Application Note

Understanding Single Frequency Network Measurements

MS2721B Spectrum Master
MS2712E/MS2713E Spectrum Master
MT8212E/MT8213E Cell Master

Preamble

This application note describes the technology of Single Frequency Networks (SFN) pertaining to digital terrestrial broadcasting and the key measurements to perform during their installation, commissioning and maintenance. It focuses specifically on measurements associated with DVB-T/H and ISDB-T technologies and emphasizes the field measurement aspects. As such, it discusses the measurements as would be performed on Anritsu's handheld field test instruments, notably the **MS2721B, MS2712E and MS2713E Spectrum Masters** and the **MT8212E and MT8213E Cell Masters**. No prior knowledge of these instruments is necessary to review this application note. However, readers may find it useful to review details for these instruments, including **Specification Data Sheets**, instrument **User Guides** and the **Digital Television Measurement Guide**, all of which can be found at the www.us.anritsu.com website.

Introduction

Historically, broadcasters have had unopposed use of large swaths of the VHF and UHF frequency bands enabling them to broadcast over whole countries using many different frequency channels reducing the potential for co-channel interference. Even with the advent of digital techniques and the proliferation of television stations, the ability to multiplex many transmissions into a single RF channel still allowed the use of multi-frequency networks (MFN).

Now, with the mobile wireless fraternity putting pressure on regulators to force broadcasters to relinquish much of their traditional frequency bandwidth, especially in the UHF range - the so-called “digital dividend” – it is becoming essential for them to consider planning for single frequency networks (SFN).

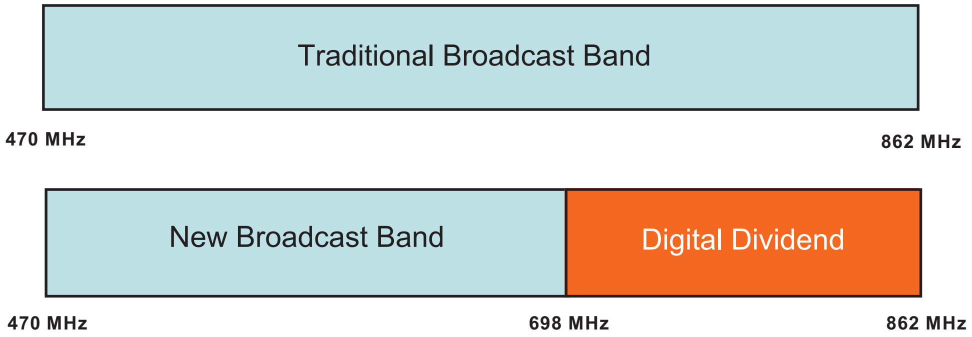


Figure 1. The Digital Dividend.

As is clear from figure 1 broadcasters or their network operators will be required to transmit the same (or greater) amount of information in fewer available channels. One way to facilitate this is to allocate one frequency channel for each broadcaster (or group of broadcasters if their transmissions are multiplexed together on the same channel) for the whole coverage area. The coverage area could be as small as a city, requiring only one or two transmitters which would not be so complex, but could also be an entire country needing perhaps hundreds of transmitters, all tuned to the same channel for each transmission. In terms of the potential interference issues (figure 2), this may seem counter-intuitive so we should first review some basic digital terrestrial television technology.

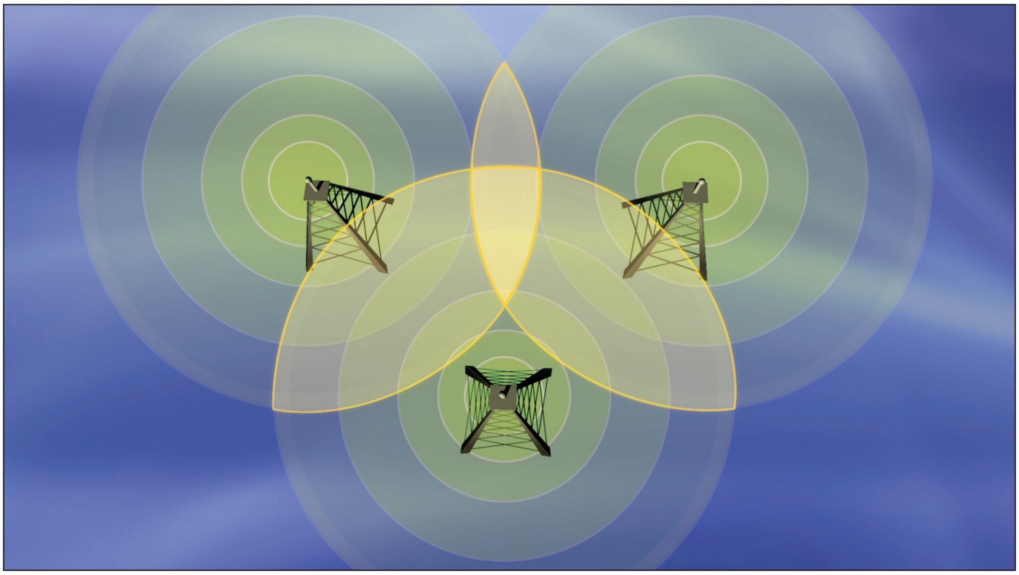


Figure 2. Potential co-channel interference.

OFDM

The majority of digital terrestrial technologies use multiple carrier orthogonal frequency division multiplexing (OFDM) techniques. Adding forward error correction (FEC) produces coded OFDM (COFDM) to improve the robustness of transmission. The two most prevalent technologies using this technique are DVB-T/H and ISDB-T.

OFDM takes a serial data stream to be transmitted and spreads it over a large number of carriers, typically more than a thousand and sometimes many thousands. The data rate conveyed by each carrier is correspondingly reduced and the symbol length is in turn extended. These modulation symbols on each of the carriers are arranged to occur simultaneously. In addition to the data carriers, there are other carriers called pilot carriers or tones which carry information about the radio channel which can be used by a receiver to aid reception.

The carrier spacing is uniform and deliberately chosen so that it is the inverse of each symbol duration. This choice of carrier spacing ensures orthogonality of the carriers which means that the influence of adjacent carriers (in fact all other carriers) on the demodulation of a particular carrier is zero. It ensures there is no crosstalk between carriers, even though there is no explicit filtering and their spectra overlap. Figure 3 illustrates this.

