A New Measurement Technique to Enable Engineers To Quickly Troubleshoot Radar Design Problems

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Abstract

Until recently, analyzing many radar signals was not a straightforward task. Modern radars depend on complex RF signals that vary with time. To truly understand system performance and troubleshoot today's complex radar signals, the time, frequency, and modulation domains all require analysis in a time-correlated fashion. Traditionally, no single test instrument was designed for this breadth of radar pulse analysis capability. Engineers were thus forced to use many different test instruments in custom-built test sets to collect sufficient data for reliable troubleshooting. Using multiple test instruments is costly, time consuming and can introduce measurement uncertainty that can lead to unreliable diagnostics. The latest generation of Real-Time Spectrum Analyzers (RTSA) solves these problems by providing the ability to trigger on an RF pulse, seamlessly capture it into memory and analyze the pulse in several time-correlated domains on a single instrument. This paper examines how the newest generation of RTSA pulse measurement technology can replace many traditional radar test sets for rapid and reliable radar systems diagnostics.

Key words:- Radar Measurement, Real-Time, Spectrum Analyzer, Cost

Introduction

Whether imaging an asteroid at a range of 55 million miles (88 million km) [1], guiding a strategic defense missile to its target with a mono-pulse tracking radar or launching a rocket propelled grenade counter measure in the blink of an eye, it is easy to see radar technology has progressed significantly in recent years. Today's advanced radars perform their amazing feats using complex signals and advanced signal processing. Unfortunately, the complexity of modern radars can present significant test and diagnostic challenges.

Most radar systems transmit RF pulses and listen between transmissions for returning signal reflections. The shape, duty cycle and amplitude of the transmitted RF pulses determine important system parameters like detection range and minimum target resolution. To validate system performance, analysis is required in both the time domain, for shape and duty cycle, as well as the frequency domain, for carrier frequency and bandwidth.

Complicating matters further, many radars use pulse compression techniques to improve range and resolution. By modulating the transmitted pulse, it is possible to separate received echo returns that overlap in time and would not otherwise be resolved into individual targets. Initially, simple modulations such as an FM chirp (linear FM sweep) were used. Compression techniques now also include a variety of phase modulations. Troubleshooting these modulated pulses presents additional test equipment demands. Compressed pulses require not only time and frequency analysis, but also modulation domain analysis. FM ramp linearity, bi-phase coding and many other modulation parameters become important metrics.

If these test requirements aren't enough, some sophisticated military radars must perform in complex spectral environments. Military radars are required to function correctly when subjected to a barrage of adjacent channel communications signals, disruptive noise jamming and intentionally deceptive jamming pulses. Capturing the intermittent radar pulse against a background of potential interferers, demands outstanding RF triggering. This can be particularly difficult to accomplish under real-world operating conditions. Spectrally dense Electronic Warfare (EW)

