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UNDERSTANDING SPECTRUM ANALYZER CALIBRATION

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Abstract: Calibrating a Spectrum Analyzer usually involves a variety of measurements, with each requiring a suitable input signal. A typical procedure generally utilizes a number of signal generators together with other pieces of equipment to generate the signals and ensure their accuracy. This paper provides an overview of spectrum analyzer calibration with discussion of the most common calibration tests, their signal requirements, and approaches for meeting those requirements.

Introduction

Analysis of the calibration procedures for 15 models from 5 different manufacturers found approximately 80 different tests were described. Many of the tests were identical, except for their names – for example Display Linearity, Scale Fidelity and Log Conformance all tested the ability of the analyzer to accurately measure relative signal levels at a single frequency, using the same measurement technique. Allowing for this duplication, the majority of calibration procedures included a core of around 20 tests, listed below. It is generally considered that these are the tests that should be performed for a spectrum analyzer calibration to be adequate and sufficient.

Frequency Accuracy
Level Accuracy
Frequency Response
Attenuator Response
Display Linearity
Displayed Average Noise Level
Resolution Bandwidth Accuracy
Resolution Bandwidth Selectivity
Resolution Bandwidth Switching Accuracy
Sweep Time Accuracy
IF Image Response
Noise Sidebands
Residual FM
Residual & Spurious Responses
Harmonic Distortion
3rd order Intercept (TOI)
Tracking generator tests

As it is beyond the scope of this paper to consider all of the listed tests in great detail, an overview is presented for each test, with additional detail for the some of the more critical or difficult tests.

Spectrum Analyzer Architecture

The tests discussed in this paper apply to the typical swept tuned superhetrodyne spectrum analyzer. Figure 1 shows the simplified block diagram for this type of spectrum analyzer. Its architecture resembles that of an AM superhetrodyne receiver, in which a mixer is used to down-convert the input signal to a lower, intermediate frequency (IF) for processing. Most spectrum analyzers use two or three stages of down-conversion, but a single conversion is shown here for simplicity. Recently, real-time spectrum analyzer instruments have become available, employing a different architecture, where the input signal is digitized over a wide bandwidth and digital signal processing techniques are used to obtain frequency domain information. The calibration requirements of these real-time spectrum analyzers will not be discussed here.

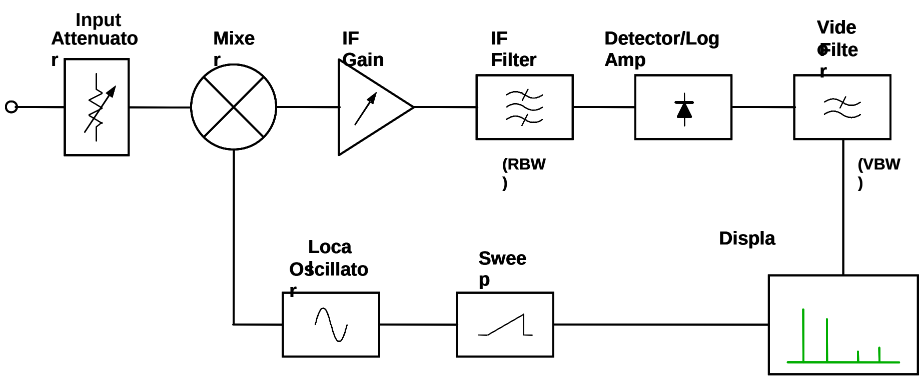

Figure 1. Simplified block diagram of a superhetrodyne spectrum analyzer

As figure 1 illustrates, a swept-tuned, superhetrodyne spectrum analyzer typically consists of the following components:

- An **RF input attenuator**, which reduces the amplitude of high-level input signals to prevent the mixer from being overloaded.

- A **mixer**, which combines the input and local oscillator frequencies to frequency-shift the input signal as the local oscillator sweeps, allowing a narrow band of input frequencies to pass through the IF gain amplifier and filter for measurement.

- A variable **IF gain** circuit, which amplifies the mixer output before passing it to the IF filter, filtering out the signals of interest. This gain is changed with reference level setting to allow the reference level at the top of the display to correspond to the required input signal level.

- An **IF filter,** which is a bandpass filter whose bandwidth is adjustable from the spectrum analyzer's front panel. This bandwidth, referred to as the resolution bandwidth, determines how well input signals with small frequency differences can be distinguished from each other.

- A **detector/log amplifier**, which responds to the IF signal level, performing a logarithmic conversion to obtain a display scaled in dB per division.

- A **video filter** which uses low-pass filtering to average and smooth the displayed trace.

- A **local oscillator**, which can be swept to generate the normal display or held constant in zero-span mode. With modern analyzers, which use frequency synthesizers as the local oscillator, the resolution of the synthesizer setting will influence the accuracy of both the display and the cursor frequency.

- A **sweep generator**, which controls the frequency of the local oscillator, and for older analog analyzers, also the refresh rate on the analyzer display. Modern analyzers generate the sweep by control of the frequency synthesizer used to generate the local oscillator frequency.

