Keysight Technologies
Addressing the Challenges of
Deploying Single Frequency
Networks DVB-T & DVB-T2

Application Note

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Contents

Introduction

Single Frequency Network (SFN) television broadcasting systems have been widely deployed, especially for OFDM based systems like DVB-T and DVB-T2 [1][2], DTMB, and ISDB-T, due to their high frequency efficiency and simple frequency planning. However, building a successful SFN system is challenging because it requires precise transmitter deployment in order to ensure good coverage.

In an SFN, two or more transmitters radiate the same signal on the same frequency simultaneously and repeaters are used to ensure good signal coverage. The receiver is thus likely to receive multiple echoes from many of these transmitters. Echo scenarios in SFN systems in the real world can generally be categorized as one of the following: post-echoes, pre-echoes, pre-echoes and post-echoes.

For an OFDM system, a guard interval (GI) is inserted between symbols to prevent inter-symbol-interference (ISI). As long as the maximum delay of the echoes is within the GI, there should theoretically be no ISI. The principle behind SFN deployment is that the echoes from different transmitters must lie within the GI and echoes outside the GI must be low enough to avoid detection so that no interference is received.

For SFN system optimization, it is necessary to distinguish problems that come from the receiver from ones that come from the network itself. Some receiver test specifications, such as MBRAI/NorDig [3-5], define the scenarios, including echo power, echo delay, and named echo mask, under which all receivers must achieve Quasi Error Free (QEF) reception with a sufficient Signal to Noise Ratio (SNR). Otherwise, reception cannot be guaranteed.

BER measurements are always important for transmitter test and operators also like to use this metric to evaluate the signal quality of the network. However, the BER metric is not very valuable for network optimization because the achievable BER depends strongly on the receiver's performance. It is more important for operators to be aware of the network characteristics that can significantly affect the ability of the receiver to recover the desired data. These characteristics include the echo power ratio and the delay spread and it is important to perform measurements at different geographic locations in order to guarantee good reception. With the help of these network metrics, operators can adjust the transmission parameters of the transmitters in the system in order to achieve optimal signal coverage.

In addition to ISI, there can be both constructive and destructive interference among the received echoes, resulting in fading and leading to self-interference. In an SFN, signals with close power strength from two transmitters may exhibit a significant power loss at the receiver because of potential destructive interference. To mitigate such a problem, the DVB-T2 standard has adopted the well-known Alamouti Multiple Input Single Output (MISO) [6] technology. In a DVB-T2 MISO SFN system, network optimization is required, just as it is for a SISO system.

SFN Echo Scenarios

Post-echo scenario

The transmission scenario and the channel impulse response for post-echoes are shown in Figure 1. In the post-echo scenario, the strongest path (main path) is from the nearest transmitter tower and the other paths are either from transmitters located further away or from reflections which arrive after the main path and have lower power levels. In Figure 1, just one echo is shown.
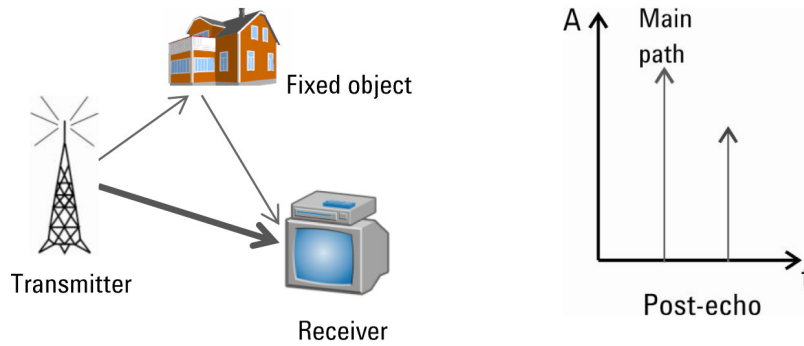

Figure 1. Post-echo scenario and the associated channel impulse response.

Pre-echo scenario

The transmission scenario and channel impulse response for pre-echoes are given in Figure 2. Pre-echoes often occur when there are repeaters nearby. For the pre-echo scenario, the strongest path is re-transmitted from the repeater and doesn't arrive first. The LOS (line of sight) path arrives first but has a lower power level.
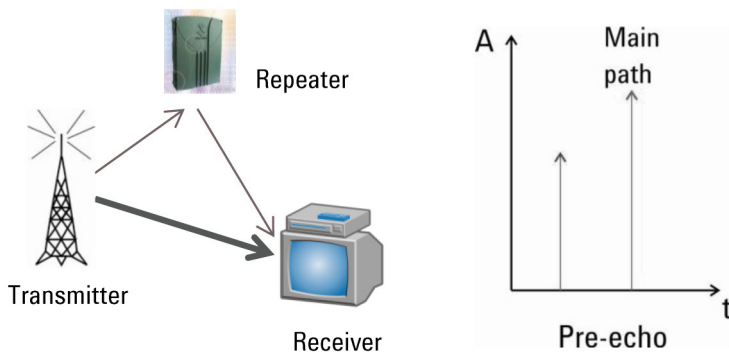

Figure 2. Pre-echo scenario and the associated channel impulse response.

