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A GaN Solid State Amplifier Replacement for a 1kW Traveling Wave Tube

(By: Frank Decker)

Advances in GaN transistor technology, including higher frequency, bandwidth and power, offer the opportunity to overcome TWT limitations with solid state power amplifiers (SSPA). These solid state designs overcome the inherent problems with electron tube TWTs of limited life and single point failure susceptibility while addressing the competing high performance airborne system requirements of kilowatt power levels and compact size.

Figure 1: GaN, QBS-609, 1kW Solid State Power Amplifier

Figure 1 is the API Technologies, QBS-609, 1kW GaN SSPA. The housing is 11.8"L X 6.1"W X 2.2"H, weighs 10.3 lb. and is a footprint replacement for a commercially available TWT amplifier. Designed for compact airborne systems, the QBS-609 operates from a +28VDC supply and is compliant to MIL-STD-704 and RTCA DO-160. With 0 dBm RF input power over the 9.2 to 9.75 GHz frequency band, the amplifier provides 1kW RF output power for up to 100usec pulse width and 10% duty cycle. Using parallel combined GaN power transistors in the final stage amplifier, the QBS-609 provides eleven health monitoring points where failure at any one or multiple points results in a soft fail condition. DC and RF connector interfaces to the amplifier include SMA RF input and TNC RF output connector, 15 pin d-sub power connector and 21 pin micro d-sub control connector. Figure 2 is a block diagram showing the major subassemblies included in the GaN SSPA.

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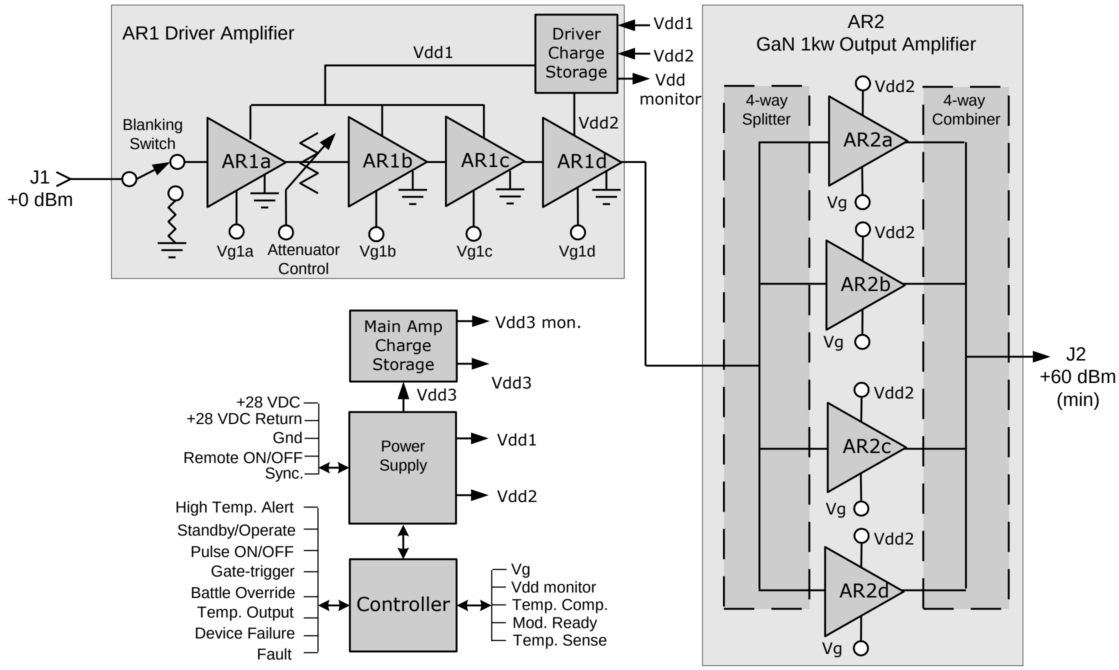

Figure 2: Block Diagram, QBS-609 GaN SSPA

The block diagram in Figure 2 shows major subassemblies in the QB-609 including power supply, charge storage board, controller, driver amplifier and main amplifier. The power supply is compliant to MIL-STD-704 and RTCA DO-160, operates from an isolated 28 VDC system supply and can be externally synchronized. With 800W maximum power capability, the QB-609 power supply provides the SSPA with +12 and +15VDC housekeeping voltages, +10 and +36VDC switched drain voltages and +10VDC continuous drain voltage. The system controller activates power supply drain voltages once the power supply stabilizes at turn-on; the controller also provides switching control to gate drain voltages during pulse RF ON/OFF periods and monitors power supply temperature and health. An opto-isolator is included in the power supply for remote ON/OFF control.

