A New Approach for an Old Problem:

Testing Secondary Surveillance Radar

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Secondary surveillance radar (SSR) has been around since World War II, based on the military's "identification friend or foe" radar system. While the radar systems have evolved, many of the test challenges have remained constant. Whether designing, characterizing, installing, maintaining or troubleshooting an SSR, one may have different requirements for testing the RF transmission. As a result, different instrumentation is often used, based on the task, or the same equipment is used throughout, requiring users to accept compromises. The former leads to higher equipment cost, the latter inefficiency and lower productivity. This article describes a new approach to these test challenges, where the same test equipment can be used without the compromises.

SSR is used in air traffic control to complement the primary radar system (see **Figure 1**). The primary radar measures the bearing and distance of aircraft or other targets using the reflections of transmitted radar signals. The SSR provides additional information, such as an aircraft's identification code or its altitude. Unlike primary radar, which only depends on signal reflection, SSR systems require the aircraft to have transponders - a transmitter responder, which receives a signal, then transmits a response. An SSR sends an interrogation signal to the aircraft requesting specific information. The interrogation signal is received by the aircraft's transponder, which responds with an encoded signal containing the requested information. Correspondingly, an SSR system has two transmitters to test: the interrogator and the transponder.

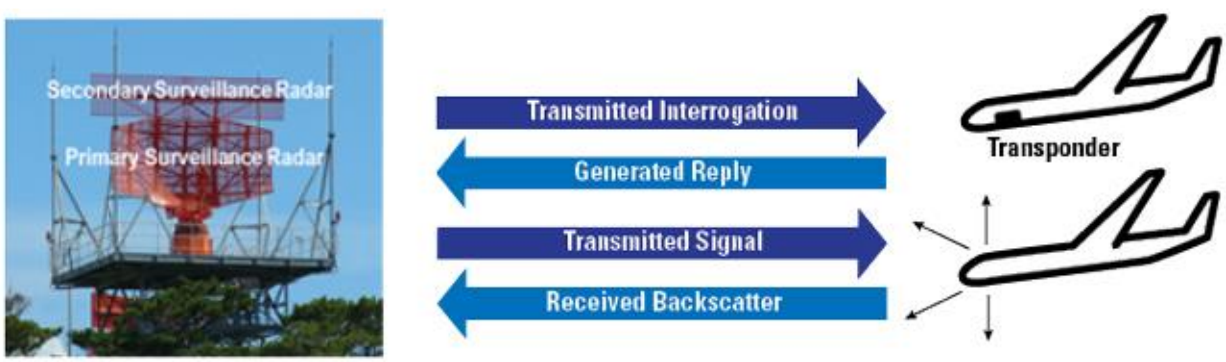

Figure 1 Primary and secondary surveillance radar systems.

The interrogation signals are categorized by modes, primarily A, C and S. The interrogation signal parameters depend on the mode (see **Figure 2**), where mode A requests identity, mode C requests altitude in 100 foot increments and mode S is multi-purpose. The time between P1 and P3 of the mode A/C and S interrogation signals are 8 and 21 µs, respectively. Mode S comprises P1 and P2 in a preamble followed by a data block of 56 or 112 bits modulated with differential phase-shift keying. Mode A and C transponders respond with 12 and 11 pulse replies, respectively, and the mode S reply includes a four pulse preamble followed by a data block of 56 or 112 bits (see **Figure 3**). Mode C does not use the D1 pulse.

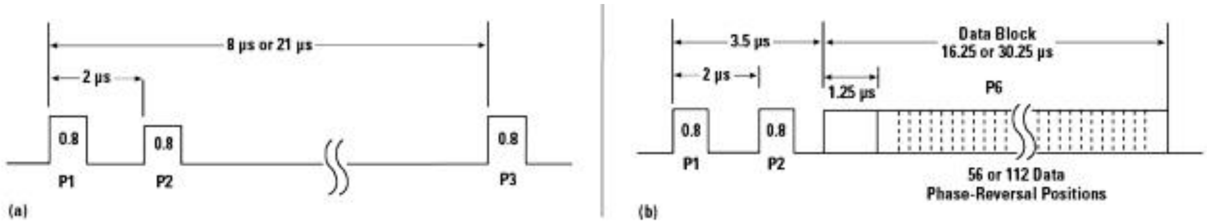

Figure 2 Modes A and C (a) and S (b) interrogation waveforms.

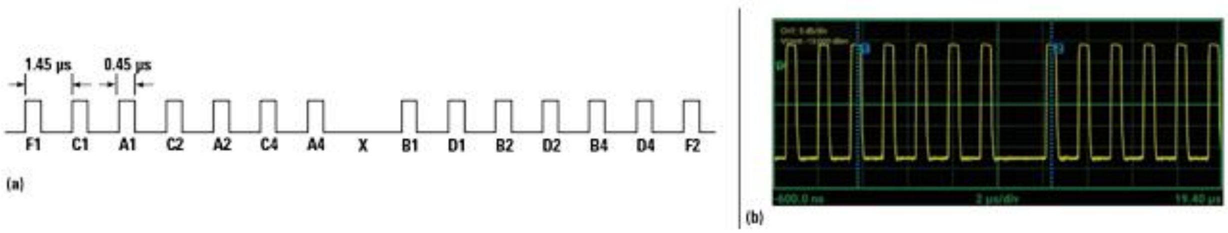

Figure 3 Mode A and C reply sequence (a) and waveform (b).

