The VSX3622, a 1.5 kW X-Band GaN Power Amplifier for Radar Application

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Abstract

Solid State Power Amplifiers (SSPAs) incorporating GaN transistors provide compact and efficient sources of microwave power. CPI EDB has developed a 1.5 kW X-band SSPA, CPI EDB model VSX3622, for radar applica-tions. The VSX3622 SSPA combines the power from two VSX3614 SSPAs, which each operate at nominal-ly 1 kW, saturated. This paper will present details of the design and performance data for both amplifiers.

Background

CPI Electron Device Business has been manufacturing microwave and radar components for more than 60 years. CPI Electron Device Business (CPI EDB) is a global company with a world-class global network of service centers. CPI EDB develops, manufactures, and repairs radar components and systems having full compliance to military stan-dards. Our design and manufacturing processes are geared for military as well as high-reliability commer-cial workmanship. CPI EDB is an ISO 9001/AS9100 certified manufacturer.

VSX3614 SSPA Design

For a given output power, size, weight, and efficiency are critically important for mobile applications. Solid state power amplifiers incorporating GaN devices have quickly found a home in mobile applications due to the high power density and efficiency of the GaN transistors. CPI EDB has capitalized on these attributes for the development of the VSX3614, the VSX3630, and the VSX3622 X-Band SSPAs for radar applications.

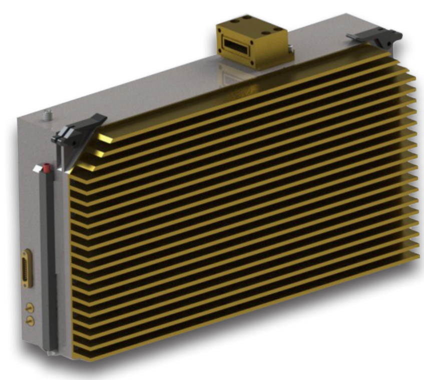

Figure 1 VSX3614 Solid State Power Amplifier

The VSX3614 design has been optimized for duty cycles to 10% duty and to allow multiple amplifiers to be combined efficiently using waveguide combiners to produce a multi kilowatt transmitter. The VSX3630 design has been optimized for duty cycles up to 20%.

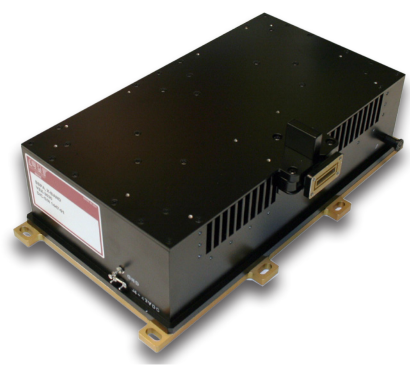

Figure 2 VSX3630 Solid State Power Amplifier

VSX3614 Electrical Design

The VSX3614 design is based on a 100 watt power device. The system block diagram is shown in Figure 3.

