Evolution of the Modern Receiver in a Crowded Spectrum Environment
White Paper

The International Telecommunications Union Radiocommunications working group (ITU-R) outlines recommendations for the regulations and procedures for federal radio frequency management. This white paper takes a look at the evolution from the analog spectrum analyzer to the modern digital receiver in line with ITU-R Recommendations. It also gives some examples of the importance of the new architecture in today's spectrum environment.

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White Paper

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Overview

The Electromagnetic Spectrum is a finite resource and its use is rapidly expanding. Unencumbered access to spectrum has been, and continues to be, critical to many government and commercial systems. As existing RF systems evolve and new communication systems are deployed, the need for additional spectrum bandwidth continues to grow. For example, to support the demand for broadband access, the number of wireless bands for Long Term Evolution (LTE) has increased from 11 to 48 since 2011. The continued coordination and future allocations are foreseen as federal spectrum is released. With federal mandates and initiatives, such as the 500 MHz of federal spectrum released for commercial use by 2020, the impact to spectrum monitoring equipment and the role of spectrum management must also evolve.

This white paper will cover the different functions of the traditional RF measurement instrument architectures and their role in spectrum monitoring. The basic spectrum analyzer architecture is discussed as well as the modern digital monitoring receiver. Unlike the role of a typical spectrum analyzer, the monitoring receiver has an operational environment that is quite different than a typical measurement instrument. In consideration of the operational environment of a monitoring receiver, the international requirements for modern monitoring receivers are defined by the International Telecommunications Union Radiocommunications working group (ITU-R), and outlined in the ITU Handbook Section 3.3.5. In the US, the NTIA Redbook, Manual of Regulations & Procedures for Federal Radio Frequency Management, references the work of the ITU-R. From signal detection, classification, and analysis to radiolocation tasks, the challenges of spectrum monitoring in a crowded and dynamic environment have had a profound impact on modern architectures design and use.

Review of RF Measurement Architectures

This review of RF measurement tools covers all classes of equipment: spectrum analyzers, signal analyzers, and receivers. There are two architectures largely grouped as analog (swept) and digital (stepped). While much of the capability of a modern analog RF measurement architecture is supported by digital processing, the functions do not change widely. However, most of the innovation and advantages of the modern digital RF measurement instrument allow a significant functional advantage for spectrum monitoring.

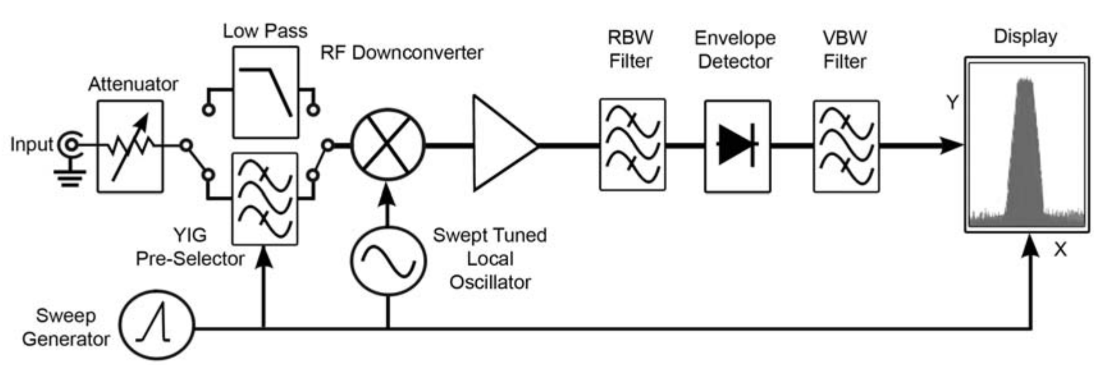

Figure 1 Block Diagram of an Analog (swept) RF Measurement Instrument

Figure 1 shows the traditional swept spectrum analyzer. The signal flow of the basic block diagram shows that after some basic filtering and signal gain management, a sweep generator will tune a local oscillator of the front-end mixer to down convert the RF signal. Additional Resolution and Video Bandwidth filter blocks condition the display of the detected energy as the amplitude of the signal will be displayed over the frequency of the sweep generator. While an analog receiver might use a similar architecture, the monitoring receiver will have much more filtering in the RF front-end referred to as pre-selection, and ideally it will comply to the ITU recommendations. In addition, monitoring receivers are architected with a parallel signal processing path after the ADC to provide operational functions such as AM or FM demodulation and recording outputs.