Pre-echoes and post-echoes

A pre-echo and post-echo scenario occurs when both a pre-echo and a post-echo exist in the transmission channel. The transmission scenario and channel impulse response are shown in Figure 3. The strongest path is re-transmitted from the repeater. The LOS signal arrives first but it has a lower power level and the paths that arrive later may be from reflections.
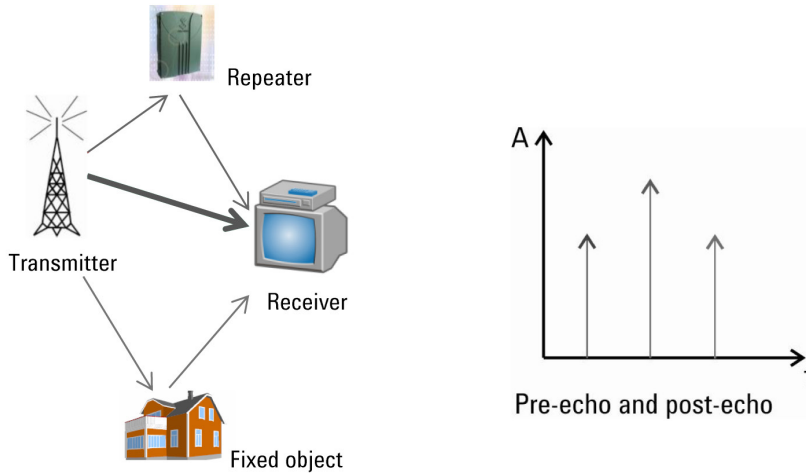

Figure 3. Pre-echo and post-echo scenario and the associated channel impulse response.

Echo mask requirements

According to the test specifications like MBRAI[3] for DVB-T, as long as the requirements of the echo mask can be met, all the receivers should achieve QEF reception. Figure 4 is an example of the echo mask defined in MBRAI[3]. The receiver must use equalization to overcome the echoes. The performance of the equalizer is mainly affected by two factors: echo delay and echo power. So it is critical for measurement instruments to provide the echo power and echo delay accurately during network deployment in order to guarantee good coverage.
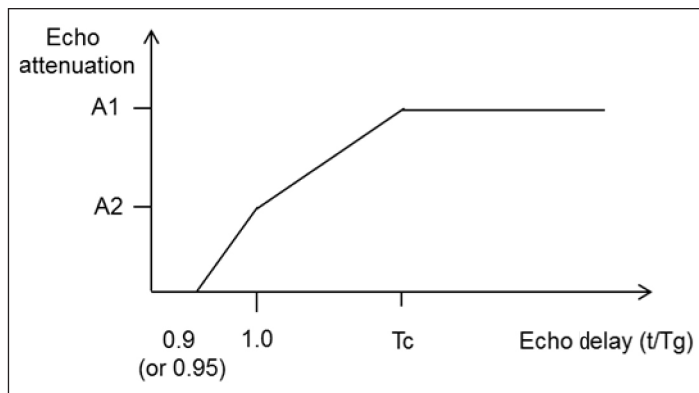

Figure 4. Example of echo mask as defined in MBRAI.

SFN Measurements

In SFN systems, the channel impulse response h(n) can be expressed as

$$h(n) = \sum_{i=0}^{L-1} \alpha_i \delta(n - \tau_i), \ \ 0 \leq n \leq N-1$$

(1)

L = the number of echoes
α_i = the complex gain
τ_i = the delay of the ith echo

The echoes in the channel impulse response will result in overlapping OFDM symbols and subsequent ISI, which may cause degradation in reception. Therefore, measurement instruments need to be able to detect the echoes and provide gain and delay for each detected echo.

As mentioned previously, in OFDM systems, a GI is inserted in order to prevent ISI. As long as the maximum delay is within the GI, theoretically there is no ISI. In order to get accurate echo patterns, an SFN analyzer should not only find the best FFT window position to do demodulation and analysis, but it should also provide the flexibility to adjust the FFT window to see the effect using different FFT window positions.

