4 kW X-Band GaN Power Amplifier and Receiver Protector for Radar Applications

George Solomon, Dave Riffelmacher, Jay Conway, Mike Tracy, Jen Moore, Matt Kirkham, and Tony Andreucci
Communications and Power Industries LLC
Beverly Microwave Division

Abstract

GaN Solid State transistors are utilized in many radar platforms and provide compact and efficient sources of microwave power. CPI has developed a 4 kW X-band SSPA, CPI model VSX3717, for radar applications. The VSX3717 SSPA combines the power from four VSX3716 SSPAs, which each operate at nominally 1.5 kW, saturated. This paper will present details of the SSPA amplifier and receiver protector used for airborne radar applications.

Background

The Beverly Microwave Division of Communications & Power Industries LLC (CPI BMD) has been manufacturing microwave and radar components for more than 60 years. Communications & Power Industries LLC (CPI) is a global company with a world-class global network of service centers. CPI BMD develops, manufactures, and repairs radar components and systems having full compliance to military standards. Our design and manufacturing processes are geared for military as well as high-reliability commercial workmanship. CPI BMD is an ISO 9001/AS9100 certified manufacturer.

VSX3716 SSPA

The VSX 3716 is the next generation of GaN power amplifiers utilizing the high-power density and efficiency of the GaN transistors. CPI has developed multiple X-Band SSPAs for radar applications. As the power density increases, the challenges of heat extraction and efficient combining also increase. This paper will discuss some of those challenges.

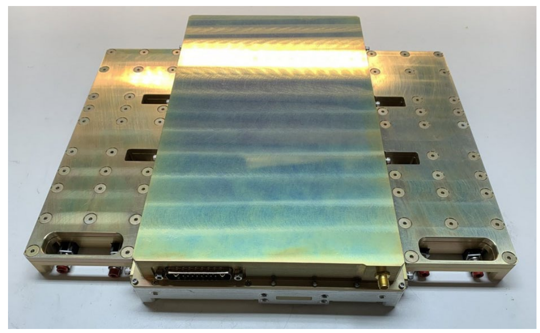

Figure 1 VSX3716 Solid State Power Amplifier

The VSX3716 design has been optimized for duty cycles up to 10% duty and to allow multiple amplifiers to be combined efficiently using waveguide combiners to produce a multi kilowatt transmitter. The VSX3716 design transfers the heat to the sides of the assembly to allow the heat to be extracted either with conduction cooling or air cooling while maintaining a constant stacking height.

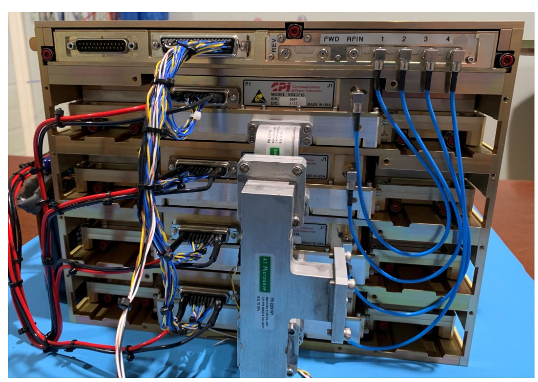

Figure 2 VSX3717 4 kW Power Amplifier

VSX3716 Electrical Design

The VSX3716 design combines eight 300 W pulsed devices to achieve the combined output power of 1500 W, nominal.

© 2021 CPI Beverly Microwave Division. All rights reserved.

GaN transistor power density continues to increase, and the desire for efficient power combining, wide bandwidth and small size drove the design. The combiner selected for this amplifier was an integrated half-height WR90 hybrid design to provide the low loss combining while maintaining the bandwidth and isolation between adjacent devices.

The eight power devices are mounted directly to the chassis while heat pipe technology is used to extract the heat from under the transistors to the sides of the amplifier. The exchanger can be either conduction, liquid or air cooled depending on the application while maintaining a common stacking height.

• Frequency:	9.0 GHz to 10.0 GHz
• RF Power Output:	1.5 kW typ saturated, 100 µsec
• Duty Cycle:	10%
• Connector, RF Input:	SMA Female
• Connector, RF Output:	Half Height WR90 waveguide
• Connector, DC:	D Sub, 15 + 2 Power
• Input VSWR:	1.5:1 Max
• Output VSWR:	2.0:1 Max
• Power in:	5 dBm nominal at 1.5 kW output
• DC Power:	+50 VDC @ 16 A typ, 10%
• Efficiency	18 – 20 %
• Cooling:	Air, Liquid or Conduction Cooled
• Control:	CAN Bus
• Temperature:	-40 to +50°C operating air temperature
•	-54 to +100°C storage
• Over-temp Protect:	Monitored internally

Table 1 Key Parameters for VSX3716 SSPA

The output power from the SSPA is show in figure 3.

