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# PUT YOUR MODULES AND END-USE DEVICES TO THE FM TEST

FM is finding new life in a variety of consumer devices. Yet these products will need to pass a battery of key tests before they see success on the market.

**WITH EACH NEW** generation of high-end mobility handheld devices, we get new capabilities. It started with digital cameras and continued with Bluetooth and GPS. Now, FM has become a standard feature.

Unlike Bluetooth, GPS, and 3G cellular, wideband FM has been around since at least the early 1930s when Edwin Armstrong first suggested it as a way to broadcast speech and music. In today's handheld devices, FM is primarily included as a way to listen to FM broadcasts. But using FM transmission, these devices also have a way to broadcast internally stored digitized music to a nearby FM receiver, such as an automobile's entertainment system.

FM is included in high-end mobility devices. As a result, users may be discriminating about how well a device's FM feature works. This impacts design as well as manufacturing, making thorough development and production testing an impending necessity.

Designers need to know how to test FM. But more importantly, they need to know how to do it thoroughly enough, fast enough, and at a low-enough cost so that the device's cost is minimally impacted while its quality and user satisfaction are kept high.

## WHAT IS FM?

In frequency modulation, the frequency of an RF signal is varied in accordance with the changes in amplitude of an analog signal. In its simplest manifestation, designers can produce an FM signal by modulating a voltage-controlled oscillator (VCO) with a modulating signal of varying voltage.

When the modulating signal is 0 V, the VCO carrier is centered. When the signal voltage varies, the instantaneous frequency of the VCO output will vary above and below that center frequency by the relationship:

$$f(t) = f_c + K_{VCO} * m_s(t)$$

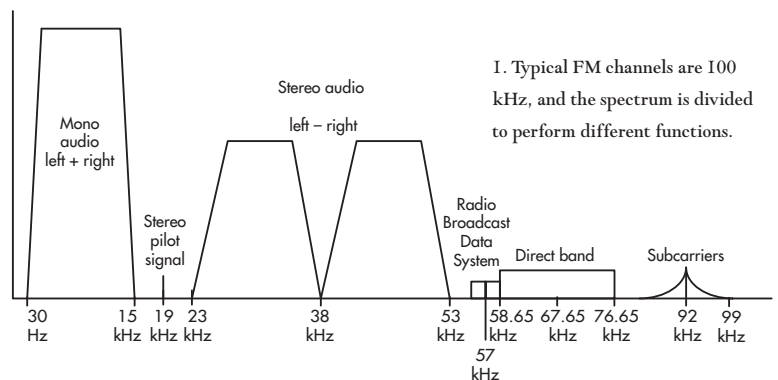
where  $f(t)$  is the instantaneous frequency,  $f_c$  is the center frequency,  $K_{VCO}$  is the VCO's voltage-to-frequency gain (given in Hz/V), and the product  $K_{VCO} * m_s(t)$  is the instantaneous frequency deviation.

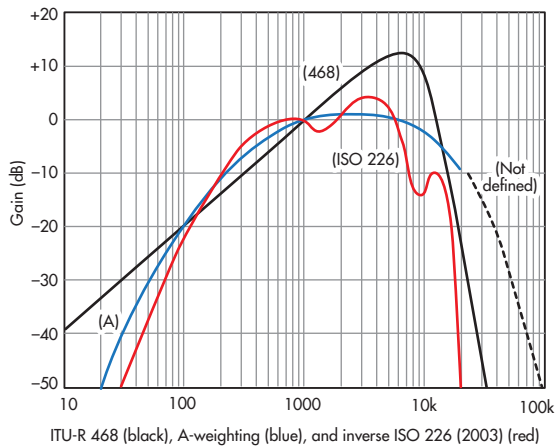
Demodulation of an FM signal is a two-step process of differentiation followed by envelope detection. One aspect of differentiation, though, is the amplification of high-frequency noise and consequent degradation of signal-to-noise ratio.

To balance that, FM signals use a high-pass transfer function called pre-emphasis that amplifies high-frequency content, and FM receivers apply a low-pass compensation transfer function called de-emphasis that attenuates both the amplified high-frequency content and the high-frequency noise.

## IN THE ABSENCE OF A STANDARD

Though there is no official industry standard for wideband FM signal specifications, there are certain common denominators. For example, all countries tend





2. Weighting filters, such as ITU-R 468, are used to condition the noise in a THD+N test so it more resembles real-world audio output conditions.

to use VHF radio spectra, typically 87.5 to 108.0 MHz, although there are countries that use additional VHF bands.