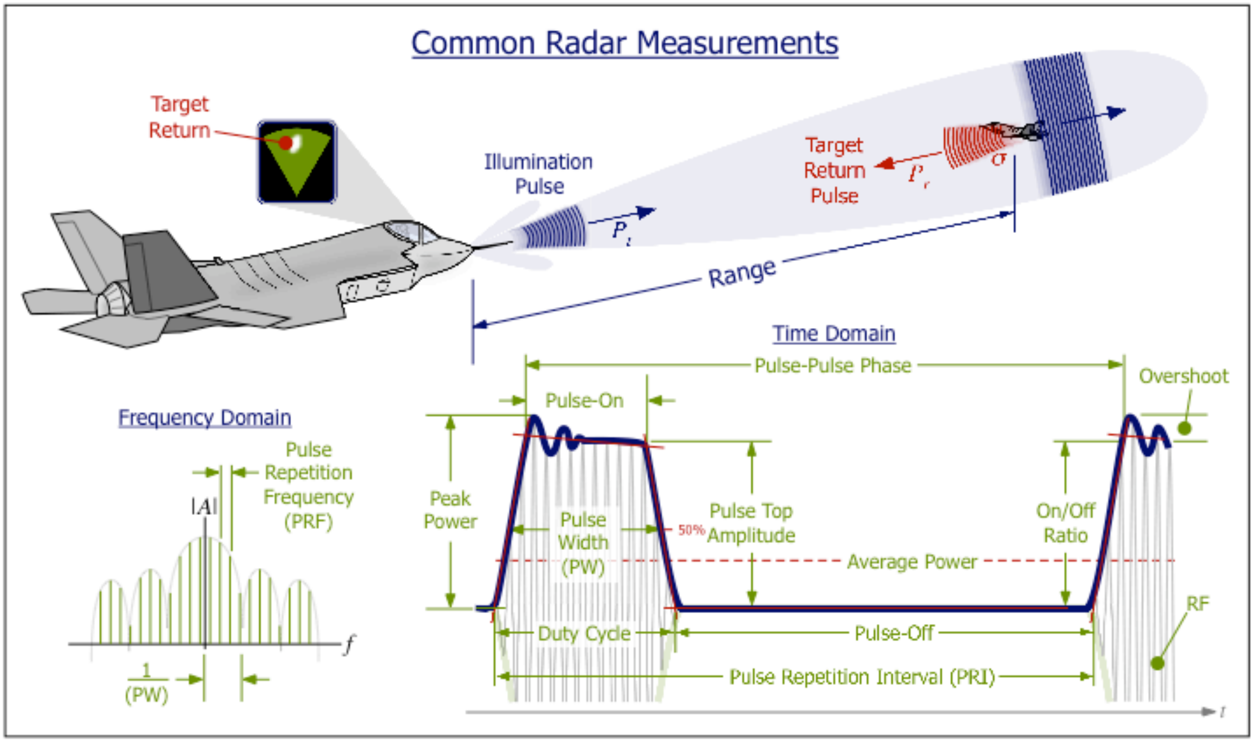


Figure #1 — Common radar measurements such as pulse repetition frequency, peak power and pulse width, that are important for in determining a radar's range and resolution are made in the time and frequency domains.

environments may contain jamming signals that are larger than the radar echo return of interest. Triggering on the weaker intermittent radar pulse can present a tough problem for the test engineer.

Diagnostic testing of modern radar systems in the time, frequency and modulation domains under difficult triggering conditions has made radar test a costly endeavor. Historically, each analysis domain required separate test instruments, which then necessitated multiple interconnections for synchronization of display events. Interference filters, trigger connections, switches, power-splitters and automating software are then added, creating a customized test set for radar diagnostics. The cost of testing the modern radar has thus grown with radar pulse complexity and operational environment.

The latest generations of real-time spectrum analyzers offer a simpler solution to many of these troubleshooting problems. To understand how the real-time spectrum analyzer simplifies these traditional test issues, we turn our attention to a brief review of signal analysis technology.

The Evolution of Radar Signal Analysis

Early radar diagnostics were performed primarily with the oscilloscope and RF diode detectors. The oscilloscope's limited frequency capability relegated its diagnostic applications to base-band waveforms (i.e. drive voltages to magnetron tubes). In the 1960s, the swept spectrum analyzer became commercially available to the industry. This provided a convenient means to display the RF spectrum and determine if base-band pulse shapes were correctly translated to microwave frequencies. The swept analyzer's "Zero-Span" (no-span, i.e. full bandwidth) added another way to view pulse amplitude versus time, and quickly replaced the much cruder diode detector. Employing both oscilloscopes and spectrum analyzers, time and frequency domain analysis of radar signals at base-band and RF was possible.

As pulse compression schemes grew in popularity, engineers needed a third test instrument -- the analog modulation analyzer. This instrument provided a means to measure the linearity of FM pulse compression (chirps). The modulation analyzer was later replaced by the more versatile Vector Signal Analyzer (VSA) that could also analyze digital phase modulation.