A simplified block diagram of an SSR is shown in **Figure 4**. Proper design and operation of SSR systems is critical to the safety and security of aviation, with testing essential both at the time of installation and on an ongoing basis. To reduce the possibility of a catastrophic event, federal aviation safety standards, such as defined by the U.S. Federal Aviation Administration, require periodic maintenance and calibration of the transponders. If any issues are found, they must be resolved expeditiously to get the system back online.

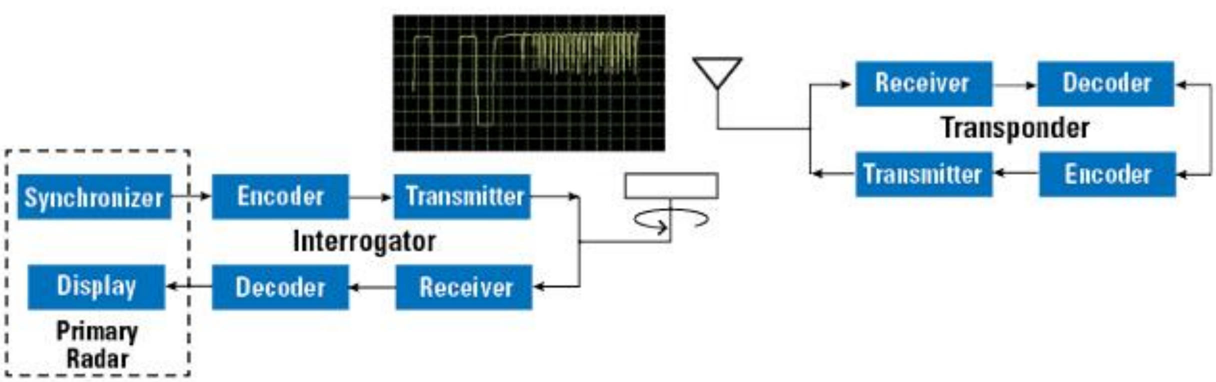

Figure 4 SSR simplified block diagram.

POWER MEASUREMENT CHALLENGES

RF power measurement is a cornerstone of the testing process to ensure proper power levels at various points in the system, verify the pulse shape and the timing between pulses, monitor the reflected power from the antenna and watch for anomalies in transmission, such as signal glitches or dropouts. One example of an anomaly is a VSWR spike caused by a faulty connection as an SSR antenna rotates.

Traditional power meters may not
(b).

The equipment used to make the RF power measurements will depend on the parameters to be measured. For example, while an average power meter may make the nominal power level and VSWR measurements, the SSR would likely need to generate a CW test signal - a special test mode that would take the system offline for maintenance. Otherwise, the pulse waveform may be too complex to accurately measure the average power without advanced triggering and time gating. However, a peak power meter can make pulse measurements, including the pulse shape and timing between pulses, and monitor for waveform glitches or dropouts (see **Figure 5**).

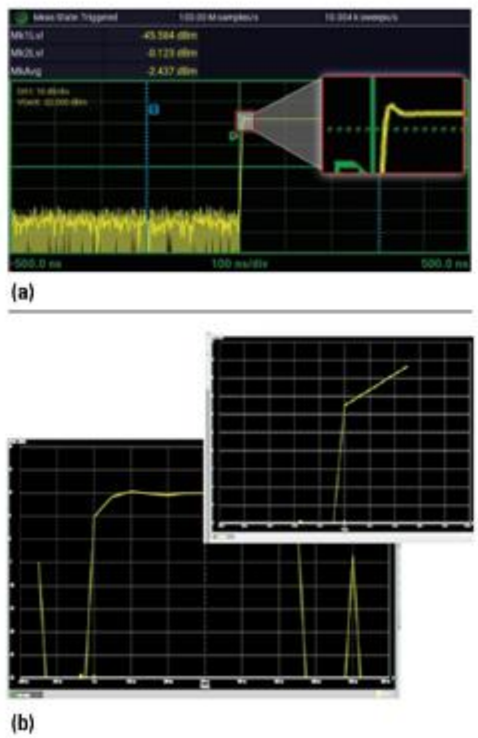

Figure 5 For accurate measurements, the power meter must have sufficient rise time and resolution (a).

RF power measuring equipment has traditionally been available in two configurations. The first is the benchtop power meter, which uses a complementary power sensor or sensors connected with an analog cable. The second is the USB power meter, typically a USB power sensor, which integrates most of the functionality of the benchtop power meter in the sensor and eliminates the display and traditional physical buttons and knobs interface. A USB RF power sensor has the advantages of being a smaller and more economical solution with simplified operation and lower measurement uncertainty. However, it also has tradeoffs: a USB sensor requires a computer to perform measurements, either with user-developed software or a graphical user interface.