Figure 5 shows a scenario with one pre-echo and one post-echo and demonstrates how to adjust FFT window position. The FFT start position, as shown in Figure 5, is set as the starting point of the FFT window. In order to measure the echo pattern accurately, the FFT window should be set to ensure that minimal ISI is introduced and to include as many echoes as possible. "No ISI range" means that if the FFT start position is set in this range, there is no overlap with the preceding and subsequent symbols of the various echoes.
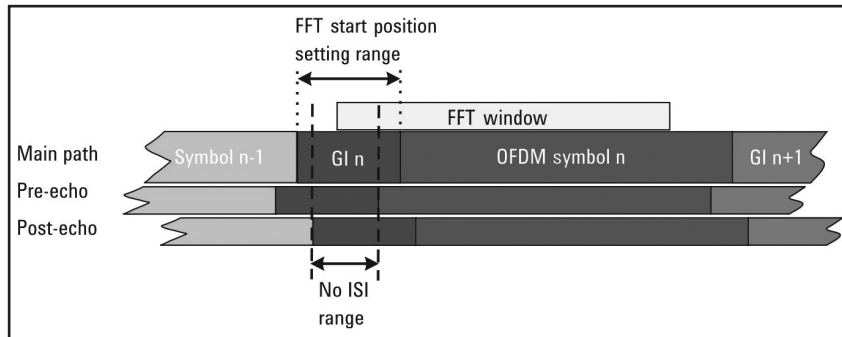

Figure 5. FFT window selection.

Echo measurement with delay within the GI

In OFDM systems, pre-defined comb-type pilot carriers are usually used to estimate and track the channel status. By using these pilot carriers for channel estimation, and with a carefully designed filter, we can detect all echoes accurately for various scenarios when the maximum echo delay is within the GI.

Extending the echo delay measurement range

Echoes in an SFN system may not conform to the echo masks defined by MBRAI/NorDig without optimization. The capability to detect echoes that violate the masks is therefore essential. Keysight Technologies Inc. measurement instruments and software offer the high degree of capability required to easily meet this advanced measurement challenge by decoding the data to provide accurate reference signals for channel estimation.

Keysight's SFN Measurement Solution

X–Series signal analyzers and the N/W6153A DVB-T/H/T2 measurement application

X-Series signal analyzers range from the high-performance (PXA), to the mid-range (MXA), the economy-class (EXA), and the low-cost (CXA). Power measurements like channel power, ACP (adjacent channel power), spectrum emission mask and modulation accuracy tests can be supported with all of these instruments. With X-Series signal analyzers, you can make measurements that are compliant with digital video broadcasting standards such as CMMB, DTMB, DVB-T/H/T2, ISDB-T/T_{sb}/Tmm, DVB-C, J.83 Annex A/B/C and audio broadcasting standards like DAB, FM Stereo/RDS and more.
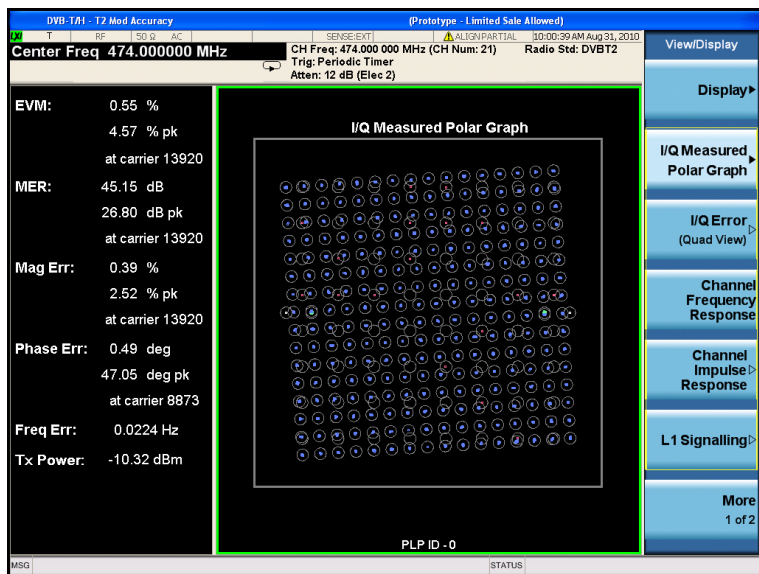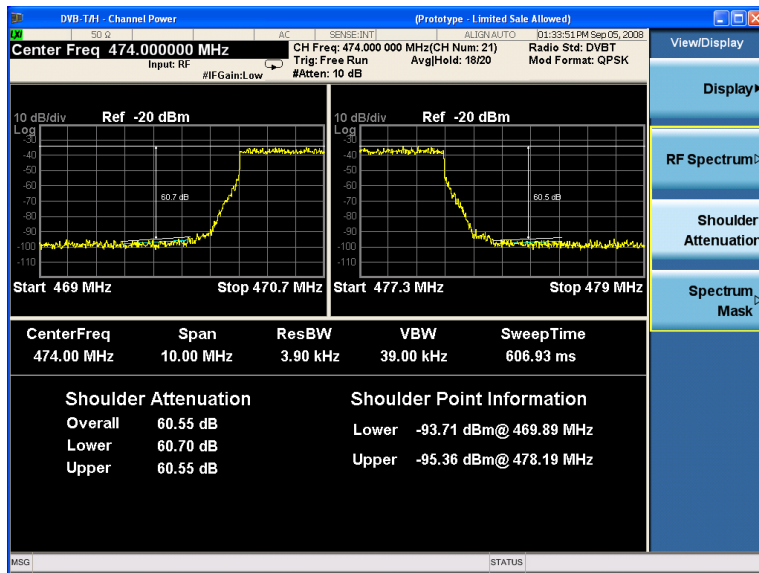
Figure 6. N6153A DVB-T/H/T2 measurement results example showing shoulder attenuation and an I/Q measured polar graph.