Unfortunately, the vector signal analyzer is not ideal for modulated pulse measurements since the VSA was initially developed for the continuous Quadrature Amplitude Modulated (QAM) signals used in the telecommunications industry. VSAs typically have rudimentary IF level-triggering ability unsuited for radar systems that must function in complex spectral environments. Even the latest VSAs lack comprehensive radar pulse analysis software, remaining focused on the consumer communications market.

The sad fact is for many, many years the radar industry had to solve its system test needs by using several test instruments that were not primarily designed for transient radar pulses. This forced radar test engineers to resort to elaborate custom-built test bays that incorporate multiple test instruments [2].

The capital investment for such custom-built test sets can be substantial. Beyond the initial hardware acquisition (about 40% of the total cost), the life cycle maintenance cost of such custom-built measurement systems has turned out to be disastrous for many organizations. Component obsolescence and the difficulty of finding qualified software developers interested in working in the test industry, have made many custom-built radar test sets a very expensive proposition [3]. As older spectrum analyzers become obsolete and fail, finding a suitable replacement can be very difficult. New analyzers may lack 100% backward software compatibility, leaving the test engineer the difficult choice between rewriting old test software, procuring obsolete used analyzers as spare parts, or rebuilding the entire test system from scratch.

Until recently, an oscilloscope, swept spectrum analyzer and vector signal analyzer represented the mainstay of affordable, commercially available test equipment for the radar engineer. The only truly comprehensive multi-domain diagnostic solution available was the custom-built test set.

The real-time signal analyzer was initially introduced around the same time the vector signal analyzer became popular. The RTSA has always had superior transient signal analysis capability relative to other test instruments, but its application to radar signal diagnostics was initially limited [4]. Unfortunately, early RTSAs were rather expensive and initial found applications mostly with SIGINT and EW missions where national security issues warranted the high cost [5].

As Digital Signal Processing (DSP) technology has improved, the affordability of RTSA technology now falls within reach of even modest budgets and offers a viable alternative to the traditional custom built test set for complex radars.

The RTSA Radar Test Approach

The real-time spectrum analyzer is fundamentally different in capability from the swept spectrum analyzer and the vector signal analyzer. The RTSA is optimized to deliver real-time triggering, seamless signal capture, and time-correlated multi-domain analysis. Its architecture is ideal for transient RF signals like radar pulses.

Unlike swept tuned and vector signal analyzers, the real-time spectrum analyzer can process time domain data into the frequency domain in real-time. This allows the RTSA to continuously analyze its input spectrum by taking super fast, real-time Fast Fourier Transforms of the input signal prior to triggering and capturing data. Conversely, other analyzers randomly capture the data, and then analyze what has been captured off-line, leaving large portions of the signal unanalyzed between sweeps or captures.

The RTSA's ability to continuously analyze the signal and trigger captures only on events of interest is ideal for many radar applications. The RTSA's unique Frequency Mask Trigger (FMT) can capture a spectrally interesting event, such as a weak radar pulse, under complex spectral conditions where other analyzers would fail. For example, received radar echo pulses are usually far below the LO to IF leakage levels created in the RF down conversion process. This makes conventional IF level triggering useless directly after the down-conversion mixer. The RTSA's FMT can easily be set to ignore the LO leakage and trigger on the much weaker pulse event. Similarly, capturing weak echo returns in challenging EW environments is easily accomplished.