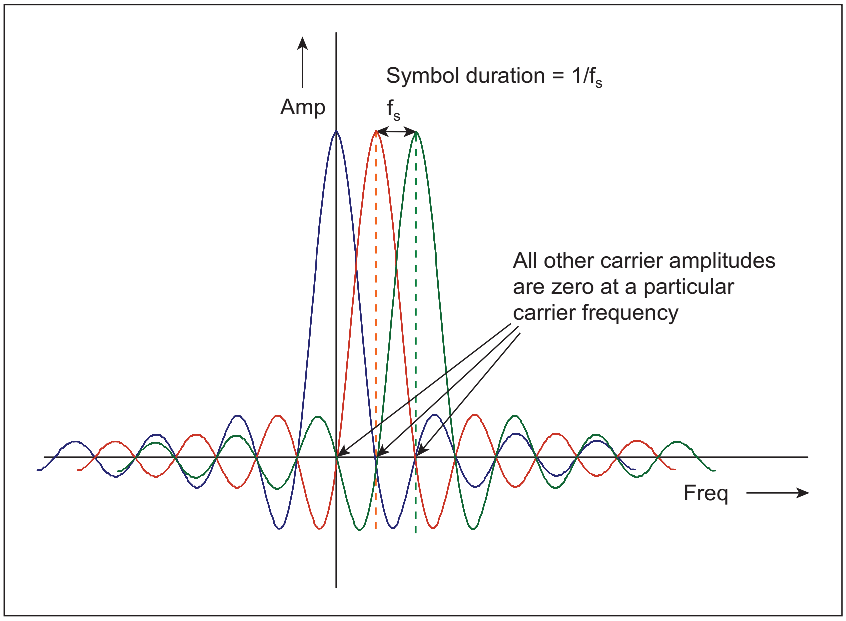


Figure 3. Orthogonality.

Guard Interval

A further refinement adds the concept of a guard interval. Each symbol is transmitted for a duration which is longer than the active symbol portion by a period called the guard interval. It is generated by copying the last fraction of the active symbol and placing it at the front of the active symbol period as shown in figure 4. The consequence is that a receiver will not experience either inter-symbol or inter-carrier interference provided that any secondary direct signals from co-channel transmitters or multi-path echoes present have a delay which does not exceed the guard interval. Figure 5 shows the reception of the main signal and its echo plus two co-channel signals from other transmitters. All signals are received within the guard interval, after which steady state of the channel is attained and evaluation of the symbol can commence.

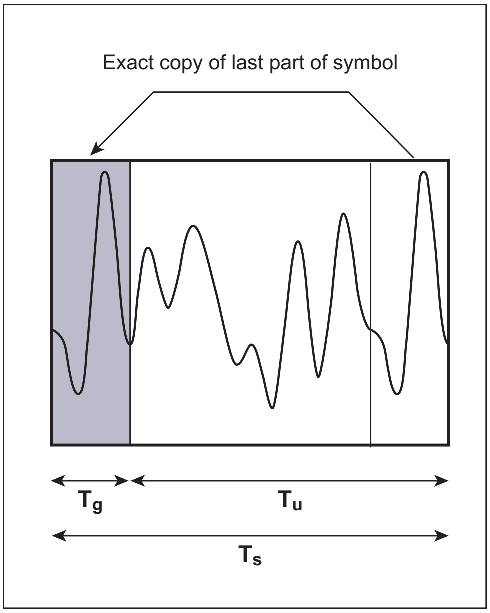


Figure 4. Guard Interval generation.

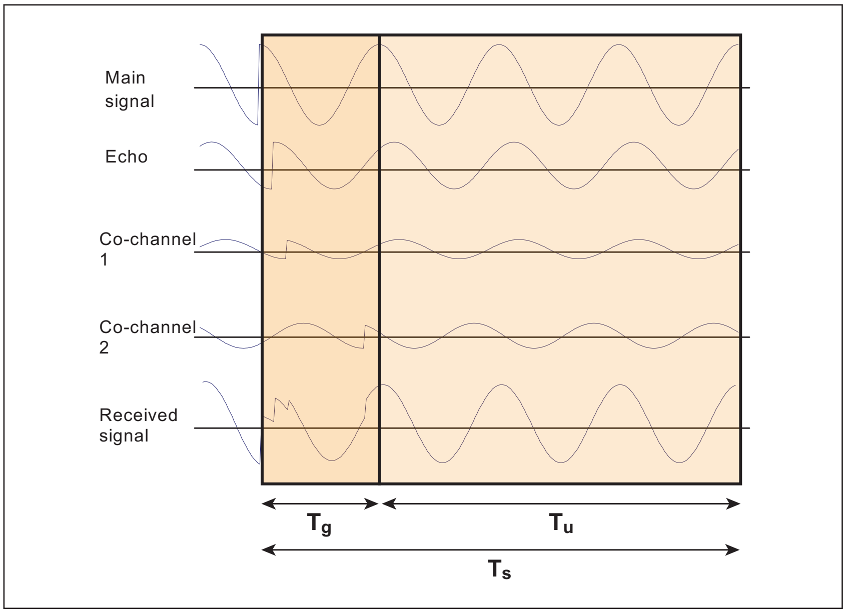


Figure 5. All signals received within Guard Interval.

Naturally, the data throughput is reduced by an amount determined by the guard interval length. With both DVB-T/H and ISDB-T, the number of carriers is scalable so that it is possible to protect against echoes with prolonged delay simply by choosing a larger number of carriers such that the guard interval need not form too great a fraction of the active symbol period. Both DVB-T/H and ISDB-T can specify guard intervals up to one quarter of the active symbol period which can protect against echo delays in excess of 200 µs depending on the chosen mode.

Figure 6 shows a basic SFN configuration. Assuming there are no programmed delays through the transmitters themselves so that each transmits the same symbol at the same time, then receiver "A" does not suffer any inter-symbol interference if the delay difference between the signals from transmitters T1 and T2 is less than the guard interval. The phase difference of the two signals received at "A" will likely cause some fading effects across the channel which can be compensated by the information supplied with the pilot carriers. At receiver "B", the propagation time from both transmitters is identical and no differential delay effects will occur.