Station bandwidth is typically 100 kHz with “center” frequencies either at successive odd (North America, South America, and the Caribbean) or even (some parts of Europe, Africa, and Greenland) 100-kHz increments. On an individual channel basis, though, there is more uniformity (*Fig. 1*).

Monaural broadcast (combined right and left subchannel audio) takes up about 15 kHz. Monaural FM receivers (e.g., receivers that combine right and left audio for reproduction by a single speaker) demodulate this portion of the FM channel.

For stereophonic receivers, a pilot tone transmitted at 19 kHz indicates a stereo broadcast and is used in doubler and tripler circuits to establish 38-kHz (for stereo) and 57-kHz (for RDS) local oscillator signals. Here, the receiver adds and subtracts the left + right subchannel and left – right subchannel to produce discrete L and R audio that can be reproduced by separate, spatially separated left and right speakers.

RDS, a digital radio data service (57 kHz), can carry narrow-bandwidth data signals (sent at 1187.5 bits/s). The remainder is used for direct band and other subcarrier services.

The licensing authorities in each country establish the acceptable characteristics for frequency stability, spectral purity, and so on for the transmitted signals. De facto reception standards have emerged for common FM devices.

But, by and large, the characteristics to be tested during design and manufacturing are not prescribed.

Instead, designers have some choices about where they want to set their design and manufacturing limits. Consequently, any testing method will need to accommodate a reasonable range of values to provide broadly applicable support.

## A CONSENSUS ON FM RECEIVER TESTS

The FM receiver’s jobs include detecting the FM broadcast signals, selecting between FM broadcast channels, accurately demodulating the RF signals, maintaining sufficient isolation between the L and R channels (minimal crosstalk), and accurately reproducing the balance between the L and R channels.

FM is an analog transfer function between audio and RF. Testing it requires both RF and audio tests. The modules and end-use devices that will make up the bulk of testing now and in the near future will use both analog and digitized audio.

Module testing is easier than end-use device testing because control, stimulus, and response are more direct. In an end-use device, the tester must work through an intermediary (the device’s CPU or control processor), and the analog output must be accurately digitized for analysis by the PC.

Those, however, are implementation details. The fundamental tests in each case—received signal strength indication (RSSI), signal-to-noise ratio (SNR), RDS sensitivity/block error rate, receiver (RX) selectivity, and AM suppression—are largely the same.

RSSI is the relative measure of incoming RF signal strength. Testing RSSI involves injecting an RF signal of known power and seeing whether the RSSI returns an expected indication-level result within design tolerances.

How sensitive is the FM receiver? To find out, use a 30% or 50% audio deviation and measure the ratio of signal + noise/noise. As the signal strength is lowered, look for the point where the ratio drops below some value (e.g., 26 dB for stereo). The lower the signal strength that still provides a minimum ratio, the higher the sensitivity of the receiver.

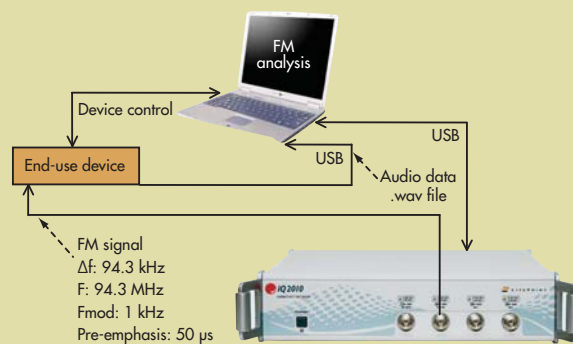
How accurate is the receiver’s data demodulation? To find out, send 26-bit data blocks to the receiver and compare the decoded result. As the signal level is lowered, note blocks with non-correctable errors. When the number exceeds 5% of those sent, that power level establishes the RDS sensitivity limit (e.g., the signal level at which errors exceed 5%).

An adequately sensitive receiver is only a partial solution. The FM broadcast band contains a group of stations spread across the band in any locality. The FM

## MULTI-RADIO TESTER APPLIED TO FM TESTING

**A LITEPOINT IQ2010** Multicom tester can be put into FM test service. The tester's vector signal generator (VSG) can provide the modulated FM signals used for the RX tests described (see the figure). The tester's vector signal analyzer (VSA) can likewise be used to perform FM TX testing.

