



- 2700 Series
- ATS-2
- APx500 Series

# FM Radio Receiver Testing with APx Audio Analyzers

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## About This Technote

In this technote, we'll discuss how to test the analog sound quality of FM radio receivers using an Audio Precision APx500 Series audio analyzer. We'll also discuss how to test the Radio Data System (RDS), which allows text, such as song title and artist, to be transmitted digitally as part of the analog radio signal. The test procedures we'll discuss can be applied to both car radios and home radio receivers. In order to test a receiver, we'll need to generate a special multiplexed test signal, play the wave file through the generator on an APx analyzer, feed it to an FM transmitter, and then analyze the analog output from the radio receiver DUT (device under test).

encoded test signal into the analyzer, and then play it through its analog generator output into an FM transmitter. The APx500 Series instruments also have a generous 32 megasample arbitrary waveform buffer—enough to hold more than three minutes of a multiplex stereo waveform. Finally, there are a range of input channel counts available: the 2-channel APx520 and 525 for stereo receivers; the 4-channel APx521 and 526, ideally suited to 4 channel car stereos; and the APx585 and 586 with channel counts of 8 and 16 respectively, which are great for multichannel surround sound.

This technote starts by reviewing the multiplex encoding technique that enables FM stereo broadcasting. Next we'll



Figure 1. FM radio test setup, with APx526, transmitter, and car stereo.

APx500 Series audio analyzers have some features that make them an excellent choice for testing the audio quality of an FM receiver. First, they support arbitrary waveform generation with sample rates of up to 192 kHz. This enables us to load a stereo multiplexed and RDS

explore the details of the Radio Data System (RDS). Then we'll demonstrate the APx MPX-RDS FM Radio Utility, which creates the multiplex and RDS encoded generator waveforms that we'll be using for our tests. And finally, we'll hook it all up and make audio measurements.

## Overview of FM Broadcasting

Frequency modulation (FM) was invented in 1933 by Edwin H. Armstrong, one of the founding fathers of radio technology. FM is a technique whereby a baseband message signal  $m(t)$  varies or modulates the frequency of a carrier wave. In broadcasting, FM is used to provide high-fidelity sound over broadcast radio. In this case, the “message” signal is music and speech, and the carrier wave is at a radio frequency within the VHF radio band, usually 87.5 to 108.0 MHz.

### Multiplex Stereo

FM radio was first used for monaural broadcasting in the 1940s, and FM stereo was introduced in the 1960s. One of the key requirements for stereo FM broadcasting was to maintain backward compatibility with the large existing base of monophonic FM receivers. This goal was achieved by using a clever scheme to multiplex the stereo signal channels as follows:

The left (L) and right (R) audio signals are first low-pass filtered at 15 kHz, and then the sum (L+R) and difference (L-R) signals of the two stereo channels are formed. The (L+R) signal is broadcast in the lower portion of the baseband spectrum (0 to 15 kHz), such that a monophonic receiver correctly receives the signal as a monaural transmission. The (L-R) difference signal is then amplitude modulated onto a suppressed 38 kHz subcarrier in the 23 to 53 kHz region of the baseband spectrum. A 19 kHz pilot tone is added to the multiplexed signal (one half the frequency of the 38 kHz subcarrier and with a precisely defined phase relationship to it). This pilot tone is used by FM receivers to detect a stereo transmission and to reconstruct the stereo signals from the multiplexed signal.

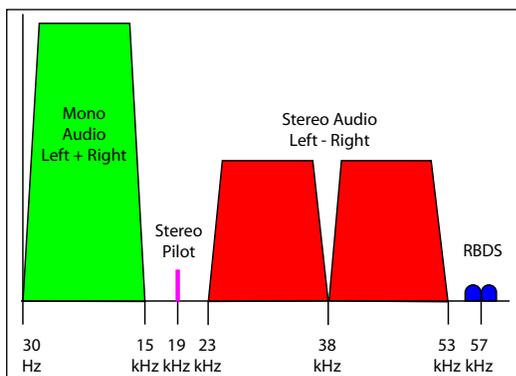


Figure 2. Baseband spectrum of a multiplex signal.

The multiplex signal shown in Figure 2 also contains a Radio Data System (RDS) signal. RDS is a communications protocol for sending small amounts of digital information in a conventional analog FM radio broadcast. It will be described in detail in the next section.