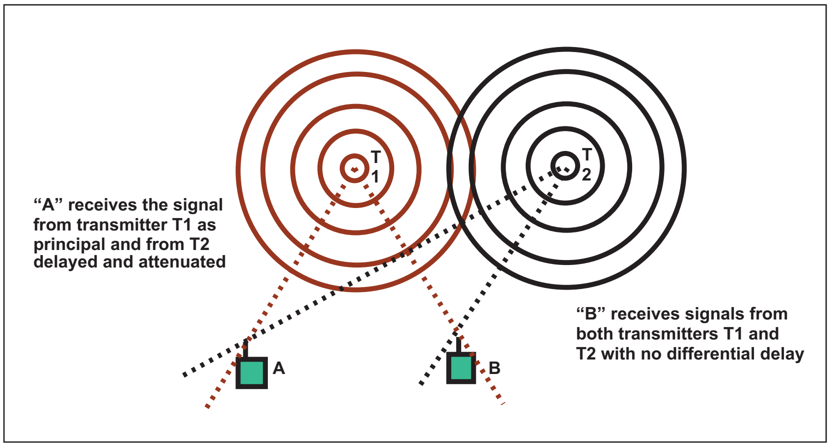


Figure 6. Single Frequency Network configuration.

Some Practical Considerations

Within the broadcasting area there will be many types of receiver ranging from fixed and portable through to mobile or handheld. A fixed receiver in a household using a highly directional antenna pointing directly at the closest transmitter will have the effect of reducing the amplitude of co-channel transmissions and echoes from different bearings. However, mobile receivers in the same area using omni-directional antennas will receive signals equally well from all directions. Thus, fixed receivers are more immune from reception of co-channel signals delayed by more than the guard interval range since they would tend to attenuate them significantly. Mobile receivers, on the other hand, do not have that capability. This is an important consideration when installing and configuring an SFN.

The impulse response or delay profile measurement is the key test. For an MFN, where the only significant co-channel signals are likely to be from echoes of the main signal, it is only usually necessary to measure delays slightly in excess of the longest allowable guard interval for the respective OFDM mode. In this case, conventional methods making use of the pilot signals within the OFDM structure are reliable enough to calculate delay and relative levels with good accuracy. However, for an SFN, especially during its installation, it is necessary to check for relative signal delays over a much longer period so that transmission delays at the respective transmitters can be calculated and programmed to ensure co-channel receptions occur within the guard interval.

This is a particularly challenging requirement of the test equipment and conventional methods can fall short. The computational algorithms should enable measurement delay times over the range ±1 ms (approximately ±1 symbol length), as shown in figure 7, with good level accuracy and also minimize the possibility of showing false or aliased responses. The latter is crucial to the efficient installation of an SFN since much time can be wasted trying to track and adjust for aliased signals.

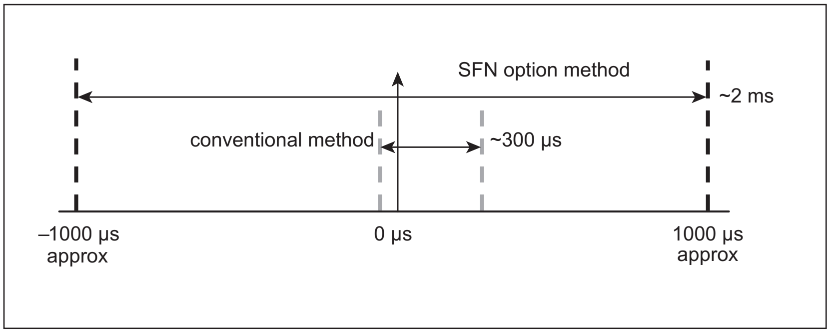


Figure 7. Delay measurement range comparison.

SFN Measurement Differences over Conventional Methods

The SFN measurement options for DVB-T/H and ISDB-T in the Anritsu handheld analyzers have the following main differences from the conventional impulse response or delay profile measurements available within the standard DVB-T/H and ISDB-T signal analysis options.

- Measurement accuracy improvement of Desired signal/Undesired signal (DU) ratio and absolute level measurement of each incoming signal
- Automatic display of the main signal absolute level calculated by discriminating the necessary signals from the impulse response and comparing these signals with the channel power measured value
- The absolute level of other incoming signals (delayed signals) can be read out by adjusting the marker and is calculated by comparing its DU ratio with the main signal level
- Aliased signal-free impulse response measurement over the approximate range of ±1 ms (depending on the channel bandwidth and mode) which enables decisive and fast delay adjustment in an SFN environment. In conventional methods using the pilot tones, aliased signals may occur when delayed signals are over one-third of the OFDM symbol time (for example, in DVB-T/H, 8 MHz bandwidth, 8K mode, this equates to 896/3 = 298 µs) and may show at different time delay positions

Measurement Principles

Outline

The SFN options perform three separate measurements simultaneously and by combining and comparing the results, the precise delay and absolute amplitude of all received signals are calculated and displayed.

Figure 8 shows the measurements performed. The basic flow for, say, an 8 MHz bandwidth DVB-T/H SFN measurement is:

1. Total channel power measured over 7.6 MHz (occupied bandwidth within 8 MHz channel)
2. Impulse response measured using two different algorithms (Power Spectrum and Transfer Function methods)
3. Aliased (pseudo-path) responses are discriminated by comparing the two impulse responses and the true impulse response is derived
4. Main signal level is automatically calculated from its proportion of the total channel power
5. Absolute level and DU ratio of delayed signals are calculated by tuning the marker to their respective positions

