeneous across the entire system, such as the terminals in a DTH system, or heterogeneous containing a variety of fixed, mobile and handheld applications.

As an example of a DTH system, Figure 2 shows the measured spectrum of a typical Direct Broadcast Satellite (DBS) TV signal. The total allocated frequency range is subdivided into separate channels with a small guard band between the channels to reduce cross channel interference. The measurements in figure 2 were made using a Keysight FieldFox handheld analyzer connected to the receiver output from a Low Noise Block (LNB) downconverter located at the DBS antenna. The antenna in this measurement contained three separate LNBs each receiving a signal from a different satellite operating in the Ku-band. The LNB horns were mounted to the common arm placed in front of a parabolic reflector antenna but slightly offset from each other so the reflector antenna directed three unique antenna beams to different satellite locations in orbit.

FieldFox was operated in the spectrum analyzer (SA) mode and configured to sweep across the standard intermediate frequency (IF) range for the LNBs of 950 to 1450 MHz. In this example, FieldFox was configured to display three measurement traces, two of which were stored to the instrument memory and measured from LNB1 and LNB2 respectively. The third measurement trace was active and captured from LNB3. In this example, markers were placed on various traces to record the relative differences between the leftmost and rightmost channels across different LNB traces. The measurement clearly showed how multiple traces and markers were useful in identifying the poor performance of one of the receivers. In this figure, trace 1 shows a rapid decrease in the received power levels in the last two channels at the high end of the frequency range. Marker 3, configured in "delta" mode, reports a -15 dB decrease in the received power level at the high end of the band relative to signal in the first channel. It is possible that the LNB3 performance has deteriorated and requires replacement.



Figure 2. Measured frequency spectrum from three Ku-band DBS receivers

When two-way communication between the user terminals and another part of the network is desired, a forward link and a reverse link must be included as part of the system design. The forward link, defined as the transmission between the earth station to the various user terminals, operates in a broadcast mode while the return link, from the user terminal back to the earth station, requires the use of a multiple access scheme in order to share the limited frequency spectrum between the multiple user terminals.

One popular multiple access technique is Time Domain Multiple Access (TDMA) which assigns the user terminal to a specific time slot to transmit its data. Slot assignments can be made on a “pre-assigned” or “on-demand” basis. Pre-assigned time slots are the easiest to implement but are not spectrally efficient when a user terminal does not have data to transmit. On the other hand, on-demand assignments are spectrally efficient and would increase total system capacity but require additional overhead for tight coordination of the numerous user transmissions.

Satellite systems also use other multiple access schemes, including Frequency Division Multiple Access (FDMA) and Code Division Multiple Access (CDMA), to improve system capacity. Further increases in system capacity can be achieved through carrier frequency re-use as described in the next section of this application note.

High Throughput Satellites (HTS)

One growth area for satellite systems is in the delivery of bidirectional broadband services aimed at the consumer market, such as voice, data, broadcast, and other professional services including corporate communications and Satellite News Gathering (SNG). These systems, referred to as High Throughput Satellites (HTS) [2], have total system capacities of over 100 gigabit per second (Gbps). To achieve this high throughput, “frequency re-use” and “spot beams” are required to improve the spectral efficiency of the satellite system. Figure 3 shows a simplified diagram of a satellite producing sets of spot beams pointed at different locations across the intended geography. The spot beams are positioned far enough apart so that the same frequency can be re-used at different locations without creating interference between the beams operating on the same frequency channel. For example, signals transmitted from the satellite that are assigned to frequency channel F1 are also assigned to several beams directed at different geographic areas. Each spot beam can carry different information to a different set of user terminals while sharing the same F1 channel. Another advantage to using spot beams is that higher gain antennas are required for creating the narrow beams which result in improved received power level at the user terminal.

The ability to increase spot beam power to a specific geographic area can reduce weather attenuation. This allows the use of Ka-band, giving operators access to less crowded bands and thus increasing bandwidth and throughput.

The example shown in figure 3 shows a total of four frequency channels, F1 through F4, that are re-used throughout the system. The frequency re-use (FR) pattern shown in figure 3 is known as the “4-color” pattern [3]. One of the advantages of a 4-color pattern is that the distance between same-colored beams is constant allowing a less complex satellite payload design. There are other patterns implemented in various satellite and terrestrial wireless systems including the 3, 6, 7 and 12-color patterns. Patterns with a higher number of colors have improved inter-beam isolation but result in less bandwidth per beam. It would first appear that spot beam application to frequency re-use seems unlimited by just increasing the number of beams and reducing the spot beam size. Unfortunately practical limitations, including the number of antennas that can be mounted onto a single satellite, antenna pointing accuracy, reduced inter-beam isolation created by antenna sidelobes, and nonlinearities in the amplifier and frequency converter components, will all reduce the overall system performance. Therefore the system designer must optimize the amount of frequency re-use and the number of spot beams for the highest system performance at the lowest overall cost.

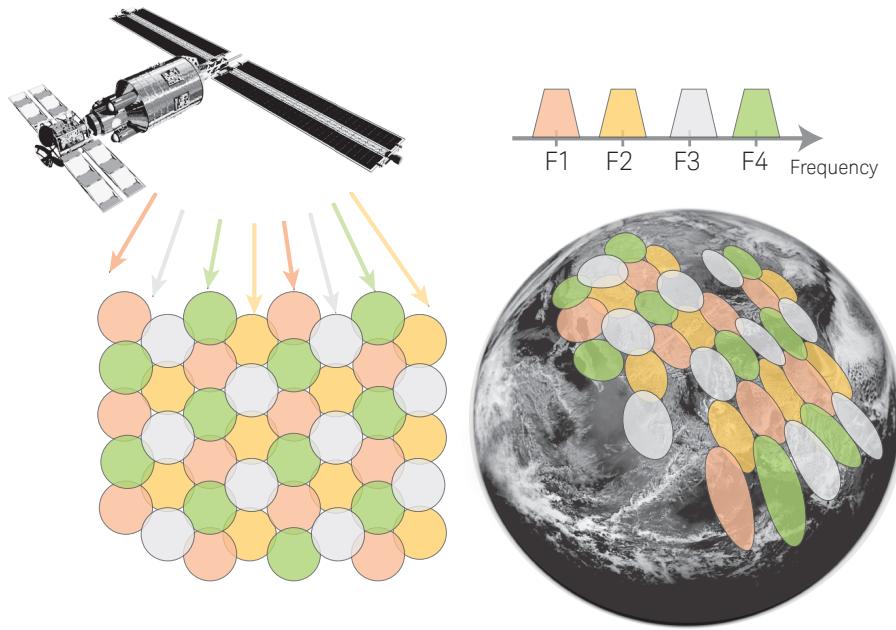


Figure 3. Frequency channel and spot beam allocations over a geographic area in a High Throughput Satellite (HTS) application