To improve the signal to noise ratio, it is a common practice to apply a pre-emphasis filter to the audio signals before breaking them into L+R and L-R components, to boost the higher frequency portion of the signal. The pre-emphasis filter has the high pass characteristic of a simple RC filter circuit (Figure 3). The amount of pre-emphasis is defined by the time constant of the RC circuit. In North America, a 75  $\mu$ s time constant is used. In the rest of the world, 50  $\mu$ s is used.

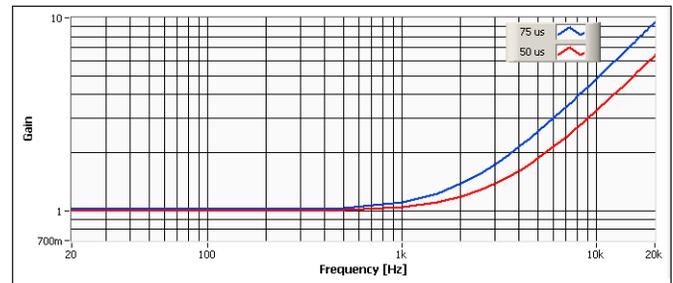


Figure 3. Pre-emphasis filters (50 & 75  $\mu$ s).

FM receivers incorporate a reciprocal de-emphasis filter, which removes the effect of the pre-emphasis. This restores the message signal to have a flat frequency response after transmission. The trade-off for using pre-emphasis and de-emphasis is that high frequency headroom is reduced.

### Radio Data System (RDS)

The Radio Data System (RDS) is a communications protocol for sending small amounts of digital information within a conventional analog FM radio broadcast. Typically, the digital information transmitted using the RDS protocol consists of short text strings such as the FM radio station’s call sign, song titles, artist names, etc., that appear on an RDS capable FM receiver. Including RDS in our test signals isn’t required. But since it’s encoded as part of the audio signal, using it better duplicates real-world conditions. It also lets us verify that the transmitter is transmitting it and the receiver is decoding it properly.

To add an RDS message to an FM stereo broadcast signal, an RDS encoder is used. The digital message is

first converted to analog. This analog message waveform is used to modulate a 57 kHz subcarrier (the second harmonic of the 19 kHz pilot tone), and then it is summed with the rest of the multiplex stereo signal. The RDS data bit rate, 1187.5 bits per second, is quite low. Therefore, RDS is only suitable for sending small amounts of text (or other data) that get updated with a time frame in the order of seconds. A decoder in the FM receiver is used to decode the RDS message, usually so that the text can be displayed.

The scheme used to encode the RDS data is illustrated in Figure 4. The bit rate is 1187.5 bits per second, which is 1/48th of the 57 kHz subcarrier frequency. The RDS message (a) first passes through a differential encoder (the equivalent of a logical exclusive OR) (b). It is then converted from non-return-to-zero (NRZ) coding to pulses (c), and then to a series of bi-phase symbols, to minimize the power of the data signal near the 57 kHz subcarrier

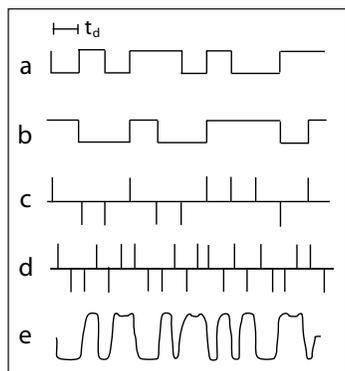


Figure 4. RDS waveforms.

(d). The bi-phase symbols are then filtered with a data-channel spectrum shaping filter to achieve the required band-limited spectrum (e). Finally, the filtered data waveform is used to modulate the 57 kHz subcarrier frequency. The waveform of the resulting modulated signal is seen in Figure 8.

## Generating MPX Encoded Signals with the APx MPX-RDS FM Utility

Audio Precision’s APx MPX-RDS FM Utility was developed to aid in testing receivers with RDS. This utility can create a file containing a multiplexed and RDS encoded waveform of stereo sine waves, and upload it to the APx500 measurement software.