The SSR measurement scenarios - installation, maintenance and troubleshooting - determine the features and performance priorities for the RF power measurement equipment. For example, portable equipment may be more important during installation, making the USB RF power sensor a good choice. They are small, lightweight and powered through the USB port of a laptop. A maintenance team may want an instrument that can be rack mounted and remotely accessed. Here, benchtop RF power meters may be the best choice, as they are easy to install in equipment racks and often have remote interface options. Troubleshooters may want better performance for diagnostics, such as wide video bandwidth, fast rise time and fine time resolution, as well as a fast trace update rate for the pulse waveform's power versus time, to aid finding anomalies in real-time. Test equipment with leading performance, fast measurement speed and computer processing would meet these requirements.

As noted, the differing test requirements and priorities will determine the instrumentation best suited for the task. This may lead to higher equipment costs to address all the scenarios or using the same equipment for all scenarios and accepting compromises, which may be inefficient and lower productivity. Because of the criticality of SSR for aviation safety, equipment compromises may not be possible, requiring the purchase of test equipment for each scenario. Unfortunately, this has several disadvantages. In an ideal scenario, the installation, maintenance and troubleshooting teams would share the equipment to maximize equipment utilization and return on investment. Purchasing separate equipment for the different teams reduces utilization and obviously adds cost. Different equipment requires multiple procedures for making the same measurements, which can double or triple the documentation and training. Also, an aberrant measurement will lead to uncertainty. Is there an actual issue with the SSR or is it simply a discrepancy between the measured values, caused by the different measurement techniques and equipment?

INTEGRATED MEASUREMENT SYSTEM

For these reasons, the test challenges posed by SSR systems would benefit from a new approach: using an instrument built with leading measurement technology that combines the utility of the traditional benchtop instrument, the flexibility and performance of USB RF power sensors and the simplicity of a multi-touch display. Used as a benchtop meter with an intuitive touchscreen display, it would provide a standalone solution for capturing, displaying and analyzing peak and average RF power in both the time and statistical domains. The instrument would have the capacity for at least four USB RF power sensors and the capability for independent or synchronized multi-channel measurements of CW, modulated and pulsed signals. The sensors should use standard USB cables, avoiding adapters to convert from specialized connectors to standard USB cables. Each sensor could be used as an independent standalone instrument when disconnected from the benchtop instrument.

TABLE 1

IDEAL POWER METER VS. TRADITIONAL INSTRUMENTS

Ideal Power Meter	*Traditional Benchtop Power Meters*
Large, intuitive, multi-touch touchscreen display.	Smaller, non-touchscreen display.
Up to four USB RF power sensors.	Up to two traditional analog sensors.
No analog cables between meter and sensor; no calibration.	Measurements must be stopped to perform calibration.
	Traditional USB Power Sensors
Large, intuitive, multi-touch touchscreen display.	Laptop or workstation required for software or manual control.
Internal RF source for verifying sensor operation.	User-provided RF source to verify sensor operation.
Synchronized multichannel measurements with a common time reference.	Common time reference measurements may require external hardware.
Standard LAN interface with optional internal GPIB interface for remote control and use with legacy ATE systems.	Different models for USB, LAN. GPIB interface requires external USB-to-GPIB converter.
Standalone, speeds time to measurement.	Requires installation of drivers, software and applications.

The sensors would cover the 1,030 and 1,090 MHz SSR bands with the capability to capture and analyze peak and average power and measure the parameters for evaluating SSR performance. With broad frequency coverage, the sensors would enable testing other radar systems operating at X-, K- and Ka-Band. Using USB RF power sensors makes the instrument essentially futureproof. New sensors can be added to address new requirements, which is not always possible with traditional power meters, as benchtop instruments can limit the performance of the sensors. **Table 1** summarizes the desired capabilities of this ideal test system compared with traditional benchtop and USB power measurement options, and **Table 2** shows the desired performance of the primary measurement parameters.

An example of an instrument which provides this flexible, high performance power measurement capability for SSR testing is the new Boonton PMX40 RF Power Meter (see **Figure 6**). It works with Boonton's real-time peak power sensors (RTP5000), real-time true average USB power sensors (RTP4000) and true average connected USB power sensors (CPS2008).

TABLE 2

PERFORMANCE CAPABILITIES

Parameter	Desired Performance
Rise Time	3 ns
Minimum Pulse Width	10 ns
Time Resolution	100 ps
Measurement Processing	Real Time
Measurement Speed	100,000/s

Figure 6 Pulse train measured on the Boonton PMX40 RF power meter.

SUMMARY

The installation, maintenance and troubleshooting of SSR systems is challenging. Each test scenario has its own priorities for RF power measurement defining the features and capabilities of the equipment making it. Historically, either different instruments were used, tailored to each measurement task, or the same equipment was used for all, requiring users to compromise test setup and performance. A better approach to solve the challenge uses a single, integrated test system combining the utility of a traditional benchtop instrument, the simplicity of a multi-touch display and the flexibility and performance of USB power sensors.