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White Paper

Understanding amplitude level accuracy in new generation Spectrum Analyzers

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Introduction

When specifying the amplitude level performance of a spectrum analyzer, there are many factors which can affect the performance and hence many parameters that must be specified and considered when selecting the right analyzer. In this paper we will examine the fundamental sources of level accuracy errors, and then look at how they are specified and how they affect real world measurements. This will include new hardware architectures from Anritsu that significantly improve the amplitude level accuracy.

The importance of amplitude level accuracy is to enable the spectrum analyzer to measure the power level of a signal to the best accuracy. This could be for the purpose of measuring:

- The power level of a single signal that is part of a more complex wide band modulation scheme (e.g. the power of a single carrier in an OFDM signal),
- The power of a specific narrow band signal that is "isolated", e.g. an oscillator or amplifier harmonic spur
- The total power of all signals within a given channel bandwidth (e.g. total power in a receiver)

These are all examples where a power meter would not normally be used to measure power level, as the frequency selectivity of a spectrum analyzer is needed where a wide band power meter/sensor would not be suitable. For all of these examples, it is important that the spectrum analyzer is correctly specified in terms of level accuracy to make an accurate and reliable measurement. In particular the effects on level accuracy of changing frequency and bandwidth, or changing input signal level, must be well understood. Measuring precisely the power of sub-carriers in a complex modulation scheme, or the power level of harmonic spurs in a transmitter, requires many settings for the bandwidth and input attenuator on a spectrum analyzer, and these all can affect the level accuracy. This in turn will affect the uncertainty in confirming the correct operation and specification of a device or in the worst case could cause a non-compliant device to be measured as "OK" and pass a quality inspection.

When specifying the level performance of a spectrum analyzer, the two areas most often considered are the amplitude level sensitivity (the lowest level of signal that can be measured) and the amplitude level accuracy (the level of accuracy on the actual measured value).

Noise floor and amplitude level sensitivity

The objective is to get as close as possible to the thermal noise floor limitation of sensitivity, which is a function of bandwidth and temperature of the receiver. This thermal noise floor is determined by the Johnson noise associated with the flow of electronic charge:

$$P = kb\ T\ \Delta f$$

Where:
P = Noise Power/
Kb = Boltzmann constant
T = Absolute Temperature (degrees Kelvin)
Δf = Bandwidth over which the noise is measured

As this is dependent on the absolute temperature and measurement bandwidth, we can then calculate the dB power for room temperature (300K) and some reference bandwidths:

1 Hz = -174 dBm.
10 Hz = -164 dBm.
200 KHz = -121 dBm (a single GSM radio channel)
3.84 MHz = -108 dBm (a single UMTS radio channel)

In spectrum analyzer data sheets, the noise level is often quoted at either 1 Hz or 10 Hz bandwidth.

Defining total level accuracy, and uncertainty

We can define as follows:

Total level accuracy = fundamental uncertainty + uncorrected systematic errors.

Fundamental uncertainty is quoted as "absolute level accuracy", usually measured at a specific frequency, attenuator setting, and input signal level. Clearly this can be used as a benchmark of the fundamental uncertainty of different instruments, but does not give a clear indication of the actual measurement uncertainty that a user will face when using different instruments in the real world. By comparing the specification of different analyzers at the same settings of frequency, attenuator and input level, then the absolute accuracy can be compared. But, this does not necessarily equate to the level accuracy each analyzer will be capable of when used in a real system for making measurements at various different levels and frequencies. The key to the real measurement uncertainty is the "total level accuracy", this includes the uncorrected systematic errors that occur for instrument settings that fall outside of the measurement conditions made for the absolute level accuracy.

So now we can re-write the above definition as:

Total level accuracy = absolute level accuracy + uncorrected systematic errors.

Separating systematic errors vs true uncertainties

Systematic errors are defined as those which can be measured and compensated for with correction algorithms, as they have a deterministic value (can be measured) and characterized. These occur due to manufacturing tolerances in the individual electronic components that cause fixed errors and device parameter setting dependencies (such as frequency or level) that are repeatable characteristics of the components (usually non-linear semiconductors) in the system.

True measurement uncertainties come from errors and variations that are not measured or characterized. These are typically due to electrical noise (thermal semiconductor junction effects) and uncompensated temperature fluctuations (assuming the components are not housed in a thermally stable environment, but are used in a regular laboratory environment). Ageing effects on components such as oscillators and switches can also be uncertainties if they fall outside the path of the compensation circuits but are still part of the signal path.