It allows us to specify the frequency and amplitude of the sine wave on each channel, and the phase relationship between them. We can also add any RDS message text in the form of an eight character Program Service (PS) name, and a Type 2A Radio Text message of up to 64 characters. In addition, we can specify the amplitudes of the pilot tone and the RDS signal, the level of pre-emphasis (choices are none, 75  $\mu$ s and 50  $\mu$ s), and the name of the .wav file.

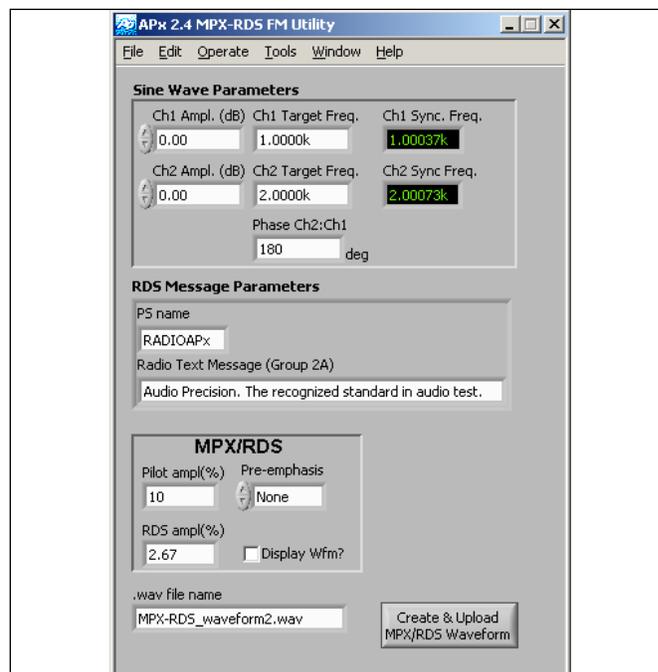


Figure 5. The APx MPX-RDS FM Utility.

The APx MPX-RDS FM Utility is available for version 2.4 or later of the APx500 measurement software. It is available on the APx Resources disc and can also be downloaded from ap.com. Note that the utility is version specific. Therefore, we need to make sure that the version of the utility matches our version of the APx500 software.

To use the utility, unzip the install package and run the setup file. The installer will install the utility in the Program Files folder on our PC. It will also place a shortcut in the APx start menu folder.

### Why the odd sample rate of 152 kHz?

To reproduce the RDS message that extends to almost 60 kHz, a sample rate of at least 120 kHz must be used. The APx MPX-RDS utility uses a sample rate of 152 kHz, because this frequency is an integer multiple of both the RDS bit rate, and the pilot tone frequency. This avoids any re-sampling that would be needed with a more conventional audio sample rate like 192 kHz. This unusual sample rate is no problem for the APx family, which can generate signals at almost any sample rate up to 192 kHz.

Why only 16 bits? A bit depth of 16 bits provides a dynamic range of about 94 dB. This is more than adequate for testing FM radio.

The utility user interface is shown in Figure 5. The white boxes containing numbers or text are controls that can be used to set the sine wave, RDS message and MPX/RDS parameters. To construct a stereo sine wave, use the Sine Wave parameter controls to specify the amplitude and target frequency of each channel, and the phase of channel 2 relative to channel 1. The amplitude controls are in dB relative to nominal full scale. A number greater than 0.0 dB can not be entered. Also, target frequencies greater than 15 kHz can not be entered, because a multiplex encoded stereo signal is low-pass filtered at 15 kHz.

Note the two boxes labeled Ch1 Sync Freq and Ch2 Sync Freq. These are indicators that show the frequencies actually being generated in the .wav file. Why are the actual frequencies different from the target frequencies selected? This is a result of how the program is designed. It automatically adjusts the frequencies such that the resulting waveforms are synchronous with the RDS message; i.e., the lower frequency is changed to the nearest frequency for which an integer number of cycles fit exactly into the period of the RDS message. The upper frequency is then changed to the nearest frequency that is an integer multiple of the adjusted lower frequency. This assures that when the .wav file in the APx analyzer’s buffer is looped, there is no discontinuity between the end and the beginning that would cause a glitch.