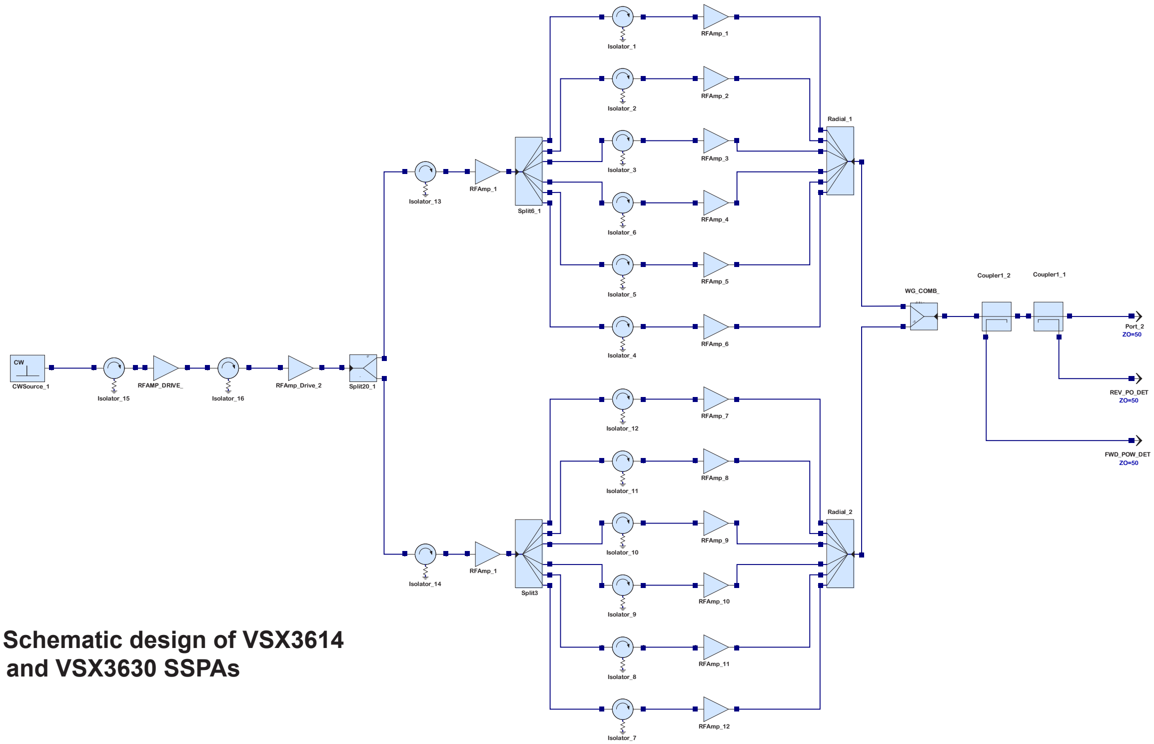

Figure 3 Schematic design of VSX3614 and VSX3630 SSPAs

The design consists of a two stage pre- driver with power split two ways and then amplified. Each secondary driver feeds a 6-way radial power divider and the 12 power stages. The signals are then recombined in two 6-way isolated, radial combiners. The isolated radial in-phase combining structure is used to sum the powers from individual transistors while maintaining isolation between adjacent devices. The combiners provide greater than 20-dB return loss for the transistors.

The 12 power devices are mounted directly to the heat exchanger to provide the best thermal interface with the lowest thermal resistance and optimum heat spreading. Figure 4 shows a computational simulation of the temperature profile of the VSX3614 at the transistor to baseplate interface. The maximum temperature rise is less than 3 °C.

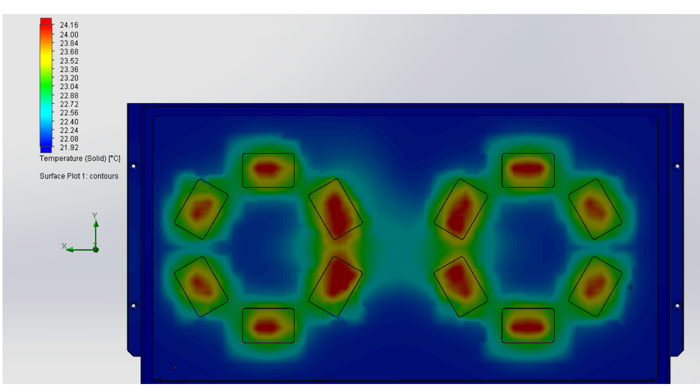

Figure 4 Thermal profile of VSX3614 SSPA

The SSPA's cascaded gain and output power at Psat is shown in Figure 5.

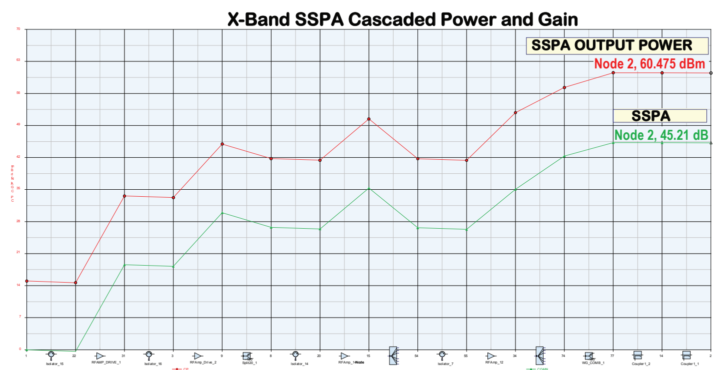

Figure 5 Cascaded gain and output power for VSX3614 SSPA

The CPI-proprietary combiners enable an overall amplifier efficiency of greater than 15% in the VSX3614 SSPA, where overall amplifier efficiency is defined as the ratio of RF output power to DC input power. The RF bandwidth is greater than 20%

The VSX3614 SSPA is O-ring sealed and internally temperature compensated. Packaged GaN FETS and MMICS ensure high reliability under extreme environmental conditions. Table 1 summarizes the data for the VSX3614 SSPA.