Satellite Payload Design

The satellite payload performs the main function of receiving an uplink signal from an earth station and retransmitting this signal as the downlink signal to a user terminal or another earth station. The lowest level describing the payload is the transponder. There are two types of transponders, namely the bent-pipe transponder and the processing transponder. The bent-pipe transponder is the most common and a simplified block diagram is shown in figure 4. The signal flow through the transponder begins on the left with the uplink signal captured by the satellite's receive antenna. A preselect filter suppresses uplink interference and provides image rejection. A low noise amplifier (LNA) increases the amplitude level of the received signal and a frequency converter, usually a down converter, converts the uplink frequency to the specified downlink frequency. For example, a typical Ku-band satellite system would operate with an uplink frequency of 14 GHz and a downlink frequency of 12 GHz. The frequency converter, with its internal mixer and local oscillator translates the 14 GHz carrier to the 12 GHz carrier. This frequency-shifted signal is then amplified by two or more stages of RF amplification and transmitted through the spot beam antenna at the output.

The diagram shows only one signal path from the input to the output though it is implied that there will be several paths through the transponder as input and output multiplexing circuits will route the signals between appropriate input-to-output antenna combinations. It is also important to note that channel redundancy is often built into these payloads to recover from a possible failure in any of the system components.

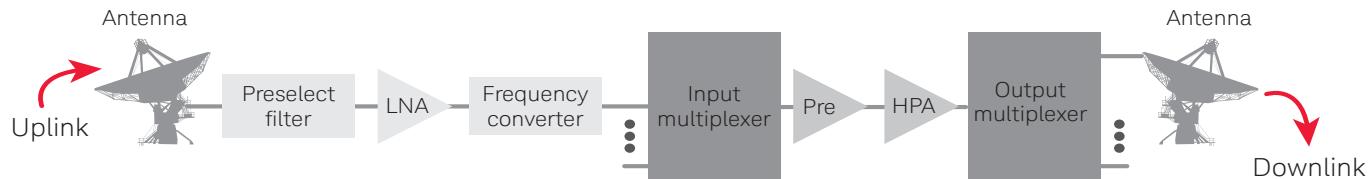


Figure 4. Simplified block diagram of a “bent-pipe” satellite payload

The second type of payload is the processing transponder. There are fewer processing transponders than bent-pipe designs but the number is increasing as advancements in communications technology allows the payload’s mission to become more complex without increasing the overall cost of the satellite. Processing transponders digitize the input waveforms to perform additional signal processing. A non-regenerative process does not demodulate the incoming waveform while a regenerative system will demodulate and re-modulate the data. Regenerative processing may improve the system’s overall signal-to-noise ratio (SNR) performance as the data only passes through one half of the total link before being recovered. This can reduce the overall noise introduced by the system. Also, regenerative payloads can eliminate the need for a gateway or hub allowing direct user-to- user connectivity and reduced latency.

Earth Station Design

A typical earth station contains at least one transmitter channel and one receiver channel. Shown in figure 5 are simplified block diagrams of these channels focusing on the IF and RF sections of each signal path. The transmitter typically receives multiple data streams and an input multiplexer routes these signals to the appropriate modulator. The modulator may produce a modulated IF operating at 70 MHz with a channel bandwidth of 40 MHz or an IF of 140 MHz with a channel bandwidth of 80 MHz. The multiple channels are added together and upconverted to the RF carrier which includes frequencies in the L, C, X, Ku, K and Ka bands. This block diagram shows a single block upconverter but some systems use modulators that directly upconvert to the desired carrier frequency in a single rack-mounted device. We will discuss converters in greater detail later in this application note.

To continue along the transmitter path, the signal is then amplified and transmitted out the large earth station antenna pointed at the satellite. The antenna may have a single polarization, dual polarization or circular polarization. This diagram shows two separate antennas but an earth station may also be configured with a single antenna for transmitting the uplink and receiving the downlink. In this case, a frequency duplexer is required to route the signals between the transmitter and receiver to the shared antenna. The duplexer is designed with high isolation between transmit and receive channels. The receiver block diagram follows a similar signal flow to that of the transmitter but only in reverse. The received signal enters the antenna and is filtered and amplified. The preselect filter rejects out-of-band RF interference. The signal is then block downconverted to the lower IF making it easier for the demodulation process. Most downlinks use an L band IF (950 MHz to 1450 or 2150 MHz), so most validation and troubleshooting measurements are made in this range. If multiple data channels are required by the system, a signal divider and output multiplexer will route the signals to the appropriate output port.