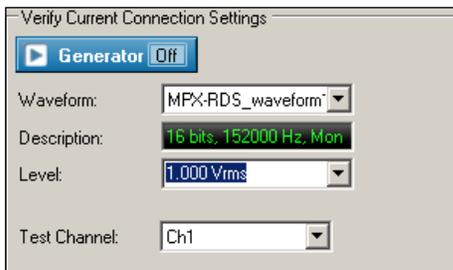


Figure 6. MPX/RDS encoded .wav file uploaded to the Signal Path Setup.

Controls to adjust the 19 kHz pilot tone and RDS signal levels are located in the box labeled MDX/RDS. In most situations, the default settings of 10% and 2.67% respectively work well. However, when creating .wav files with high frequency test signals at high amplitudes, it may be necessary to increase the levels to ensure that the pilot tone and RDS data can be resolved by the FM radio. The high frequency pre-emphasis applied to the FM signal exacerbates the problem further. Pilot tone may be increased up to 70%, and RDS up to 30%. However, it is preferable to leave these at their defaults and reduce the audio level instead if possible.

By default, the utility populates the .wav file name control with the file name “MPX-RDS\_waveformN.wav”, where N is an integer that is incremented each time a waveform is created. We can choose any filename by replacing the default with a file name of our choice.

Once the *Create & Upload MPX/RDS Waveform* button is clicked, the waveform is uploaded to the current Signal Path and Measurement in the APx software (Figure 6).

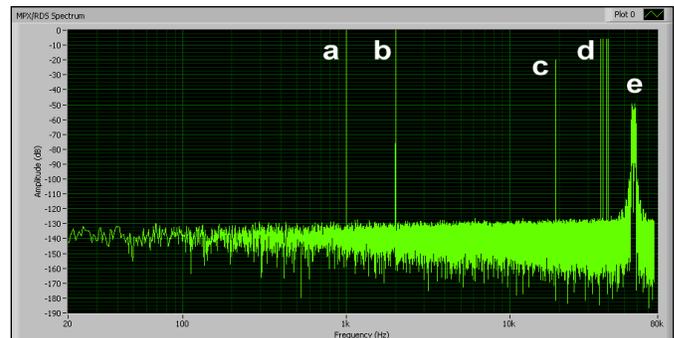


Figure 7. MPX/RDS Signal Preview window.

If the *Display Wfm?* button in the utility is clicked *on* before creating the waveform, the utility brings up a Signal Preview window as shown in Figure 7. This window has tabs which allow us to preview the waveforms and spectra of the original sine wave signals, the multiplex signal, the RDS signal, and finally the complete composite multiplex signal with RDS. The spectrum shown in Figure 7 is for the default settings of a 1 kHz tone on the left channel and a 2 kHz tone on the right channel. Note the signals at 1 kHz (a) and 2 kHz (b) in the baseband (L+R), and the corresponding L-R components that show up at  $38 \pm 1$  kHz and  $38 \pm 2$  kHz (d), which are 6 dB lower than the L+R components. We can also see the 19 kHz pilot tone at -20 dB (c), and the RDS message signal modulating the 57 kHz suppressed carrier (e).

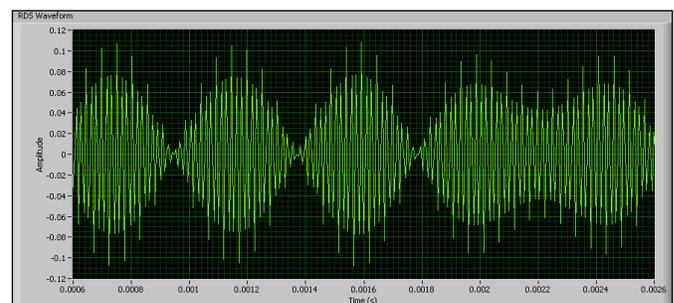


Figure 8. RDS signal waveform in the Signal Preview Window.

Figure 8 shows a portion of the RDS message signal waveform. Don’t worry about the spikes on the signal—

they're artifacts of the digital signal processing and will be eliminated when the file is output through the analog generator's DAC.

Using the Signal Preview window can be instructive. For example, consider a stereo signal with equal amplitude but out-of-phase 1 kHz sine waves. The spectrum of that multiplex signal is shown in Figure 9.