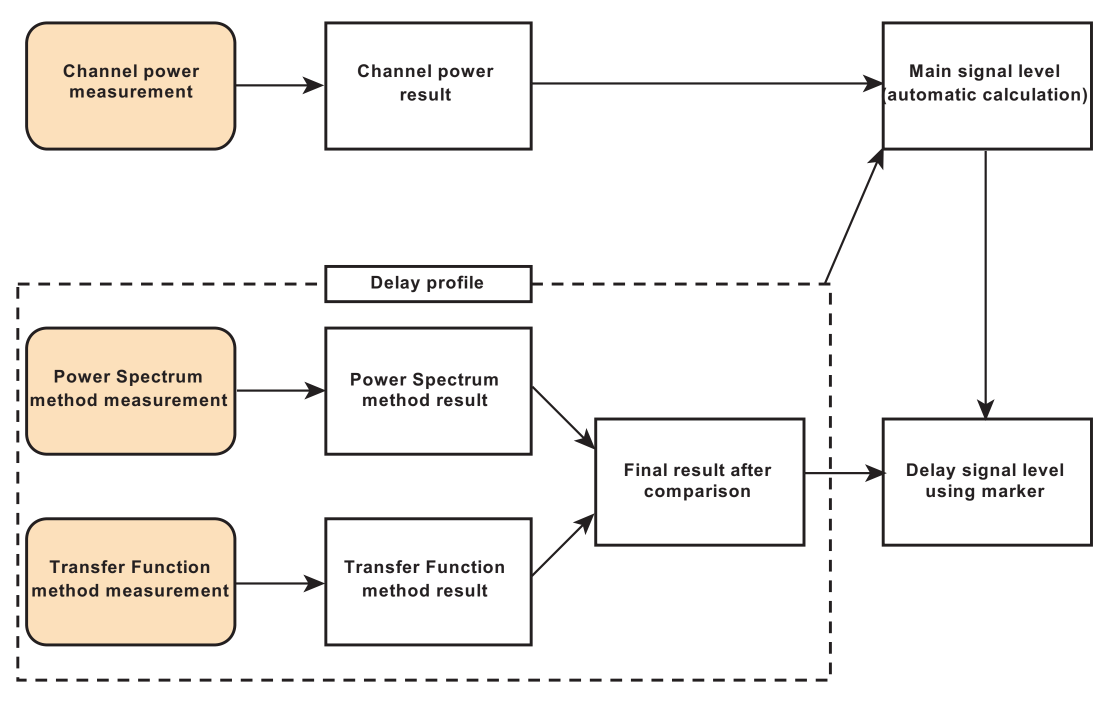


Figure 8. SFN measurement flow.

Channel Power

In figure 8, for the measurement of channel power, the total signal power within the 7.6 MHz occupied part of the 8 MHz channel is simply measured at the terminal input. This measurement uses the same method as the channel power measurement (or field strength measurement) of the standard Anritsu digital television options and, in principle, will produce identical results under the same signal conditions. However, in order to produce a more stable power reading, the measurement within the SFN options is performed using an averaging factor 100 times greater than that used for the standard options.

Impulse Response

The impulse response measurement calculates the incoming signal DU ratio and delay times. Two calculations are performed simultaneously using different algorithms and the results of each are compared to produce the final impulse response for display. The two measurement methods are:

i. Power Spectrum method
ii. Transfer Function method

Each method has its particular benefits and their combination produces a highly accurate, alias-free measurement (table 1).

	Power Spectrum Method	**Transfer Function Method**
Benefits	• Accurate DU ratio can be acquired even under deteriorated signal conditions	• Time advance or lag can be discriminated towards main signal • Aliased signals not likely to occur under good signal conditions
Potential issues	• Time advance or lag cannot be discriminated towards main signal • Aliased signals likely • Fixed aliased signals likely to appear irrespective of signal quality	• When signal level is poor and with many multi-path signals over the guard interval delay, DU ratio accuracy may be degraded

Table 1. Merits and caveats of impulse response methods used.

Field Strength Measurement (Height Pattern Measurement)

This section introduces a method to measure electric field strength for a specific broadcast station in an SFN environment. Field strength is measured using a receiving antenna attached to the measuring instrument and the measured input voltage is converted to field strength by adding the compensating antenna factor for the particular antenna used. Thus:

Field Strength (dBμV/m) = Terminal Voltage (dBμV) + Correction Factor (dB)

Antenna correction factors vary with frequency and Anritsu instruments are delivered with compensation tables for many of its antennas already installed. Alternatively, compensation tables for other antennas can be easily downloaded to the instrument.

Antenna height pattern measurements can determine the effects of ground reflected signals. A receiving antenna may receive signals in a direct line from the transmitter but also a signal which bounces back from the ground. At the receiving location, these waves will interact differently at different heights depending on their respective phase relationship. By plotting field strength against antenna height it is possible to select an optimum antenna height for reception at that particular location and also to determine the field strength of the directly received signal, especially for horizontally polarized transmissions. For horizontal polarization, the ground reflection coefficient is approximately 1 so the direct signal field strength will be half the peak field strength measured during the height pattern measurement. Figure 9 shows a typical height pattern.

It is assumed in the subsequent description that the higher level signal is to be measured; transmitter A in figure 9. If using a directional antenna, align it directly to the transmitter to be tested and select the corresponding antenna correction table on the instrument. It should be noted, however, that the antenna gain will be different if signals are received from an alternative direction and, therefore, the correction factor will also be different. This will lead to errors in field strength measurement of non-aligned signals.

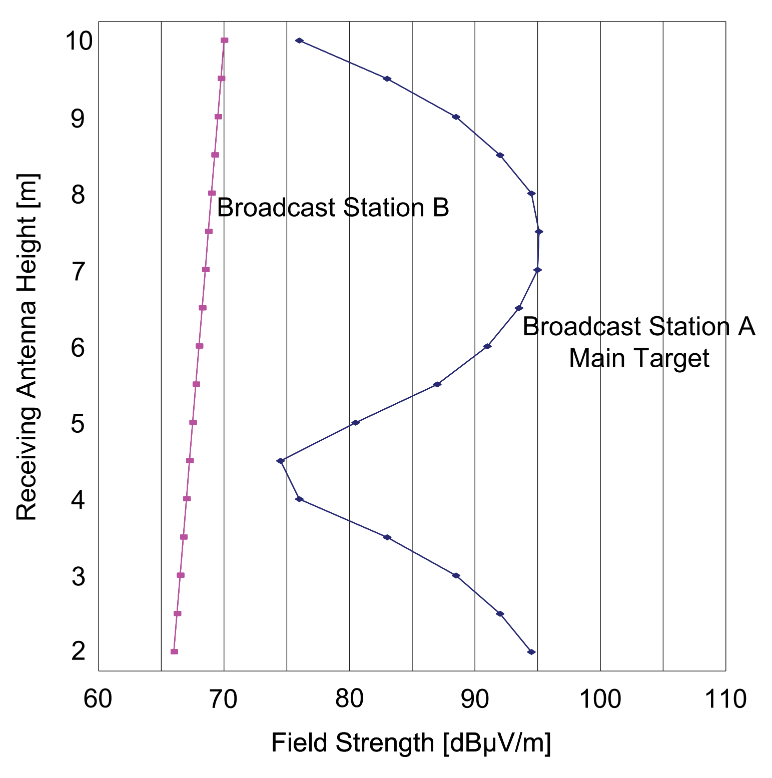


Figure 9. Typical antenna height pattern measurement.

Measurement Procedure

1. Antenna direction adjustment

Turn the antenna in the direction of the incoming signal of interest. Normally, direct the antenna towards the direction of the broadcast station to be measured.

