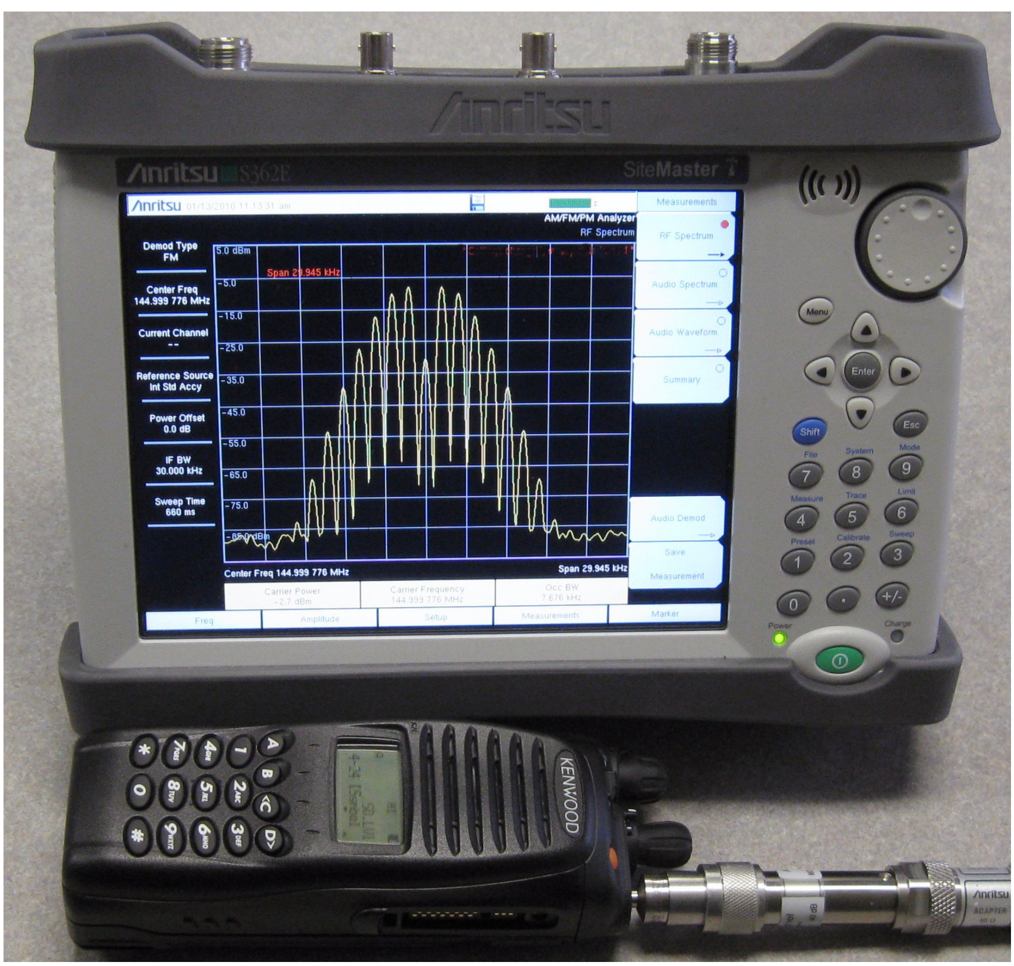
Application Note

AM/FM/PM Modulation Measurements

With the Anritsu E-Series Spectrum Master™ and Site Master™

Introduction

This application note describes how to make accurate modulation measurements using the **Anritsu E-Series MS2712E** and **MS2713E Spectrum Analyzers** and **S332E and S362E Cable/Antenna/Spectrum Analyzers**, equipped with **Option 509, AM/FM/PM Analyzer**. The user should have basic familiarity with the **E-Series** spectrum analyzer operation. More information for these instruments, including specification data sheets and their **Measurement Guide**, can be found at the *www.us.anritsu.com* website. Chapter 6 in the Measurement Guide covers the **AM/FM/PM Analyzer (Option 509)** operating modes and has menu key maps to facilitate navigation through the various menus. It will be helpful to review Chapter 6 in conjunction with this application note.



Basic Operation

The AM/FM/PM Analyzer mode may be selected from the Main Menu. Access the Main menu by pressing the Menu key, or pressing "Shift" Mode. Then select the AM/FM/PM Analyzer mode.

The AM/FM/PM Analyzer mode includes basic spectrum analyzer functionality. This is useful for selecting the appropriate IF bandwidth (IFBW) to use for modulation measurements. Unlike the Main menu selected Spectrum Analyzer mode, the spectrum analyzer functionality in the AM/FM/PM Analyzer mode has its Resolution Bandwidth (RBW) coupled to the spectrum analyzer span and is not otherwise adjustable within the AM/FM/PM Analyzer mode operation. This is important to remember since an incorrect span (and thus RBW) may adversely affect the Occupied Bandwidth (OccBW) measurements shown in the AM/FM/PM Analyzer mode summary data screen and elsewhere. The span should be such that the signal being measured has an OccBW about 20 to 75% of the span. The minimum spectrum analyzer span in the AM/FM/PM Analyzer mode is 10 kHz and the maximum span is 20 MHz. Note that these span limits do not apply to the Main menu selected Spectrum Analyzer mode.

Frequency Tuning

The **E-Series** instrument should first be tuned to the signal being measured by selecting Freq from the lower left menu bar soft keys in the AM/FM/PM Analyzer mode screen. The Set Carrier Freq to Center sub-menu key can also be used if the desired signal is already on the screen but not centered in the AM/FM/PM Analyzer's spectrum analyzer mode.

The Demod Type (AM, FM, or PM) should be selected by pressing the AM/FM/PM Analyzer mode's Setup key (bottom center of the menu bar soft keys) and then pressing the Demod Type key, in the right side sub-menu, until the desired mode (AM, FM, or PM) is underlined.

The IFBW selection key is just below the Demod Type in the Setup screen. The IFBW selected for modulation measurements should be wide enough to pass the signal being measured, but not excessively wide that it passes unwanted modulation harmonics, adjacent channel signals or interference, noise, etc that can degrade the measurement accuracy. The AM/FM/PM Analyzer mode's IFBW is user selectable in 1, 3, 10 steps from 1 kHz to 300 kHz.

The AM/FM/PM Analyzer mode provides an easy to use single-button amplitude Ref Level adjustment feature. This helps to maximize the SNR without overloading the IF ADC, which is particularly important when making AM modulation measurements. If the signal level varies over time, it may be necessary to adjust the Ref Level as needed to keep the signal level within the desired range to avoid overloading the ADC or being too weak to make accurate measurements.

To adjust the amplitude Ref Level select Amplitude in the AM/FM/PM Analyzer mode menu bar, then press the Adjust Range key in the right side sub-menu. It may be necessary to press the Adjust Range key twice to get the signal properly centered.