The N6153A DVB-T/H/T2 measurement application is one of more than 25 measurement applications in the Keysight X-Series. It runs inside the PXA, MXA, EXA and CXA signal analyzers and provides one-button, standard-based power and modulation analysis for DVB-T/H/T2 signals. It can be used to make the SFN measurement for DVB-T/H, SISO, and MISO DVB-T2 networks.

Key parameters for the DVB-T/H/T2 measurement application:

- Radio standard: DVB-T, DVB-H and DVB-T2 (versions 1.1.1 and 1.2.1)
- Channel bandwidth: 5/6/7 /8 MHz in DVB-T/H; 1.7/5/6/7 /8/10 MHz in DVB-T2
- FFT Mode: 2K/8K in DVB-T, 2K/4K/8K in DVB-H, 1k/2K/4K/8K/16K/32K in DVB-T2
- Modulation: QPSK/16QAM/64QAM in DVB-T/H; QPSK,16/64/256QAM in DVB-T2

Measurements:

- Power measurements
  - Channel power
  - Shoulder attenuation
  - Adjacent channel power
  - Spectrum emission mask
  - Power statistic CCDF
  - Spurious emission
- Modulation accuracy measurements, including:
  - MER, EVM, magnitude error, phase error, frequency error, clock error amplitude imbalance, quadrature error, phase jitter, carrier suppression, SNR
  - Channel frequency response, including amplitude vs. subcarriers, phase vs. subcarriers, group delay vs. subcarriers
  - Channel impulse response, supporting SFN test
  - BER results
  - TPS decoding and L1 signaling
  - MER monitor

Test configuration and system parameters

In the test configuration in Figure 7, the Keysight N5182A or N5182B MXG vector signal generators can be used for signal generation and the N5106A PXB baseband generator and channel emulator is used to simulate the DVB-T and DVB-T2 SFN networks. An N9020A MXA signal analyzer, is used for the SFN measurement. Different scenarios such as pre-echo, post-echo, pre-echo and post-echo, and long delay echo for the DVB-T system, and scenarios for the DVB-T2 MISO system, can be evaluated using this configuration.
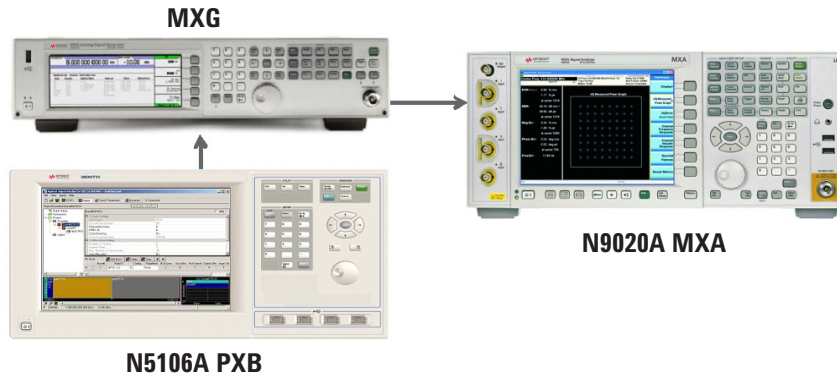
MXG

N9020A MXA

N5106A PXB

Figure 7. SFN test instrument configuration using the N5182A or N5182B MXG, N5106A PXB, and N9020A MXA.

Table 1. Parameters for an SFN measurement for a DVB-T system

Standard	DVB-T
Bandwidth	8 MHz
Center frequency	474 MHz
FFT size	8 k
Guard interval	¼ (224 us)
Constellation	64QAM

Post-echo scenario

The post-echo profile used in this test is shown in Table 2. The delay of the second path is set to 210 us, a little smaller than the GI (224 us) designated as a parameter of the DVB-T system in Table 1.