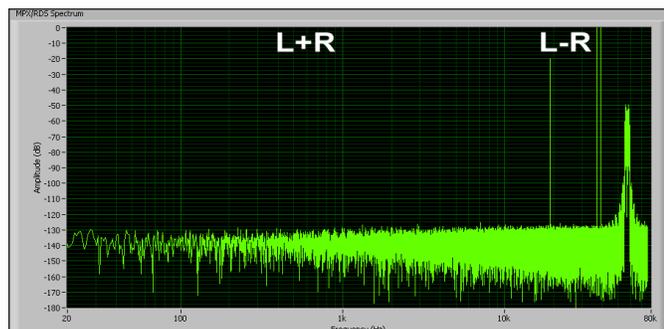


Figure 9. Spectrum of multiplex encoded inverted sine waves at 1 kHz

Notice the absence of a 1 kHz baseband component. In this case, since the left and right channels are identical but out of phase, the L+R signal is zero. Contrast this with Figure 10, the equivalent spectrum when the two channels are in phase. In this case the L-R component is zero, resulting in no modulation components around 38 kHz.

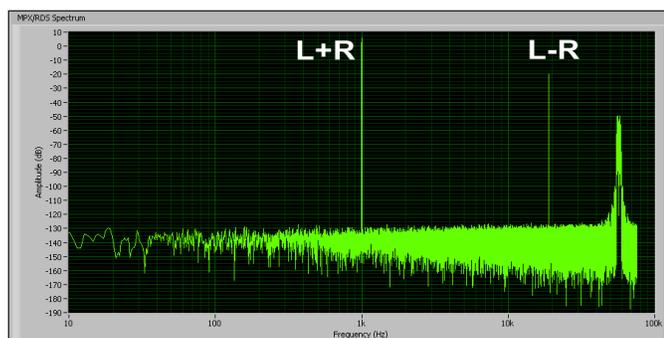


Figure 10. Spectrum of multiplex encoded in phase sine waves at 1 kHz.

## Testing Procedures

To test an FM receiver, we will need a small FM transmitter or exciter (exciters are small transmitters that typically are used to drive an RF power amplifier to create a more powerful signal). The transmitter takes the monaural or multiplexed stereo signal (with or without RDS) and modulates an RF frequency within the FM band.

## Transmitter Selection

FM transmitters are available from various vendors, with solutions varying from inexpensive do-it-yourself kits to professional grade broadcast equipment. For this technote, we used a small 2 – 20 Watt FM exciter (“A” in the chart) with a list price of approximately \$2,600 USD. Its specs, and those of two other exciters from well established manufacturers, are listed for comparison.

XMTR	THD+N (75 kHz dev)	S/N Ratio (75 kHz dev)	Crosstalk (30 Hz – 15 kHz)	Freq Response
A	0.25 % (“distortion”)	70 dB	not given	40 Hz – 15 kHz +/-0.5dB
B	0.025 %	75 dB	60 dB	30 Hz – 15 kHz +/-0.1dB
C	0.005%	85 dB A-WTD	80 dB	10 Hz - 15 kHz +/-0.1dB

Table 1. Transmitter specification comparison.

Keep in mind that the audio quality of the transmitter must be better than the receiver we are testing, or we’ll be measuring the transmitter’s limitations and not the receiver’s. When comparing transmitter specs, note that some companies may be more conservative in their numbers than others, and that testing methodologies can differ. Sometimes the testing conditions are not stated, which makes comparison difficult.

We can use exactly the same test procedure to test the quality of a transmitter instead of a receiver. In this case we’d want the highest quality receiver possible. But in our test set up, we use minimal RF power (about 2 watts) and a direct shielded connection. Using higher power levels and an antenna would not be permitted in most environments due to the RF interference that would be created. For real-world transmitter testing where the stimulus must be extremely brief, our High Speed Tester software (HST) combined with our 2700 Series analyzers is ideal.

## Test Hook-up

Figure 11 shows a block diagram illustrating an FM receiver test. Note that only one generator channel of the APx instrument is connected to the transmitter, because the multiplex waveform already includes both the left and right stereo channels. From the transmitter, we feed the signal to the receiver via a direct connection to minimize outside interference, and to reduce spurious radiation from the transmitter. Our main RF output is an N connector, so we use an N to BNC adaptor, with a 50 Ω inline

BNC terminator, to provide an appropriate load for the transmitter. A 50 Ω BNC cable adapted to the receiver at one end completes the RF connection. We tune both the transmitter and receiver to the same frequency—one that doesn't interfere with a local broadcast station. Now, we complete the loop by taking the audio outputs of the radio receiver and connecting them to the APx analyzer inputs.