Modulation Measurement Summary Screen

The Modulation Measurement Summary (MMS) screen is selected by pressing Measurements in the AM/FM/PM Analyzer mode menu bar, then Summary in the right side sub-menu bar. The MMS screen displays:

- RMS Deviation/Depth
- Peak+ Deviation/Depth
- Peak- Deviation/Depth
- (Pk-Pk)/2 Deviation/Depth
- Carrier Power
- Carrier Frequency
- Occ BW
- AM/FM/PM Rate
- SINAD
- THD
- Distortion/Total V_{rms}

The first line in the MMS screen shows the RMS value of the FM/PM deviation, or the AM depth. The RMS deviation value shown in the MMS screen, Figure 1 on the next page, is for 10 kHz sinewave PM modulation and thus it is related to the (Pk-Pk)/2 deviation by 1/Sqrt(2).

The Peak+ Deviation/Depth is the peak positive phase deviation for PM, peak positive frequency deviation for FM, or the peak positive amplitude for AM.

The Peak- Deviation/Depth is the peak negative phase deviation for PM, peak negative frequency deviation for FM, or the peak negative amplitude (depth) for AM.

The (Pk-Pk)/2 Deviation/Depth is the mean value of the positive and negative modulation peaks. The Carrier Power displayed is that of the signal within the IFBW.

The Carrier Frequency displayed is the center frequency of the measured signal based on counting zero crossings of the entire signal within the IFBW.

The Occ BW displayed is the occupied bandwidth at the user's selected dB below carrier or by the percent of total signal power received.

The AM/FM/PM rate is the modulation rate (frequency).

The SINAD displayed is the Signal + Noise + Distortion to Noise + Distortion power ratio in dB.

The THD displayed is the Total Harmonic Distortion ratio, i.e., the percent power ratio of the power sum of the harmonics to the fundamental signal power.

The Distortion/Total_V_{rms} displayed is the percent voltage ratio of the (THD+N)/Total_V_{rms}, where THD+N (Distortion) is the total output signal voltage (including harmonics, noise and intermodulation products) without the fundamental modulating tone. I.e., the fundamental modulating tone is notched out.

It is important to remember that SINAD, THD and Distortion/Total_V_{rms} measurements only makes sense for single-tone sinusoidal modulation.

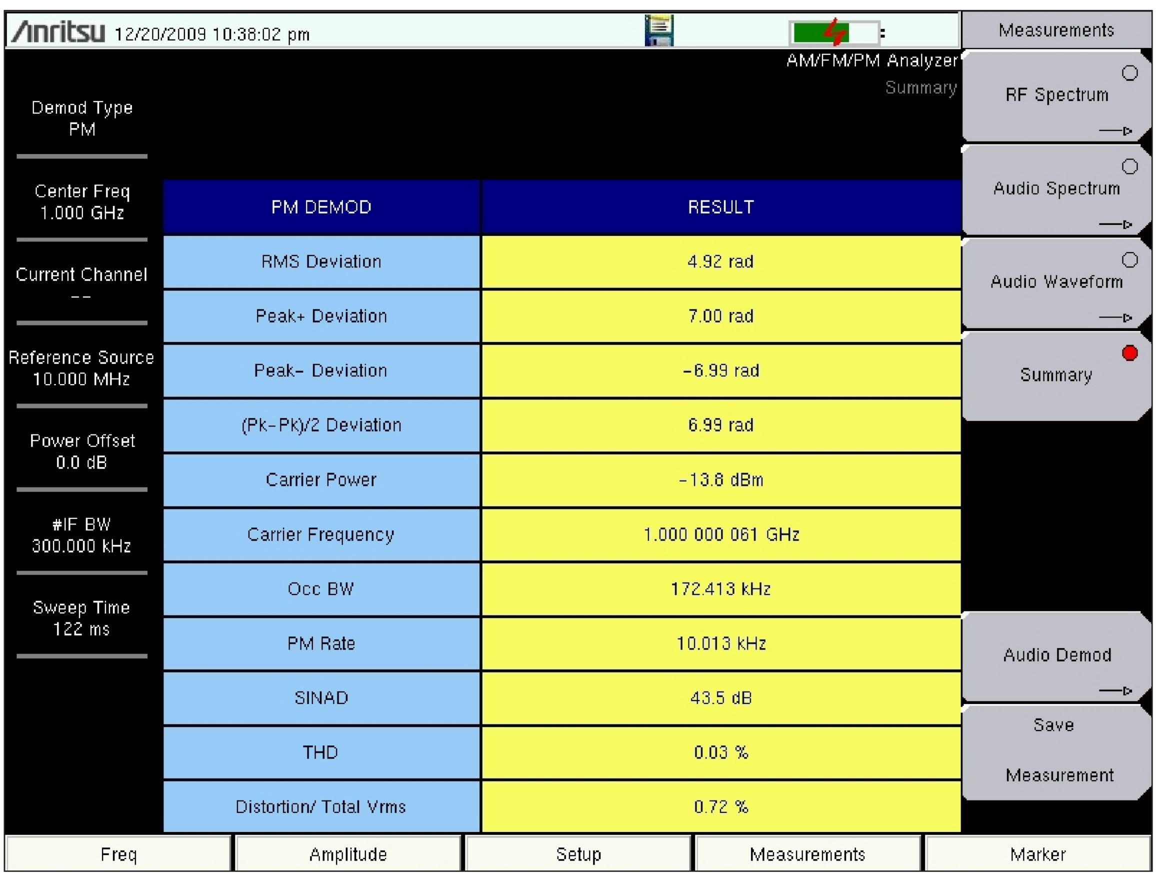


Figure 1. The AM/FM/PM Analyzer's Modulation Measurement Summary Screen.

More accurate AM depth and FM/PM deviation measurements will be obtained when the SINAD is greater than 30 dB and the THD is less than 5%. Low SINAD and high THD may be indicative of a poor SNR, incorrect Ref Level setting, too narrow an IFBW, interference, tuning error, etc.

The demod type selected, the center freq, reference source, power offset, IFBW, etc are shown to the left of the MMS screen. This information is useful for troubleshooting problems when the modulation measurement does not make sense, e.g., due to an incorrect IFBW.

AM Modulation Measurements

AM modulation measurements may be made over the 10 Hz to 100 kHz baseband modulation rate range. When making AM modulation measurements the IFBW should be slightly wider than twice the highest baseband modulation rate, yet it should not be excessively wide. If unsure of the signal's RF occupied bandwidth (OccBW), use the RF Spectrum mode to measure it.

Again, it is important to adjust the amplitude Ref Level to ensure that the modulated signal does not overload the instrument's IF ADC and front-end mixer. Note that its possible to have the desired signal level adjusted properly without ADC overload, but strong nearby (out of passband) signals may overload the front-end mixer. There are separate warning messages displayed on the screen for overloading, including "ADC Error" and "Sat Error."

As 100% AM modulated signals have a peak power 6-dB higher than the unmodulated carrier power, its possible to adjust the Ref Level for proper IF ADC level without modulation and then to have the positive modulation peaks overload the ADC, possibly causing degraded measurement accuracy. Thus its generally best to adjust the Ref Level when the signal is modulated.