Table 2. Post-echo profile

i	α_i (dB)	τ_i (us)
1	0	0
2	−1	210

In this scenario, the optimal FFT start position is 0/8 GI so that both the main path and the second path can be included in the FFT window. The channel impulse response result for the post-echo scenario is shown in Figure 8. The blue bar shows the GI range, and the MER results and cell ID are shown at the top of the screen. In the Peak Table on the left-hand side of the screen in Figure 8, the delay and level of each detected path are listed, showing that both paths can be detected correctly for this scenario.
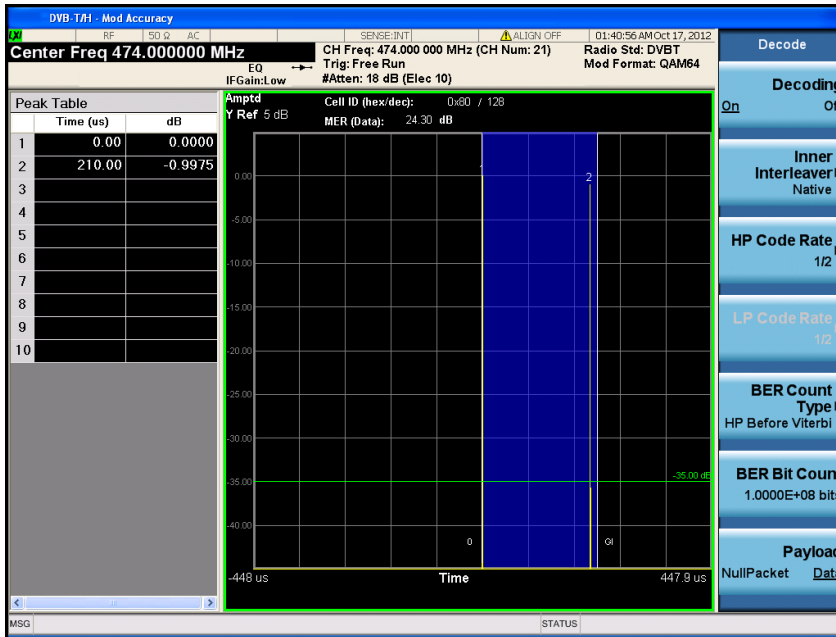

Figure 8. Post-echo scenario channel impulse response result.

Pre-echo scenario

The pre-echo profile used in this test is shown in Table 3. The delay of the second path is set to 210 us.

Table 3. Pre-echo profile

i	α_i (dB)	τ_i (us)
1	−1	0
2	0	210

In this scenario, the optimal FFT start position is 8/8 GI so that both paths can be included in the FFT window. The channel impulse response result for the pre-echo scenario, shown in Figure 9, demonstrates that the signals can be detected correctly.
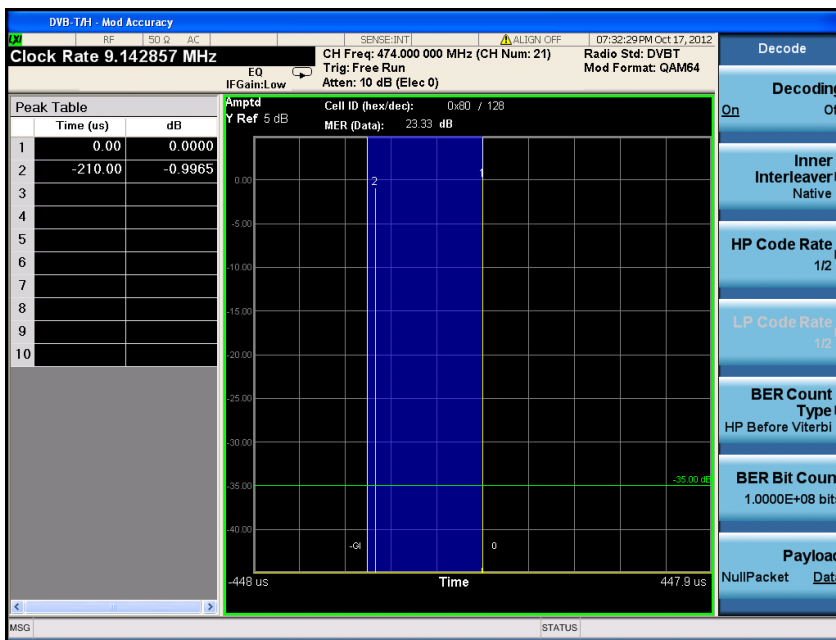

Figure 9. Pre-echo channel impulse result.

Pre-echo and post-echo scenario

The pre-echo and post-echo channel profiles used to simulate this scenario are listed in Table 4.