Frequency Range	7.6 to 9.6 GHz
Peak RF Power	1 kW, saturated
Pulse Width	0.2 to 100 microsecond
Small Signal Gain	50 dB small signal,45 dB at nominal output power
Duty Cycle	10%
Pulse Droop	0.5 dB
Output Power Flatness	1 dB, over selected bandwidths
Harmonic Output	-40 dBc maximum
Inter Pulse Noise Power Density	-165 dBc/Hz maximum
Prime Power	42 VDC at 13 Amps
Weight	11 pounds, including air heat exchanger

Table 1 Key Parameters for VSX3614 SSPA

Output power as a function of frequency and temperature is plotted in Figure 6 for the VSX3614 SSPA. This data was taken at 100 µs pulse widths at 10% duty.

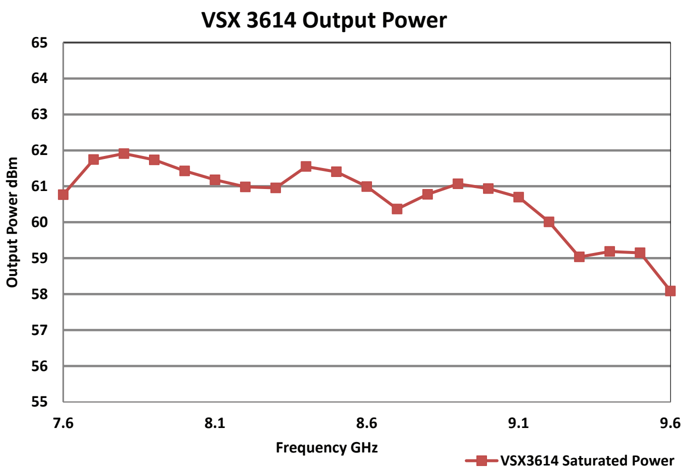

Figure 6 VSX 3614 output power at room temperature

VSX3614 SSPA Life Test

CPI EDB tests the GaN transistors and the SSPA design under pulsed RF conditions to validate the robustness of the devices and amplifier design. A 1000+ hour life test was conducted on the VSX3614 amplifier while operating at 100 µs pulse width and 5% duty factor. The VSX3614 SSPA was operated, at ambient temperature, in a rack assembly that mimicked the cooling air flow of a system configuration. The RF output was monitored for peak power using a USB pulsed-power sensor and the phase stability was monitored using a quadrature-detector-type phase bridge. The power and phase data was automatically logged every 5 minutes for the duration of the life test. Power supply voltages and currents and the ambient temperatures were recorded periodically.

CPI EDB's 1.5 kW Power Amplifier, the VSX3622

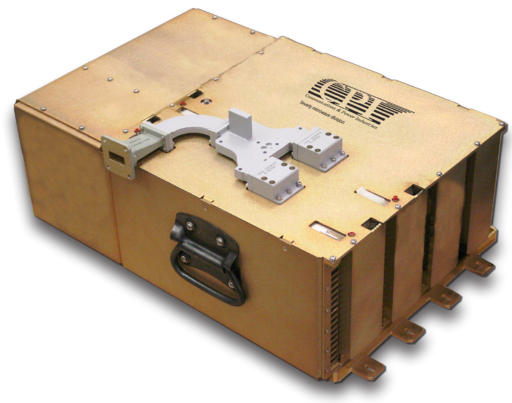

Figure 7 VSX 3622 is two VSX3614 SSPAs combined with fan box and slots for power supply

The VSX3622 amplifier was designed for mobile, air-cooled applications. As such, the overall size and weight and efficiency are driven by the choice of the power combiners. The generation of the 1.5 kW of output power from the coherent addition of two lower power SSPA bricks. The output combiner used for this amplifier is a half-height WR90 magic T with a load port for combining isolation. The system will also include a waveguide isolator, forward and reverse power samplers in the system packaging.

