22-KW NEXT GENERATION LOW COST S-BAND SOLID STATE TRANSMITTER FOR SURVEILLANCE AND AIR TRAFFIC CONTROL RADARS

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ABSTRACT

This paper presents the development of a low-cost 22-kW Solid-State Transmitter (SST) operating over 2.7-2.9 GHz, for modern surveillance and air-traffic control radars. 22-kW peak power with a pulse width of 50 μs and 5% duty cycle is achieved by combining fifty 500-W High Power Solid-State Amplifiers using a low-loss (0.2 dB) radial combiner. Other key performance parameters are: pulse-to-pulse stability (MTI improvement factor) >75 dBc, pulse droop < 0.6 dB, MTBCF >100,000 hours, instantaneous bandwidth of 200 MHz, extremely high pulse fidelity, and self pulsing low voltage operation for safety and high efficiency. The design has following additional features: modular, front accessibility of components, hot replacement of power supplies and high power amplifiers for easy maintenance, complete remote monitoring and maintenance system (RMMS), use of commercial off-the-shelf (COTS) components, fail-soft operation and redundancy of critical components such as power supplies, driver amplifiers and fans for cooling.

I. INTRODUCTION

Modern and future surveillance and air-traffic control radar systems require performance that can not be achieved by currently used Klystron transmitters. For a Klystron transmitter, the MTI improvement factor is ~60 dBc, MTBCF is ~5000 hours, instantaneous bandwidth is ~15 MHz, and operating voltages are ~45-80 KV which are difficult to regulate [1]. Further, the output peak power of a Klystron transmitter is 1 MW. Lower peak power solid-state transmitters [2] (12-kW) have been developed. Pulse compression technique is used to allow the use of lower peak power.

Modern and future surveillance and air-traffic control radars require low cost, state-of-the-art performance, use of off-the-shelf components (COTS) while achieving higher power levels, low cost, and high reliability. This paper presents a development of a 22-kW S-band Solid-State Transmitter (SST). Low cost manufacturing methods for fabrication of high power amplifiers are used. Transmitter utilizes COTS components without compromising the high reliability and performance. State-of-the-art performance and the key features for maintainability and availability have been obtained. Critical performance parameters are mentioned above in the abstract section. The 22-kW SST, which addresses above requirements and overcomes the limitations of a Klystron transmitter and complexity and higher cost of earlier versions of SSTs [2]. This transmitter was specifically developed to meet ASR-11 Digital Airport Surveillance Radar specifications. However, modular design is adaptable to meet requirements for other applications requiring different power levels, pulse widths and duty cycles.

II. TRANSMITTER DESIGN

A block diagram of the 22-kW Solid-State Transmitter (SST) is shown in Figure 1. The overall gain of the SST is 32 dB, which is achieved by two stages of amplification. The output power of the first stage (driver) amplifier is >500-W across 2.7-2.9 GHz band. The output stage consists of fifty 500-W high power amplifiers (HPAs) which are combined using a 50:1 low-loss reactive, center fed, coaxial/waveguide combiner network in a radial configuration. The fifty 500-W amplifiers are combined to produce a minimum of peak output power of 22-kW across the 2.7-2.9 GHz band. The fifty parallel HPAs used in the final stage provide fail-soft performance for a graceful degradation. As shown in Figure 1, the first driver stage is designed to provide full redundancy by automatic switching to an alternate standby amplifier, when the amplifier exhibits a failure or reduced output power. A slope attenuator is used to provide flat input power to the fifty output stage amplifiers across the 2.7-2.9 GHz band.

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Two HPAs share a common cold plate, voltage regulator and bite circuitry which all form the LRU. Six 42.5V power supplies and two 28V/-15V/5V power supplies are used. Power supplies are all connected in parallel. The transmitter requires only three 42.5V and one 28V/-15V/5V power supplies, thus providing additional power supplies for redundancy and high reliability.

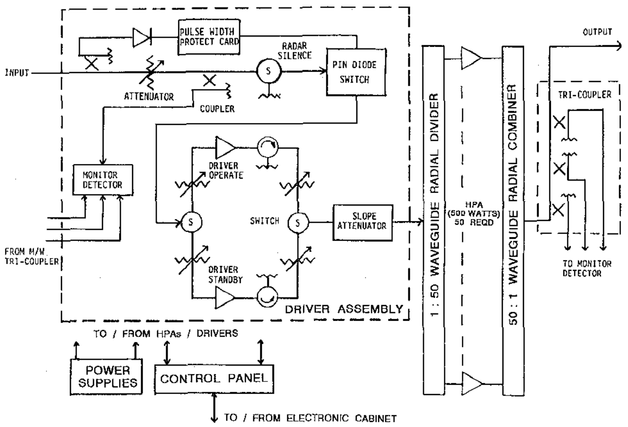

Fig. 1 Block Diagram of an S-Band 22-kW Solid-State Transmitter

The transmitter is an air cooled unit that uses four fans for the output stage (three required, one redundant), while two fans are used for driver stage (one required, one redundant). A control panel monitors the status of the transmitter, for input and output power, status of HPAs, power supplies, driver amplifiers, monitor detector, VSWR caution and fault, air flow and temperature, etc. The condition of the transmitter is provided on a local panel and signals are transmitted for use at a remote site.