FM Modulation Measurements

FM deviation measurements may be made from 10 Hz to 100 kHz deviation over the 10 Hz to 100 kHz modulation rate range, subject to the modulation index (M) and the RF OccBW. In general, M should be between 0.1 to 20, but may be as high as 50 for modulation rates from 100 Hz to 1 kHz. The RF channel OccBW should be less than the maximum 300 kHz IFBW to ensure accurate measurements.

For accurate FM modulation measurements, the IFBW should be wide enough to pass 95% or more of the OccBW. However, if off-the-air (OTA) measurements in a crowded spectrum, e.g., Land Mobile Radio (LMR) are being made, it may be necessary to limit the IFBW to something close to or less than the LMR channel bandwidth. E.g., 10 kHz for a 12.5 kHz narrow-band (NB) UHF channel or 30 kHz for a wideband (25 kHz) UHF channel to reduce errors caused by nearby activity. Again, use of the spectrum analyzer modes may be desirable to determine the OccBW and check for adjacent channel activity in order to select the most appropriate IFBW. Also, see the Carson's Rule for occupied bandwidth discussion in the Appendix.

Figure 2 shows a 30 MHz signal, FM modulated by a 50.0 kHz sinewave. The actual peak FM deviation is 120.24 kHz to produce an 85 dB deep Bessel carrier null. This is the first Bessel carrier null (2.4048 Fm). The null depth in this spectra is limited to about 70 dB due to the elevated noise floor from internal local oscillator (LO) phase noise. Figure 3 shows the MMS summary display screen of the modulation parameters. As can be seen, the OccBW is 310 kHz and exceeds the 300 kHz IFBW. Thus the poor 23.6 dB SINAD and 6.59% THD.

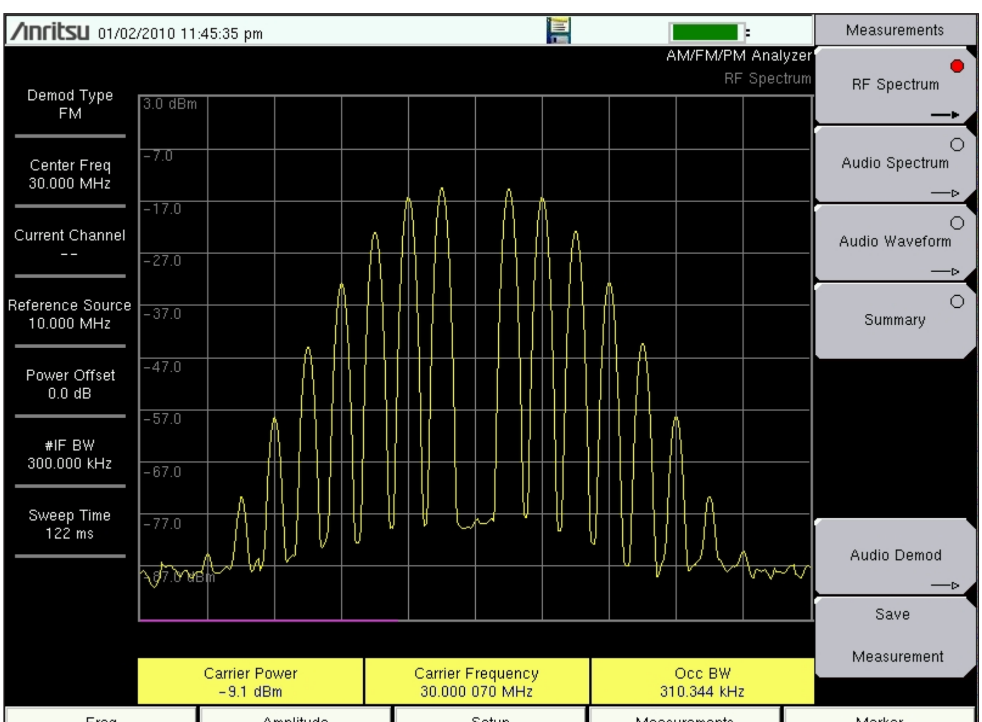


Figure 2. 30 MHz signal with F_m = 50 kHz, F_{dev} = 120.24 kHz.
Note the deep Bessel carrier null.

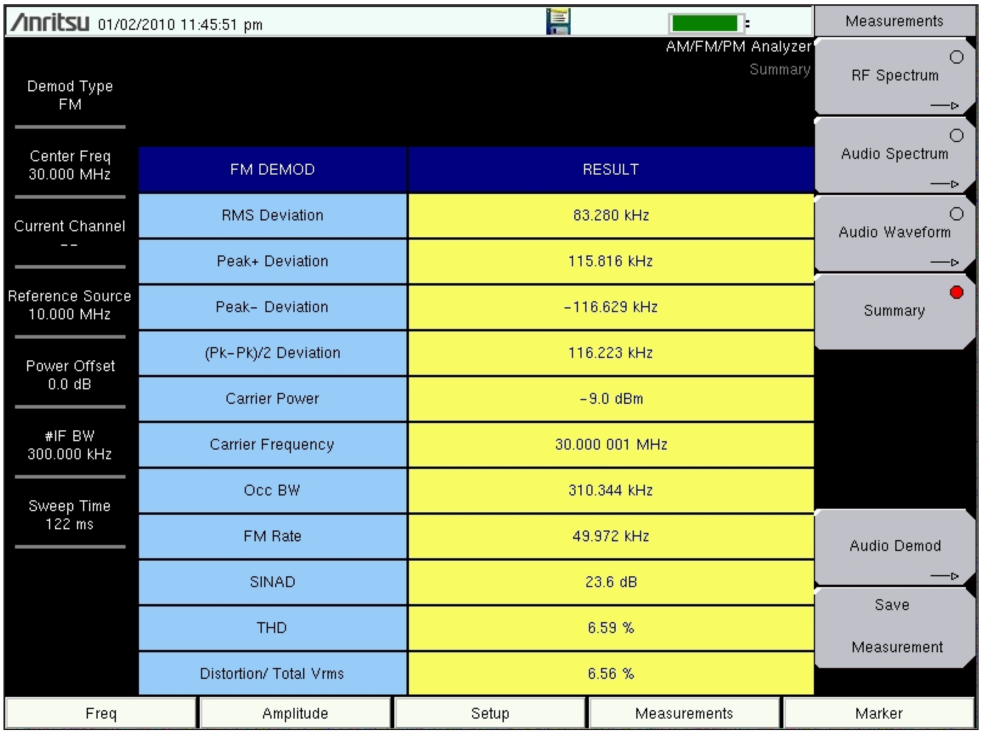


Figure 3. The MMS summary display screen for the 30 MHz signal in Figure 2 with F_m = 50.0 kHz and F_{dev} = 120.24 kHz.

To reduce the OccBW to about 200 kHz and be well within the 300 kHz IFBW, the modulating frequency was reduced to 30 kHz and the deviation set to 72.144 kHz for the first Bessel carrier null. The MMS summary display screen for this signal is shown in Figure 4. Note that the SINAD increased from 23.6 dB to 48.4 dB, the THD dropped from 6.59% to 0.36%, and the deviation measurement accuracy improved from 3.35% to 0.26%.