The analog architecture does not capture the phase information of a signal, and thus is not suitable for the monitoring or decoding analysis of modern digital signals. Further, some important monitoring receiver functions, like automatic gain control (AGC), have limited implementations in analog RF measurement instruments. The importance of filtering and the AGC function will be discussed later.

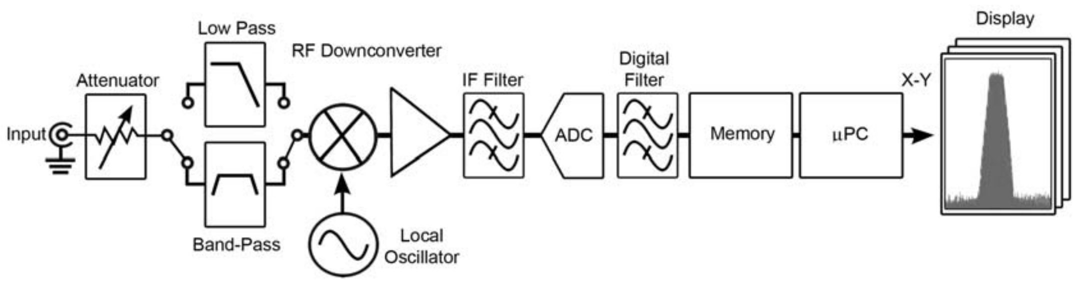

Figure 2 Basic Block Diagram of Digital (stepped) RF Measurement Instrument

The block diagram of a digital RF measurement instrument is shown in Figure 2. The signal flow at the RF front-end is similar to block diagram of the analog RF measurement instrument. However, due to the limited bandwidth of the YIG Pre-Selector, the RF front-end filters could be replaced by a bank of band-pass filters or other filter tracking technology if the bandwidth of the signal is wide (typically > 30 MHz). The local oscillator is fix tuned (or stepped) during the signal acquisition or dwell time required to process a signal of interest. The analog-to-digital converter (ADC) determines the bandwidth of the signal acquisition and the resultant signal is converted into a digital baseband. The real-time processing or storage of the signal into memory is largely dependent upon the functional requirements of the RF measurement instrument.

Signal and Spectrum Analyzers vs. Monitoring Receivers

Signal and spectrum analyzers are typically designed to fulfill the industry measurement requirements including the high dynamic range of radios complying with wireless communications standards (such as WCDMA and LTE) or wideband high frequency radars (such as Automotive Radar Collision Avoidance systems).

As technology becomes more advanced with radios and radars, this will drive the performance of the signal and spectrum analyzer architectures:

- Dynamic range to measure adjacent channel noise of multi-standard/multi-carrier wireless basestations (-88 dBc dynamic range for WCDMA ACLR)
- Bandwidth and frequency of Collision Avoidance radar systems (77 GHz @ 2000 MHz BW).

Innovation and performance are driven by industry requirements in this class of instruments, and the unique offerings are often optimized to provide test margin in the development stage of new products for the industry. As a result, the signal and spectrum analyzer will typically be designed with respect to the following signal conditions:

- The signal is typically known, so there are modest requirements on the use of pre-selection to maintain the signal path integrity and harmonic suppression of signals from the device under test
- The instrument is typically used in a controlled environment where the user can turn on or off a signal
- Outside of a controlled environment, shield room or open area test site, the signal is usually connected to a cable, not an antenna

The advantage of the signal and spectrum analyzer products tends to be leadership in measurement performance and key parameters such as: phase noise, noise figure, displayed average noise level (DANL), dynamic range, level accuracy, bandwidth, measurement frequency, and real-time display persistency. The signal and spectrum analyzer also benefit from application specific software analysis to simplify the setup and measurement to verify standards conformance.