Thermal design of the HPAs and air cooling is such that the maximum junction temperature is <135°C for obtaining >100,000 hours of transmitter MTBCF [3]. The cabinet was designed so that all critical components are accessible from the front for easy maintenance and "hot replacement" of HPAs and power supplies.

III. 500-W HIGH POWER AMPLIFIER DESIGN

The heart of the SST is the Solid-State High Power Amplifier (HPA). The S-Band HPA design began with the selection of an architecture to meet the overall power gain, efficiency, and thermal requirements for high reliability. The circuit topology is chosen based on the performance of the latest available S-Band Si Bipolar transistors such that the minimum number of transistors are required to be combined to provide the overall output power for the HPA while no single transistor junction temperature would exceed 125°C. This requirement resulted in the circuit topology of one transistor driving one transistor driving four paralleled transistors. This is also important since the combiner loss increases with the number of transistors to be combined.

A block diagram of the 500-W HPA is shown in Figure 2. The architecture for the HPA consists of three stages of amplification that amplifies a 5-W input signal to a 500-W output signal. The first stage is a 25-W power transistor that supplies 19-W minimum to the second stage. The second stage transistor is an 150-W device having a minimum gain of 8.0 dB followed by a third stage of four paralleled 150-W transistors as seen in Figure 2. A four way power divider/combiner consisting of 2 levels of branchline microstrip couplers is used to excite and collect power from the four parallel output stage transistors. A transistor with an output power of 150-W is selected to be combined in a 4-way combiner to obtain 500-W of output power.

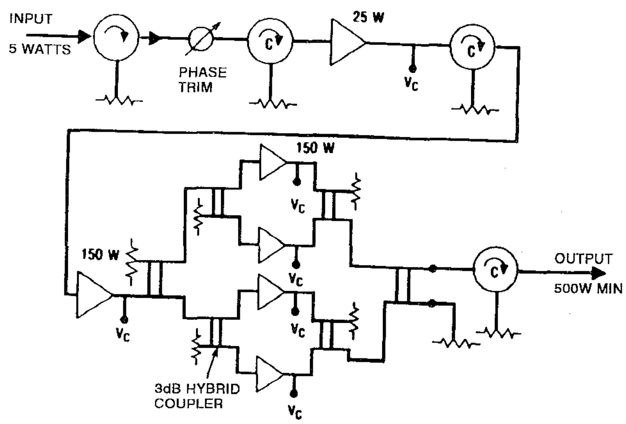

Fig. 2 Block Diagram of a 500-W High Power Amplifier

A photograph of the 500-W HPA module is shown in Figure 3. The performance of the 500-W HPA is presented in Table 1. The HPA consists of a low cost network that is fabricated in a high dielectric constant, low loss palletized microstrip package. The HPA contains input and output isolators that along with the divider/combiner allow for "hot replacement" of the amplifier. "Hot replacement" of the amplifier allows the transmitter to operate while a failed set of modules are being replaced.

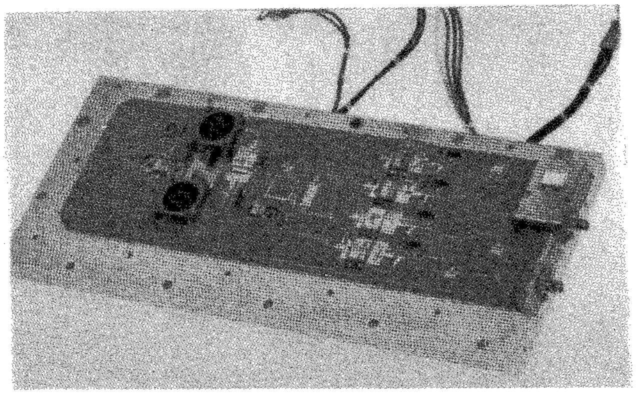

Fig. 3 Photograph of the 500-W High Power Amplifier

Table 1 Measured Performance of the 500-W High Power Amplifier (Pulse Width: 50 μs; Duty Cycle: 5%; Input Power: 5W)