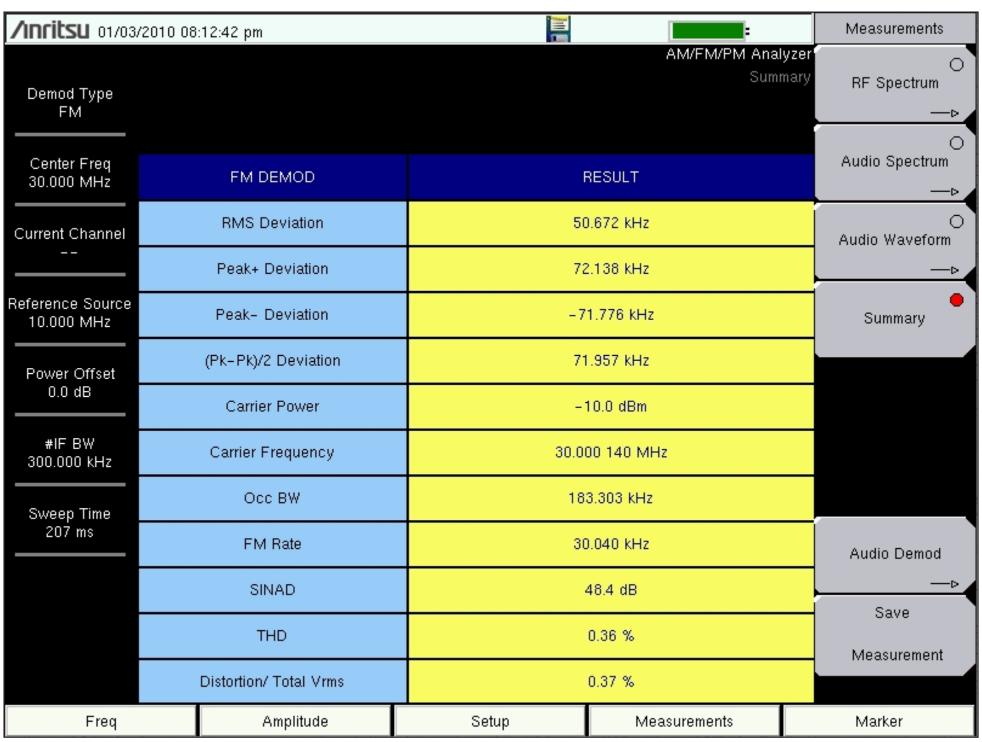


Figure 4. The MMS summary display screen for the 30 MHz signal with F_m = 30 kHz sinewave modulation and F_{dev} = 72.144 kHz.

PM Modulation Measurements

Accurate PM deviation may be measured from 0 to 93 rads for modulation rates from 10 Hz to 10 kHz. Useful PM deviation measurements may be made to 200 rads for modulation rates less than 1 kHz. The IFBW should exceed 95% of the PM signal's occupied bandwidth, but not be excessively wide that unwanted noise and any OTA adjacent channel signals degrade the modulation measurement.

Figure 5 shows a 1 GHz signal phase modulated with a 1 kHz sinewave at 100 rads. Figure 6 shows the measured modulation data in the MMS display screen. The measured OccBW is 210.5 kHz. The Carson Rule for PM estimated bandwidth is 202 kHz.

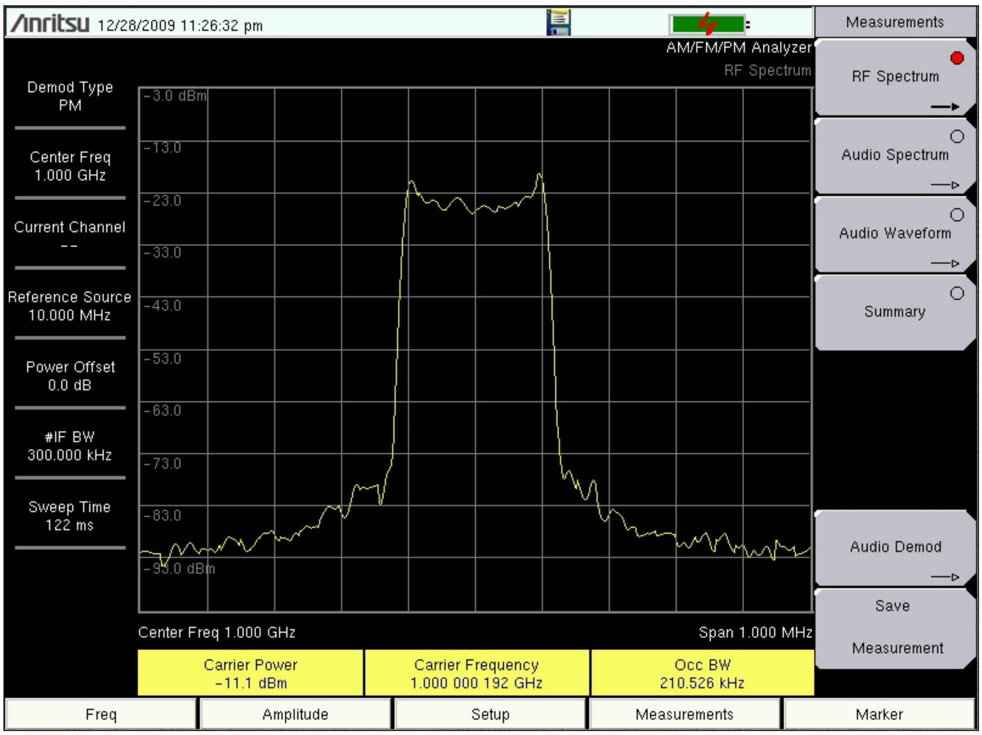


Figure 5. 1 GHz signal phase modulated with 1 kHz and 100 rads phase deviation.