The system's FM test software program will support up to 12 discrete FM signal frequencies with selectable power and channel (L or R). By expeditious choice of frequency assignments and signal analyses, a single test involving multiple frequencies will yield measurements for total harmonic distortion plus noise (THD+N), third-order intercept point (IP3), pilot suppression, channel flatness, stereo balance, and right/left channel crosstalk.



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receiver must be able to select among those stations to approach ideal single-signal reception. Strong adjacent stations, particularly in the presence of a weaker selected signal, can produce sideband signal energy in the latter's channel and result in de-sensitization.

Designers cannot achieve selectivity that is perfect. But through careful design, it's possible to limit the extent of unintended signal energy in the selected signal's channel. Testing for selectivity would involve injecting discrete FM signals of different carrier frequencies and different signal levels so weak-signal selection can be simulated with a strong adjacent-channel signal.

By setting the in-channel signal level to the lowest level just before the SNR begins to degrade, and by raising the level of the out-of-channel signal to a point where the SNR begins to degrade, designers can find the minimum out-of-channel signal level that causes SNR to fall away.

In the absence of a standard, designers should design for optimal selectivity based on design-cost budget and end-user expectations. That should determine the minimum power level of the out-of-channel signal before SNR degradation occurs.

In AM suppression testing, designers want to measure the FM receiver's rejection of amplitude modulation of the signal. An FM signal can become amplitude modulated during fading, by transmitter distortion, and by other conditions.

To test the suppression, supply the device with an FM signal having known AM modulation (say, 30%) so the device receives a signal with both FM and AM characteristics. By measuring the voltage of the device's audio output, and repeating the test without AM, designers can measure the output level ratio, which is a measure of suppression.

## AUDIO TESTS IN THE DESIGN PHASE

FM receivers are meant to deliver sound. The purity of that sound is directly related to the degree to which unintended audio-frequency signal components are reduced. For example, a modulating tone of 1 kHz that is a pure sine wave and is passed through a perfectly linear audio chain would produce a 1-kHz end tone.

To the extent that the signal sine wave is not perfect, and the audio chain not perfectly linear, there will be energy related to the harmonics of that modulating tone (e.g., 2 kHz, 3 kHz, etc.). The ratio of the harmonic energy compared to the fundamental provides a measure of harmonic distortion.

There are essentially two measures: total harmonic distortion (THD) and total harmonic distortion plus noise (THD+N, also called SINAD). THD+N is considered a better representation of real-world conditions because it includes noise in the result, and people do hear noise in addition to signal content.

But harmonically related distortion is not the only type that can impact the end signal. Intermodulation can cause non-harmonically related signal products where, for example, two closely spaced tones of equal amplitude will, because of nonlinearity, mix to produce sum and difference signal components.

A measure of this intermodulation distortion (IMD) will provide an additional measure of end-signal distortion. A special case of IMD measurement, where designers consider only the distortion caused by third-order products (e.g.,  $2f_1 - f_2$  and  $2f_2 - f_1$ ), is called a third-order intercept point, or IP3.

Testing for THD uses a high-purity tone (typically 1 kHz) and adjusts the system for 100% deviation (e.g., a full audio-signal modulation). The output is then examined for the presence of the applied and other frequencies.

THD is defined as the rms voltage of the harmonics compared to that of the fundamental tone. There is no specification for maximum allowed THD. Different circuit designs will yield different THD values. This measure provides a way to compare the actual value to the design target value.

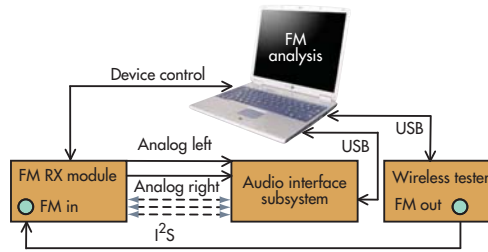
THD+N is considered a more telling measure of design performance because it measures everything on the output signal rather than just individual harmonics. It is the sum of rms signal components (excluding the fundamental) over a specific bandwidth.

Noise shaping using “weighting filters” such as ITU-R 468 is often used to provide more correlation with what is actually “heard” (Fig. 2). For example, noise that is out of the most sensitive hearing frequency region is weighted lower.

In an ideal case, modulating signals of equal amplitude applied to the left and right channels should result in an FM receiver producing left- and right-channel audio signals with equal power and of a power level consistent with design targets. Signal level should also be high enough so noise added by the system does not affect what is heard.