By measuring and compensating the maximum number of systematic errors, the total level accuracy of an analyzer can be improved to give best measurement accuracy.

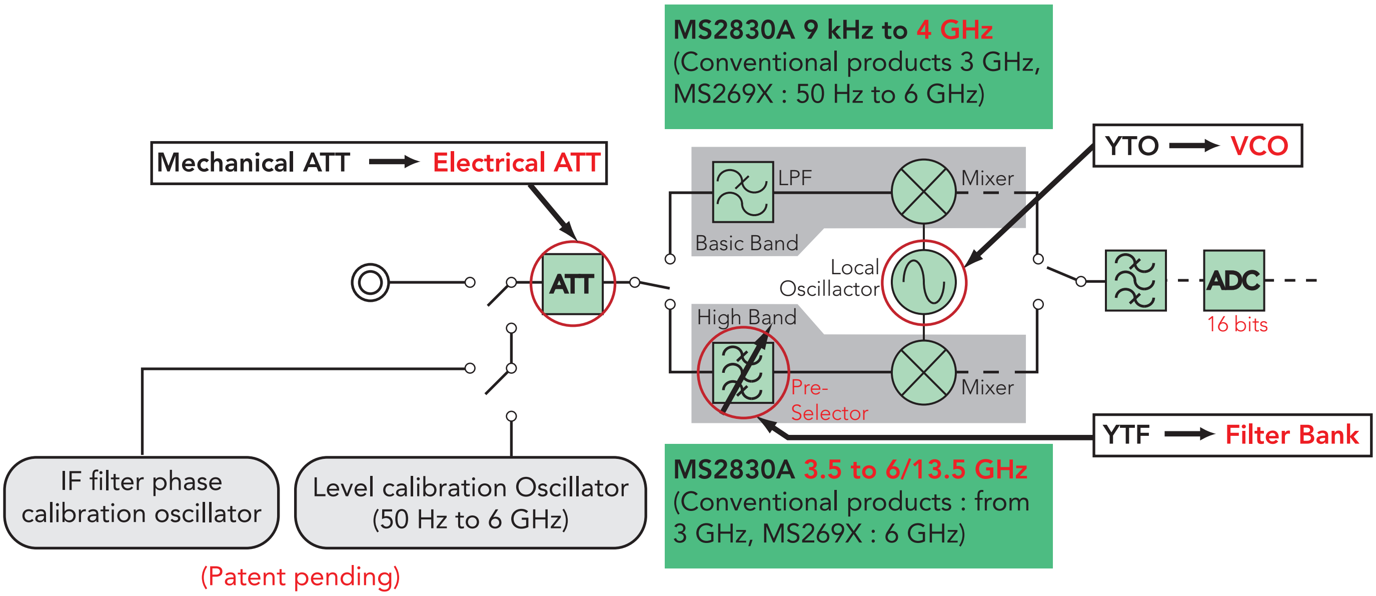
How hardware implementation affects total level accuracy

The hardware implementation of the spectrum analyser has a major effect on the ***total level accuracy*** of the analyzer. This defines which circuits are included into the compensation system, and what parameters are included into the compensation. Traditional designs of high performance bench top analyzer have used compensation circuits that operate at only a single fixed frequency and level setting.

Anritsu has implemented a unique new compensation technique in the MS8230A and MS2690A series of spectrum analyzers. This uses a frequency swept reference source to calibrate the whole receiver chain across a wide frequency band, which effectively minimizes all systematic errors. Alternative solutions are only making such a calibration at single frequency (e.g. 50 MHz) and so when the measurement frequency is changed from this value then an additional uncompensated uncertainty is introduced. This means that a frequency response uncertainty must be added to the absolute accuracy.

The Anritsu architecture also routes the calibration signal through the front switching attenuator, so it is automatically corrected in any measurement at any attenuator setting. Again, alternative solutions do not pass calibration signals through the input attenuator, and so input attenuation switching uncertainty must be added to the total absolute accuracy.

This technique is shown in figure 1 below.