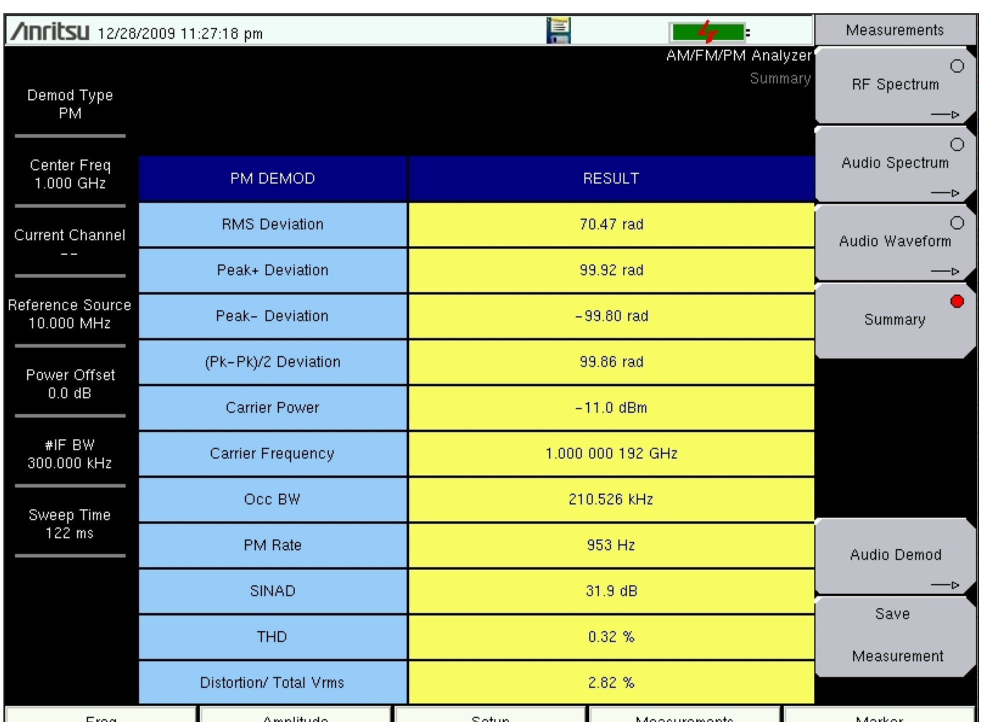


Figure 6. The PM Demod mode MMS display screen data for the Figure 5 PM signal with 1 kHz modulation and 100 rads phase deviation.

Signal Standards

E-Series instruments have a large library of predefined signal standards. These standards provide default setup parameters for the particular wireless service selected. The selected signal standard sets the default center frequency, channel spacing, and span for the intended wireless service. Depending on the standard selected, the RBW, IFBW, VBW, Auto RBW, Auto VBW, RBW/VBW ratio, Span/RBW ratio, Ref Level, Demod Type, Demod On/Off, etc may be set or may be left "as is." Thus some of these parameters may need to be set, as needed, by the user for the intended application. To select the measurement from the Signal Standard menu the Signal Standard soft key, on the right side sub-menu, can be selected to bring up the Signal Standard menu. Scroll down with the knob to the desired Signal Standard and press enter. This will set the Center Freq to the default value for that Signal Standard and return the instrument to the RF Freq menu. At the top of the right side sub-menu, the desired RF measurement frequency can be entered with the Center Freq key.

Audio Demodulation

The **Anritsu E-series Site Masters** and **Spectrum Masters** have an audio demodulator and speaker to allow listening to the demodulated signal's baseband audio. To select this feature press Measurements, Audio Demod, On, and Demod Type (FM Wide or FM Narrow Band). The speaker audio level may also be adjusted with the Volume key and the tuning knob.

Demodulated Audio Waveform and Spectral Displays

The demodulated audio may be viewed in oscilloscope mode by pressing Measurements in the lower menu bar, then Audio Waveform. Pressing Audio Waveform again will allow adjustment of the sweep time. In the AM demod mode the vertical scale range is –100% to +100% modulation peaks. In the FM demod mode the scale is in percent of IFBW and is adjustable. In the PM demod mode, the vertical scale is in millirads and adjustable (maximum 3,140,000 milli-rads). The vertical scale adjustment key is below the Sweep Time key.

The demodulated audio may also be viewed in audio spectrum analyzer mode by selecting Measurements and then the Audio Spectrum key. A second push of this key will bring up the audio Span key. For AM modulation the vertical scale is calibrated in modulation percentage. For FM it is calibrated in percent of IFBW and is adjustable by the key below the Span key. For PM modulation the vertical scale is calibrated in rads/milli-rads and is adjustable.

Occupied Bandwidth Measurements

Occupied Bandwidth (OccBW) measurements may be made in both the Spectrum Analyzer and in the AM/FM/PM Analyzer modes. In the Spectrum Analyzer mode, the OccBW setup is accessed by pressing “Shift” Measurement on the keypad, then “Occ BW” in the right-side sub-menu bar. Then enable it by the On/Off key at the top of the right-side sub-menu bar. Note that if ACPR (Adjacent Channel Power Ratio) is already enabled, it will be turned off by enabling OccBW.

In the AM/FM/PM Measurement mode, the OccBW is measured and displayed as part of the Measurements Summary screen and as part of the RF Spectrum display. Note that the OccBW measurement parameters are not user adjustable in the AM/FM/PM Measurement mode, but are in the RF Spectrum display mode. Note, again, that the IFBW used for OccBW measurements is the RBW and the RBW is coupled to the RF Spectrum mode’s span. The RF OccBW should be 20% to 75% of the span.

In the RF Spectrum mode, the user can select the method used to compute OccBW: “% Int Pwr” or dB below carrier (dBc). To make this selection, first press the RF Spectrum soft key in the right-side sub-menu to enter the OccBW parameter sub-menu.

The “% Int Pwr” method measures the OccBW based on the percentage of power specified by the user within the OccBW, from 0% to 99.99%. The dBc method measures the OccBW at the user specified dB below the carrier power.

In the AM/FM/PM Analyzer’s RF Spectrum display, the Carrier Power, Carrier Frequency and OccBW are displayed at the bottom of the screen above the menu bar.

Adjacent Channel Power Ratio Measurements

Adjacent Channel Power Ratio (ACPR) is a Spectrum Analyzer mode measurement function. It is not available in the AM/FM/PM Measurements mode. Though it is often used in conjunction with OccBW and modulation measurements, particularly in LMR systems due to adjacent channel interference issues and FCC emission mask regulations. The ACPR mode cannot be active concurrently with the OccBW mode.

To enable ACPR, select the Spectrum Analyzer mode from the Main menu, then select "Shift" Measure on the main keypad, then ACPR from the right side screen menu keys, then enable with the On/Off key at the top of the right side sub-menu.

For ACPR measurements the user specifies the main channel bandwidth, the adjacent channel bandwidth and the channel spacing by soft keys on the right side ACPR sub-menu bar. Span may also be specified, which indirectly specifies the RBW/IFBW. Lower and upper channel limit lines are shown on the screen in ACPR mode.

Emission Mask Measurements

Emission mask measurements may also be made in the Spectrum Analyzer mode from the Main menu, then select "Shift" Measure on the main keypad, then "More" and "Emission Mask" from the right screen menu keys. A limit line may be used as the emission mask. For more information see "Segmented limit lines" in Chapter 3 of the User Guide and "Emission Mask" in Chapter 2 of the Measurement Guide or use "Online Help" from the MS2712/13E product page on the US.Anritsu.com website.