Table 4. Pre-echo and post-echo profiles

i	$-\alpha_i$ (dB)	τ_i (us)
1	−10	0
2	0	105
3	−10	210

The optimal FFT start position for this scenario is 4/8 GI. The channel impulse response result for this pre-echo and post-echo scenario is shown in Figure 10.
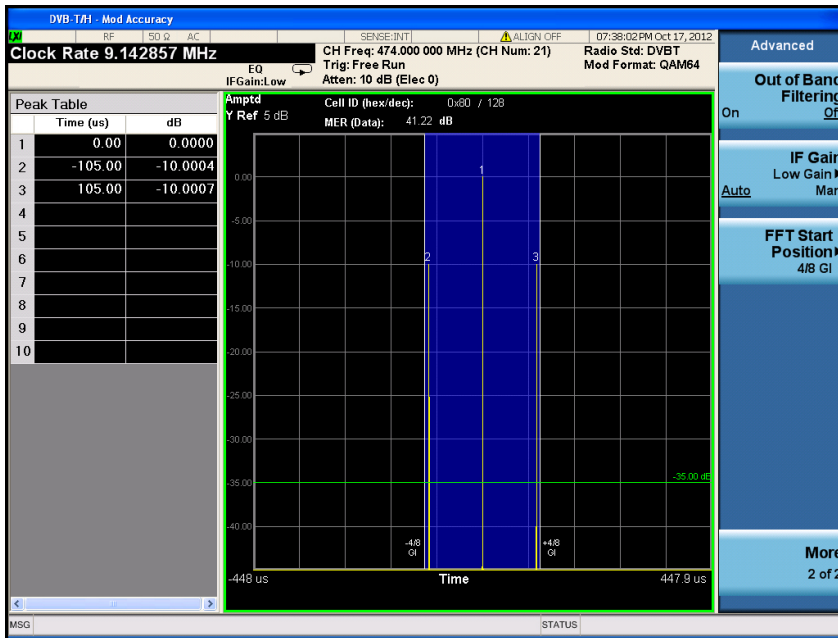

Figure 10. Pre-echo and Post-echo response result.

Scenario with long delay echoes

The long delay echo scenario represents a case where the second path is emanating from a distant reflection, so that its level is relatively low and its delay is larger than the GI. Long delay echoes may occur in a network without SFN optimization, so it's important for the measurement instrument to have the ability to measure them. In the channel profile used to simulate this scenario, shown in Table 5, the delay of the second path is set to 440 us, which is almost twice the GI (224 us).

Table 5. Echo with long delay profile

i	α_i (dB)	τ_i (us)
1	0	0
2	−20	440

The optimal FFT start position for a long delay profile is 0/8 GI, and decoding must be turned to on in the measurement software to eliminate the image echo caused by the long delay echo. Figure 11 shows the channel impulse response when decoding is off. In this case, only pilot sub-carriers are used for channel estimation and as a result, the long delay echo is severely distorted and an image echo appears within the GI range. Figure 12 shows that if decoding is turned on when both pilot and data sub-carriers are used for channel estimation, the long delay echo power is closer to the real value and the image echo is eliminated.
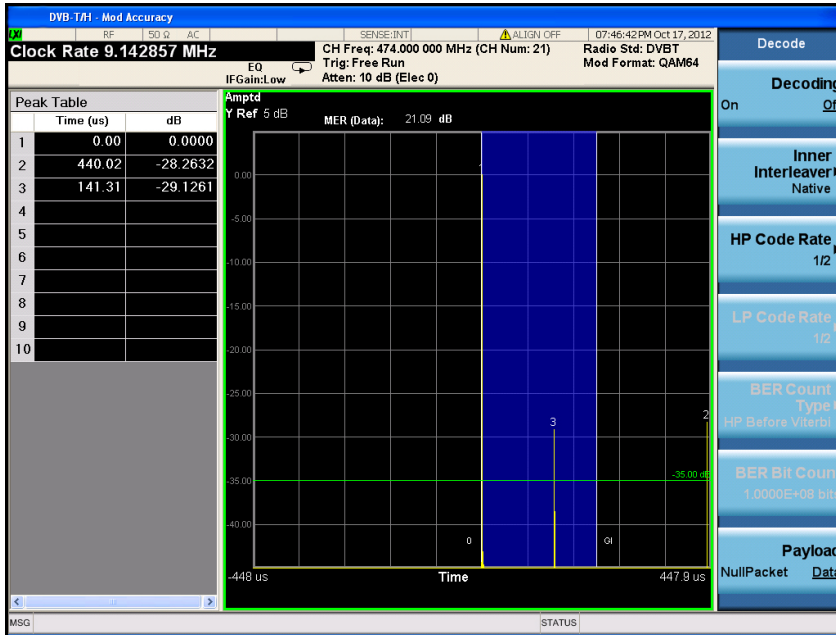