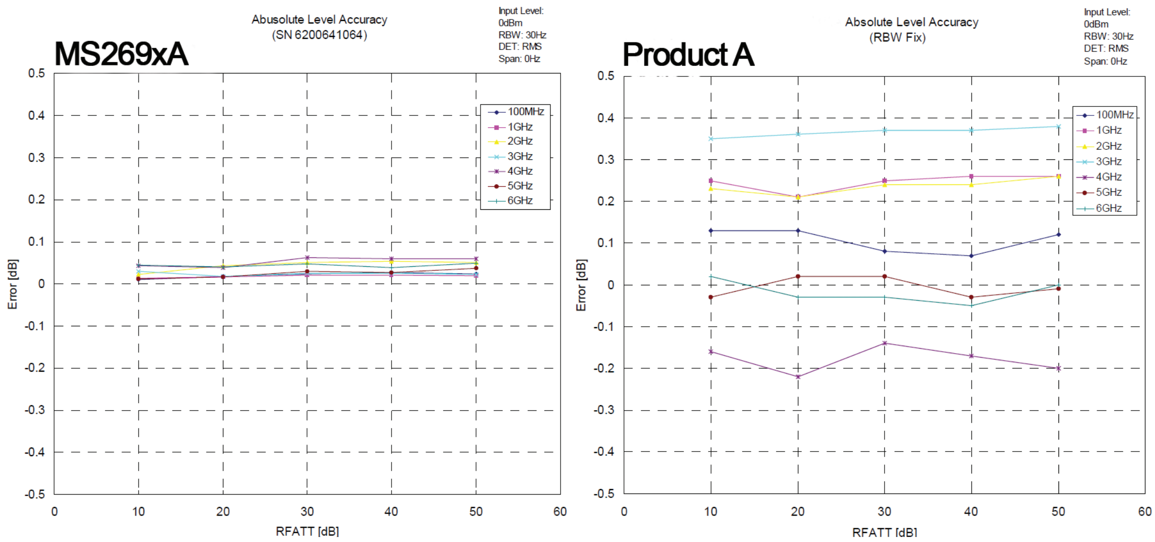


It is seen in figure 1 that the calibration signal is swept across the frequency range 50 Hz to 6 GHz in the MS2690A series (and to 4 GHz in the MS2830A series), this validating the compensation across this whole range, and in addition this compensation circuit includes the input level attenuator as well as the whole receiver chain. This level accuracy is maintained across the whole 6 GHz frequency range and with the full range of input attenuator settings (up to 4 GHz in the case of MS2830A).

By using the above techniques, Anritsu is able to reduce the systematic errors by having a much more comprehensive compensation circuit. This means that the actual measurement uncertainties the user has when making real measurements is significantly reduced. The dependency on frequency, input level, and input attenuator setting are all compensated automatically in the measurement.

The result of the above correction techniques provides a significant improvement in the useable accuracy of the spectrum analyzer.

This is shown in figure 2 below.



In figure 2 we can see the difference between the Anritsu MS2830A absolute level accuracy versus a conventional Spectrum Analyzer from another supplier. The impact of the Anritsu calibration circuits can be seen with two effects.

Firstly, there is a minimum of absolute frequency variation for the Anritsu MS2830A, so the level accuracy does not change out of specification when frequency is changed. This is seen in the very small difference in error between the different colored graphs for each frequency in the range. This is very different to that of Spectrum Analyzer "Product A", which introduces an additional 0.6 dB of level uncertainty due to frequency (range of error from +0.38 dB to -0.22 dB for the different colored graphs that show each frequency). This is because the "absolute accuracy" is only valid at the frequency of 50 MHz where it is calibrated, and the frequency variation adds this additional uncertainty error of up to 0.38 dB).

The second effect is that the flatness of the level accuracy is significantly affected by the setting of the RF attenuator (the range on the X axis of the chart). It is seen that at each individual frequency, the RF Attenuator level setting adds an additional 0.1 dB of uncertainty for Product A, whereas the Anritsu MS2830A has less than 0.03 dB of variation across the RF Attenuator level setting.

The result of these differences means that although the two Spectrum Analyzers may be specified with a similar absolute level accuracy, the Product A has an actual "Total" level accuracy of up to 0.4 dB due to additional uncertainties that are not compensated.

Frequency reference related level accuracy errors

Beyond the total level accuracy due to the different compensation schemes used, further level uncertainties are introduced by the type of component technology used in the spectrum analyzer. Traditional spectrum analyzers use a YIG type RF local oscillator (YIG Tuned Oscillator, or YTO), providing the reference frequency for the RF down-conversion mixer. The YIG oscillator is based on Yttrium Iron Garnet as a ferro-electric material that changes resonance frequency according to strength of a magnetic field applied. This allows for a high quality (low noise) reference oscillator with a wide tuning bandwidth.