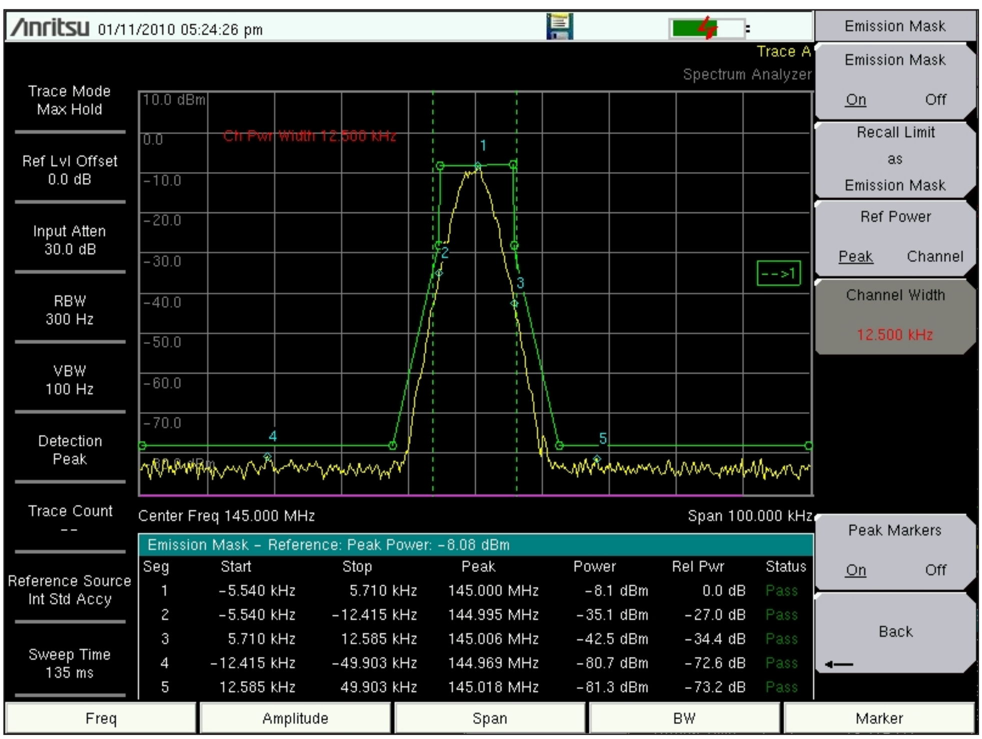


Figure 7. Emission Mask measurement of a 145 MHz P25 transmitter.

Measurement Issues

There are several FM and PM modulation measurement issues to be aware of for deviation, modulation rate, OccBW, and ACPR measurements. As previously discussed, selecting the correct IFBW is critical for FM and PM deviation and rate measurements. Too narrow an IFBW may cause errors due to sideband attenuation. Too wide an IFBW may cause errors due to unwanted noise, adjacent channel signals, poorer SINAD and THD, etc. Too narrow an IFBW attenuates sidebands and thus may provide incorrect OccBW data. Another issue is that of very narrow spectral lines in the modulated signal. If the IFBW is too narrow, the OccBW measurement may be of only one narrow bandwidth spectral line rather than the desired signal. Too wide an IFBW may degrade the FM/PM modulation rate measurement by several percent.

Modulation Measurement Resolution and Accuracy

For AM modulation the RMS and (Pk-Pk)/2 depth has 4-digits resolution from 00.00 to 99.99%. For FM modulation the RMS and (Pk-Pk)/2 deviation has 1 Hz resolution. For PM modulation the RMS and (Pk-Pk)/2 deviation resolution is 0.01 rads.

Spurious Signals

RF over-driving the **E-Series** instruments may produce unwanted spurious signals. There are also internal spurs present without any external input signal. Refer to your particular **E-Series** instrument's specifications for spurious signal information.

LMR Radio Modulation Measurements

E-Series instruments with the AM/FM/PM Analyzer (Option 509) are well suited to making 2-way radio carrier frequency, modulation, ACPR and OccBW measurements. Since the maximum RF power input to the **E-Series** instruments is +26 dBm, the radio's transmit signal must be attenuated by an external power attenuator or the RF sampled by a directional coupler, antenna, etc to avoid RF overload damage.

Note that if the radio being tested radiates RF from its antenna near the **E-Series** instrument, there may be unwanted RF ingress that produces internal spurs and/or degrades the measurement accuracy. An RF power attenuator or directional coupler with dummy load should be used when possible.

Digital mode LMR radios present some unique modulation measurement and adjustment issues. E.g., APCO-25 (aka Project-25, P25) and NXDN (Next Generation Digital Narrowband) digital radios both use 4-level Frequency Shift Keying (FSK). P25 refers to this as C4FM (Constant envelope 4-level FM).

Further, due to Nyquist and shaping filters, both have frequency deviations that make a trajectory over the symbol time that exceeds the specified deviations at the symbol sample times.

Thus when these signals are measured non-synchronously with conventional FM deviation meters, the peak deviation measured will be greater than the specified deviation when measured at the correct symbol sample time. **E-Series** instruments equipped with the P25 and/or NXDN options can measure the FM deviations at the prescribed symbol sample times. Shown below are the digital radio FM deviations for P25 and NXDN measured by **E-series** instruments equipped with the appropriate (P25, NXDN) option and with the AM/FM/PM Analyzer making conventional FM deviation measurements.

a) P25 12.5 kHz narrowband (NB) digital mode uses 4-level FSK with ±1800 Hz and ±600 Hz FSK deviations. The frequency shift trajectory over time is such that conventional deviation meters should measure a maximum of 2827 Hz (1800π/2 Hz) peak deviation.

b) NXDN 12.5 kHz NB 9600 bps digital mode uses 4-level FSK with ± 2400 Hz and ±800 Hz FSK deviations. The frequency shift trajectory over time is such that conventional deviation meters should measure a maximum of 3056 Hz peak deviation.

c) NXDN 6.25 kHz NB 4800 bps digital mode uses 4-level FSK with ±1050 Hz and ±350 Hz FSK deviations. The frequency shift trajectory over time is such that conventional deviation meters should measure a maximum of 1337 Hz peak deviation.

When making OccBW and ACPR measurements of analog and digital LMR radios, you may need to experiment with the IFBW to make accurate and stable measurements.

As the modulation rate resolution is 1 Hz, fractional Hertz PL-tone measurements will be rounded to the nearest 1 Hz.

Figure 8 shows the spectra from a Kenwood NX-300 NXDN narrowband radio. The radio is operating in the 6.25 kHz ultra-narrowband (UNB) NXDN digital mode. Figure 8 shows the FM Demod mode MMS display screen data for the NX-300 radio. Note that the 6.25 kHz digital mode uses 4-level Frequency Shift Keying (FSK) with ±350 Hz and ±1050 Hz frequency shifts. Note, too, that the SINAD, THD, and Distortion measurements are meaningless in this digital data test signal example.