Figure 11. Long delay echo profile measurement result (Decoding off).
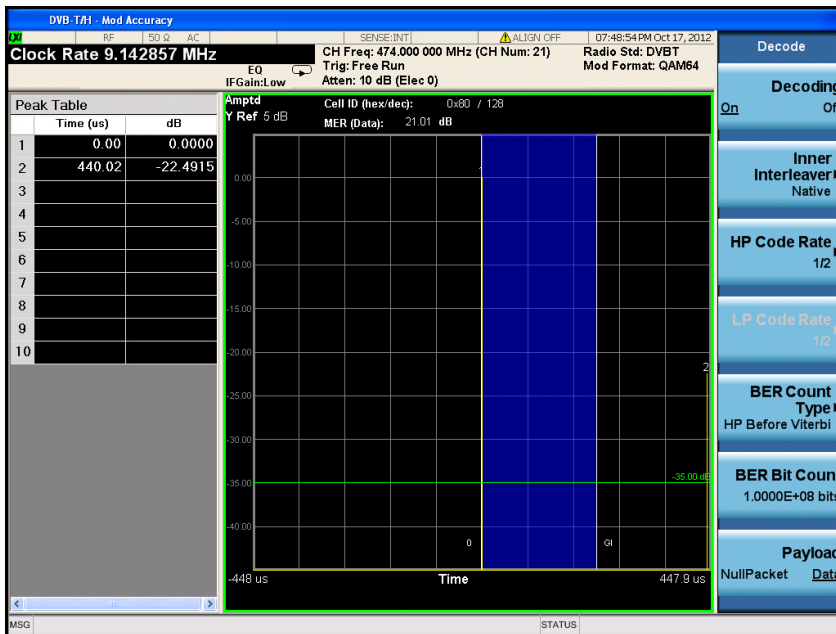

Figure 12. Long delay echo profile measurement result (Decoding on).

For DVB-T SFN networks, with the solution provided by X-Series signal analyzers and the N6153A measurement application, both echo power and delay can be detected accurately for various channel profiles, including pre-echoes, post-echoes, pre-echoes and post-echoes, and even for echoes with delays longer than the GI.

SFN measurements for DVB-T2 MISO systems

The simplified block diagram for a DVB-T2 MISO measurement is shown in Figure 13. The same information is transmitted by each transmitter, but the second transmitter (TX2) transmits a slightly modified version of each pair of constellations in the reverse order in frequency [7].
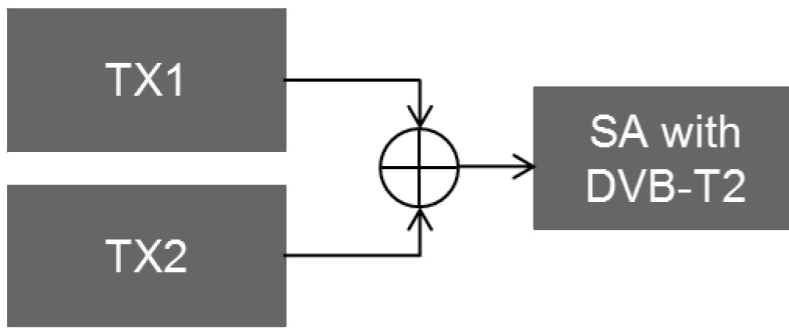
MISO-SFN measurements are being adopted as part of the DVB-T2 standard requirements. The DVB-T2 standard defines a number of configurations that make the system suitable for various uses, from low data rate mobile services to HDTV programming. In this example, we are using the VV018 configuration from the Validation and Verification (V&V) test group.

The parameters of the DVB-T2 system are listed in Table 6. Both pre-echo and post-echo scenario evaluations are described below.

Table 6. System configuration for DVB-T2

Standard	DVB-T2
Transmission mode	MISO
Bandwidth	8 MHz
FFT size	32 k
Guard interval	1/16 (224 us)
Constellation	Rotated 256QAM
Pilot pattern	PP2

Post-echo scenario

In the post-echo scenario in the DVB-T2 SFN network shown here, the signal from the second transmitter has a lower power level and arrives after the signal from the first transmitter. The detailed parameters are shown in Table 7.

Table 7. Post-echo profile

Tx antenna i	$α_i$ (dB)	$τ_i$ (us)
1	0	0
2	−1	190

In this scenario, the optimal FFT start position is 0/8 GI, which allows for both paths to be included in the GI range of the FFT window. The channel impulse response results are shown in Figure 14. From the Peak Table, it is easy to distinguish which path comes from transmit antenna 1 (Tx1) and which path comes from transmit antenna 2 (Tx2). The blue bar shows the GI range. Also, cell ID and MER results are shown, and provide auxiliary information for the network measurement.

