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CONTROLLERS: THE UNSUNG HEROES OF HIGH-POWER TWTAS AND MICROWAVE POWER MODULES

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While the development of new gallium nitride (GaN) RF power transistors and MMICs is garnering attention, traveling wave tube amplifiers (TWTAs) and compact microwave power modules (MPMs) remain the most viable technology for generating truly formidable amounts of RF power from about 1 GHz well into the millimeter-wave region. As a result, these devices will continue to be the first choice for ground, airborne, and shipboard-based radar, electronic warfare, and satellite communications systems. While microwave engineers and designers are usually familiar with basic amplifier function, many are not aware of the importance of a high-power amplifier's controller. Considering that the controller orchestrates the amplifier's functions, protects it against damage or catastrophic failure, and extends the system's operating lifetime, familiarity with controllers can result in more accurate system specifications and the most reliable products.

There are generally two types of high-power amplifiers used for RF power generation which employ traveling wave tubes (TWTs) — the traditional TWTA and the newer microwave power module, or MPM. These two devices differ in one major respect. A traditional TWT-based high-power amplifier integrates within a single enclosure the TWT itself, along with RF input and output hardware, digital interface and protection circuits, forced-air cooling, and a power supply. In contrast, an MPM does not have all required functions integrated within the module, as it is designed to exploit the benefits of TWTs in a far smaller form factor and uses lower voltages than a traditional TWTA. The MPM is conduction cooled and employs a miniature version of the TWT (the booster-TWT) driven by a solid-state power amplifier that is integrated with power and control circuits in a very compact enclosure.

A typical TWT high-power amplifier architecture is shown in **Figure 1**. It consists of three primary modules: the TWT, the controller, and the high-voltage power supply that provides the voltages to the TWT's heater, cathode, collectors, and focus electrode or grid. The power supply and its power management subsystem are critical components in both TWTAs and MPMs, employing extremely dense, intelligent power sources and incorporating various types of protection circuits.

Formidable Tasks for the Controller

The controller has the arduous task of controlling and protecting the entire system under potentially hostile electrical and environmental conditions. It monitors the "health" of the amplifier by measuring cathode voltage, TWT helix current, TWT and power supply body temperature and other parameters. Acting as the interface between the amplifier and host system, the controller conducts various "housekeeping" functions and serves as a Built-In Test (BIT) system. For maintenance and diagnostic purposes, it also keeps a log of all that occurs during system operation.

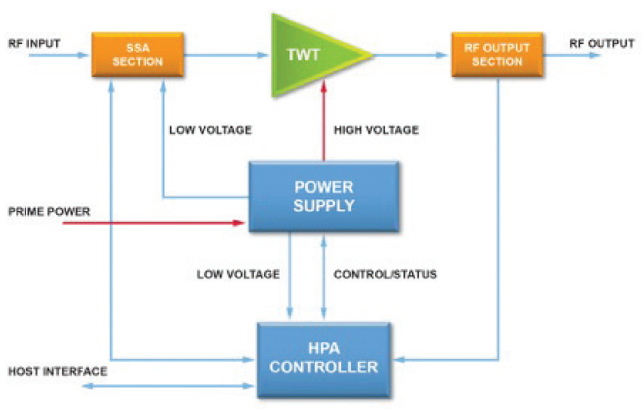

FIGURE 1

Figure 1: A "classic" TWT-based high-power amplifier showing the TWT, power supply, and controller subsystems

One of the most challenging aspects of controller design is ensuring that the controller can perform its critical functions without failure when subjected to voltages up to 25 kVDC, high-energy switching up to 10 Joules, extreme temperatures ranging from -54 °C to +125 °C, and high-vibration levels of up to 20 G rms. In addition, switching currents as high as 100 A/ms and short-circuit currents of thousands of amperes are present. In this "charged" environment, the controller must monitor and provide reliable status indications of every critical parameter to protect sensitive components such as microprocessors, microcontrollers, FPGAs, memory devices, and analog-to-digital converters, as well as the TWT itself.

The energy-intensive environment surrounding the controller can also cause false alarms or anomalous behavior. Noise produced by the power supply switchers can produce extremely sharp noise spikes of nanoseconds in duration, which can occupy several megahertz of bandwidth. These spikes can corrupt critical signals of the system such as the Serial Peripheral Interface (SPI), Inter-Integrated Circuit (I2C) and other serial data lines.

Meeting the Challenges

Before amplifying the input signal, a TWT requires a heater warm-up time of about 180 seconds, an "operate" command from the host interface, and focus electrode/grid control (-1.1 kVDC to +500 VDC) signals. The controller must orchestrate these signals and execute commands in the right sequence under any and all conditions. If the sequence of these signals is incorrect, the TWT could be damaged by accidentally transmitting RF output power of up to 10 kW peak. Consequently, the controller must be designed in a "safe-state" configuration to keep the TWT inactive during initial power-up, standby, or when transmission is not desired. Microcontrollers and FPGAs are extremely well suited to perform this task, as they can be programmed to react in milliseconds to unsafe or out-of-spec operating conditions.