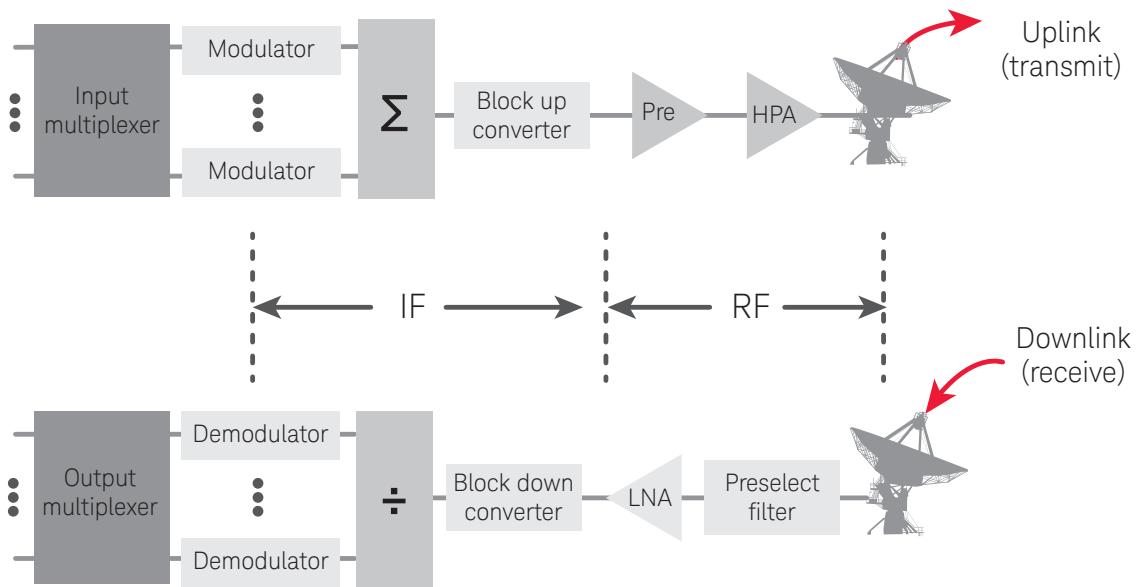


Figure 5. Simplified block diagrams of an earth station transmitter (upper) and receiver (lower)

Earth Station Maintenance and Troubleshooting

With the focus on the IF and RF subsystems of an earth station, the testing and equipment requirements for maintaining and troubleshooting the station are shown on table 1. Table 1a shows a list of typical test requirements for an earth station including the antenna and associated components. Some of these tests are required during the installation of a new system while others are part of periodic maintenance and performance verification. For example, antenna sidelobe testing is typically part of the initial acceptance test and may also be performed should the system experience degradation in the overall performance. On the other hand, antenna alignment may be performed more regularly to optimize system performance or when the antenna's motor servo systems need repair or replacement. As many of the system components are exposed to the outdoor environment, including the antenna and associated transmission lines, there is a chance that moisture could build up in the lines and cause extensive damage. Therefore, periodic testing of the RF performance of these transmission lines can prevent expensive repairs if left unattended. It is also important to periodically verify that the output power level, occupied bandwidth and adjacent channel power from the transmitter are within specification, otherwise system performance could be degraded, creating interference to other satellite and wireless systems.

Table 1. Earth Station Maintenance and Troubleshooting Requirements

(a) Testing requirements	(b) Equipment requirements
Antenna	<ul style="list-style-type: none"> - Power meter - Spectrum analyzer - Vector network analyzer - Line sweeping (DTF/time domain) - RF source (CW and swept) - DC source Voltage/current meter
Transmission lines	<ul style="list-style-type: none"> - Cable and waveguide loss - Rotary joint VSWR - Fault location
Transmitter	<ul style="list-style-type: none"> - HPA performance - Converter performance - Occupied bandwidth - Adjacent channel power - Frequency stability
Receiver	<ul style="list-style-type: none"> - LNA performance - Converter performance - Interference - GPS (mobile applications)
System	<ul style="list-style-type: none"> - EIRP - G/T, C/N - BER

While the test requirements listed on table 1a are only a subset of the total requirements needed for earth station system installation, maintenance and verification, they provide some insight into the broad range of test equipment required to support these efforts.

Table 1b shows a list of RF and DC test equipment required to support earth station maintenance and troubleshooting. The list includes an RF power meter, spectrum analyzer, vector network analyzer, and line sweeping equipment. There is also support equipment that includes RF and DC sources and DC voltage and current meters. While the equipment requirements can be fulfilled with separate specialized instruments, the FieldFox combination analyzer includes all of these functions in a single handheld instrument. The remainder of this application note details several of the measurements listed on table 1a. For these examples, FieldFox is operated in different modes for each measurement type.

Antenna Measurements

Earth stations operating with GEO satellites require a fairly simple pointing and tracking system due to the fact that the system TT&C center maintains satellite orbit within a tight angular position. On the other hand, non-GEO satellites can require complex tracking systems in order to follow the satellites' orbit [1]. For GEO satellites, antenna pointing can be optimized by tracking a beacon signal transmitted by the satellite. With a new satellite installation, antenna pointing can be manually accomplished using a spectrum analyzer connected to a monitor port along the received signal path. As the earth station antenna is moved across a small angular displacement, the measured signal level will increase and decrease as the antenna's boresight direction moves across the direction of the satellite. To optimize the antenna pointing accuracy, FieldFox includes a maximum amplitude hold function, referred as "max hold", that will maintain the highest signal level as the antenna is moved. This max hold measurement can be compared to an active measurement as the antenna is moved. The antenna peak is properly pointed when the active trace lines up with the max hold trace.

Figure 6 shows two measurement examples when using the max hold trace while simultaneously displaying the active or "live" trace. Both examples were captured using FieldFox with two measurement traces displayed. Figure 6a shows a typical swept spectrum configured with a 100 kHz frequency span. As the antenna was rotated, the peak amplitude of the active trace, shown in blue, moved up and down as the received amplitude changed. The max hold, shown in yellow, maintained a record of the maximum level recorded at each frequency across the span. Pointing was optimized when the peak in the blue trace equaled the max hold peak and no further increase in power level was observed.

A second approach for maximizing the received amplitude uses the "zero span" on FieldFox. Figure 6b shows this measurement with the spectrum analyzer tuned to the center frequency of the beacon and the instrument display now sweeping in time. Once again, the max hold and an active trace allow a visual aid when optimizing the received signal level and associated antenna pointing. One advantage of the zero span mode is that the sweep rate can be adjusted to approximately the same time it takes for the antenna movement across an axis. This technique is very useful when measuring the antenna sidelobe levels, which will be discussed next.

