HIGH PERFORMANCE, SOLID-STATE HIGH VOLTAGE RADAR MODULATORS

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Abstract

Switching power supplies and solid-state high voltage modulators are being used to upgrade conventional tube-type radar modulators, extending their operating lifetimes. The new technology is cost-effective, improves reliability, and delivers better protection to the RF amplifier than conventional transmitter designs.

In 2003, DTI upgraded the X-band radar transmitters in the Cobra Judy system on the USNS Observation Island. DTI built the complete transmitter, including all electronics required from ship power to modulating the two 100 kW average power TWTs. Based on the success of this effort, DTI is employing similar solid-state technology to the transmitter driving the Cobra Judy S-band phased array radar. Installation of the sixteen-TWT S-band transmitter upgrade is scheduled for early 2006.

DTI is also developing a new transmitter for the Haystack Ultra-Wideband Imaging Radar (HUSIR) in Westford, Massachusetts. This transmitter will drive four W-band (94 GHz) high power gyro-devices, and will be capable of future expansion to sixteen tubes. The design builds on both the upgraded Cobra Judy X-band transmitter, and DTI's development of a modulator for the Navy Research Laboratory's 94 GHz Warloc gyroklystron in 2002.

This paper will discuss the key pulsed power technologies common to these radar transmitters, with emphasis on the system requirements for pulse stability and control.

I. BACKGROUND

DTI has pioneered the replacement of obsolete transmitter vacuum tubes and crowbars with solid-state, high voltage switches. In many cases, complete transmitters have been replaced.

The high voltages switches are built from solid-state modules containing from four to twenty individual transistors (typically IGBTs) connected in series. The voltage rating of each module is between 3 kV and 12 kV, depending on the module design, and peak current ratings range from 30 A to over 5,000 A. Multiple modules are placed in series to meet the specific transmitter cathode voltage. An external gate drive controls all modules simultaneously, with risetimes as low as 30 ns. This modular construction leads to flexibility, economy, and ruggedness, and allows common module designs to be applied across a range of transmitter designs.

The radar amplifier tubes driven by the upgraded transmitters are typically either cathode pulsed or mod-anode / grid pulsed. For cathode pulsed systems, a directly-connected solid-state high voltage modulator (a compact, solid-state, highly-regulated HVPS and modulating switch) is a viable replacement for "hard-tube", active-switch modulators, and thyratron / pulse forming networks. In normal operation, the cathode switch is closed for the duration of the desired pulse, and presents a very low impedance between the power supply and the cathode. A solid-state cathode modulator provides fully variable pulsewidth (50 ns – DC), adjustable on a pulse-to-pulse basis, and supports pulse repetition frequencies up to 400 kHz.

By opening very fast (<1 μs) when a fault is detected, the series switch blocks power from reaching the cathode, without disrupting the power supply. When the fault has cleared, the transmitter can resume operation in microseconds.

For grid or mod-anode modulated systems, this same high voltage, solid-state switching technology can replace the typical vacuum tubes in the modulator. Both single sided (pull-down) and push-pull configurations have been realized. These switches can be combined with a cathode series switch for crowbar replacement, allowing the entire power control interface to the RF amplifier tube to be solid-state.

II. RECENT RADAR TRANSMITTERUPGRADES

The systems discussed below are examples showing the breadth of potential radar transmitter upgrades possible through the incorporation of high voltage, solid-state switching. Solid-state technology has proven to be a viable and cost-effective replacement for the obsolete components in these transmitters, significantly improving the reliability of the transmitter, enabling extended

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Figure 1. USNS Observation Island. The Cobra Judy S-band radar array is located aft of the Cobra Judy X-band dish.

performance in terms of pulse flexibility and stability, and delivering better protection to the RF amplifier.

A. Cobra Judy X-Band Transmitter Upgrade

In 2003, DTI installed an upgrade to the X-band radar transmitter in the Cobra Judy system on the *USNS Observation Island* (Figure 1). DTI built a completely new transmitter, including all electronics and controls between ship power and the two, 100 kW average power TWTs, retained from the original design. (Figure 2).