Drain voltage outputs from the power supply are applied to driver and main amplifier charge storage subassemblies (Figure 2). During RF pulse transmission, all peak current requirements are provided by the charge storage subassemblies since the power supply connection to the charge storage board is gated OFF. RF pulse amplitude and phase distortion are minimized by switching the power supply OFF during RF pulse transmission.

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As shown in the Figure 2 block diagram, the RF section of the QBS-609 consists of driver amplifier AR1 and GaN 1kW output amplifier AR2. Driver AR1 has 3 gain stages AR1a, AR1b, AR1c driving a final output amplifier AR1d. AR1 is a compact design with overall dimensions 5.4"L X 1.9"W X 0.90"H.

Amplifiers AR1a through AR1c are designed using discrete surface mount components on a microstrip printed wiring board (PWB). An SP2T blanking switch is located before AR1a and a 20dB voltage variable attenuator (VVA) is located between stages AR1a and AR1b. The blanking switch is turned ON during RF pulse transmission and OFF when no RF is present. In concert with the blanking switch being in the OFF state, all QBS-609 transistors are pinched OFF when RF pulses are not present resulting in a minimum 80dB isolation between RF pulse ON and OFF periods. The VVA sets the QB-609 overall gain to 60dB so with 0 dBm RF input, RF output power is 1kW. In addition to setting overall amplifier gain, the VVA provides gain compensation over the -45°C to +85°C operating case temperature range. Driver amplifiers AR1a to AR1c provide +48 dBm of output power to final stage driver amplifier AR1d.

Amplifier AR1d (API part number QB-1008) is a 350W multi-chip module (MCM). Figure 3 is a picture of the QB-1008; the package size shown is 1.4"L X 1.8"W X 0.3"H containing GaN transistors in a four 100W amplifier configuration. The QB-1008 is a hybrid amplifier useing a combination of microstrip, stripline and lumped constant circuits to perform impedance matching and RF splitting and combining functions. Gain stability, 2nd harmonic filtering and bias distribution circuits are integrated into the impedance matching and combining circuits. The QB-1008 generates 350W (minimum) peak RF output power across the 9.2 to 9.75 GHz frequency band.

Figure 3: QB-1008, 350W MCM amplifier

Figure 4 is a plot of the QB-1008 saturated RF output power and efficiency vs. frequency. Minimum saturated output power is 55.5 dBm (355W) and minimum efficiency 34%. When integrated into the AR1 driver assembly, AR1 provides a minimum of 350W RF peak power with 65 dB gain. RF output from AR1 is applied to the RF input port of the QBS-609 final stage amplifier (AR2) shown in the Figure 2.