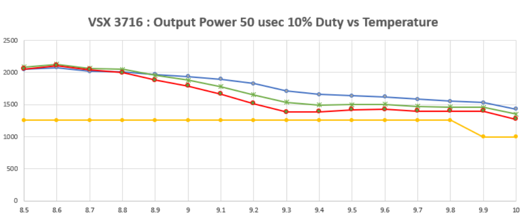

Figure 3 RF Output Power VSX 3716 SSPA

A multiple stage amplifier that operates over a wide operating temperate range requires the ability to control the operating point of the devices dynamically to optimize performance. CPI utilizes internally developed software to measure and control the device current over the operating temperature range, that also provides a very robust heath and monitor status of each device.

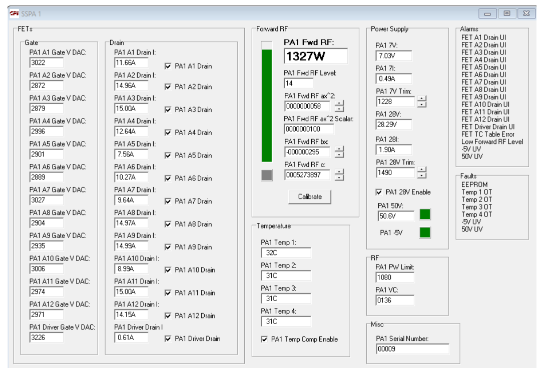

Figure 4 CPI CANTRACE Software

The software monitors the pulsed current of each transistor and actively adjusts the gate to maintain optimum performance. The software also monitors peak RF power, power supply metrics and multiple unit temperature readings.

VSX3717 HPA Electrical Design

The VSX3717 design combines four of the VSX3716 s with a waveguide combiner, and a master control and driver module.

• Frequency:	9000 to 10000 MHz
• RF Power Output:	4 kW min, saturated
• Duty Cycle:	10%
• Connector, RF Input:	SMA Female
• Connector, RF Output:	WR90 waveguide
• Input VSWR:	1.5:1 Max
• Output VSWR:	2.0:1 Max
• Power in:	0 dBm nominal at 4 kW output
• DC Power:	+50.5 VDC @ 65 A typ, 10%
• Efficiency	15%
• Cooling:	Air, Liquid or Conduction Cooled
• Control:	Ethernet
• Temperature:	-40 to +50°C operating air temperature
•	-54 to +100°C storage
• Over-temp Protect:	Monitored internally

Table 2 Key Parameters for VSX3717 HPA

© 2021 CPI Beverly Microwave Division. All rights reserved.

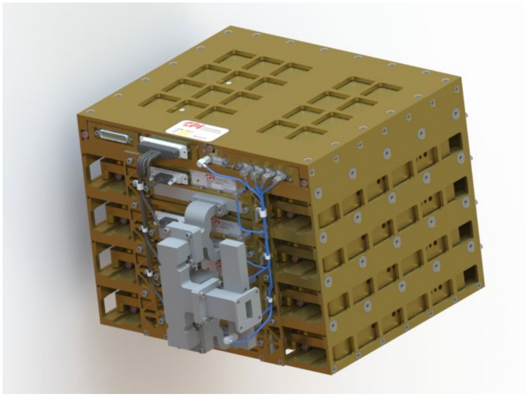

Figure 5 VSX 3717 is four VSX 3716 SSPAs combined with Master Control Assembly

The VSX3717 amplifier was designed for liquid-cooled airborne applications. The combiner was selected to optimize size and weight. Two half-height waveguides from two SSPAs are combined in phase to form full-height WR90 waveguide. The output combiner is a full 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.

Figure 6 Output combiner for VSX3717 HPA

The combiner provides a excellent combining efficiency over the frequency range in a small footprint. The output power is plotted from 8.5 to 10 GHz.