The solid-state upgrade of this transmitter features three 100 kW, 50 kV switching high voltage power supplies. Together, these power supplies eliminate the original inductrol, large T/R set, and vacuum tube post regulator. Only two of these HVPSs are needed for full-power operation of the radar, providing N+1 redundancy in operation. All three power supplies operate through a separate diode combiner / controller, which balances the output from each supply. In the event of a HVPS failure, the remaining two supplies will provide uninterrupted, full power capability for the radar, significantly improving its overall availability. The high voltage power supplies feed an upgraded capacitor bank, similar to the original transmitter design. A solid-state opening switch, located in series between the capacitor bank and the TWT cathodes, replaces the crowbar. This switch, which is normally closed, provides sub-microsecond interruption of power in the event of a TWT arc. Again, the opening of the switch does not discharge the capacitor bank or disable the HVPSs, allowing the radar to resume operation immediately after the arc has cleared. This is a significant performance improvement over the lengthy period required to recover from an arc in the original transmitter design.

Figure 2. Cobra Judy X-band DC power supplies and controls installed on-board the USNS Observation Island.

Behind the Observation Island's 10 m dish antenna, two solid-state switches and their controls replace the original vacuum tube floating deck mod-anode modulator. The risetime, flattop, and droop of the pulses generated by this design are significant improvements over the original switch tube.

The entire X-band transmitter is controlled and monitored through a three-level control system. At each element of the transmitter, hard-wired controls provide fast response to faults, and communicate status and commands to the subsystems. A commercial PLC provides state control and system status information for the entire transmitter. Finally, a PC-based computer system is used to communicate with the PLC, and record performance and diagnostic information. This is a significant improvement over the previous method of communicating between the transmitter room and the remotely located Cobra Judy operators via intercom or phone.

B. Cobra Judy S-Band Transmitter Upgrade

The COBRA JUDY S-band phased-array radar became operational in 1981. The radar's transmitter hardware is nearly 25 years old, and many of its components have become difficult to support, or are obsolete. Based upon the success of the X-band upgrade, DTI was awarded a contract to upgrade the S-band system in December 2004. DTI's upgrade will replace all of the electronics systems in the transmitter between ship's power and the 16 TWTs, and provide greatly enhanced control, fault handling, and diagnostic capabilities. Five new subsystems will replace the existing Power Distribution Unit (PDU), inductrol, power supplies, and filter cabinet, and eliminate the single-point-of-failure grid modulators and associated circuitry in the grid modulator cabinet. The only major remaining transmitter components will be the TWTs, their solenoids, the solenoid power supplies and ion pump controllers. The program is scheduled for completion in early 2006.

***C. Sondrestrom** Radar*

The Sondrestrom Radar Facility is located in Sondre Stromfjord, Greenland, and operated by SRI International under an NSF cooperative agreement. The facility conducts observations on the edge of the polar cap, the cusp, and the northern part of the auroral oval. Recently,

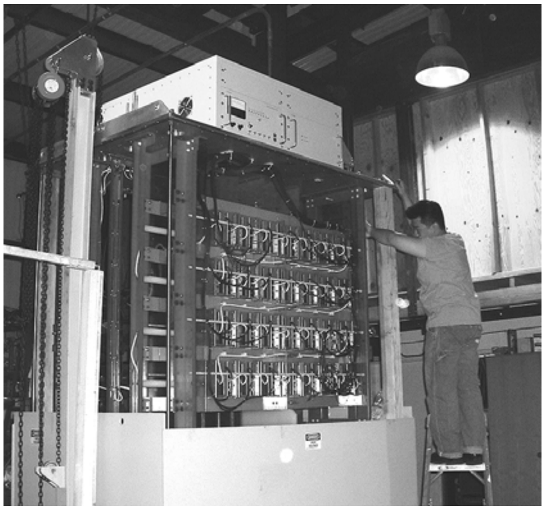

Figure 3. Installation of Sondrestrom modulator (150 kV, 300 A). The modulator's high voltage components are suspended from the tank lid. The assembly can be lifted out of the tank using an internal chain lift or an overhead crane.