Typically, high-quality audio bandwidth is 20 Hz to 20 kHz. Realistically, the audio bandwidth of an FM receiver will be somewhat narrower (say, 30 Hz to 15 kHz). By varying the modulation signal’s frequency from, say, 30 Hz to 15 kHz and keeping the power level constant, designers can find the lower and upper frequency limits where the output rolls off by 3 dB.

Crosstalk in a stereophonic system relates to the presence of one channel’s signal on the other channel. As described earlier, FM stereo is not produced by transmitting separate right- and left-channel signals but,



3. Module testing uses standard stimulus signals and an interface to convert the analog or I<sup>2</sup>S outputs into standardized files (e.g., .wav files) for analysis.

rather, by a sum and difference of L + R and L – R signals.

That process can result in some excess L signal on the R channel and vice versa. At later stages of the receiver, some L signal may be induced onto an R channel path and vice versa. In any case, designers want to ensure that minimal excess signal from one channel is present on the other.

Designers can measure crosstalk by placing a single-tone signal on one channel while keeping the other channel’s modulation input at zero. If the signal is applied to the left channel, designers sample both channels and compare the output signal level of the opposite channel to that of the intended channel. That provides a crosstalk ratio. Designers can make this test at different frequencies to see to what extent any crosstalk is frequency related.

The 19-kHz pilot signal tells an FM receiver that a stereo-modulated signal is being received. It also provides the signal source for the 38-kHz and 57-kHz signals. This 19-kHz tone is in the audible range of the human ear, but above the transmitted audio bandwidth  $((57 \text{ kHz} - 38 \text{ kHz}) / 2)$ , so the FM receiver will filter the 19-kHz tone. The remaining finite signal must be verified to be below some threshold because it would otherwise distract from the audio being transmitted.

## TRANSMITTER CHARACTERISTICS

The FM subsystems in today’s

advanced wireless devices are more than FM receivers. FM transmitters are also included primarily as a means for sending stored music content to another FM receiver. In a car, for example, a device with MP3 music content and FM TX capability could send that content wirelessly to the car’s entertainment system without the need for any cables or connectors.

The key is to ensure that the FM TX function will provide a signal that is stable and minimally distorted. Also, the FM TX function may be required to do more than transfer audio between devices; it may be used to transfer GPS information to the car radio as well as simple (RDS) data messages. As with the FM receiver, the FM transmitter (TX) requires two kinds of tests: RF and audio quality.

Designers perform RF tests to verify TX power, the bandwidth its signal occupies, the quality of the audio modulation, its frequency accuracy and stability, and its RDS digital functionality.

Designers have to ensure that the power design targets have been met. The power range must be verified. The most critical parameter is maximum power because the licensing authorities do specify such, and it is different in different countries.

To test this, designers must verify that the device produces a signal of power level consistent with the regulatory maximum threshold (typically 0 to +5 dBm). In testing the device, it should be instructed to transmit at its maximum power level, and that signal must be accurately measured and compared to the specified maximum. In some cases, during this test, the device may be calibrated.

To determine the occupied bandwidth, again using maximum power (for worst-case results), the signal

is captured and analyzed in the frequency domain to affirm that it is confined to the channel spectrum. The test should look well beyond the 100-kHz channel bandwidth to ensure that 99% of the transmitted signal power is confined inside the intended channel.

As expected, successful modulation-accuracy testing hinges on a very accurate and stable signal source. The transmitted signal can contain audio, pilot, and RDS data. The deviation contributions from all of them will affect total frequency deviation. So, designers must apply a known audio signal, a preset deviation for the 19-kHz pilot tone, and a preset deviation for the RDS modulated data and then measure and verify the deviation each contributes.

The FM TX will, in fact, emulate an FM broadcast, albeit at much lower power. The FM TX, however, will not be held to the tight frequency tolerances of an FM broadcast station. Instead, the frequency should be tested to verify that it is within the pull-in range of a typical FM receiver.

Unlike in FM RX, where we need to check the block error rate, we just need to ensure that a data

signal produces the correct modulation deviation to check RDS and that SNR is high enough to allow dependable demodulation.

### AUDIO TESTS

Unlike in RX testing, where the device's audio output is used to verify various audio-related tests, TX testing relies upon the test instrument to provide those measurements based on the device's transmitted signal. Essentially, then, designers must use an audio source signal with known characteristics and measure how well the FM TX device modulates that source.