Frequency Range	7.6 to 9.6 GHz
Peak RF Power	1.5 kW, saturated
Pulse Width	0.2 to 100 microsecond
Small Signal Gain	50 dB small signal, 45 dB nominal output power
Duty Cycle	10%
Pulse Droop	0.5 dB
Output Power Flatness	1 dB, over selected bandwidths
Harmonic Output	-40 dBc maximum
Inter Pulse Noise Power Density	-165 dBc/Hz maximum
Prime Power	42 VDC at 25 Amps @ 10% Duty Cycle

Table 2 Key Parameters for VSX3622 SSPA

CPI EDB conducted a temperature test on the VSX3622 SSPA. The pair of amplifiers comprising the VSX3622 SSPA were mounted on a chassis and cooled with a fan mounted in the box at the end of the enclosure. As shown in Figure 7, the two adjacent slots will house the system power supply cooled by the same fan. The thermal profile shown in Figure 8 depicts the chamber ambient air in blue and the output from four thermocouples; two mounted on the body of the units and the other two mounted in the output air plenum. The graph shows that the unit operating at 100 μs pulse width and at 7% duty has a temperature rise of 15 -18 °C above ambient air temperature.

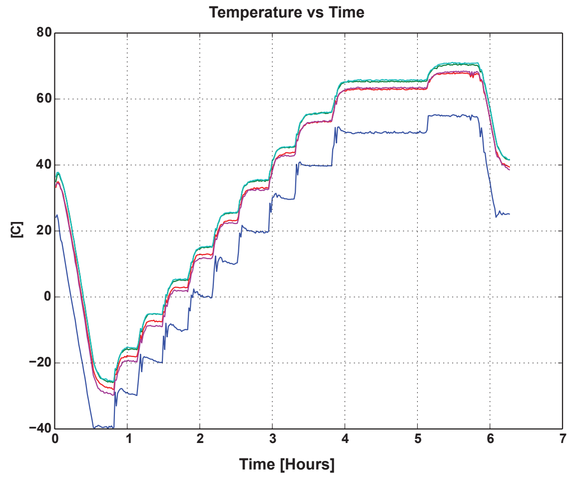

Figure 8 Temperature profile for VSX 3622

Data was measured and recorded every minute in the profile while frequency swept data was measured periodically. The RF output power was plotted across frequency and temperature.

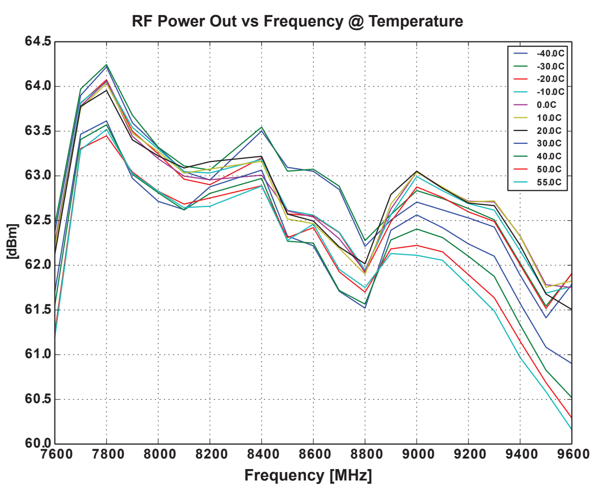

Figure 9 Power vs. frequency and temperature for VSX3622

Power data from the pulsed power meter was measured at the 5% and 95% portion of the 100 μs pulse to record pulse amplitude droop. The RF output power droop is plotted as a function of frequency and temperature in Figure 10.

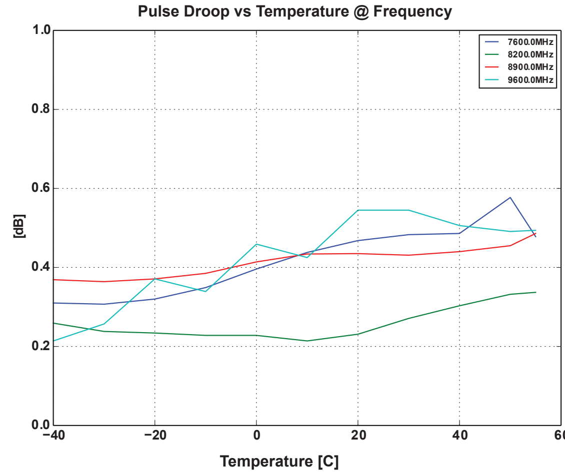

Figure 10 Pulse amplitude droop vs. temperature for VSX3622

Output power versus input power and frequency was measured at the temperature extremes and 25 °C.