DTI built and installed a solid-state modulator, rated at 150 kV, 300 A peak, 500 kW average, to replace the obsolescent klystron modulator and crowbar in the radar transmitter (Figure 3). A sample pulse at the modulator output is shown in Figure 4. This system was installed and commissioned by DTI in September 2003.

D. AN/SPQ-9A

The AN/SPQ-9A is a high resolution, narrow beam X-band radar designed for air surveillance and early warning against hostile aircraft and sea-skimming, anti-ship missiles. Installations have been operational in the U.S. Navy fleet since 1975.

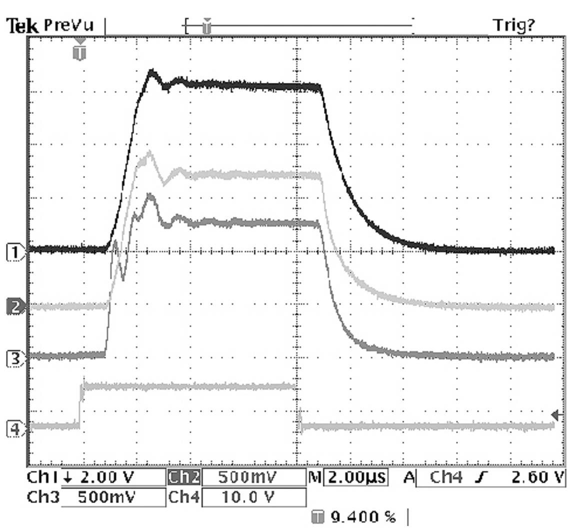

Figure 4. Sondrestrom Modulator Pulse (trace 1 - 130 kV, trace 2 - 120 A). Modulator gate pulse shown in trace 3. Measurements made at the modulator output, and show the cable impedance mismatch. Ringing is not seen on the klystron cathode.

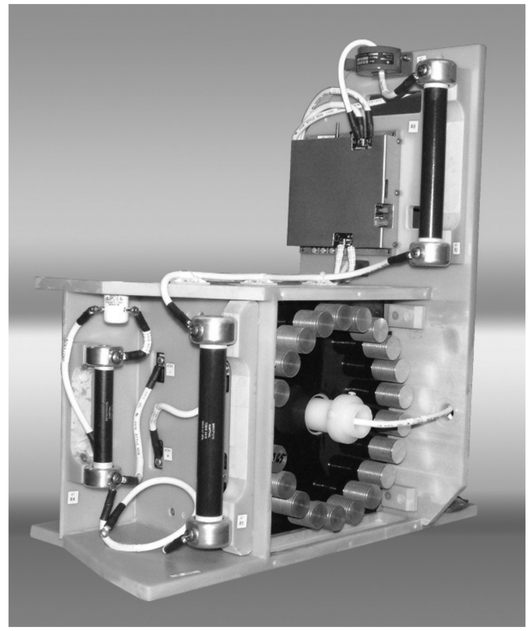

Figure 5. This solid-state cathode modulator assembly replaced the entire AN/SPQ9A mod-anode modulator (HVPS, PFN, SCR switch, pulse transformer, test load), and crowbar circuit.

After nearly thirty years of service, parts obsolescence, decreasing reliability, and increasing maintenance costs, mandated an upgrade to the radar's transmitter. DTI's development of reliable, high power solid-state switches offered the Navy the opportunity to replace the transmitter's outdated components and greatly extend the life of the radar system.

Under contract with the Naval Surface Warfare Center's Port Hueneme Division (PHDNSWC), DTI will build sixteen fully MIL-Qualified AN/SPQ-9A modulator upgrade kits for on-board installation (Figure 5). The kit includes high voltage power supply, storage capacitor, filament supply, and solid-state modulator.

The upgrade replaces the original mod-anode modulation scheme with a solid-state cathode modulation / tube protection arrangement. Replaced items include the original cathode HVPS and set point variacs, filament transformer - limiter, and the entire mod-anode modulator (HVPS, PFN, SCR switch, pulse transformer, test load), and crowbar circuit.

The upgrade promises significant benefits for the AN/SPQ-9A installed base.