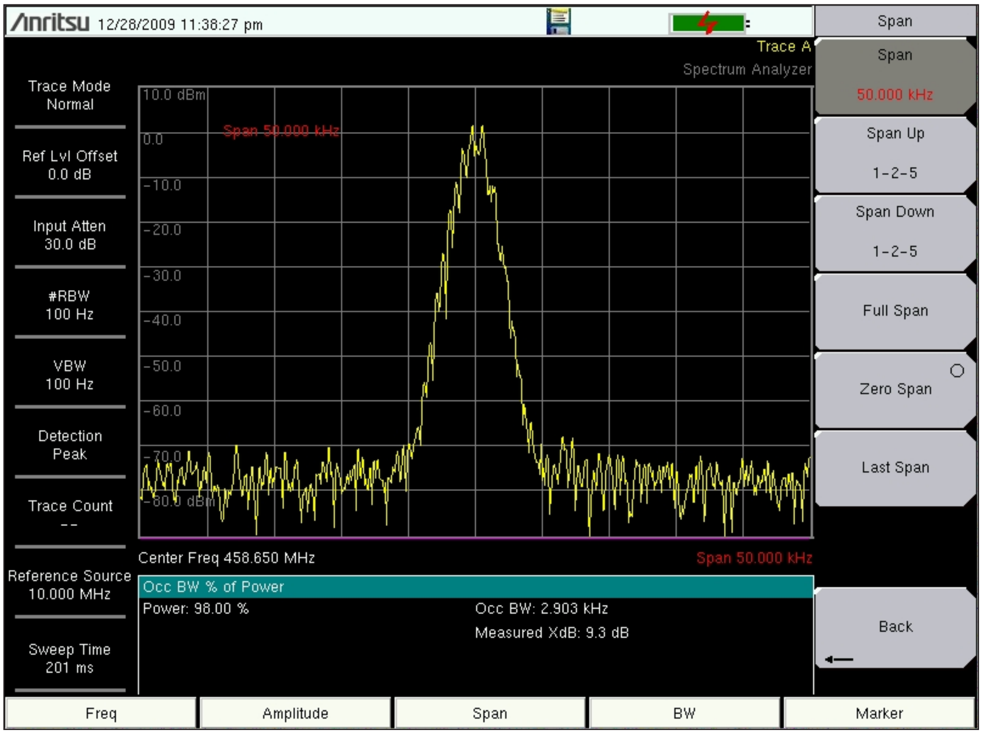


Figure 8. Spectra from Kenwood NXD-300 NXDN radio in the ultra-narrowband 6.25 kHz 4-level FSK digital mode.

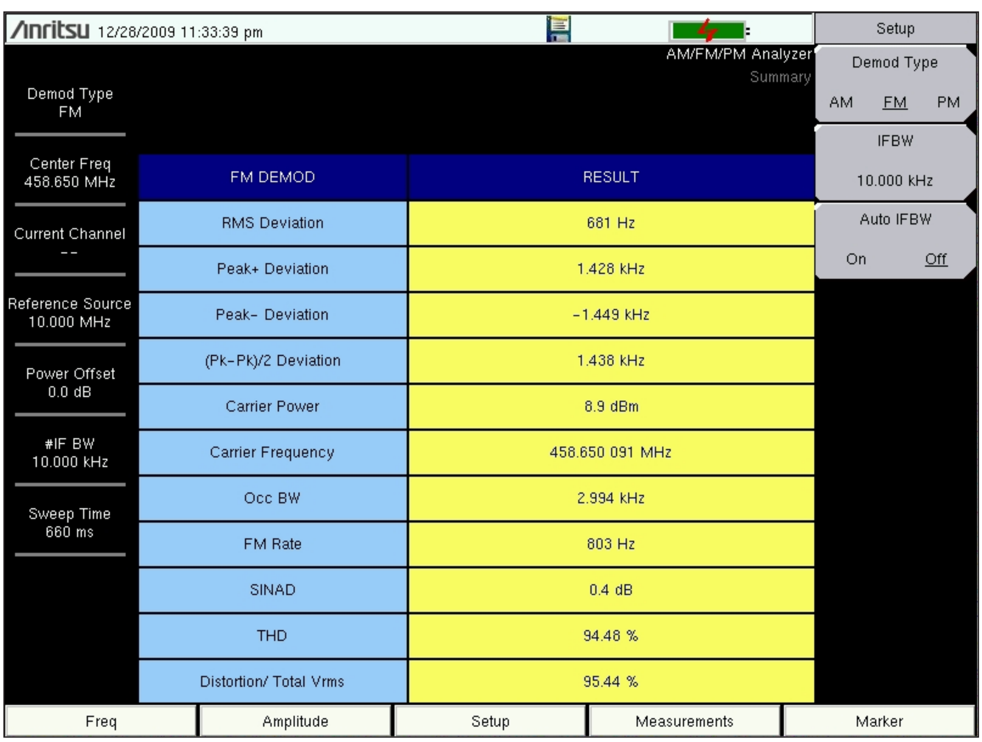


Figure 9. The FM Demod mode MMS display screen data of the Kenwood NXD-300 NXDN radio in the ultra-narrowband 6.25 kHz mode

Figure 10 shows the same NX-300 NXDN radio operating in the 6.25 kHz UNB deviation test mode. The modulation rate is 600 Hz. Figure 11 shows the AM/FM/PM Analyzer MMS data for the test radio.

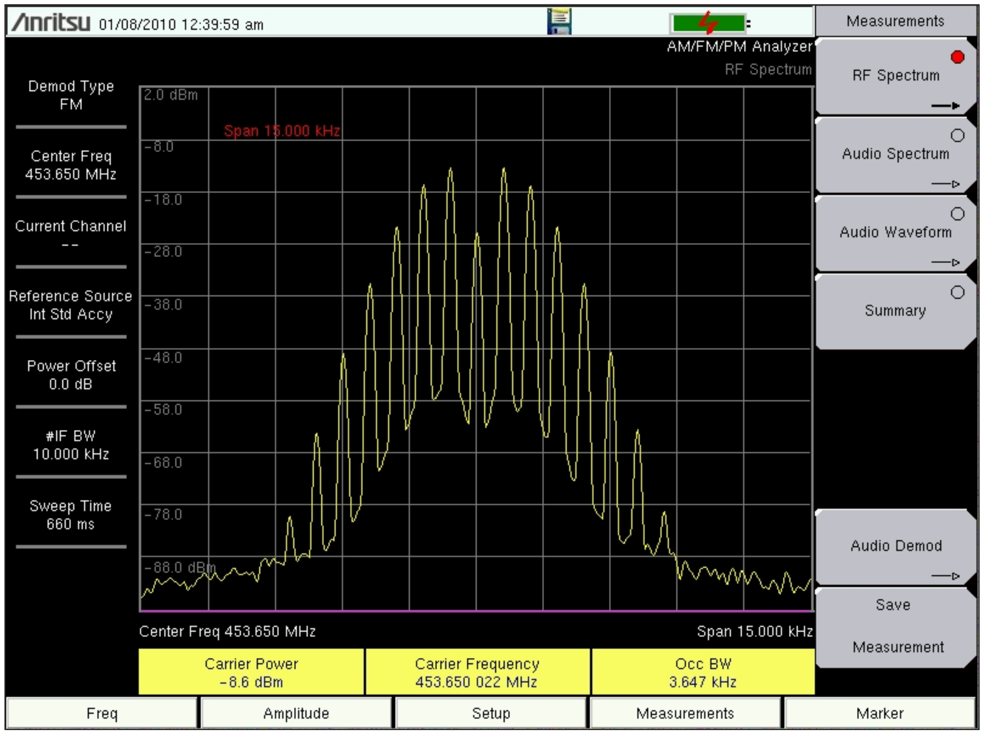


Figure 10. Spectra from the Kenwood NX-300 NXDN radio in the ultra-narrowband (UNB) 6.25 kHz deviation alignment mode.