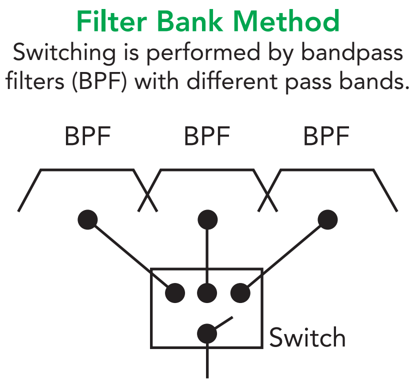
Such YIG technology is susceptible to performance variations over temperature as the device normally warms up and temperature cycles during operation. These temperature variations provide an additional level accuracy that drifts slowly over time as the device warms. New generation spectrum analyzers, such as the Anritsu MS2830A Spectrum Analyzer, have moved to a VCO type local oscillator, and this has much lower temperature fluctuation and performance degradation. Historically, YIG oscillators were chosen for Spectrum Analyzers due to their excellent low phase noise required in high performance receivers. These new generation spectrum analyzers have used the very latest low noise VCO component technology to now produce a Local Oscillator that matches the required specifications for a high performance spectrum analyzer.

YIG Tuned Filter (YTF)

In a traditional spectrum analyzer, the high band pre-selector filter is also implemented using YIG technology as the frequency selectivity/tuning element. This is again due to the historical high performance of YIG elements as frequency tuneable devices. But as we have seen, this technology does not give a completely flat amplitude response versus frequency, and is sensitive to temperature fluctuations changing the frequency response (and hence changing amplitude response). YFT filters suffer from "self-heating" as they naturally become warmer due to the interaction of the electro-magnetic fields with the ferrous materials used in the YIG crystal sphere, where absorption of electro-magnetic fields in the YIG sphere causes heating in the material as energy is absorbed. The heating causes a change in the physical size and properties and hence the frequency characteristics of the YIG sphere, and consequently the amplitude response is changed because frequency versus amplitude is not precisely linear in the YTF.

Filter Bank architecture

New generation spectrum analyzers are now replacing YTF filters with the filter bank architecture for the high band pre-selector filter. This replaces a single tuneable YIG filter with a series of switchable filters that can be configured to give the desired selectivity. This filter is used to select the correct frequency band when the analyzer is used in the range higher frequency ranges (normally 4 GHz to 13.5 GHz). Below 4 GHz then no band filter is required, and above 13 GHz then a YTF is still used as the wider bandwidths mean the filter bank is not an effective solution. So when operating a spectrum analyzer in the range from 4 GHz to 13.5 GHz then the choice of high band pre-selector filter type will have an effect on measurement performance.



The filter bank technique uses a set of Band Pass Filters (BPF), and these each have typically a bandwidth of 400 MHz. A switch is then used to select a matrix of different BPF to give the required high band selectivity. These filters are implemented using printed circuit techniques, to give low cost, low power consumption, and high stability. The stability comes from there being no tuneable or variable circuits involved.

The dis-advantage of the filter bank is that it does not have the same level of selectivity (the filter resonator has a lower Q value). This means that the analyzer may not have such strong rejection of out of band signals, as they may pass through the filter and be down-converted by the receiver/mixer chain.

	Filter Bank	YTF
Advantage	Fast frequency sweeping and settling time, only limited by switching time and no tuning/sweep time. Stable passband characteristics (fixed BPF, no variable characteristics) Low Power Consumption Low Cost	Wide Bandwidth Low insertion loss High Q selectivity enables good rejection of out of band signals
Disadvantage	High insertion loss Lower Q (wider pass band) degrades rejection of out of band signals	Slow settling time due to response characteristics of magnetic ferrous materials. Stability errors and post-tuning drift, including temperature stability. High power consumption High cost.

Specifying total level accuracy in a spectrum analyzer

When we are considering the different factors discussed in the previous section, we can see now how to specify and evaluate level accuracy in spectrum analyzers, and how the differences in new technology impact these specifications.

"Absolute level accuracy" is the baseline for level accuracy. For a known reference signal of fixed frequency and level, the accuracy of measurement of this reference is the absolute level accuracy. This is normally quoted at the frequency and level at which the spectrum analyzer has its compensation circuits, so that the best possible accuracy is quoted. Of course, this level accuracy is not valid outside the frequency range or input attenuator range used for the compensation circuits.

For a traditional spectrum analyzer using single frequency compensation circuits (e.g. 50 MHz), then an additional uncertainty, called "Frequency Response accuracy" must be added, to represent the additional uncertainty due to the frequency, if the measured signal is at any frequency other than the compensated frequency. This is because the amplitude response of the frequency selective circuits (RF local oscillator, RF mixer, IF filters) is not constant across all frequencies. Where the spectrum analyzer is using a calibration oscillator which is swept over the whole RF band (rather than fixed frequency), then this uncertainty is eliminated.