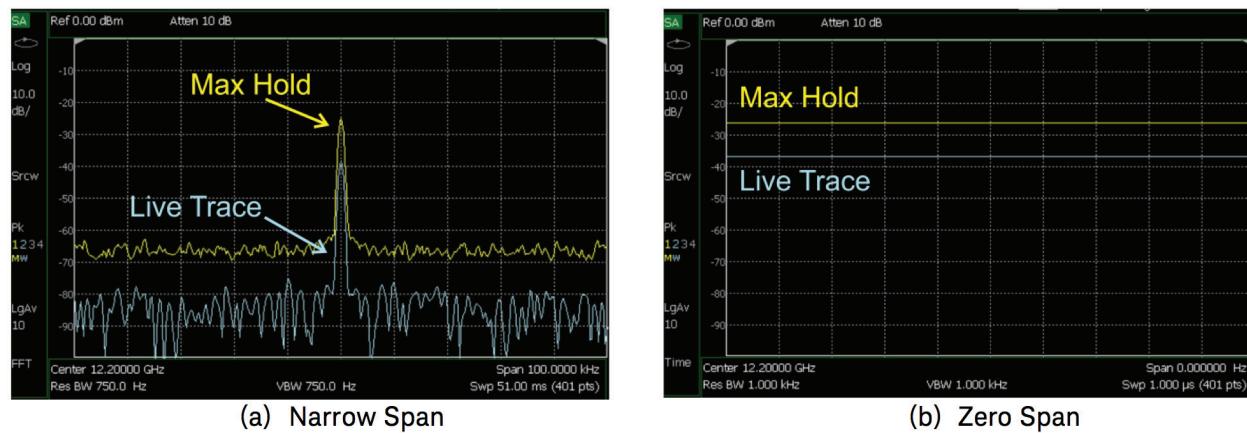


Figure 6. Measurement of satellite beacon as antenna was rotated using FieldFox set to (a) narrow frequency span and (b) zero span

Because geosynchronous satellite orbital slots are specified at every 2° of longitude, earth station antennas must have high gain and low sidelobe levels. If the gains of the antenna sidelobes are too high, the earth station antenna will produce high levels of interference to the adjacent satellites, especially when those systems share the same frequency spectrum and antenna polarization. For example, a single-beam earth station reflector antenna having a diameter greater than 100 wavelengths should have a sidelobe level determined by the following equation [4].

$$\text{Sidelobe Gain (dBi)} = 29 - 25 \log_{10} \theta,$$

where the angle θ is specified in degrees relative to boresight and the gain value is relative to an isotropic antenna. One way to measure the relative sidelobe level of an earth station antenna is to transmit a signal from the desired antenna and record the received signal level at another earth station as the desired antenna is rotated over a narrow angular displacement. The displacement should cover the main beam and the peaks of the two adjacent sidelobe levels. The same technique can be applied to capture the receive antenna pattern by using a fixed transmit antenna and a rotated receive antenna. In general, the measurement of sidelobe level in the transmitter antenna is of most importance as this signal potentially creates interference to other satellite systems if the sidelobes are out of specification.

Sidelobe levels are typically measured using a similar technique as antenna pointing, where a spectrum analyzer is placed in zero-span mode and the analyzer's sweep time is approximately synchronized with the sweep in angular displacement. Figure 7 shows the simulated measurement of the received signal as the earth station antenna was scanned over a ± 15 -degree angle from boresight. The measurement was recorded using FieldFox configured with zero-span mode, max hold and a sweep time set to approximately the slew rate of the antenna movement.

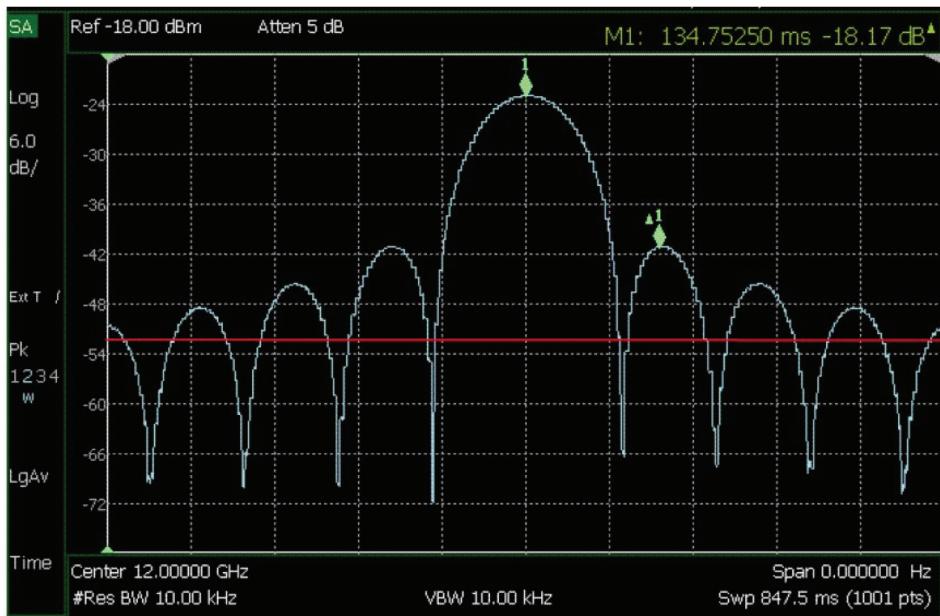


Figure 7. Measured antenna pattern using FieldFox configured in zero span mode with max hold

In general, unless the antenna becomes damaged or affected by the surrounding environment in some way, pattern measurements are not typically performed on a frequent basis, as the satellite system would be taken out of service. On the other hand, environmental conditions, such as rain and humidity, can affect other parts of the system especially the interconnecting transmission lines including many coaxial and waveguide components. Maintenance and troubleshooting of these transmission lines may occur more frequently and rely on measurement techniques called line sweeping and distance-to-fault, which will be discussed in the next section.