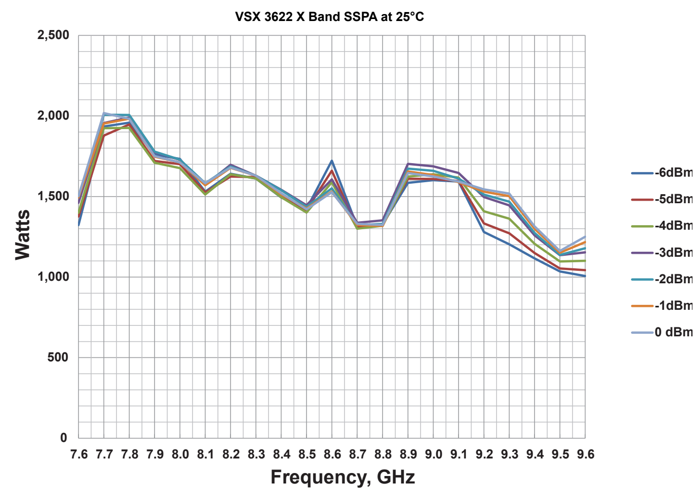

Figure 11 Output power vs. frequency and input power at 25 °C for VSX3622

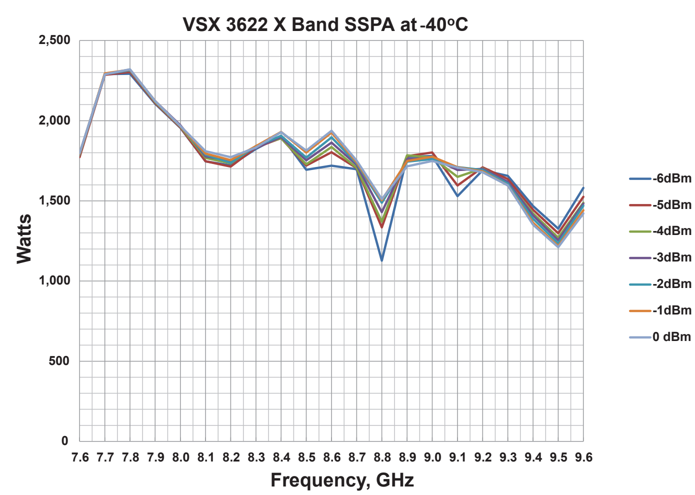

Figure 12 Output power vs. frequency and input power at -40 °C for VSX3622

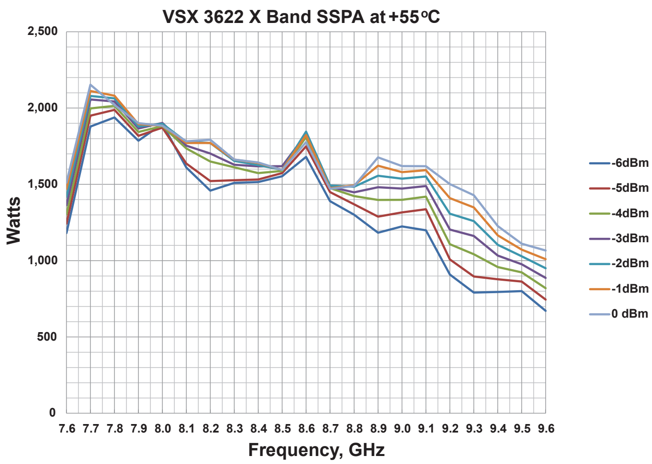

Figure 13 Output power vs. frequency and input power at 55 °C for VSX3622

The data measured at 55 °C indicates the design could use more drive power at the higher end of the band to fully saturate the output devices.