In Signal Path Setup in the APx500, set the output configuration to analog unbalanced with one channel active. Set the input configuration as needed for the receiver outputs being tested (analog unbalanced for preamp or tuner outputs, or analog balanced for speaker terminals or professional FM monitor receivers). Speaker outputs must have the proper dummy loads attached.

Utility. This way, the audio can be lowered, but the FM pilot and the RDS signal that are also created by the utility will not get attenuated.

The transmitter RF output must also be adjusted to provide sufficient level for full FM quieting, yet not too high as to overload the receiver's front end. Since the transmitter is directly connected to the receiver, a minimal RF level is needed. Many receivers have an FM stereo indicator, an RDS indicator, or a signal strength meter to help determine sufficient signal strength.

### Making Measurements

With the hookups completed, the generator and transmitter at the right level, and the receiver tuned to the

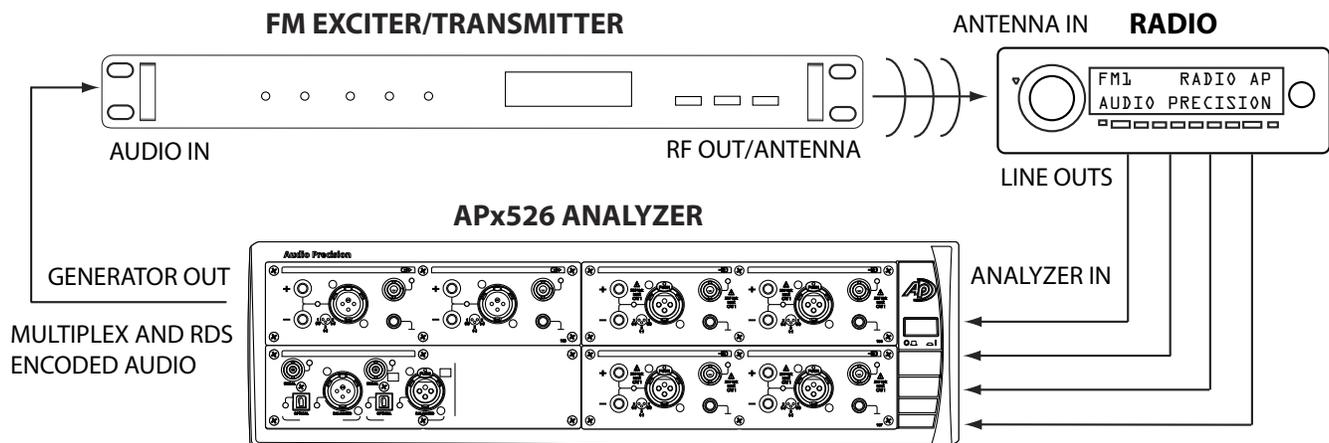


Figure 11. Block diagram illustrating an FM receiver test with an APx500 series audio analyzer.

### Level Calibration

It is important to calibrate the APx analyzer's analog generator output level to full modulation of the transmitter. We set the transmitter to display deviation on its display or meter. Now, using the APx MPX-RDS RF Utility, we create a test signal with 1 kHz at 0 dB on both channels, and upload it to the APx generator. Then we turn on the generator, and adjust the APx analog output level and/or the transmitter input level until we get a reading of 100% modulation ( $\pm 75$  kHz deviation) on the transmitter. Once calibrated, we go to Reference Levels in the APx500 measurement software and set dB<sub>R</sub>G to equal the current signal output level.

From this point on, we will not alter the APx analyzer's output level nor the transmitter's input level. Any reduction in audio level will be made using the APx MPX-RDS RF

correct frequency, it's now time to make measurements. We generate the default test signal from the APx MPX-RDS FM Utility—1 kHz on the left channel, and 2 kHz on the right, both at full level—and load it into the APx generator. If an RDS message is being received and decoded by the receiver, it should be visible on the receiver's display (Figure 12).



Figure 12. Radio receiver displaying RDS text.