Line Sweeping and Time Domain Measurements

Line sweeping is a measurement of the frequency response of a long transmission line, such as a coaxial cable or waveguide, connecting a transmitter to its antenna or between an antenna and its receiver. The measurement reports the signal attenuation and return loss of the complete transmission path. Line sweeping may also be used to estimate the physical location of a fault or damage, along a transmission line using the Distance-to-Fault (DTF) measurement available in FieldFox cable and antenna test (CAT) or vector network analyzer (VNA) modes. DTF is a mathematical transform of the measured frequency response into the time domain.

Figure 8 shows examples of DTF measurements through several sections of WR-90 X-band waveguide. The first section is a coaxial-to-waveguide adapter with the coax port connected to FieldFox. Next, it is connected a 6-inch length of straight rigid waveguide which is then followed by an 18-inch length of flexible waveguide. For these measurements, the flexible waveguide, or “flexguide”, is either terminated in a matched waveguide load or the end flange is left open. FieldFox is configured to measure the return loss, as the S-parameter S11, as a function of frequency. FieldFox is switched to the DTF mode, also referred to as the time domain transform mode. In time domain mode, the x-axis is time and the y-axis is amplitude. The time domain result for this simple transmission line system is shown in figure 8. When examining the DTF display, large peaks are located at the points where discontinuities exist along the transmission line.

The measurement in figure 8a contains two traces, one trace has the flexguide terminated in a matched load and the other trace has the flexguide left open-ended. Both traces show a first peak at the coax-to-waveguide adapter located at time equal to zero. For the measurement with the open-ended flexguide, there is a second large peak at the location of the open. When the flexguide is terminated using a matched load, the amplitude of the peak is very low in comparison. Markers placed at the peak of each reflection report the electrical distance and the associated physical location to the discontinuity. For example, the location of the open circuit at the end of the flexguide is measured at 675 mm, which is the total length through the adapter, straight waveguide and flexguide. FieldFox automatically calculates the dispersion of the waveguide (propagation velocity that changes as a function of frequency) when the WR-90 is selected from the waveguide and cable electrical properties table. This ensures accurate distance to fault.

As a comparison, assume that this transmission system was exposed to the environment and water has leaked into the waveguide. For the example shown in figure 8b, a section of the flexguide was partially filled with water. When examining the time domain response, there was a large peak in the response that corresponds to the location of the water-filled waveguide. Once again, a marker was used to measure the physical distance to the water, which was 384 mm from the input. Obviously, this technique is ideal when troubleshooting problems in the feed lines of an earth station.

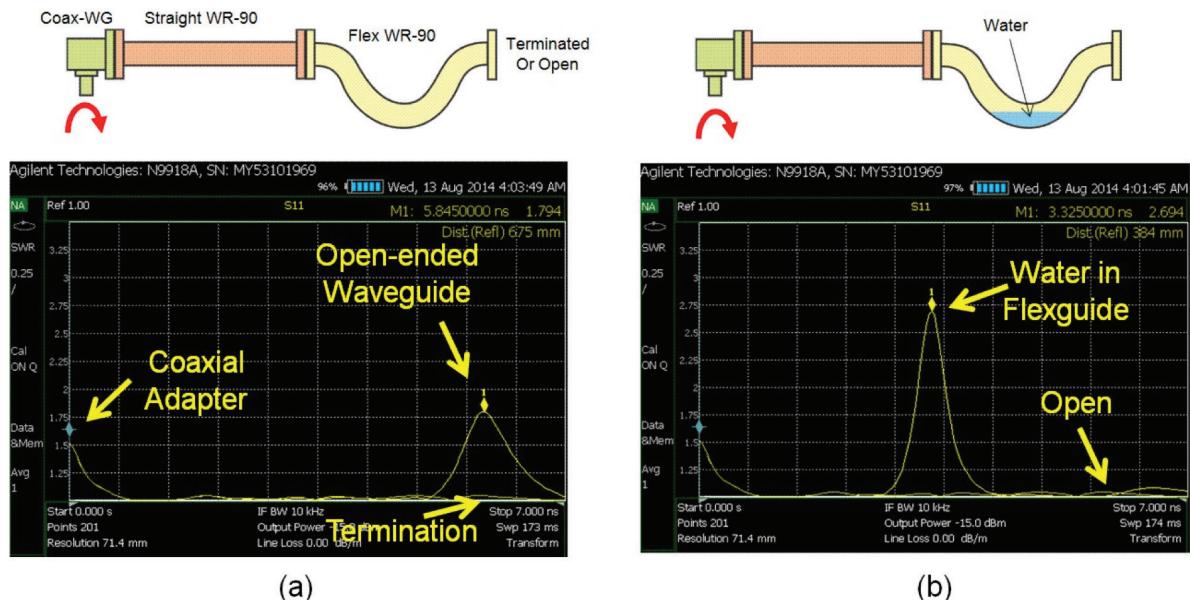


Figure 8. Time domain measurements of a system of waveguide components

Occupied Bandwidth and Adjacent Channel Power Ratio Measurements

As mentioned in the previous section, the transmitted signals are designed to operate within a specified frequency bandwidth, or channel, in order to not interfere with those signals occupying the adjacent channels. Unfortunately nonlinearities in the active components of any RF system creates distortion, often called intermodulation distortion or spectral regrowth, resulting in an increase of the signal's occupied bandwidth (OBW) in the surrounding channels and guard bands.

Figure 9 shows an example of a digitally-modulated 44-GHz signal. The test signal was created using a Keysight PXG vector signal generator configured with 64 QAM modulation. This modulated signal was amplified and the spectrum was measured using FieldFox operating in spectrum analyzer mode. The test configuration included a high power attenuator placed between the amplifier and FieldFox to prevent overloading the front end of the analyzer and potentially damaging the instrument. The measurement shows the spectrum of the amplified signal configured to operate just below the amplifiers saturation point. The display also shows that the occupied bandwidth is 52.50 MHz and channel power is 21.08 dBm. The occupied bandwidth measurement is part of the “one button” suite of channel measurements provided by the spectrum analyzer mode in FieldFox. It should be noted that FieldFox can be configured with an external USB power sensor for those test cases requiring the highest accuracy and/or peak power measurements.