Pulsed waveforms are shown in Figures 14 and 15 at an operating frequency of 9.0 GHz. Figure 14 shows the output power of a 10 µs pulse at a pulse repetition frequency of 1 kHz. Figure 15 shows the output power of a 100 µs pulse at a pulse repetition frequency of 1 kHz. Power is measured with a pulsed power meter. These waveforms were taken at ambient temperature.

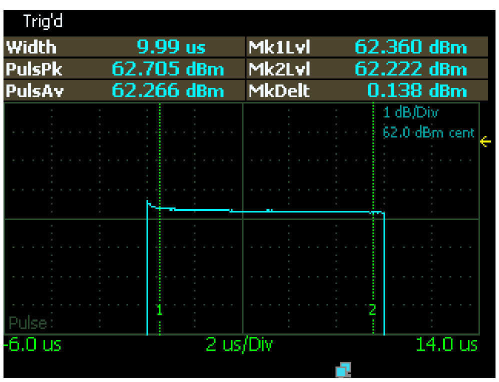

Figure 14 Power at 1 µs pulse width and 1 kHz pulse repetition frequency.

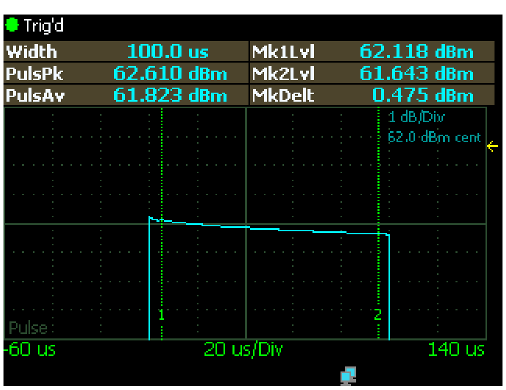

Figure 15 Power at 100 µs pulse width and 1 kHz pulse repetition frequency

In Figure 16 the pulse phase droop data is plotted. Figure 17 shows the AM and PM noise data.

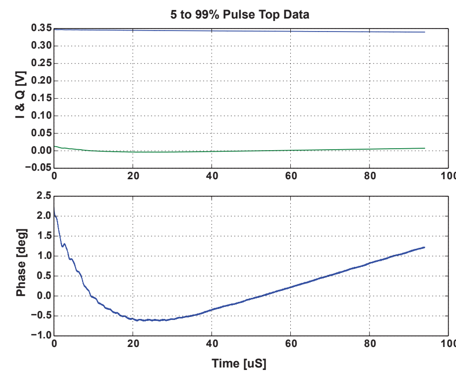

Figure 16 Pulse droop and phase data as a function of time across a 100 µs pulse for VSX3622

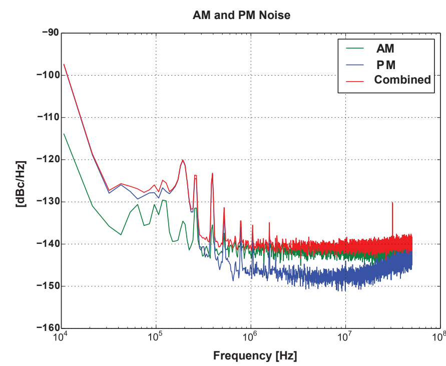

Figure 17 AM and PM noise for VSX3622

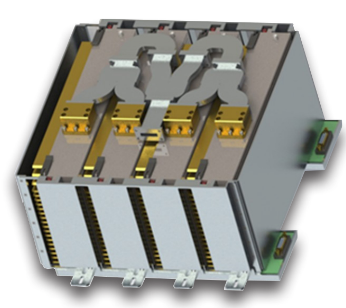

Figure 18 Four-amplifier module providing 2.5 kW at X-band

Summary

CPI EDB has developed and extensively tested the VSX3614, the VSX3630 and the VSX3622 SSPAs. CPI EDB has demonstrated efficient and compact combining of multiple amplifiers at X-band. These amplifiers extend CPI EDB's proud heritage of high-power, high-reliability RF transmitters into a new technology regime. CPI EDB's GaN SSPAs can be readily combined into amplifiers with other form factors for power levels from 1 kW to 20 kW in a cost-effective manner at frequency ranges from L-band to X-band. Figure 18 shows one such form factor with four SSPAs power combined to generate 2.5 kW at X-band.