Monitoring Receivers

Monitoring receivers are typically designed with measurements and functions in line with the ITU-R Recommendations. Modern monitoring receivers are primarily digitally based receivers dedicated to fast detection of unknown signals. The primary function of the monitoring receiver is the extraction of signal content. Signal content can include:

- Spectrum occupancy (compliance to ITU and national spectrum allocation recommendations)
- Signal location
- Signal identification and classification
- Bit stream analysis and decoding (where lawfully allowed)

Unlike the drivers of the design requirements for a spectrum/signal analyzer, the main differences in the requirements of a monitoring receiver lie in the challenges operating in the dynamic spectrum environment.

Challenges of Radio Monitoring in a Crowded Spectrum Environment

Radio monitoring receivers are designed to handle a challenging signal environment. These tasks are often characterized by the following conditions:

- Receiver site cannot always be pre-determined
- Instrument settings are typically fixed during measurements
- Signal environment during a measurement is not controlled by the user

Here are some examples of how these challenging signal environments can influence the design of a monitoring receiver and relate to how these can directly impact the RF performance parameters.

Receiver Site

A spectrum management authority only has access to certain rooftops where other buildings obstruct the sight or where there are commercial wireless base stations close to the receiver. The strong signals could block the receiver or create signal artifacts like intermodulation products that cover a weak signal on interest. In an international military camp, there could be neighbors that are transmitting a strong signal that could have a similar impact.

Fixed Instrument Settings

As strong signals in one band will require the input level to be set to prevent overload, this might determine the input level across the entire RF unless strong filter rejection is employed. Also, if a strong signal is dynamic, such as a radar, and is only on for short periods of time during a scan cycle, detecting weak signals coexisting in that band that might be harmful to that radar would not be possible unless the monitoring receiver could adapt to the dynamic signal environment. An example here might be an Air Traffic Control (ATC) radar rotating at 13 rpm coexisting with a small signal stronger that the return signal of an incoming aircraft.

Control of the signals

An interference signal or a signal collected in an uncooperative environment cannot be repeated on demand by the operator, so signals have to be detected whenever they occur. This impacts the design for probability of intercept (POI) and the ability to instantly detect or trigger on a changing spectrum environment.

When understanding the impact to the design of the monitoring receiver, it is important to consider the influence of second order intermodulation intercept (IP2). IP2 is one of the key performance parameters of a radio monitoring receiver as it relates to real-world environments and signal conditions. Take the example shown in Figure 3 of the reception of weak signals in the Air Traffic Control (ATC) radio band, an airplane communication radio at a great distance (black) with a nearby intermodulation product (IP2 in blue). The IP2 signal is a product of strong signals from the FM broadcast band (blue) and TV band signal (blue) and cause a product that could cover the weak signal (the ATC signal). IP2 performance can be improved by a lower amplification or by attenuation in the receiving instrument. However, this reduces the sensitivity so the signal of interest could be buried in the noise. An interference signal impacting the ATC communication could also be obscured.

A combined measurement of IP2 and noise figure (at same instrument settings) will demonstrate how good a receiving instrument will perform in such a scenario.

Pre-selected filtering can reduce the effect of intermodulation before it happens. Since the pre-selection filters attenuate the power of the strong signal in the environment of the band of interest and automatic gain control (AGC) is used, it can assure the low level signals will be seen within a pre-selected band if the IF filtering allows.