A traditional spectrum analyzer uses the level compensation circuits to define absolute level accuracy with only a fixed setting on the input attenuator. When the input attenuator is at a different level to that used for the compensation reference signal (e.g. compensation signal may be -25.0 dBm and the input attenuator set to 10 dB attenuation) then the absolute level accuracy is no longer valid. So an additional term of level uncertainty, the "Input attenuator switching uncertainty" must be added as an additional level accuracy term. Where the spectrum analyzer has an architecture that includes the input level attenuator into the compensation circuits, then this uncertainty is eliminated.

For a typical bench top spectrum analyzer operating in the range up to 13 GHz, and operated in normal laboratory conditions with temperature specified as 20 - 30°C, we see the following level accuracy specification:

Absolute Level Accuracy = ±0.33 dB (±0.36 dB over full temperature range)
Frequency Response = ±2.0 dB (±2.7dB over full temperature range)
IF Frequency Response = ±0.45 dB
Input attenuator switching uncertainty ±0.7 dB

This gives a total level accuracy of ±3.48 dB when combined linearly, and a value of ±2.19 dB when using RSS method.

Note: the Root Sum Squares (RSS) method is used by manufacturers to combine the individual errors into a total uncertainty. This is based on the individual errors being statistically independent and hence unlikely to all occur in the worst case simultaneously. Hence RSS method can be applied to calculate a "typical" uncertainty error.

The charts below show the specification of a standard spectrum analyzer, where each uncertainty error is specified separately as they are independent sources of error. This is compared to the Anritsu MS2830A where the broadband compensation method and high stability oscillator / filter technology is used. In this case, the amplitude level accuracy is specified as the combined RSS value, as the compensation circuit removes the independence of the individual error sources. This is shown for both the standard frequency ranges of 3.5 GHz and 13 GHz.

@ 13 GHz		Standard Spectrum analyzer	Anritsu MS2830A
Reference level	error (dB) ±	0,70	
Frequency	error (dB) ±	2,00	
Absolute accuracy	error (dB) ±	0,33	
IF freq response	error (dB) ±	0,45	
	RSS sum (dB) ±	**2,19**	**1,80**

@ 3,5 GHz		Standard Spectrum analyzer	Anritsu MS2830A
Reference level	error (dB) ±	0,30	
Frequency	error (dB) ±	0,45	
Absolute accuracy	error (dB) ±	0,33	
IF freq response	error (dB) ±	0,40	
	RSS sum (dB) ±	**0,75**	**0,50**

Conclusion

It has been seen that the total level accuracy of a spectrum analyzer is a key parameter to understand the ability of the instrument to measure the power level of signals that being captured and analyzed. The total level accuracy is defined as the addition of the absolute level accuracy and the un-corrected system errors that are not compensated by the analyzer's own correction circuits.

The new generation of performance bench top spectrum analyzers (such as the Anritsu MS2830A series) have architectures that significantly minimize the uncorrected systematic errors. Key improvements are in the area of the wide bandwidth compensation circuits, and the switch away from YIG based frequency components (YIG reference Oscillator and YIG Tuned Filter) to technologies that offer more stable performance (VCO and Switched Filter Bank) for operation up to 13.5 GHz. These changes significantly reduce the number of uncompensated systematic errors.

The effects of these changes are seen when looking at the total level accuracy of different spectrum analyzers. Additional level accuracy errors due to frequency and input signal level / attenuator setting are eliminated. These errors must still be included when specifying total level accuracy for spectrum analyzers that do not have these features and are using traditional architectures.

When evaluating a spectrum analyzer level accuracy, it is now important to recognise if the analyzer is of an older traditional type design or the newer advanced architecture. An older type must be specified for level accuracy with additional terms of measurement frequency and input attenuator setting (due to single frequency calibration) in addition to the absolute level accuracy. An advanced architecture (that has compensation circuits across wide frequency band and includes input attenuator) is only specified in the single "total level accuracy" that includes all of the above level accuracies.

It has also been shown that implementation of newer designs and technology such as low noise VCO and passive filter banks allow the cost to be reduced without reducing performance. The use of more advanced electronic component technology has allowed the replacement of expensive and less stable YIG based circuits (YIG oscillator and YIG Tuned Filter) with improved stability circuits at lower cost.

Specifications are subject to change without notice.

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