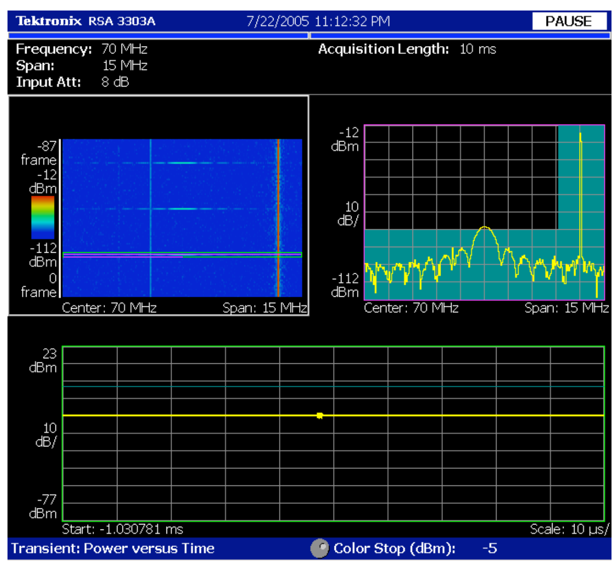


Figure #2 — Frequency Mask Trigger (FMT) can reliably trigger on a pulse spectrum despite the strong LO. Reliable IF power level triggering would be very difficult.

The RTSA is also a multi-domain instrument capable of displaying time, frequency and modulation domain measurements. This allows the RTSA to replace several traditional instruments with a single portable unit. Since each measurement domain is derived from the same seamless time record, measurements are precisely time-correlated. The operator can place a marker on a spectral or modulation anomaly and correlate it with the exact pulse that produced it. Time-correlated displays greatly enhance the diagnostic insight and reliability by providing a critical causality component. Traditionally, such precise time correlated displays between separate instruments were difficult to obtain, requiring synchronization of multiple instruments.

Using a single instrument for radar testing has other advantages in measurement accuracy. Take for example, the peak detectors used in the typical swept spectrum analyzer that can provide a different measurement result than the RMS detectors commonly found in the VSA or RTSA. The real-time analyzer derives all of its display domains from the same time sampled signal record, automatically ensuring complete agreement between domain displays.

Manual control of the RTSA is also simplified, as settings in one display domain automatically transfer to the appropriate axes in the corresponding domains.

Using a single instrument also eliminates the many test system life cycle considerations. In the past, when a dedicated radar test set had an instrument fail, replacement or upgrade of that instrument often became cost prohibitive. In recent years, this trend seems to have grown worse. Increasing component obsolescence rates due to the redistribution of world manufacturing, poorly matched component life spans, the use of external consumer computers and the high rate of operating system turns, make many test instruments a poor choice for long life aviation and marine radar programs. A single box instrument built with the best industrial practices is likely to have a far lower life cycle cost than a collection of interdependent instruments designed primarily for consumer device test.

Similarly, the software investment in the traditional radar test set can be fraught with hidden costs. Using a single instrument with factory supported analysis programs eliminates the burden of in-house software efforts. This is particularly important as radar test software and schema age. Finding qualified individuals with an interest in modifying one-of-a-kind test set software that is more than a few years old is an expensive proposition.

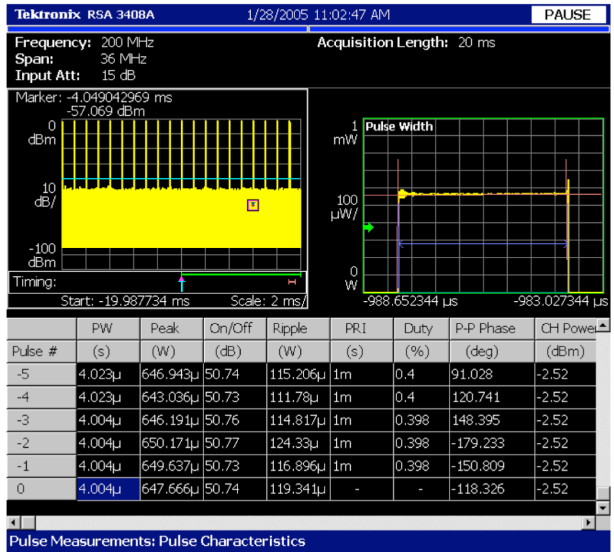


Figure #3 — The real-time spectrum analyzer's radar pulse analysis software is sufficient to replace many custom-built measurement systems.