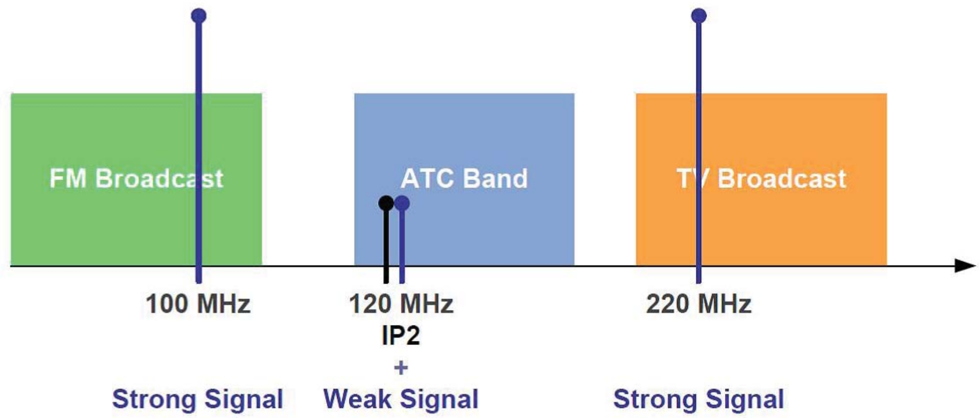

Figure 3 Challenging real world environments dictate RF performance requirements

Evolution of the Monitoring Receiver

Unlike the signal/spectrum analyzer, the monitoring receiver will likely be placed at a remote location from the operator and be setup to perform tasks by remote control that usually has several networked receivers at the same time. Due to limitations with range sighting and ability to set antennas in fixed or mobile locations, the location of the monitoring receiver may be co-located with other transmitters or localized transmitters (radios and cell phones) which may be operated near the sensitive receiver. Thus the architecture of the monitoring receiver will have several additional functions that are unique for its operation:

- Tracking pre-selection to ensure the signal is optimized in the band of interest
- Automatic gain control (AGC) that senses changes in the RF environment to ensure the integrity of the signal content being collected
- Audio processing and real-time demodulation for listening
- DDC's – digital downconverters that provide real-time resampling of digital IQ data for down stream analysis of multiple different signals within the acquisition bandwidth
- Fast scanning and triggering on changing RF environment to improve POI
- Increased temperature range for remote operation in harsh environments
- Digital IQ output for capture record and replay function
- The ability to operate in extreme conditions and maintain accuracy without the need for periodic calibration

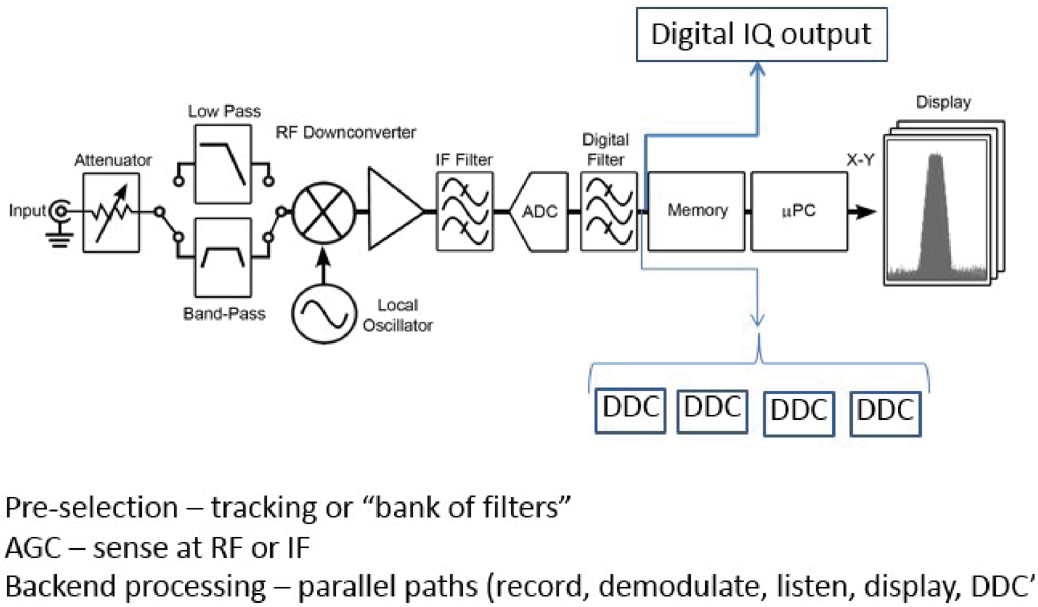

Figure 4 Modern Digital Monitoring Receiver

Real-world example

In a real-world example to demonstrate the principles of a modern receiver with pre-selection filtering and AGC, Figure 5 shows a signal condition with a strong in-band signal. To protect the receiver and provide an adequate noise floor to observe signals of interest, a user may have set the input attenuation of a receiver at 15 dB.

The Red Warning in the lower left-hand corner of the display warns the user that the signal conditions of the receiver are currently in RF overload as it spans between 500 – 700 MHz. The intermodulation effects of an overloaded front-end can be seen sharply between an approximate 60 MHz span at the center of the display. This roughly outlines a pre-selection filter band.

While not shown separately, the pre-selection filter would allow for valid measurements in other frequency bands such as signals near 540 MHz where the noise floor at the marker [M1] is shown to be 23.37 dBuV.