- A **display**, which shows the spectrum of the measured input signal. As the local oscillator sweeps, the spectrum analyzer digitizes the measured signal levels, storing them for subsequent display as a complete spectrum. (Older analyzers without digital storage used long-persistence CRT displays that displayed the spectrum trace as the sweep progressed.) Modern analyzers usually also offer a variety of marker, readout, and measurement functions which utilize the measurement data obtained during the sweep, often employing digital signal processing.

Test Descriptions and Signal Requirements

Frequency Accuracy

For a modern analyzer employing a frequency synthesiser for the local oscillator, the basic frequency accuracy of the analyzer depends on its frequency reference. This can be measured directly by testing the analyzer 10 MHz frequency reference output. Frequency display and frequency span accuracy are influenced by other factors, such as synthesizer resolution and divider performance, and are typically tested using signals obtained from calibrated frequency synthesiser instruments.

Level Accuracy

This test measures the absolute accuracy with which the analyzer will display a signal level. Analyzer specifications often quote absolute accuracy at a single, relatively low frequency. The test is typically performed with a signal of known level, obtained by measuring the output of a signal generator with a power sensor immediately before applying the signal to the analyzer, or by connecting the signal source via a power splitter to allow simultaneous level measurement with a power sensor.

Frequency Response

This test determines the frequency response or flatness of the analyzer, relative to its response at a reference frequency. The test is typically performed with a signal of known level at the frequencies required, obtained by measuring the output of a signal generator with a power sensor immediately before applying the signal to the analyzer, or by connecting the signal source via a power splitter to allow simultaneous level measurement with a power sensor.

Attenuator Response

This test checks the accuracy of the input attenuator steps. Analyzer performance is typically specified at the reference frequency used to specify frequency response accuracy, so this test is also performed at that frequency. Testing requires a signal source with known attenuation performance of sufficient accuracy at the reference frequency. Alternatively, a general purpose signal generator can be operated at a constant output level setting with external calibrated step attenuators.

Display Linearity

This test verifies the analyzer amplitude linearity over a wide dynamic range. Performance is a function of the analyzer IF circuits, which operate at a fixed frequency, and therefore only requires testing at a single frequency with fixed input attenuator and reference level settings. Testing requires a signal source with high-precision attenuation linearity as a reference standard. Alternatively, a general purpose signal generator can be operated at constant output level setting with external precision step attenuators as a reference standard.

Displayed Average Noise Level

This test measures the analyzer noise floor without an input signal and is performed with a 50 Ω terminator at the input. To reduce test time, the test is usually performed at a relatively high resolution bandwidth setting, with the result reported normalised to either 1 Hz or 10 Hz bandwidth, as most manufacturers usually specify analyzer noise floor at these narrow bandwidths.

Resolution Bandwidth Accuracy

This test measures the accuracy of the 3 dB bandwidth of the IF (resolution) bandwidth filters, and is repeated for each resolution bandwidth setting. The test is usually performed with an input signal of constant amplitude and frequency (typically 50 MHz or 100 MHz), varying the analyzer center frequency to determine the filter response.

Resolution Bandwidth Selectivity

This test measures the characteristic of the IF (resolution) bandwidth filters to ensure the cut-off is sufficiently steep to allow the analyzer to resolve any low level signals close in frequency to a high level signal. The test determines the 60 dB bandwidth, the result expressed as a the ratio between 3 dB and 60 dB bandwidths, known as the shape factor. Test method is identical to the resolution bandwidth accuracy test.

Resolution Bandwidth Switching Accuracy

This test evaluates any residual gain changes that may occur as the resolution bandwidth filter settings are changed. The test is usually performed with an input signal of constant amplitude and frequency, changing the analyzer resolution bandwidth setting with constant center frequency (typically 50 MHz or 100 MHz) and span settings to determine any variation in the displayed signal level.

Sweep Time Accuracy

In the zero span mode, the analyzer remains tuned to a fixed frequency and displays the time domain characteristics of the signal level much like an oscilloscope. This test determines the accuracy of the horizontal time axis, typically using an amplitude modulated signal such that a specific number of modulation rate cycles are displayed and the time/division can be determined.

IF Image Response

When the local oscillator and input signals are heterodyned (mixed) in the mixer, signals are generated at the sum and difference frequencies of the two signals and the IF filters select the desired combination (usually the sum frequency). However, if another signal were also present, at a much higher frequency such that it mixed with the local oscillator to produce a difference frequency equal to the IF center frequency, the analyzer would also respond to this unwanted signal, known as the IF image frequency. In practice, use of double or triple conversion techniques, harmonic mixers and pre-selectors complicate the situation, but IF image frequencies exist, and the analyzer responses at these frequencies is usually tested. This test requires signals of known amplitude over a wide range of frequencies.