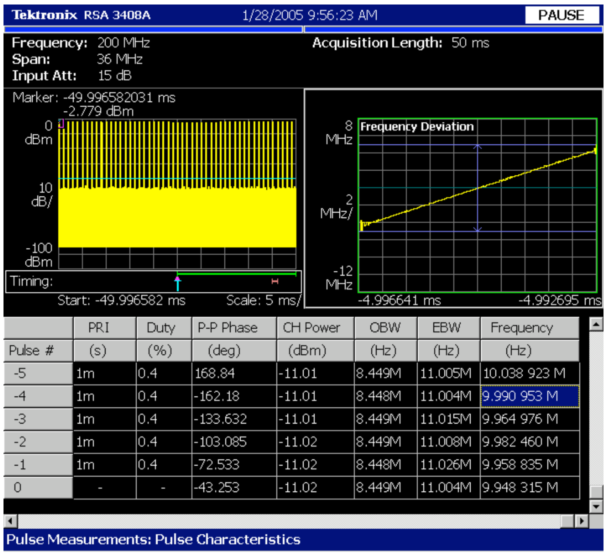
RTSA Multi-Domain Analysis Capability

Comparing the analysis ability of traditional analyzers to the RTSA, we find the RTSA contains the most complete set of built-in radar diagnostics available.

A modern RTSA is equipped with three modes of spectral analysis: swept SA emulation, swept SA with spectrogram, and real-time spectrum analyzer. Swept SA emulation mode allows frequency spans far wider than the unit's sampling bandwidth and is useful for radar measurements like harmonic attenuation. SA with spectrogram is similar, but includes the spectrogram helpful for capturing echo return patterns. Real-time mode is similar to a VSA, but includes the real-time pre-analysis used for triggering a data capture. In real-time mode, the RTSA can also provide the power versus time display necessary to view the time domain pulse shape.

The real-time analyzer's pulse measurement software can now replace most custom Automatic Test Equipment (ATE) measurement code. Important radar pulse information, such as pulse width, peak power, on/off ratio, pulse ripple, pulse repetition interval, duty cycle and pulse-pulse phase shifts can be measured directly on the RTSA with its unique automatic pulse measurement software. The statistics for each received pulse are automatically calculated and displayed, eliminating the need for external computers.

In addition to the basic pulse statistics, pulse compression modulation can be viewed using the RTSA's demodulation measurements. FM chirp linearity, bi-phase modulation, Doppler shifts and pulse doublet phase changes can be readily viewed in the appropriate modulation domain. Furthermore, these displays are time correlated to the power versus time, spectrum and spectrogram display domains, improving diagnostic speed and reliability. A marker placed on a bit error in the phase versus time display will time correlate automatically to the pulse that produced the error in the power versus time display. In most cases, these built-in measurements can effectively accomplish what used to take a rack full of equipment and thousands of lines of ATE software.



	PRI	Duty	P-P Phase	CH Power	OBW	EBW	Frequency
Pulse #	(s)	(%)	(deg)	(dBm)	(Hz)	(Hz)	(Hz)
-5	1m	0.4	168.84	-11.01	8.449M	11.005M	10.038 923 M
-4	1m	0.4	-162.18	-11.01	8.448M	11.004M	9.990 953 M
-3	1m	0.4	-133.632	-11.01	8.449M	11.015M	9.964 976 M
-2	1m	0.4	-103.085	-11.02	8.449M	11.008M	9.982 460 M
-1	1m	0.4	-72.533	-11.02	8.448M	11.026M	9.958 835 M
0	-	-	-43.253	-11.02	8.449M	11.004M	9.948 315 M

Figure #4 — Time correlated RTSA display domains provide confirmation of a linear FM chirp in the power versus time and pulse measurement displays.

Switching to RTSA technology for a single box radar test solution also has some other unique benefits. For example, the RTSA is capable of overlapping FFT frames for enhanced spectral and spectrogram display quality. Digital FFTs are executed on a frame of contiguous time sampled points (i.e. 1024 points). Unlike most vector signal analyzers, the real-time signal analyzer can overlap data FFT frames. This has an effect similar to stretching out the time axis on the spectrogram or reducing the flicker/jerky display of the frequency spectrum. Overlapping FFTs can be very helpful for accurate visualization of pulse patterns in the spectrogram.