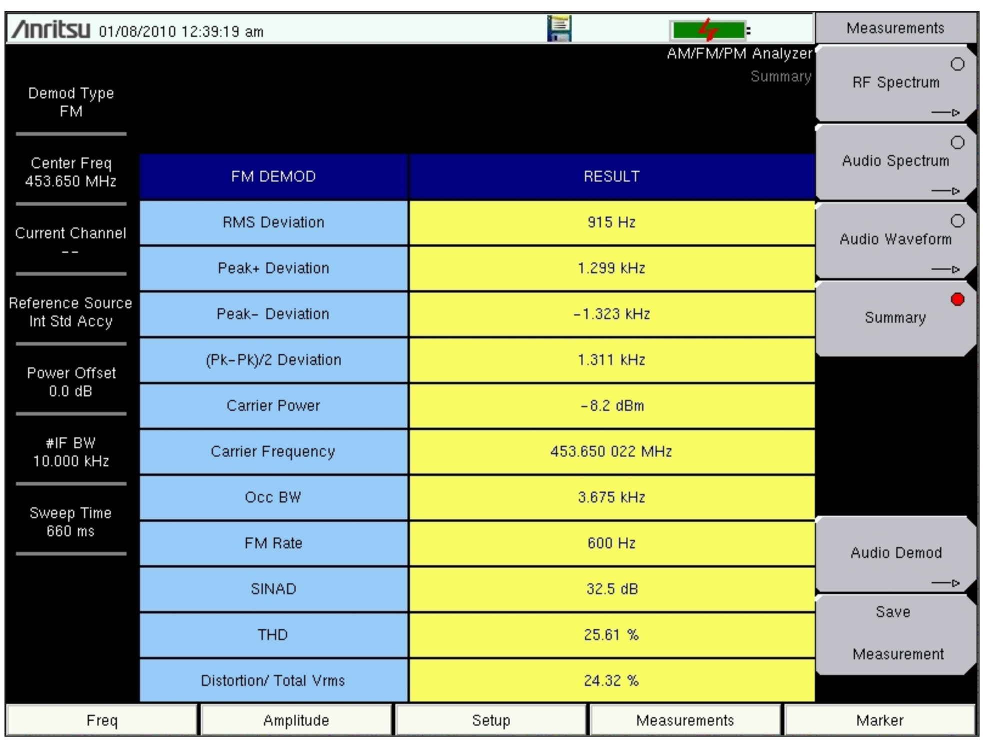


Figure 11. The FM Demod mode MMS display screen data of the Kenwood NX-300 NXDN radio in the 6.25 kHz ultra-narrowband (UNB) deviation alignment mode.

Conclusion

This application note covered the main measurement features of the **E-Series** AM/FM/PM Analyzer Option-509. There are several measurement features in this option that were not covered (or not covered in sufficient detail) here. The reader is encouraged to review the Anritsu Measurement Guide, especially Chapter 6, AM/FM/PM Analyzer (Option 509), and Chapter 2, Spectrum Analyzer. Additional information, especially for the OccBW, ACPR, Markers, and Trace functions, can be found there.

Appendix

FM and PM Modulation Discussion

Carson's Rule for FM and PM Bandwidth

Carson's Rule provides a useful approximation for the bandwidth of FM and PM modulated carriers:

$BW = 2\,(Fdev + F_m)$ for FM modulation
$BW = 2\,(Pdev + 1)F_m$ for PM modulation

where BW = the occupied bandwidth in Hz containing approximately 98% of the modulated signal's power
F_{dev} = the peak frequency deviation in Hz
F_m = the highest frequency in the modulating signal, in Hz
P_{dev} = the peak phase deviation in Rads

Carson's Rule is useful for estimating the minimum IFBW needed for FM and PM modulation measurements when Fm and Fdev or Pdev are known.

PM and FM modulation are related by

$P_{dev} = F_{dev}/F_m$, which is also the FM modulation index M

This can be seen by setting the Carson Rule bandwidth equations for PM and FM (above) equal to each other and solving for Pdev. This relationship is useful for checking PM deviation operation and calibration when only an FM signal generator is available. Using a high-quality FM signal generator and the Bessel null technique, accurate PM operation and calibration checking can be done. As an example, a PM demod test was made of the 30 MHz signal with 50 kHz FM sinewave modulation and 120.24 kHz peak deviation previously shown in Figure 2. The MMS display summary is shown in Figure 12. As can be seen, the PM (Pk-Pk)/2 deviation was measured at 2.45 rad, 1.9% higher than the true 2.4048 rad. The measured PM deviation accuracy was likely impaired by the measured 310 kHz OccBW slightly exceeding the 300 kHz IFBW. Note that the bandwidth estimated by Carson’s Rule is 340.48 kHz.

Note that:

a) PM is the time integral of FM.

b) FM is the time derivative of PM.

c) The FM carrier frequency deviation is proportional to the amplitude of the modulating signal and is constant with respect to the frequency of the modulating signal.

d) The PM carrier phase deviation is proportional to the amplitude of the modulating signal, constant with respect to the frequency of the modulating signal.

e) The PM carrier frequency deviation is proportional to the frequency of the modulating signal.

f) The PM carrier phase vector rotates at the modulation rate.

g) The FM carrier phase deviation is proportional to its frequency deviation and inversely proportional to the modulating frequency

Figure 12. MMS display screen for PM demod measurement of the 30 MHz signal shown in Figure 2 with 50 kHz sinewave FM modulation and 120.24 kHz deviation.

Bessel Function Nulls

Bessel function nulls may be used to check the FM and PM operation and accuracy of the **E-Series** AM/FM/PM Analyzer Mode. The FM deviation that produces a Bessel null (carrier, first sideband, second sideband, etc) is a function of the Bessel roots and the modulating frequency, F_m, as shown below:

$F_{dev} = J_n Fm$

where J_0 *= 2.4048, 5.5201, or 8.6537 for the 1st, 2nd or 3rd carrier nulls.*
J_1 *= 3.8317, 7.0156, or 10.1735 for the 1st, 2nd or 3rd first sideband nulls.*

In order to do accurate Bessel null FM modulation testing, the signal generator should have a very linear and symmetrical FM modulator with low residual FM noise. Such a signal generator should produce a 60 to 80 dB deep first carrier null (J0 = 2.4048). E.g., a 1 kHz single-tone modulation with a 2.4048 kHz deviation. A shallow null indicates a poorly performing signal generator and thus the deviation accuracy using the Bessel Null technique will likely be poor. Further, null depth tends to decrease at the higher modulation rates and deviations due to signal generator performance degradation.

RMS and Peak Deviation/Depth Relationship

For single-tone sinusoidal FM modulation the peak deviation is the SQRT(2) times the RMS deviation. This is not true for multi-tone and non-sinusoidal modulation signals.

This is also true for AM modulation. The AM modulation positive peak and negative peak (depth) are the SQRT(2) times the RMS depth. This is not true for multi-tone and non-sinusoidal modulation signals.

References

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