- There is significant reduction in the number of TWT failures.
- The radar's crowbar is eliminated, itself a source of major problems.
- Personnel safety is enhanced. Diagnostics and test points are available without accessing the high voltage sections of the transmitter
- TWT arcs no longer cause system downtime because transmitter operation is resumed on the next pulse.

In addition, the new solid-state modulator can operate with a damaged tube. A TWT having mod-anode arcing

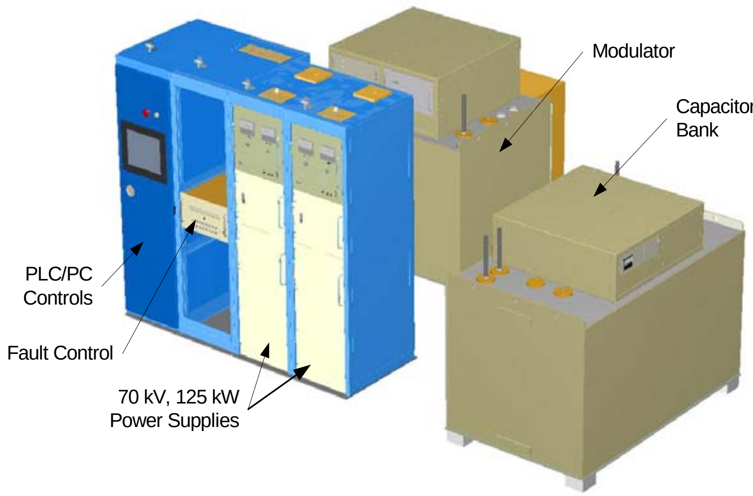

Figure 6. HUSIR transmitter HPA mechanical design. The driver electronics are similar.

conditions, or excessive mod-anode leakage will perform flawlessly in systems modulated by solid-state devices. These tubes would otherwise have to be scrapped or re-built.

III. HUSIR

Over the next four years the Haystack Observatory Radar in Westford, Massachusetts will be upgraded by the addition of a millimeter-wave radar that will improve the facility's resolution almost ten-fold. The new radar, called the Haystack Ultra-WideBand Satellite Imaging Radar, or HUSIR, is being developed by MIT Lincoln Laboratory, to support the observatory's space surveillance radar program. The upgrade is scheduled for completion in 2009. As part of the program, Diversified Technologies, Inc. (DTI) was awarded a contract in July 2004 for the design and construction of the radar's new transmitter.

The HUSIR transmitter design consists of two similar, but nearly independent transmitter strings: one for the driver gyroTWT, and a second for two HPA gyrotwystrons. The transmitter will provide all of the electrical connections to the gyrodevices, except for RF input, RF output, and superconducting magnet cooling. All of the power handling and control, from the primary-power input to the cables feeding the gyrodevices, will be integrated within this system.

The transmitter upgrade consists of four major subsystems: (1) high voltage DC power supplies, (2) an energy-storage capacitor tank with droop compensation, (3) floating, cathode-referenced modulator tanks, and (4) control systems, including PLC, PC, and a separate fast fault control The entire transmitter will be configured in eleven enclosures: three high voltage power supply cabinets, two capacitor tanks, two modulator tanks, two PLC and PC control racks, and two fault control units. The mechanical layout of the HPA group of the transmitter is shown in Figure 6 (the driver transmitter is not shown, but is similar to the HPA group).

IV. SUMMARY

Over the last five years, DTI has upgraded approximately twenty-five radar transmitters around the world, in both military and civilian applications, at average powers ranging from 3 kW to over 500 kW. The use of solid-state technology to replace conventional switch tubes and obsolescent components has significantly increased the performance and reliability of each of these systems. Through these efforts, DTI has shown that a typical RF amplifier VED, including magnetrons, CFAs, klystrons, TWTs, and gyrotron-based systems can be successfully driven using a combination of highly regulated, switching power supplies and solid-state switches. Furthermore, this capability has been proven applicable to all of the major transmitter topologies, including cathode, mod-anode, and grid pulsed systems.

V. REFERENCES

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