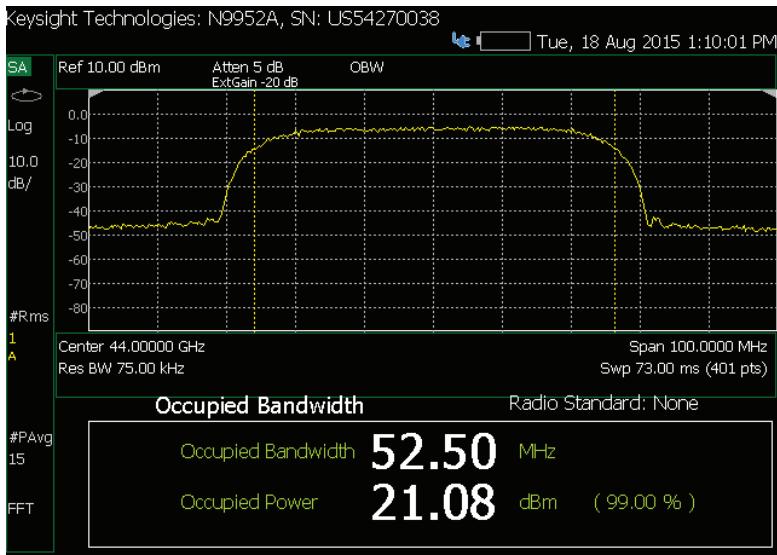
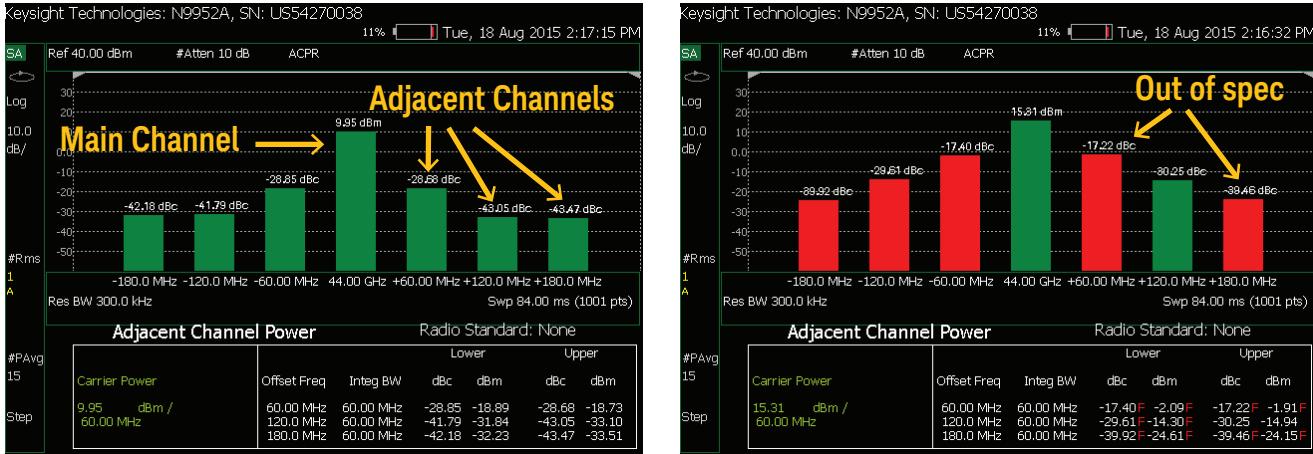


Figure 9. Measurement of the spectrum and occupied bandwidth from a 44-GHz digitally-modulated input signal.

The measurements shown in figure 10 display the Adjacent Channel Power Ratio (ACPR) for this same amplifier. ACPR reports the amount of unwanted energy in nearby channels relative to the signal power in the main channel. This type of interference is common for modulated signals and primarily created by energy splatter out of the assigned frequency channel and into the surrounding upper and lower channels. This energy splatter can be generated by faulty modulation, switching transients and intermodulation distortion. ACPR levels rapidly increase when an amplifier reaches its output power limit and begins to saturate. For example, the measurement in figure 10a displays the relative ACPR levels when the amplifier was operating just under its specified saturation level. The power levels in the main channel and the three upper and lower channels are displayed as bar graphs. In this case, the main channel power of the non-saturated amplifier was 9.95 dBm and the relative adjacent channel power in the nearest channels were approximately -29 dBc each. As the amplifier entered saturation, there was a sharp increase in the ACPR as shown in figure 10b. When the amplifier was saturated, the ACPR of nearest channels increased from -29 dBc to -17.4 dBc, while the main channel power only increased from 9.95 dBm to 15.3 dBm. For this saturated amplifier condition, FieldFox displayed five of the ACPR bars highlighted in red. For this measurement, FieldFox was configured with limits to display an out-of-spec condition when ACPR levels exceeded a predetermined value. In this example, the three adjacent channel limits were entered as -20, -30 and -40 dBc respectively. Measurements below these limits are displayed as green, outside the limits in red.



(a) Non-saturated amplifier

(b) Saturated amplifier

Figure 10. Measurement of Adjacent Channel Power Ratio (ACPR) using a high power amplifier

Filter Loss and Group Delay Measurements

Filters are used quite extensively in all communication systems. In earth station applications, they are typically integrated into the high-performance upconverters and downconverters. Filters are used primarily for their out-of-band rejection in both uplink and downlink paths. Filter performance is measured using a VNA that displays the scattering parameters (S-parameters) of the two-port device. The measured S-parameters are a function of frequency and are related to specifications of insertion loss, return loss, group delay, and out-of-band rejection. The bandwidth of the filter and its ripple response are measured quantities that are typically determined by using the marker functions on the VNA.

The highest measurement accuracy when measuring any two-port device occurs when the S-parameters are measured using a two-port VNA having a full two-port calibration [5]. FieldFox should be calibrated to remove the effects of the test cable and adapters that are required in order to connect the filter to the analyzer. There are several options for calibrating FieldFox, including the popular "QuickCal" that eliminates the need for an expensive calibration kit to be carried into the field.