Noise Sidebands

This test evaluates the ability of the analyzer to display a signal without adding its own close-in noise which would tend to broaden the skirts of the displayed response. Performance is determined by the phase noise of the analyzer local oscillator, and the test is often called phase noise. It requires a signal source of sufficiently low phase noise such that it does not significantly influence the measurement result. The test is usually performed at a single input frequency, and the noise sideband level is measured at a number of offset frequencies from the input frequency (usually referred to as the carrier frequency). Analyzer specifications may list performance in terms of dBc (level of the noise below the carrier), for specific resolution bandwidth settings, or in terms of dBc/Hz (level of the noise below the carrier, normalised to a 1 Hz bandwidth). Results are generally obtained in dBc directly from the analyzer display, and a number of correction factors must be applied to obtain a value in dBc/Hz. These are:

- 1 Hz BW Normalisation, subtract 10 log (BW in Hz) dB.
- Correction for Non Rectangular BW filter, subtract 10 log 1.2 dB.
- Correction for log amplifier compression of noise peaks and measurement of noise average rather than RMS, add 2.5 dB.
- Correction for Analyzer Noise Floor contribution at low Signal to Noise Ratio, 10 dB SNR gives 0.4 dB error, 3 dB SNR gives 1.8 dB error (alternatively, treat as uncertainty contribution).
- Reference Source Phase Noise contribution, 10 dB margin gives 0.4 dB error, 0 dB margin (source noise comparable to analyzer) gives 3 dB error so treat as establishing upper limit for analyzer noise.

Alternatively, most modern analyzers include phase noise measurement capability, allowing a direct readout of phase noise in dBc/Hz, where the analyzer itself applies all the required normalizations and corrections.

Residual FM

This characteristic of the analyzer is related to its local oscillator phase noise at offsets close to the carrier, but is often considered (and measured) in terms of residual frequency modulation. To perform a test, a low residual FM signal source is required. The measurement technique typically uses the analyzer IF filter response as and FM slope demodulator. By arranging for the signal frequency to coincide with a liner portion of the filter response, the filter slope in dB/Hz is first determined by introducing a small frequency change in the input signal and measuring the displayed amplitude change. Next, the analyzer is placed in zero span mode, operating at the same point of the analyzer IF filter so that any signal level changes observed are due to residual FM. Hence, the residual FM can be calculated by multiplying the peak to peak amplitude change by the dB/Hz slope value.

Residual & Spurious Responses

These tests are somewhat dependent on the specific analyzer model, based on its design architecture and manufacturer's recommendations. Some tests require an input signal to explore responses close-in to the displayed signal, requiring an input signal which itself has no close-in residuals and adequately low noise sidebands and phase noise. Other tests may explore low-level residual responses that occur under no-signal conditions, requiring only a 50 Ω terminator to be applied to the analyzer input.

Harmonic Distortion

This test checks for any harmonics of the input signal generated internally by the analyzer. Unwanted harmonic generation occurs within the analyzer mixer, and depends on the level of the input signal at the mixer. Analyzer performance may be specified in terms of harmonic response for a given input signal level and attenuator setting, or more commonly, a mixer level independent specification is given in terms of the second harmonic intercept (SHI). It is important to ensure the input signal used for testing is sufficiently free from harmonics, and often general purpose signal generators do not provide low enough harmonic content such that use of external low-pass filters is required to correctly determine analyzer performance.

3rd Order Intercept (TOI)

The analyzer mixer can also generate unwanted intermodulation products if the input signal contains two or more input frequencies. If two input signals at slightly different frequencies are present, second and third intermodulation products are generated. The generation of second order products is related to unwanted harmonic generation, and is effectively tested by the harmonic distortion test so it is only the third order intermodulation products that are measured. Like harmonic performance, third order intermodulation performance is usually specified in terms of an intercept value. To make the measurement, two input signals of equal level and slightly different frequency are required. The signals are obtained from two signal generators connected simultaneously to the analyzer via a power splitter. As the third order products depend on the level of the input signals, it is often necessary to have knowledge of the input level to an accuracy better than that which the specifications of typical signal generators and power splitters will allow, so measurement of the input presented to the analyzer is also made with a power sensor.

Tracking generator tests

If a tracking generator (usually optional) is fitted to the analyzer, some testing of its output signal frequency and amplitude is performed.

Conclusions

Many of the tests share similar test setups, such as a signal generator connected to the analyzer input, but explore different analyzer performance characteristics. This allows for many tests to be performed without the need to reconfigure the setup, which can be particularly advantageous when measurements are automated. However, it is often necessary to use different signal generators to cover the required frequency range or use sources with signal characteristics appropriate for the particular tests being performed.

Tests can also be somewhat interdependent, with the results of one test relying on successful completion of one or more previous tests. For example, the resolution bandwidth accuracy test relies on the analyzer having an accuracy centre frequency and an accurate level linearity, tested in the frequency accuracy and display linearity tests respectively.

Some care is required interpreting results, such as the need to apply corrections in the noise sidebands/phase noise.

Spectrum analyzer calibration can be a complex process, but an understanding of the signal sourcing requirements will ensure that valid results will be obtained.