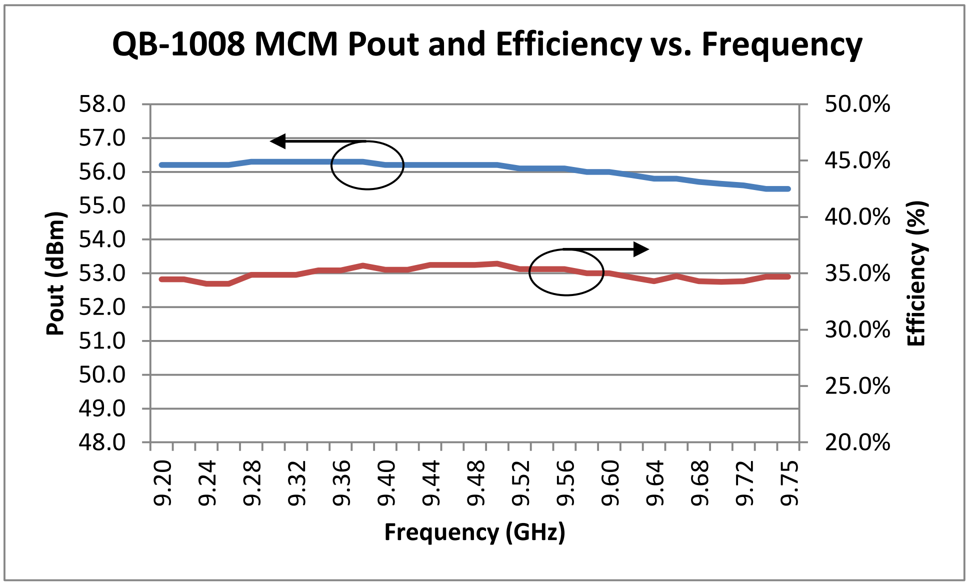

Figure 4: QB-1008 Saturated Power Output and Efficiency vs. Frequency

The QBS-609 final stage power amplifier (AR2) configuration is shown in the Figure 2. Components in AR2 include input distribution board, four QB-1008 modules and an output combiner. The input distribution board provides a 4-way RF power split to the 350W driver input signal. The four RF signals from the splitter drive the final stage QB-1008 amplifiers. In addition to an RF splitting function, the distribution board provides gate and drain voltage to the amplifiers and interconnect lines to various control and monitor components located on the output amplifier. Four QB-1008 amplifiers generate 1kW of combined peak output power in the final stage amplifier of the QBS-609. AR2's QB-1008 packages is identical to driver stage AR1d (Figure 3) except they have an integrated waveguide launch designed into the package. The waveguide launch allows the RF output to be directly coupled into a waveguide combiner. The four final stage amplifiers are mounted directly to the chassis to keep thermal resistance at a minimum.

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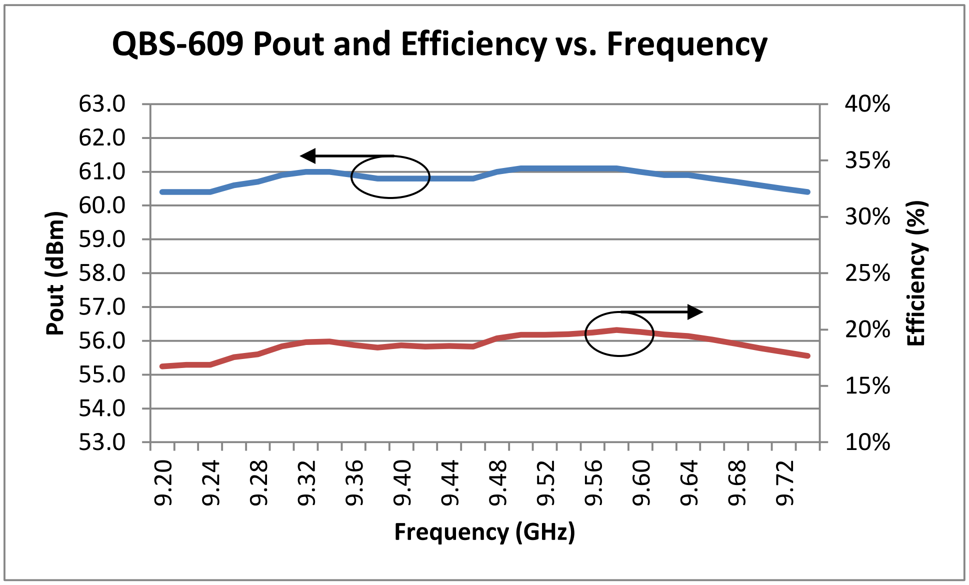

Figure 5: QBS-609 Saturated Power Output and Efficiency vs. Frequency

Figure 5 is a plot of power output and efficiency for the integrated QBS-609 amplifier at 100 usec pulse width and 10% duty cycle. Input power is constant at 0dBm. As shown in Figure 5, average output power across the 9.20 to 9.75 GHz frequency band is 60.8 dBm (1202W). Average power added efficiency is 19% when operating from a +28VDC supply with average current of 22.5A. Pulse rise and fall times are less than 300 nsec. With a 100 usec pulse at 1kW output power, amplitude droop across the pulse is less than 1.0 dB. The RF pulse ON/OFF ratio is 80dB (min) at 1kW output power. Second harmonics are greater than 65 dBc relative to power at the fundamental frequency.

Performance of the QB-609 is controlled at the system level with commands sent to the QBS-609's embedded controller. Remote ON/OFF and Standby/Operate commands received by the QBS-609 ready the SSPA for transmission. To transmit, the QBS-609 receives a Gate Trigger command that turns all amplifier stages ON. A Pulse ON/OFF signal is received to turn the blanking switch ON and disconnect the power supply from the charge storage subassemblies. The RF pulse is applied to the SSPA during the period that the Pulse ON/OFF command is present. The QBS-609 can also receive a Battle Override command that disables any internal shutdown or control functions affecting operation during battle situations.

The QBS-609 provides the system with several monitor outputs. A case temperature reading is provided along with a high temperature warning and internal temperature monitoring that shuts the QBS-609 down when an over-temperature condition is reached. A device failure alarm informs the system that one or more devices have failed even though the failures may have minimum effect on power output.

This article demonstrates how advancements in GaN transistor technology provide the ability to replace limited life and single point failure, compact TWT amplifiers with GaN solid state amplifiers, A GaN 350W MCM (API part number QB-1008) is presented and forms the basis for the 1kW QBS-609 amplifier. A block diagram and circuit descriptions of compact subassemblies are provided for the API, QBS-609, 1kW SSPA. Measured performance of the QBS-609 is presented showing final unit performance.