The stereo signal can now be measured on the APx analyzer. Note the stereo separation of only 40 dB in Figure 13. The FM transmitter claims to have “up to 50 dB

of stereo separation,” which isn’t a useful specification, as “up to 50 dB” could mean only 40 dB. So, we can’t conclude if this crosstalk is from the transmitter or receiver or both. If we want to make accurate crosstalk/separation measurements, we’ll need to use a better transmitter.

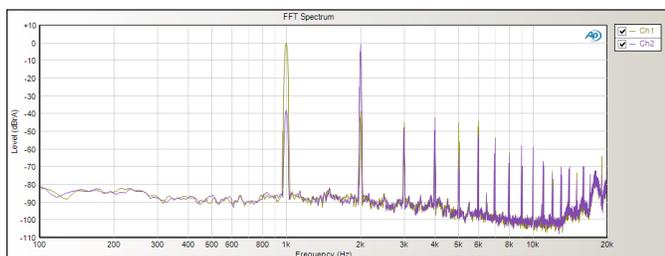


Figure 13. FFT of sine wave test; left channel 1 kHz, right channel 2 kHz.

Be careful of this crosstalk when doing audio measurements. For example, if we try to measure the THD +N of one of the stereo channels in Figure 13, the result could be higher or lower than if a monaural signal is measured, due to the effect of in or out-of-phase crosstalk from the other channel.

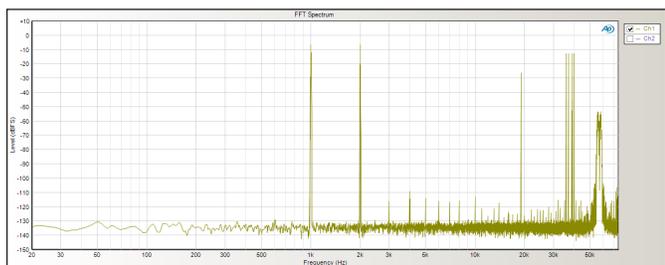


Figure 14. FFT of the MPX/RDS encoded .wav file measured using digital loopback.

We can use the APx500 analyzer to look at the spectrum of the MPX/RDS encoded .wav file. Simply add another Signal Path to the project, configure the output for one of the digital types (e.g., Digital Unbalanced), and set the Input Configuration to Loopback. Then, add a Signal Analyzer measurement to the signal path, run the measurement, and select the FFT Spectrum (Figure 14).

The APx MPX-RDS FM utility can be used to generate sine waves of any frequency and amplitude. Many basic audio tests can be performed with sine waves. For a greater variety of FM radio test signals, versions of most of the signals included on the APx-CD1 disc are available as multiplexed and RDS encoded stereo .wav files. This collection of 41 encoded signals is contained on the APx

Resources disc. It includes a variety of frequency sweeps, a level sweep, a multitone, and other useful signals.

Audio tests that are appropriate for FM receivers are similar to those for other devices. The first place to start would be measuring the “big six” (level, frequency response, THD+N, phase, crosstalk, and signal-to-noise ratio). The only requirement is that the signal be multiplex encoded, either by our utility, or by using pre-encoded files.

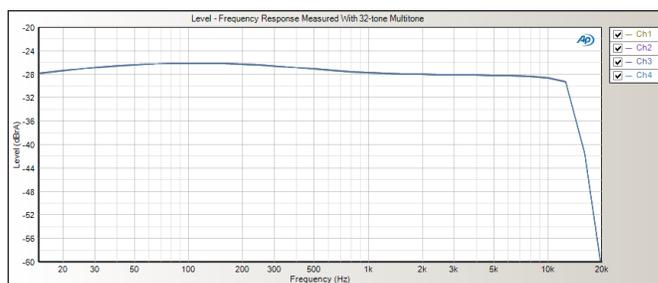


Figure 15. Frequency response measurement.

Figure 15 shows a frequency response measurement using a 32 tone multi-tone stimulus signal. Note the sharp high end roll-off due to the 19 kHz multiplex filter present on all FM receivers.

## Related Downloads:

**Technote 104: Introduction to the Six Basic Audio Measurements**

<http://ap.com/display/file/8>

## Additional Resources:

**RDBS standard (US only)**

<http://www.nrscstandards.org/>

**RDS Standard (rest of the world)**

<http://www.iec.ch/>



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