2. Connect an antenna to the Anritsu instrument

Connect the antenna. It may be necessary to insert an attenuator between the antenna and instrument if there is excessive input signal. The attenuator value can also be compensated for on the instrument to obtain the actual field strength value.

3. Set the channel (frequency) to measure

4. Adjust the reference level

This can be done automatically using the Auto Reference Level function.

5. Set measurement parameters

For correct measurement, set the necessary transmission parameters as follows.

  i. Mode, GI, TPS (DVB-T/H), TMCC (ISDB-T) information
  ii. FFT start position as necessary
  iii. Antenna (correction factor) for field strength
  iv. Impedance
  v. Impedance loss

The Detect Parameter function will set the Mode, GI and TPS or TMCC information automatically. Set the other parameters manually as required. By adjusting the FFT start position it's possible to reduce the possibility of alias signal display. Refer to the section, "Reducing the Possibility of Aliased Signal Responses" later in this note.

6. Finely adjust the antenna direction

Adjust the antenna direction so that the target incoming signal level peaks. There are two methods to adjust the antenna direction.

  i. Adjust the antenna so that the channel power peaks
  ii. Adjust the antenna so that the main signal level (incoming signal of the target transmitter) peaks

The antenna direction can be adjusted using only the channel power on the condition that the incoming signal of the target transmitter is significantly larger than any other incoming signal level. In this case the channel power measurement within the standard signal analysis options is most useful allowing for fast adjustment.

When the incoming signal of the target transmitter is not significantly greater than a signal from another source, then the channel power adjustment method may not be reliable. In this case, it is necessary to use the SFN impulse response option to identify the correct response and use this to peak the signal.

7. Adjust the antenna height to the position to make a measurement

8. Adjust reference level as necessary

When changing the antenna height, "over-range" or "under-range" may appear on screen depending on the signal level received. Use the Auto Reference Level function to optimize the reference level setting.

9. Take measurement

The SFN impulse response measurement discriminates all received responses. Record the level of the target transmitter response, usually the largest and located at position 0 μs.

10. Record measurements (create height pattern graph)

Plot the measurements taken in the previous step onto a graph as shown in figure 10. These can be in field strength units or directly as power.

Adjust the antenna height to a new position and repeat from step 8 until complete.

11. Calculate field strength

It is likely that a graph similar to figure 10 will be created for the main signal (target transmitter) level. It will peak at a certain height (or heights) and may have a minimum point. The peaks represent the height at which the main direct signal and ground reflected signal combine in such a way as to fully add together. This is usually the case for horizontally polarized signals and the ground reflection coefficient is close to 1. This being the case, the peak field strength will be twice the field strength of the directly received signal. If the field strength units are in dBμV/m, this calculates as 6 dB less than the peak value.

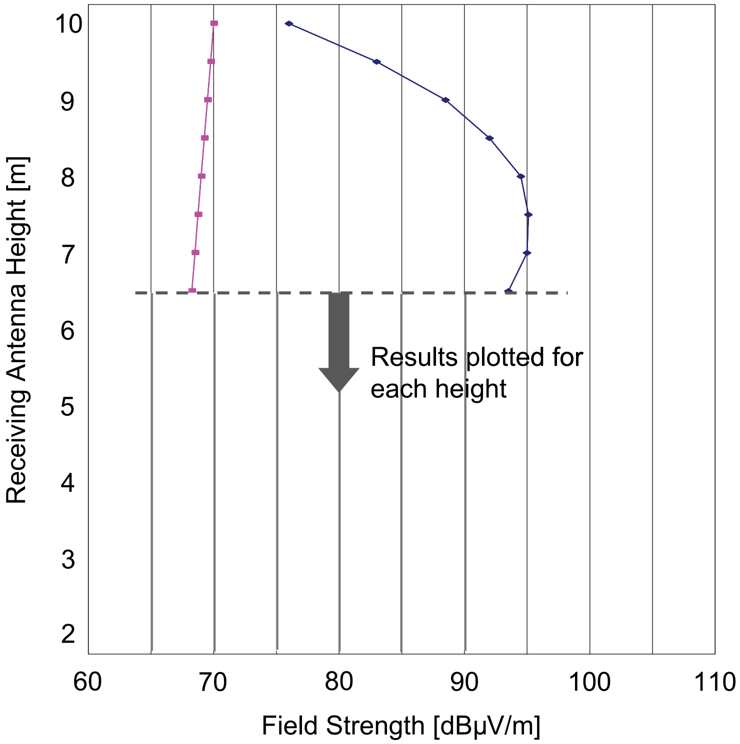


Figure 10. Antenna height pattern progress.

Delay Time Measurement

In an SFN environment, all areas of reception must receive all significant signals transmitted from different transmitters within the allocated guard interval. Although the network planning should strive to minimize multi-path effects, a further complication is that some of these transmitted signals may also be reflected from large buildings or mountains which further spread the signals received. Part of the installation process of an SFN is to measure these delays and adjust the launch timing within the transmitters to ensure no signals stray beyond the guard interval. These considerations should be taken into account when deciding on the measurement positions.

Measurement Procedure

The first five actions in the procedure are identical to those for the field strength and height pattern measurement described above. The final step is to measure the impulse response (delay profile) and to use the markers to identify the delays of the various incoming signals. It is important to discriminate and identify the origin of each signal so that appropriate launch delays can be set in the respective transmitters. The following section shows how this may be done.

Judgement of Incoming Signals

The following conditions can be helpful to judge the incoming signal.

i. Knowledge of the network layout and the approximate relative positions and directions of the various in-range transmitters will help to determine which transmitter's signal will arrive first
ii. Delay time differences among the incoming signals will also help to assign each response to the different transmitter
iii. If there is little or no network information available, delayed signals can be assessed using methods described in the section, "Emphasizing Target Incoming Signals"

The measurement displays the incoming signal with the highest signal level at time 0 µs. If the transmitter delivering this signal can be easily identified by adjusting the antenna direction slightly and noticing the level change as the alignment worsens or improves then it may be assumed that another transmitter exists at the delayed signal position. Even if there is no knowledge of the transmitter delay times, just identifying which signal arrives first at the measurement position facilitates a reliable reference point for all other signal receptions.

When the level relationship among incoming signals is reversed as may happen while measuring the height pattern, as in figure 11, the delayed signal will assume the 0 µs position instead. However, the relative delay between the signals is not changed, only that the original main signal is now shown as a negative delay (advanced signal). Pressing the +/- hard key on the instrument front panel will place the measurement marker to the mirrored position instantly and measurement can resume.