The measurements shown in figure 11 display the S21 transmission response of a band pass filter centered at 1 GHz. FieldFox includes a marker search function that automatically determines the filter bandwidth using a target value, in this case at -3 dB. The measured insertion loss is -1.57 dB and the filter 3-dB bandwidth is 15 MHz. Another important characteristic of a filter is its transmission phase, and associated group delay response. In communications systems, it is important to have a linear phase response across the pass band to avoid distortion in the desired signal.

Another way to specify a linear phase response is to have a flat group delay response in the pass band. Shown in figure 11, as the blue trace, is the measured group delay response of this filter. Markers are placed at the center and at the peaks near the band edges. In this case, FieldFox was configured with uncoupled markers so different traces can have marker placement at different frequencies. By default, FieldFox configures the markers as coupled so they track each other in frequency on up to four traces at one time.

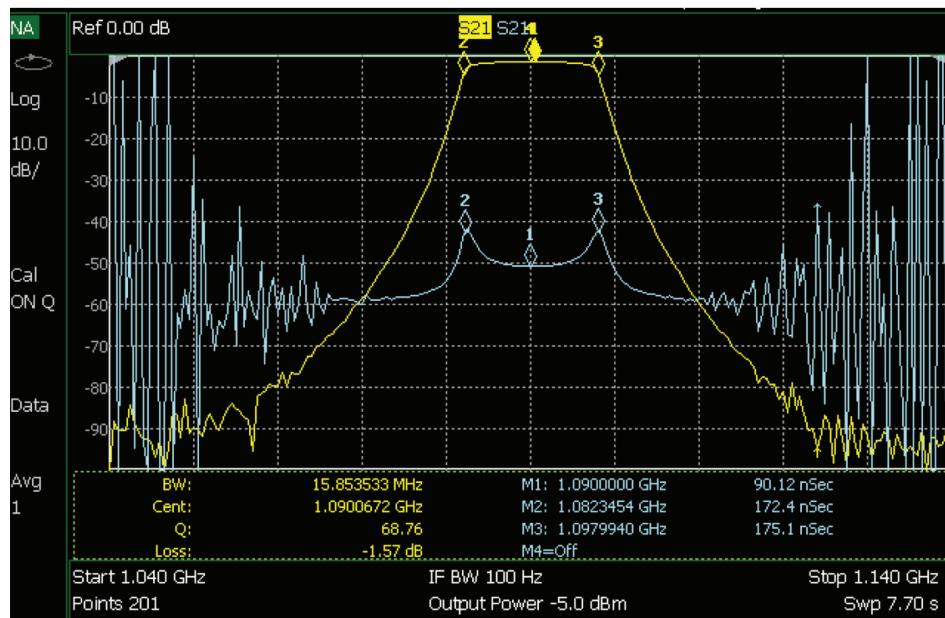


Figure 11. Measured transmission response of band pass filter

Frequency Converter Measurements

Frequency converters provide translation between a modulated signal's intermediate frequency (IF) and the uplink, or downlink, RF frequency of the system. Figure 12 shows a diagram of a typical block down-converter (BDC). The BDC translates a large block of frequencies captured from the satellite downlink to a lower frequency for additional signal processing and demodulation. BDCs typically use a single internal local oscillator (LO) for frequency translation. The IF from commercial BDCs is typically in the L-band frequency range, 950 MHz to 1450 or 2150 MHz [1]. Other types of downconverters are designed with an IF in the VHF range, typically 70 MHz or 140 MHz. These types of "frequency synthesized" downconverters will have two LOs (double conversion) and can be used to tune to a specific communications channel. Channel bandwidths for these downconverters are typically 40 MHz or 80 MHz wide, providing a high level of dynamic range and adjacent channel rejection.

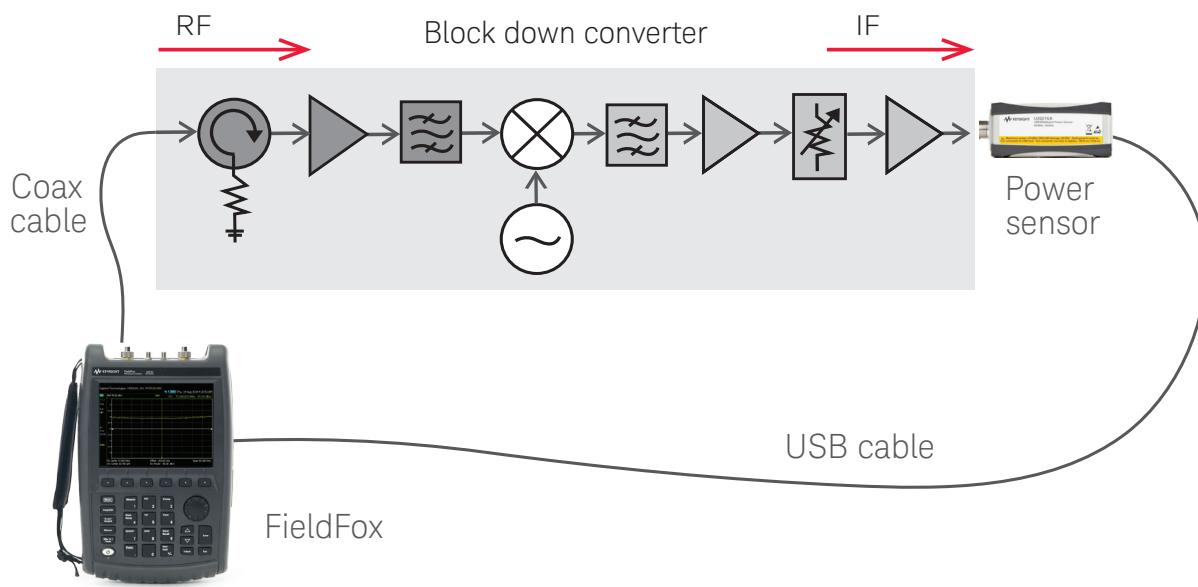


Figure 12. Frequency block downconverter and associated test configuration

Ideally, a downconverter only changes the center frequency of the signal and does not alter or distort the signal in any way. Unfortunately, the RF/IF components along the converter path create some level of distortion to the signal and it is up to the design engineer to select components that minimize these effects. Several types of test equipment are required to fully characterize the performance of a frequency converter. For example, intermodulation distortion (IMD), harmonic and spurious levels can be measured using a spectrum analyzer whereas return loss is typically measured using a vector network analyzer for its speed and accuracy. FieldFox can be operated in either spectrum analyzer mode or network analyzer mode to perform these required measurements in one single handheld instrument.