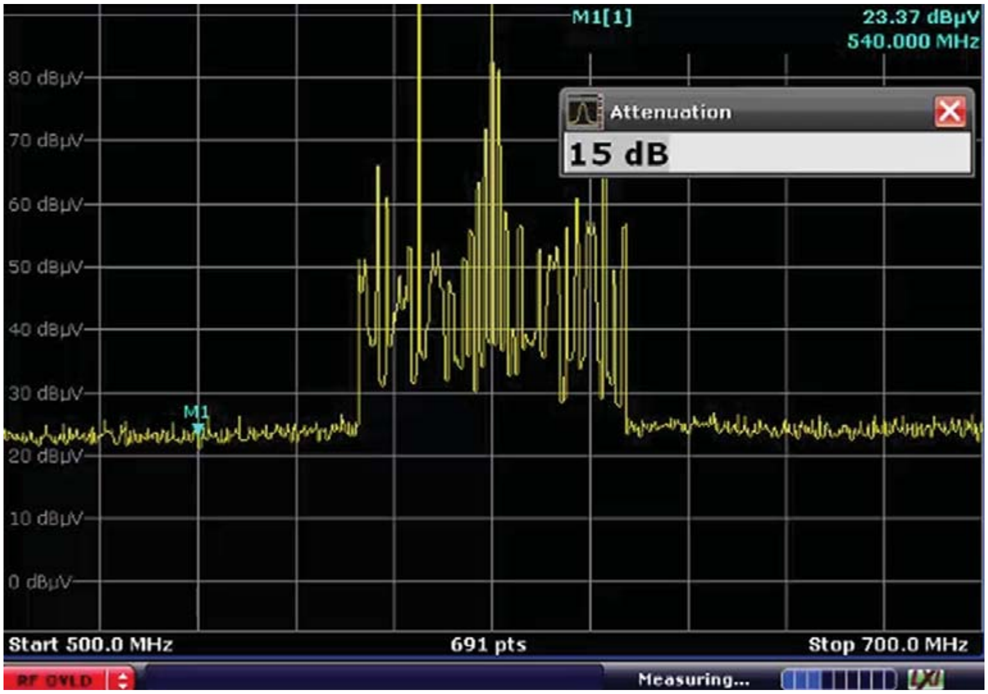

Figure 5 Overloaded signal conditions during a wideband scan

To alleviate the overload condition, the RF front-end attenuation needs to be changed to 30 dB, as shown in Figure 6. With valid measurement conditions across the span, the impact to noise sensitivity can now be seen as the noise floor has increased almost 13 dB at the 540 MHz marker [M1].