The results show the diversity benefit of using of the MISO technique in an SFN. In SISO-SFN, large echoes of long delay are often considered to be tough cases due to sub-carrier fading. For example, sub-carriers may be completely nulled out by a 0 dB echo. MISO essentially improves the signal reception quality in an SFN.
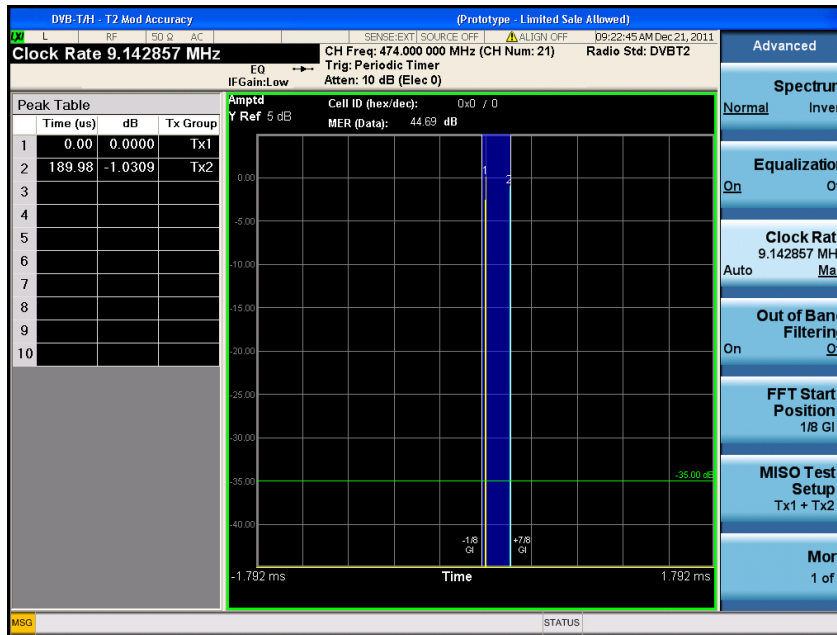

Figure 14. DVB-T2 MISO with post-echo channel impulse response results.

Pre-echo scenario

In the pre-echo scenario in the DVB-T2 SFN network shown here, the signal from the second transmitter has a higher power level and arrives after the signal from the first transmitter. The detailed parameters are listed in Table 8.

Table 8. Pre-echo profile

Tx antenna i	α_i (dB)	τ_i (us)
1	−1	0
2	0	190

In this scenario, the optimal FFT start position is 8/8 GI. The channel impulse response results are shown in Figure 15 and indicate that the signals can be detected correctly.
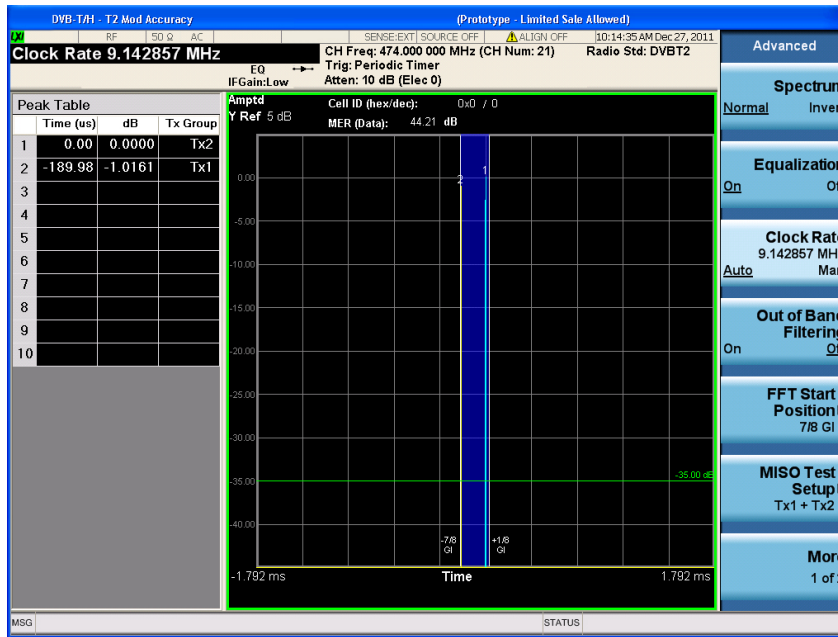

Figure 15. DVB-T2 MISO with pre-echo channel impulse response result.

Testing a DVB-T2 MISO SFN network with the Keysight measurement solution made up of an X-Series signal analyzer and the N6153A measurement application, allows echo power and delay to be detected accurately for both post-echo and pre-echo scenarios.

Conclusion

SFN systems offer many potential advantages, but to realize the full benefit of these systems, they must be planned very carefully. The accurate measurement of network characteristics provides the foundation for proper SFN planning. Keysight's SFN measurement solution provides a reliable way to perform the required tests for pre-echo, post-echo, and pre- and post- echo scenarios, even for echoes with delay outside the GI, and allows for precise SFN network planning and deployment. Not only is Keysight's SFN measurement solution being used around the world both in the lab and out in the field to perform DVB-T and DVB-T2 network deployment, but its flexibility and powerful capabilities are now being applied to the deployment of other systems as well, including ISDB-T.

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3. EICTA MBRAI, "Mobile and Portable DVB-T/H Radio Access; Part 1: Interface specification".

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Related Literature

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Keysight Digital Video and Broadcast Audio Measurement solutions, Brochure, Literature number 5991-1011EN

N6153A & W6153A DVB-T/H with T2 X-Series Measurement Applications, Technical overview, Literature number 5990-3569EN

X-Series Signal Analysis, Brochure, Literature number 5990-7998EN

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