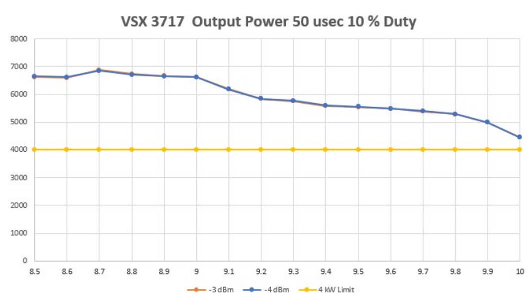

Figure 7 HPA output Power vs Frequency

The system level software allows the adjustment of the insertion phase for each SSPA thru the GUI interface to optimize performance and allow for easy maintenance.

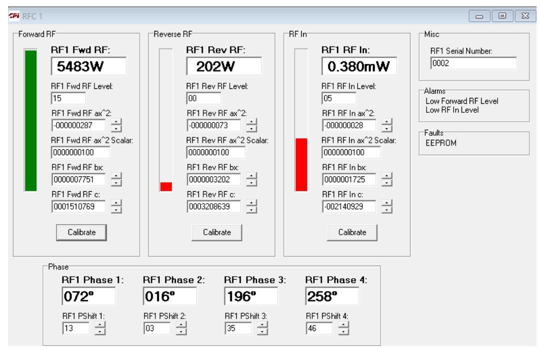

Figure 8 Master Control GUI and Phase Control

A pulsed output waveform is shown in Figure 9 at an operating frequency of 9.5 GHz with a pulse width of 8 µs. Power is measured with a pulsed peak power meter. This waveform was collected at ambient room temperature.

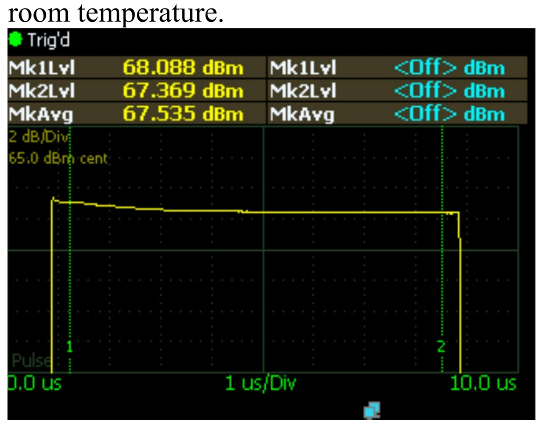

Figure 9 Output power at 8 µs pulse width

© 2021 CPI Beverly Microwave Division. All rights reserved.

CLX2222 Receiver Protector Electrical Design

CPI has been producing receiver protectors for over 70 years with extensive expertise to draw from. CPI provides many products that cover many frequency ranges and power levels from Watts to Megawatts. The CLX2222 design covers the frequency range of 9 to 10 GHZ and the typical performance is shown in Table 3.

- Frequency: 9.2 to 9.7 GHz
- Extended Frequency: 9.0 to 10.0 GHz
- High Power Conditions/Performance:
  - RF Fault Power Input: 8 kW peak
  - RF Normal Power Input: 800 W peak
  - Duty Cycle: 20% max, 5% typ
  - Pulse Width: 8 µs max
  - Flat Leakage Power: 17 dBm max
  - Spike Leakage Power: 20 dBm max
  - 3-dB Recovery Time: 500 ns max
- Low Power Performance
  - Input Return Loss: 12 dB min
  - Output Return Loss: 14 dB min
  - Linear Gain: 29 to 33 dB
  - Noise Figure (25ºC): 3.0 dB max (2.7 dB typ)
  - Output P1dB: 12 dB min
  - Gain Variation (Frequency): 1.0 dB max
  - Gain Variation (Temperature): 0.025 dB/dB/ºC max
- RF Input: WR90 waveguide
- RF Output: SMA Female
- DC Power: +15 VDC 400 mA max, -15 VDC 150 mA max
- Temperature: -40ºC to +85ºC

Table 3 Key Parameters for CLX2222

The CLX2222 utilizes a combination of plasma and solid state technologies to achieve ideal performance for this integrated receiver protector and LNA. This is accomplished while also maintaining a low profile within the system (1.125" x 5.62" x 2.75").