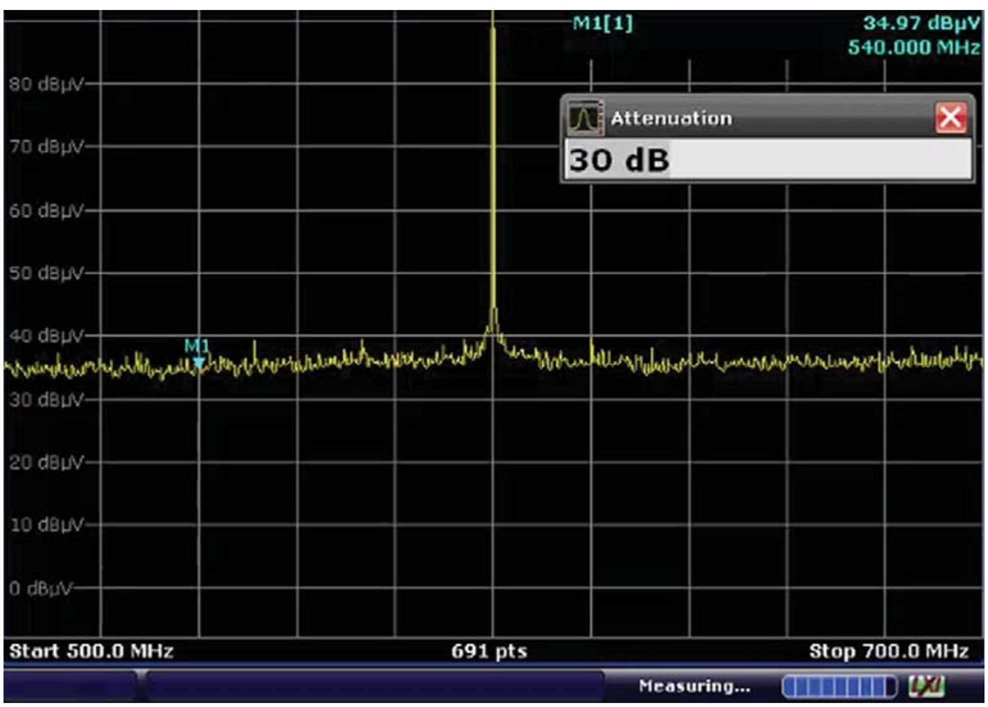

Figure 6 Attenuation adjusted to 30 dB to remove overload condition

While Automatic Gain Control (AGC) can be implemented in several fashions, with RF or IF detection and adjustment, the benefits of AGC can be immediately seen in Figure 7. AGC can enable a receiver to sense and adapt this signal input to optimize dynamic range and avoid overload conditions from strong signals, or dynamically changing signals across successive scans.

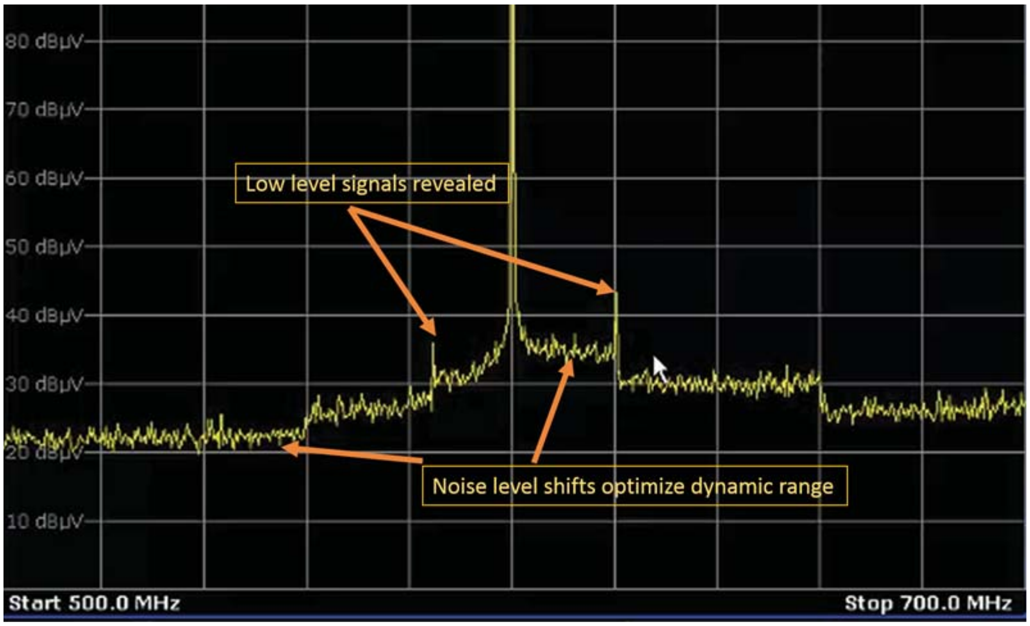

Figure 7 Automatic Gain Control

Comparing the valid measurement conditions of Figures 6 and 7, when a receiver has a fixed attenuation across a band of interest, low level signals can be masked. AGC provides the automatic adjustment of the noise floor to optimize the noise sensitivity across the entire sweep range of the receiver.

Summary

While the re-allocation of spectrum for commercial wireless services is both a federal mandate and a significant source of revenue for the federal government, coexistence studies and spectrum monitoring functions will grow in importance. Spectrum analysis has evolved into the requirements for monitoring receivers that are substantially different than the spectrum analyzers that dominate the work benches of engineers designing RF devices. The modern digital monitoring receiver has evolved to operate in the challenging real-world environments.

About Rohde & Schwarz

Rohde & Schwarz is an independent group of companies specializing in electronics. It is a leading supplier of solutions in the fields of test and measurement, broadcasting, radiomonitoring and radiolocation, as well as secure communications.

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