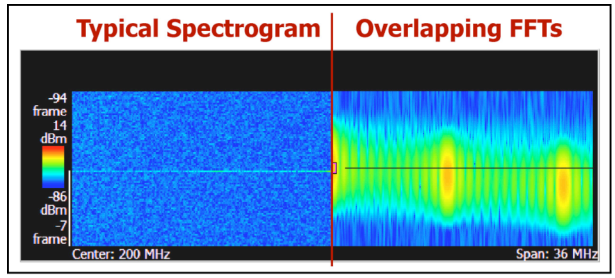


Figure #5 — The RTSA's overlapping FFT capability can effectively stretch the spectrogram in time to reveal detail that is not apparent in the typical VSA display.

Other Radar Test Considerations

There are other considerations that motivate radar test professional to adopt the RTSA test approach, beyond the comprehensive radar pulse pattern measurement software, FMT and overlapping FFTs.

Field portability is one such consideration. The vast majority of radars are installed on mobile platforms, ships, planes, missiles etc. The benefits of a portable single box test solution easily lifted by one individual are substantial when working on mobile radar platforms.

Similarly, there are important benefits to using the same test instrument for development, manufacturing and field diagnostics. In the past, engineering would often use several high-end test instruments to develop a radar, production would employ slightly different equipment installed in an automated test set rack and the field technician would use a custom built portable box. Using different test tools at each stage in a system's life cycle can create measurement agreement problems that are costly to pinpoint. Elimination of measurement discrepancies by using a single instrument for laboratory, production and flight line can result in significant savings.

When it comes to disposing of test systems at the end of a radar program's life, the versatile RTSA makes test equipment liquidation a simple matter. A quick check of online electronics liquidators will reveal an extensive array of specialty radar test sets selling for fractions of one percent of their original value. These custom test sets have effectively no secondary market [6]. The Real-time Spectrum Analyzer would not only offer greater liquidation value, but likely could be reusable on the next radar program.

Conclusion

Relative to traditional multi-instrument test approaches, the present generation of real-time spectrum analyzers offers significant savings in setup time and test system cost.

The unique radar pulse measurement software available for the real-time spectrum analyzer is a suitable replacement for a wide range of radar test set applications. The radar pulse measurement software provides standard pulse measurements and works seamlessly with the time correlated multi-domain displays that are ideal for compressed pulse evaluations.

Employing a single RTSA for radar troubleshooting improves measurement precision relative to a multiple test instrument custom integrated solution. Unique real-time spectrum analyzer capabilities such as the frequency mask trigger and overlapping FFT, further enhances displays, while improving diagnostic ability in complex real-world spectral environments.

Many radar test applications stand to benefit by simply employing the single box real-time spectrum analyzer and pulse measurement software rather than embarking on the traditional custom-built radar test set.

References:-

[1] Steven J. Ostro, Radar Reconnaissance of Near-Earth Objects at the Dawn of the Next Millennium, Near-Earth Objects, Vol. 822 of the annals of the New York Academy of Sciences, May 30, 1997.

[2] Chen Zili, Cao Guozhu, Dun Yi, Radar Equipment Integrated Maintenance Platform, Radar, 1996. Proceedings CIE International Conference, page 550 – 553, Oct. 1996.

[3] T. Hoppin, Strategies for Mitigating Risk Related to the Obsolescence of HP8566/68 Spectrum Analyzers in ATE Systems, IEEE Autotestcon Proceedings, pages 608 – 620, October 2002.

[4] Tektronix, Signal Monitoring, Surveillance and Real-Time Spectrum Analysis, Tektronix Application Note 37W-18576-0, page 2, June 2005.

[5] Tektronix, Fundamentals of Real-Time Spectrum Analysis Primer, Tektronix Application Note 37W-17249-1a, page 2 – 6, April 2005.

[6] BPB Surplus, Website http://www.bpbsurplus.com/subcat10.html, July 25, 2005.

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