This same phenomenon may also occur under the following conditions.

i. When the DU ratio between the target incoming signal and other signals is small
ii. When antenna height is changed
iii. When the antenna direction is changed

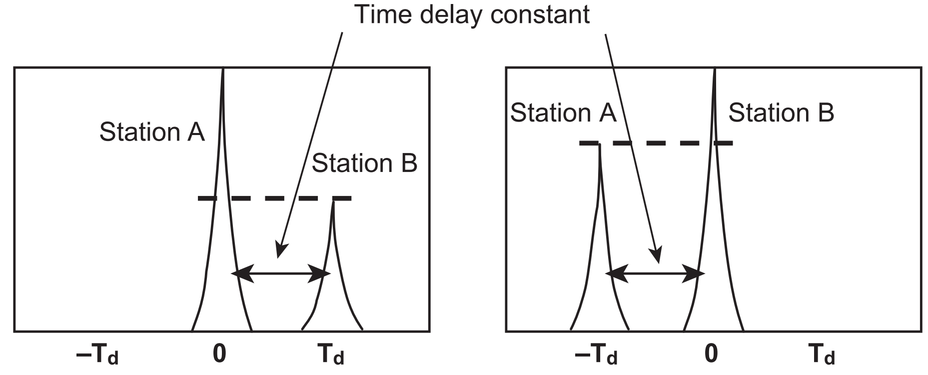


Figure 11. Signal reversion effect.

Reducing the Possibility of Aliased Signal Responses

The SFN impulse response measurement techniques adopted within Anritsu instruments are designed to minimize the occurrence of pseudo-path (aliased) responses so that time is not wasted trying to detect them and eliminate them from measurement. This they do exceedingly well compared with standard techniques using pilot signals. However, there are a few occasions when the display of aliased signals is more likely.

i. When there exists a strong delayed signal well over the guard interval range
ii. When there are a large number of incoming signals
iii. When the FFT start position is not set appropriately

By adjusting the FFT start position so that the main delayed signals fit within the guard interval range, the impulse response from the transfer function method can be improved and so can eliminate aliased responses from the measurement. The FFT start position can be automatically set during the Detect Parameters function or can be set manually as shown in figure 12.

This example shows that the analysis of the combined incoming signal will not start until after all signals have been received.

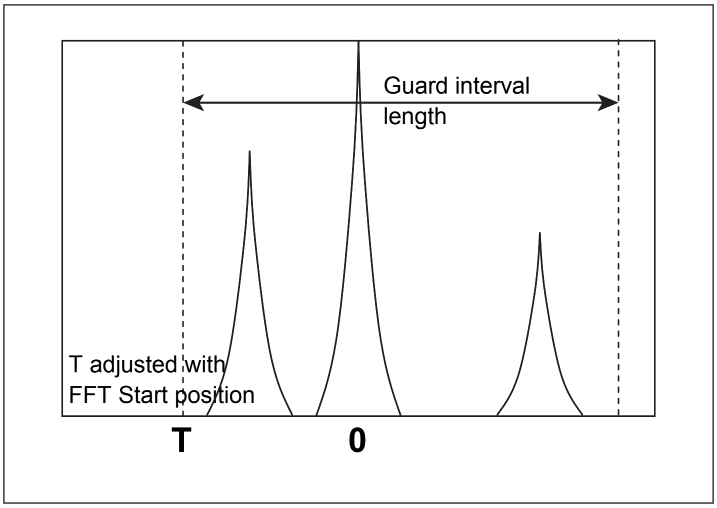


Figure 12. Alias signal reduction using FFT Start position.

Emphasizing the Target Incoming Delayed Signals

Sometimes, when using a highly-directional antenna aligned directly to the nearest transmitter site, other delayed signals from other sites on different bearings are attenuated significantly enough that it may be difficult to take a reliable delay measurement. The following techniques will help to emphasize the delayed signals more in comparison to the main target signal.

i. Change the antenna direction slightly
ii. Use a non-directional antenna or weak-directional antenna such as a dipole antenna
iii. Prepare several highly-directional antennas and direct each antenna towards a target broadcast station and connect each through a combiner before connecting to the measuring instrument

Each of these methods has the net effect of reducing the DU ratio between each of the received signals by reducing the directional qualities of the receiving antenna system making identification and measurement of all signals easier (figure 13).

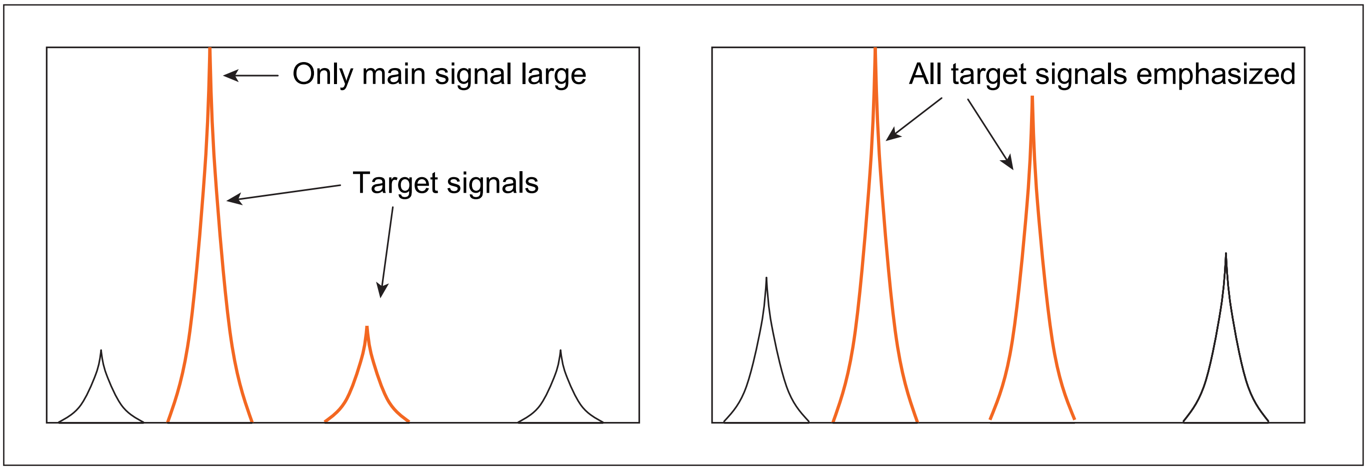
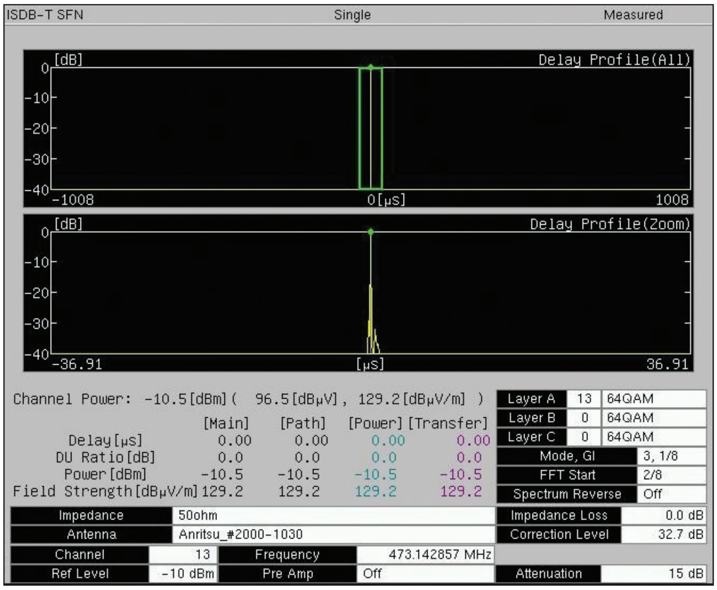