Other important specifications for any earth station frequency converter include conversion gain, gain flatness and gain stability over temperature. The measurement of these parameters requires test equipment capable of sweeping a signal generator across a range of input frequencies and measuring the amplitude response across the associated range of output frequencies. Fortunately, FieldFox can be configured to measure the frequency conversion parameters using its internal source and a connected USB power sensor. This test configuration is shown in figure 12, where FieldFox is connected to the input of the BDC and the power sensor is connected to the output. The same configuration can also be used to measure the conversion gain of an upconverter. In frequency converter mode, FieldFox is configured to operate as a swept source and the USB power sensor, connected to FieldFox, measures the signal level from the output from the converter. To accurately measure the conversion gain, the test configuration is first calibrated across the input frequency range by directly connecting the power sensor to the end of the test cable that connects FieldFox to the converter.

During calibration, FieldFox provides an on-screen wizard, providing step-by-step instructions for performing each part of the process. After RF calibration, the power sensor is connected to the converter output for test. The conversion gain, in dB, or output power, in dBm, is then displayed directly on FieldFox.

Figure 13 shows a measurement of the conversion gain of a Ka-band downconverter. The downconverter was tuned to an input channel centered at 20.7 GHz. The FieldFox source was swept over a range of 20.5 GHz to 20.9 GHz and the power sensor measured the IF from 50 MHz to 90 MHz. The measured conversion gain at the center of this band is 45.8 dB as shown by the marker value. While not important for this measurement of a single downconverter, it is possible to place the USB power sensor over 80 meters away from FieldFox. This would be useful when measuring a complete system having the input located at a large distance from the output test location. In this case, the USB power sensor will use a commercially available USB cable extender to extend the distance between the power sensor and FieldFox.

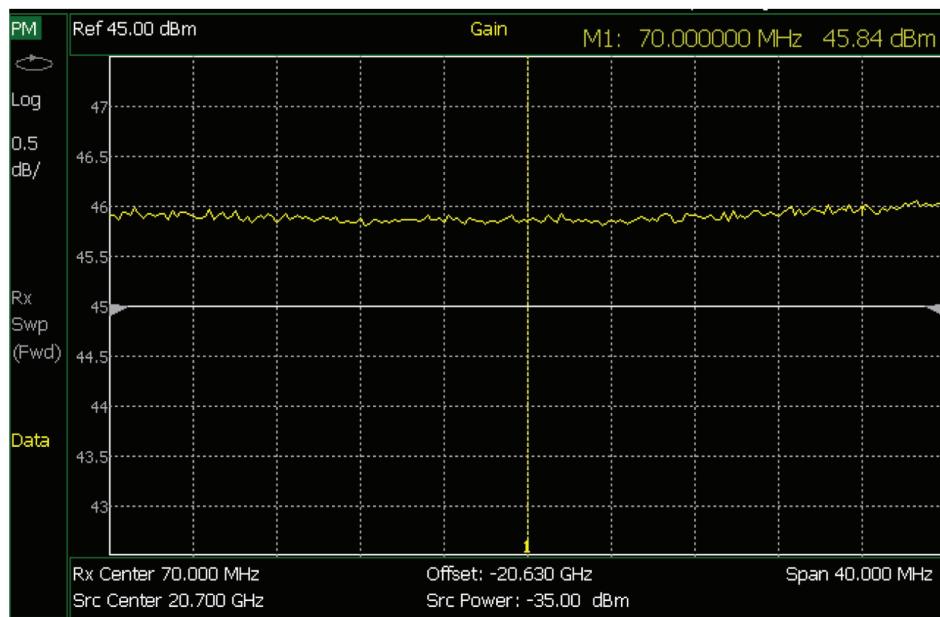


Figure 13. Measurement of the conversion gain for a Ka-band to 70 MHz earth station downconverter

Remote Measurements and Control

In the previous section, it was mentioned that a USB power sensor can be separated from FieldFox by up to 80 meters. But it is also possible to control FieldFox when placed in a remote location. There are several ways to monitor and control FieldFox under remote conditions. For example, when FieldFox is connected to the monitor port of a remote earth station, it is possible to observe live measurement on an iPhone, iPad or PC. It is also possible to control FieldFox wirelessly through the Remote Viewer app that runs on an Apple iOS device. The iOS interface is configured to show the same instrument panel as FieldFox, allowing the instrument to be directly controlled from the iOS device.

In another example, a PC or laptop can be connected to FieldFox either through a wired or wireless internet connection. The Remote Display software running on the PC will display the FieldFox instrument panel allowing live measurements and direct control of the instrument. Wireless connectivity is provided through a USB WiFi hub or similar device connected to the USB port of FieldFox. As the FieldFox is a sealed instrument, it is possible to leave the instrument exposed to a variety of outdoor weather conditions.

Conclusion

Satellites and earth stations are complex systems requiring high performance and reliability. New broadband technologies, including frequency re-use and spot beams, are greatly improving system capacity while achieving lower service cost and higher reliability. In order to assure the highest uptime for the earth stations, routine maintenance and occasional troubleshooting and repair must be done quickly, accurately and in any weather condition. Breakthrough technologies have transformed the way these systems can be tested in the field while providing higher performance, improved accuracy and capability. It was shown that a single FieldFox handheld analyzer can replace multiple instruments including a spectrum analyzer, vector network analyzer, signal generator and power meter with frequency coverage up to 50 GHz. FieldFox's lightweight portability replaces traditional methods of transporting multiple benchtop instruments to the earth station site.

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