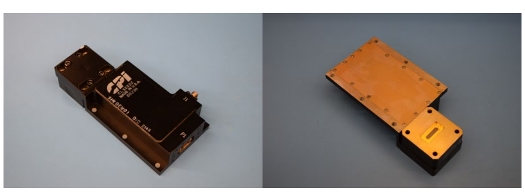

Figure 10 Low profile, WR90 input, SMA output CLX2222

The plasma section of the device is made up of a low-Q bandpass filter with a vacuum tube that forms a plasma when high power signals are presented. With a plasma formed, a virtual short is presented and the signals are reflected back to the source. The plasma section is more commonly known as the pre-TR, whose bandpass response can be seen below. Because of this low Q and minimal dielectric loading, the insertion loss is almost negligible. The advantage of the plasma section is in power handling; the more power the better the short which makes for a very robust limiter for high-power radar systems.

Figure 11 Band Pass Performance

The diode limiter will suppress high power signal to about 50 dBm when the pre-TR plasma forms to reflect higher power signals. The breakdown power of the pre-TR can be observed in the performance of the full assembly. With 50 dBm input to the unit, the recovery time of the device improves by approximately 10%. Notice that the recovery time stretches as input power is increased but drops when the pre-TR forms its plasma. Longer pulse width will also increase recovery time.

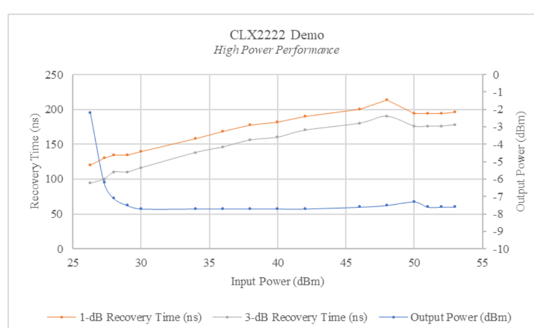

Figure 12 High Power Performance (f_c = 9.5 GHz, PW = 8 µs, du = 20%)

© 2021 CPI Beverly Microwave Division. All rights reserved.

The solid state section of the device is a chip-and-wire assembly that employs silicon PIN diodes for limiting and attenuation, and GaAs LNA MMICs following in the chain. When high power is present the PIN diodes are biased using a feedback circuit within the device. The diodes can also be biased with an external blanking command as well providing over 70 dB of attenuation. These features provide both passive and active protection for the radar system. Figure 13 is the block diagram for a typical receiver protector.

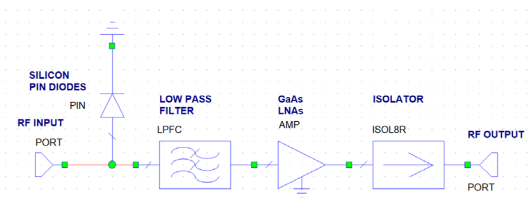

Figure 13 Main Transmission Path Block Diagram

The limiter is designed in a proprietary air-coax structure. This medium's air loading reduces dielectric losses and prevents possible substrate failure that is a risk for microstrip and stripline designs. The effect of the low loss transmission line can be seen in the noise figure measurement of the stackup.

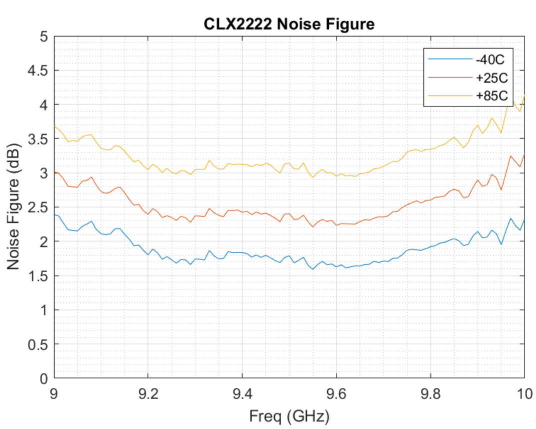

Figure 14 Noise Figure over Temperature

Integration of the RP and LNA into one assembly removes additive losses of adapters and connectors within the system. The combined assembly provides the radar with a robust low noise assembly which improves system sensitivities.

Summary

CPI has the ability to provide both VED and solid-state solutions for multiple radar applications. The paper shows the latest evolution of the solid-state technology and improvement on power density, software control and health and status monitoring. CPI combines transmitter and receiver protector capabilities to provide high-power solutions for radar developers. CPI continues to stay at the forefront of developing RF technology and looks forward to working with radar customers to meet the needs of tomorrow's radar systems.

Please contact the experts at CPI for questions on our SSPAs.

ElectronDevices@cpii.com
Cpii.com/bmd
+1(978)922-6000

© 2021 CPI Beverly Microwave Division. All rights reserved.