Figure 13. Emphasizing target signals.

Measurement Display Examples

The following screen shots show some typical measurements associated with SFN networks. They each depict an ISDB-T SFN network but, of course, similar measurements can be made on DVB-T/H SFN systems.

Figure 14a shows a single response at 0 μs and no other indicating there are no delayed signals present, either from a multi-path of the main signal or a secondary co-channel transmitter.



Channel Power: -10.5[dBm](96.5[dBμV], 129.2[dBμV/m])

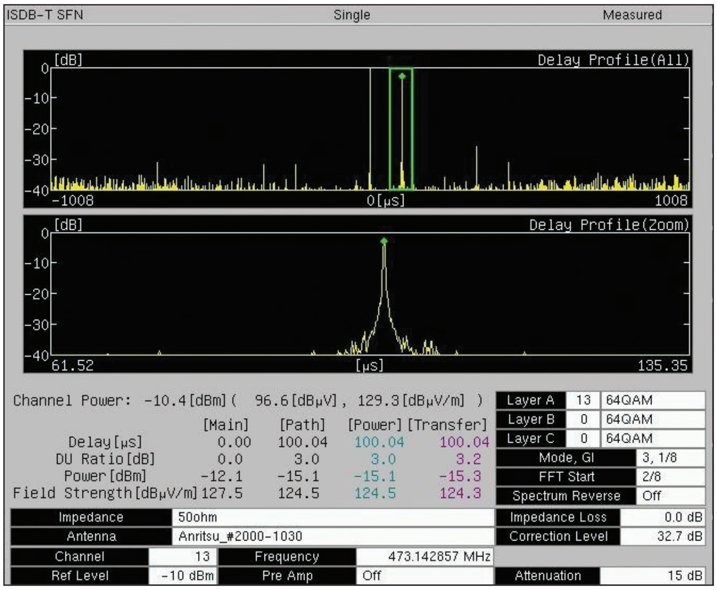
	[Main]	[Path]	[Power]	[Transfer]
Delay[μs]	0.00	0.00	0.00	0.00
DU Ratio[dB]	0.0	0.0	0.0	0.0
Power[dBm]	-10.5	-10.5	-10.5	-10.5
Field Strength[dBμV/m]	129.2	129.2	129.2	129.2

Layer A	13	64QAM
Layer B	0	64QAM
Layer C	0	64QAM
Mode, GI	3, 1/8	
FFT Start	2/8	
Spectrum Reverse	Off	

Impedance	50ohm	Impedance Loss	0.0 dB
Antenna	Anritsu_#2000-1030	Correction Level	32.7 dB
Channel	13	Frequency	473.142857 MHz
Ref Level	-10 dBm	Pre Amp	Off
Attenuation	15 dB		

Figure 14a. Single signal reception.

Figure 14b is displaying the main signal and another co-channel signal delayed by about 100 μs with a DU ratio of about 3 dB. Note, too, that the display is showing the results from both the algorithms, labelled [Power] and [Transfer] and in green and purple respectively, from which it derives the actual net result. This is a user selectable function and the display of these measurements can be switched off if desired. The net result is shown in the [Path] column.



Channel Power: -10.4[dBm](96.6[dBμV], 129.3[dBμV/m])

	[Main]	[Path]	[Power]	[Transfer]
Delay[μs]	0.00	100.04	100.04	100.04
DU Ratio[dB]	0.0	3.0	3.0	3.2
Power[dBm]	-12.1	-15.1	-15.1	-15.3
Field Strength[dBμV/m]	127.5	124.5	124.5	124.3

Layer A	13	64QAM
Layer B	0	64QAM
Layer C	0	64QAM
Mode, GI	3, 1/8	
FFT Start	2/8	
Spectrum Reverse	Off	

Impedance	50ohm	Impedance Loss	0.0 dB
Antenna	Anritsu_#2000-1030	Correction Level	32.7 dB
Channel	13	Frequency	473.142857 MHz
Ref Level	-10 dBm	Pre Amp	Off
Attenuation	15 dB		

Figure 14b. 100 μs delayed signal.