The actual tests are like those done in RX. We have THD, THD+N, signal power and balance, bandwidth, and crosstalk. In RX testing, we assume the transmitted signal is near perfect and all distortions occur in the audio chain. But in TX testing, we assume that the modulating source is near perfect and all imperfections occur in the modulation and RF chains.

Just like an FM broadcast system, the FM TX device will apply pre-emphasis. It's important for the test system to have pre-emphasis setting so it can match it with the test instrument's de-emphasis to get accurate results.

### DESIGN VS. MANUFACTURING TESTING

The full testing regimen described is appropriate for development where design verification is the primary objective. Once a design is proven, the testing regimen can be scaled down because the designer is no longer verifying the design. Instead, designers are trying to detect manufacturing defects and cull out failed or substandard units.

Usually the difference between design and manufacturing testing is more one of degree than substance.

For example, in verification tests that should involve more steps, a manufacturing test could use fewer steps as long as they catch a component or manufacturing defect.

The objective in verification testing is to fully stimulate and accurately measure response to prove out the design. Time is not of the essence. Repeatability and accuracy are.

In manufacturing, the ideal objective is to catch every device with a component or manufacturing defect. Time and cost are critical. If some tests can be completed in parallel without compromising result accuracy, they should be done in parallel to save time and cost.

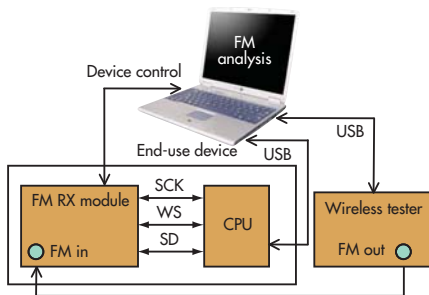
### TESTING AT THE FM BLOCK LEVEL

Modules are a key part of most multi-radio wireless devices. An FM block would typically have an FM signal input and produce either analog right- and left-channel audio outputs or integrated interchip sound (I<sup>2</sup>S) outputs (*Fig. 3*).

An interface subsystem would use the module's outputs and create digitized equivalents such as .wav files. These would provide the input data for the FM RX tests. Module inputs and outputs are basic and standard, so a test system as shown in *Figure 3* could be used to test any of them with no need for special module-specific software.

In an end-use device, FM is just a small sub-block. It is typically interfaced to the control processor (CPU) that controls the FM sub-block. The interface to the control processor is usually through an I<sup>2</sup>S interface or analog signals plus a control interface for changing FM frequency, for example (*Fig. 4*). Here, using the same tester, designers would input the same kinds of test signals.

However, the analog or I<sup>2</sup>S is not



4. For testing an end-use device, designers no longer need the interface subsystem. But, they may need to provide the CPU with device-specific software to produce the standardized digital output (e.g., .wav files) used for analysis.

available to be brought out to the FM analysis tool. Instead, designers would need to develop software that runs on the CPU that translates the digitized equivalents, such as .wav files. In other words, the interface subsystem is integral to the end-use device and would require device-specific software to create the analysis-required digital output.

The CPU would use its own analog-to-digital converter (ADC) to digitize the analog audio signals. Other than that, though, the testing would be identical. Designers would use the same FM input signals and analyze the digitized output data for the desired test metrics. Most modern devices feature a USB port that enables data to be transferred back to the measurement system. Alternatively, if the libraries are available to it, the CPU can perform the analysis itself.

### SUMMING IT UP

Despite the lack of an industry-standard specification for FM RX and TX, FM capabilities are being

added to wireless end-use devices, and they will have to be tested to verify that design targets have been met and that mass-produced devices are free of component or manufacturing defects. Commercially available multi-radio testers can be used for FM RX/TX test (*see "Multi-Radio Tester Applied To FM Testing," p. 50*).

FM testing is essentially a test of an analog transfer function. The input must be known to evaluate the measured results. Testing FM RX requires an RF and audio test. Most measurements are performed on an audio signal. Testing FM TX requires an RF test and audio stimulus, and most measurements

are performed on a demodulated RF signal, again using audio quality metrics.

The same types of tests are used for both design verification and manufacturing quality checking (*see the table*). The difference is in degree rather than substance. In manufacturing, where it is possible to perform some tests in parallel (e.g., concurrently) without compromising the results accuracy, designers should do so because it shortens test times and costs. There are some tests where the same stimulus can be used to measure many results. It's like getting something for free since no additional time is involved.



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