As a manufacturer of high-power TWT-based amplifiers for more than two decades, dB Control has developed and consistently enhanced its controller capabilities. The company employs FGPAs, microcontrollers, and other digital components, along with dedicated firmware and other proprietary techniques, to manufacture controllers that meet or exceed the most stringent military requirements for current and next-generation airborne systems. For example, the "universal" embedded amplifier controller shown in Figure 2 embodies all of the characteristics and functionality described above and operates from a single +15 VDC, draws only five Watts, and measures 6 x 2.5 x 0.9 inches.

The embedded controller's primary function is to protect the critical elements of the system by monitoring the diverse parameters of the TWTs such as helix current up to 600 mA, cathode voltage from five to 25 kV, over-temperature of 125°C, and output reflective power of up to 100 W average. As these parameters vary depending on the TWT used in the amplifier, the controller is designed to accommodate each one. The controller provides built-in test features through several communication protocols such as RS-232, RS-422, RS-485, or Ethernet which let the host interface continuously retrieve the system's status (manually or automatically) identified as either ones or twos after power is applied. The controller can also receive commands such as model identification query, status query, operate, and standby from the host interface through the serial interface, and execute these commands in less than 20 ms after receipt and acknowledgment.

The microcontroller provides overall supervision, host communication, self-test, and technician-assistance features through the serial interface. To provide protection from transient events, it verifies board and system configuration, communication with a remote control panel, communication with other controllers, and periodically verifies FPGA configuration. The protection circuits continuously monitor the system's critical parameters by collecting feedback from its various elements, including temperature readings from -54° to 150°C, cathode voltage, helix current, reflected output power from the TWT, and input under-voltage.

In pulsed systems a pulse measurement function programmed into the FPGA detects the input gate signal to protect the TWT from over-duty ranging from three percent to 30 percent, over-pulse width of two to 300 μs, and over-frequency of 200 to 100 kHz. The high-speed pulse-capture capability in the protection circuits accepts RF detector signals which are conditioned, scaled, digitized and transmitted by the FPGA through the serial interface. The extensive programmability of the FPGA provides many features, including configurable functions via tailored logic loads, polarity, and mask registers to provide a common logic load for multiple systems. The FPGA controls a 12-bit ADC and compares configurable thresholds against digitized voltage inputs such as cathode voltage (scaled down from five to 25 kV to less than 10 VDC) and detected RF output power (-80 mV) from the TWTs. The latter is typically amplified and inverted from -80 mV to +10 VDC.

The FPGA also captures and analyzes digitized data, performs gate-pulse measurements of two to 300 μs at frequencies up to 100 kHz, and provides voltage-to-power conversion using a lookup table, along with peak detection. To provide an additional measure of safety, the FPGA keeps the I/O signals in a safe state. The microcontroller can detect any FPGA malfunction on the next polling cycle and take appropriate action. The controller has extremely high immunity to noise, and can be reprogrammed in place, thus helping eliminate product returns to the factory for firmware updates.

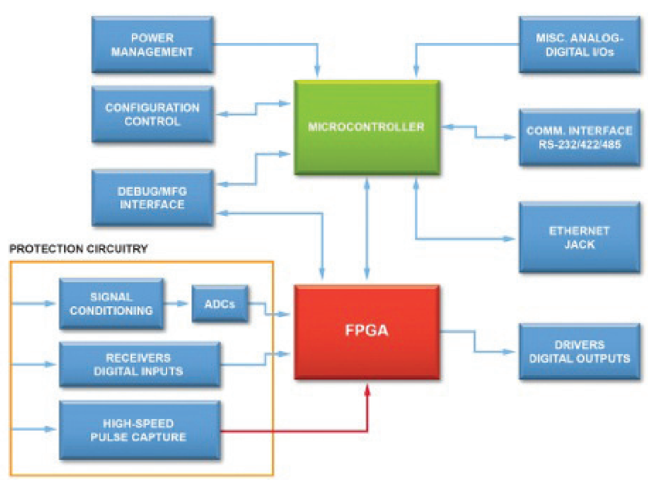

FIGURE 2

Figure 2: A typical high-power amplifier controller architecture control from dB Control incorporating an FPGA and microprocessor

Summary

The controller is one of the most important subsystems in a TWTA or MPM, not just because the amplifier cannot function without it, but also because it provides the essential functions to keep the amplifier operating for many tens of thousands of hours without fail. While the controller's importance is most obvious in space applications where onsite "repairs" are impossible (or at least highly impractical and expensive), its necessity in ground, airborne, and shipboard platforms is just as critical, as mission failure is absolutely unacceptable in military systems where lives are at stake.

It's no wonder that an increasing number of RF and microwave systems that traditionally employed analog components to perform basic functions now rely on digital controllers. dB Control's high-power amplifiers utilize controllers that leverage the programmability of the FPGA, as well as sophisticated microcontrollers, to make extensive controller functionality possible within the size, weight, and power constraints imposed by many military and defense contractors. As demands placed on controllers continue to increase, so too will the controller's ability to meet them.

For more information, please visit our website.

www.dbcontrol.com