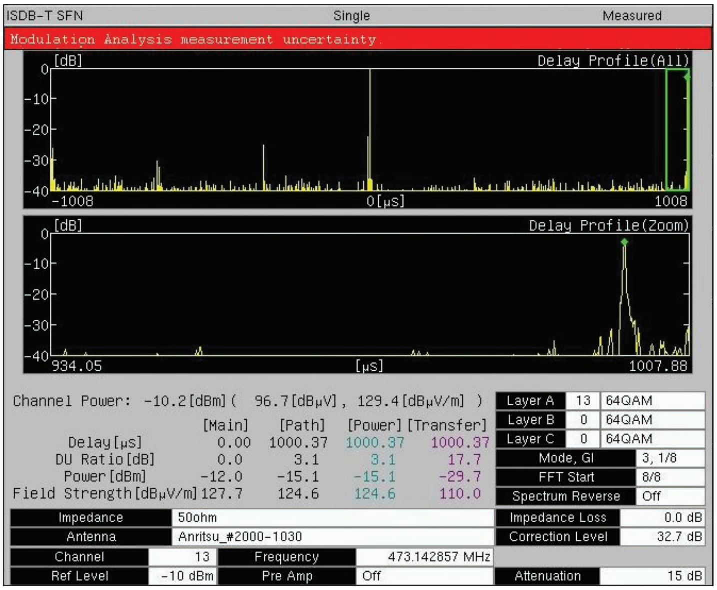
Both figures 14c and 14d show measurements where the status bar in red has been activated. The highlighted text reads, “Modulation Analysis Measurement Uncertainty”. This doesn’t necessarily mean there is anything wrong with the measurement, only that the unit has detected a measurement condition which may give rise to an erroneous result and the user is being advised to check.

Some signal conditions which may cause this are where there are many incoming signals, when there is a large signal detected way beyond the guard interval or when the input signal level is poor.

Displaying the Power and Transfer results can be particularly useful under these conditions because they help the user determine the measurement reliability.

The delay time is usually calculated from the power spectrum method. By comparing the level measurement in the Path and Power columns gives an indication whether the result is good. If they are the same, as in figure 14c, then the measurement is valid. If they are different, as in figure 14d, there is likely to be some uncertainty associated with the display.

The most likely reasons are either that a valid delayed signal has been removed from the display because it was wrongly judged as an aliased signal or that an aliased signal remains displayed after being determined to be good. In either case, adjustment of the FFT start position may improve the analysis.



Modulation Analysis measurement uncertainty.

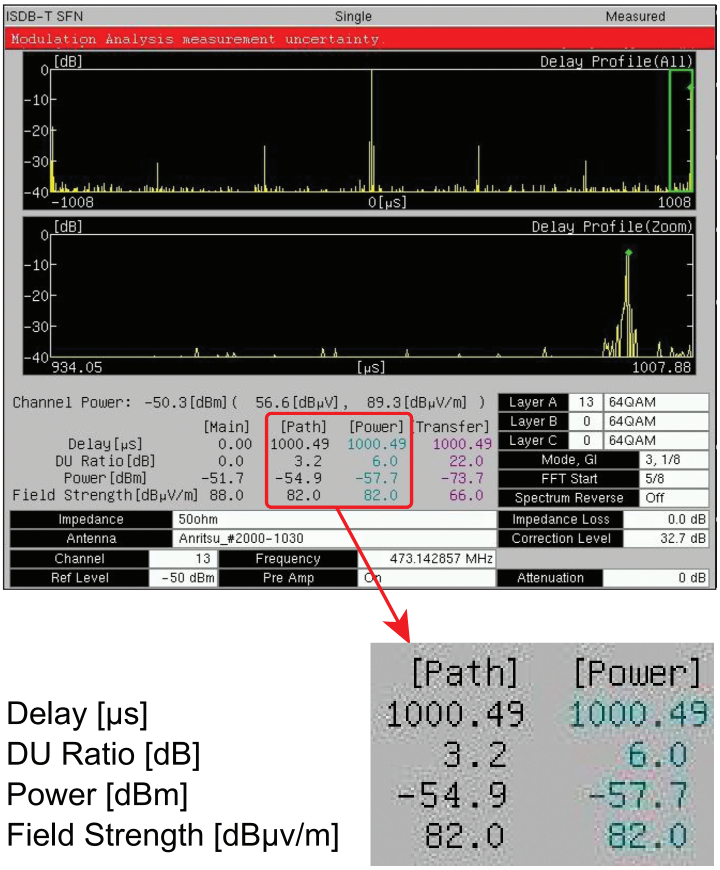
Channel Power: -10.2[dBm](96.7[dBμV], 129.4[dBμV/m])

	[Main]	[Path]	[Power]	[Transfer]
Delay[μs]	0.00	1000.37	1000.37	1000.37
DU Ratio[dB]	0.0	3.1	3.1	17.7
Power[dBm]	-12.0	-15.1	-15.1	-29.7
Field Strength[dBμV/m]	127.7	124.6	124.6	110.0

Layer A	13	64QAM
Layer B	0	64QAM
Layer C	0	64QAM
Mode, GI	3, 1/8	
FFT Start	8/8	
Spectrum Reverse	Off	
Impedance Loss	0.0 dB	
Correction Level	32.7 dB	
Attenuation	15 dB	

Impedance	50ohm		
Antenna	Anritsu_#2000-1030		
Channel	13	Frequency	473.142857 MHz
Ref Level	-10 dBm	Pre Amp	Off

Figure 14c. Good signal judgement.



Modulation Analysis measurement uncertainty.

Channel Power: -50.3[dBm](56.6[dBμV], 89.3[dBμV/m])

	[Main]	[Path]	[Power]	[Transfer]
Delay[μs]	0.00	1000.49	1000.49	1000.49
DU Ratio[dB]	0.0	3.2	6.0	22.0
Power[dBm]	-51.7	-54.9	-57.7	-73.7
Field Strength[dBμV/m]	88.0	82.0	82.0	66.0

Layer A	13	64QAM
Layer B	0	64QAM
Layer C	0	64QAM
Mode, GI	3, 1/8	
FFT Start	5/8	
Spectrum Reverse	Off	
Impedance Loss	0.0 dB	
Correction Level	32.7 dB	
Attenuation	0 dB	

Impedance	50ohm		
Antenna	Anritsu_#2000-1030		
Channel	13	Frequency	473.142857 MHz
Ref Level	-50 dBm	Pre Amp	On

	[Path]	[Power]
Delay [μs]	1000.49	1000.49
DU Ratio [dB]	3.2	6.0
Power [dBm]	-54.9	-57.7
Field Strength [dBμv/m]	82.0	82.0

Figure 14d. Possible aliased signal display.

Conclusion

This application note has described the technology and key field measurements pertaining to broadcast single frequency networks, specifically DVB-T/H and ISBD-T. It also has highlighted the unique methodology and techniques used within the SFN measurement options of Anritsu handheld analyzers that reduce the possibility of aliased signal occurrence thus speeding the installation and commissioning of networks. It has also shown how some common problems can be interpreted from the measurement displays so that broadcast technicians can be more productive in the field. Further incite can be obtained by visiting www.us.anritsu.com and downloading the product specification sheets and Digital Television Measurement Guide.

Notes

Notes

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