Frequency (GHz)	2.7	2.8	2.9
Output Power (W)	590	607	531
Amplitude Droop (dB)	0.47	0.22	0.21
Efficiency (%)	28.8	32.4	30.2
Rise Time (ns)	<100	<100	<100
Fall Time (ns)	<20	<20	<20
Input VSWR	<1.4:1	<1.4:1	<1.4:1
Harmonics (dBc)	32	52	50
Phase Across the Pulse (°)	28.1	20.7	16.0
Phase Deviation From Linear (°)	±5.6	±s2.8	±2.0

Two HPAs are mounted on a common cold plate and share a common voltage regulator and bite circuitry. The MTBCF of the HPA is calculated to be >156,000 hours.

IV. 50:1 POWER DIVIDER/COMBINER DESIGN

The 50:1 power divider/combiner is a center fed, reactive, air-dielectric non-resonant radial transmission line structure that yields very low dividing/combining loss, low VSWR, and excellent phase and amplitude balance among the radial ports.

The radial ports are equally spaced along the circumference of parallel plate TMo, o mode radial transmission lines and are coupled to the radial line by shorted coaxial probes. A combination of coaxial line and parallel plate radial line impedance matching techniques are employed. This unit is both failure tolerant and hot replacement capable. The insertion loss of this unit for both the divider and combiner was measured at <0.25 dB, minimum isolation measured >11 dB, amplitude and phase variation were ±0.2 dB and ±3° respectively, and the VSWR was <1.25:1. A photograph of the power divider/combiner can be seen in Figure 4 (22-kW S-Band Solid State Transmitter).

V. SST FABRICATION

The Solid-State Transmitter shown in Figure 4 develops 22-kW of output power from 50 high power amplifiers arranged in a radial configuration around a radial power divider/combiner. The input and output connections between the HPAs and the power divider/combiner are made with phase matched sets of low cost semi-rigid coaxial cables.

Two HPAs are mounted on a common cold plate that share a voltage regulator and a fault monitoring bite circuit. This dual HPA configuration represents the basic LRU for the transmitter. The transmitter utilizes low cost manufacturing methods for the fabrication of the HPAs. The transmitter utilizes off-the-shelf-components of commercial grade without compromising high reliability and performance.

VI. PERFORMANCE OF SST

A photograph of the 22-kW SST is shown in Figure 4. The performance of the 22-kW SST is presented in Table 2. The critical parameters of MTI improvement factor >75 dB, instantaneous bandwidth of >200 MHz, output power of >22-kW and high pulse fidelity are achieved over the 2.7 GHz to 2.9 GHz frequency band. Measured amplitude droop across the pulse was <0.6 dB, phase across the pulse <50° and phase deviation from linear <±7°, which are critical parameters to obtain low range sidelobes. The calculated MTBCF for the transmitter >100,000 hours for a loss of 6 HPAs or loss 0.86 dB peak power. A complete remote monitoring and maintenance system (RMMS) is provided.

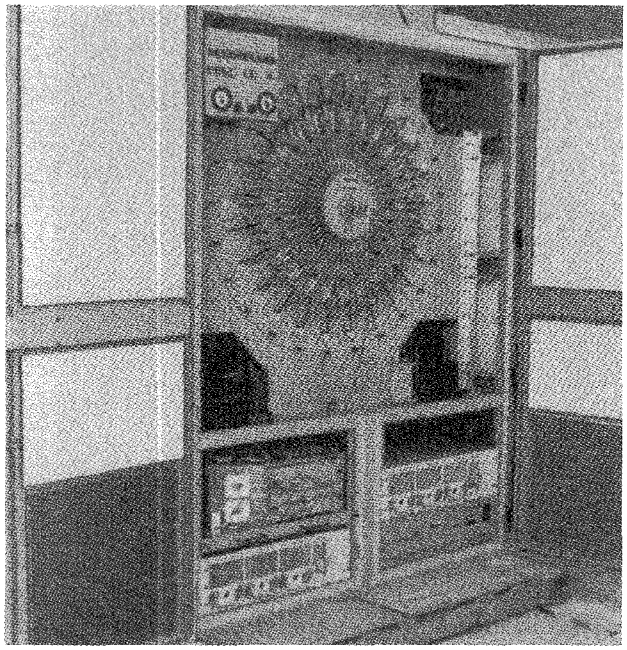

Fig. 4 Photograph of the 22-kW Solid State Transmitter

VII. CONCLUSIONS

The design, fabrication, development and performance of a state-of-the-art 22-kW Solid-State Transmitter has been presented. this transmitter achieves low cost (including low life cycle costs), high reliability, maintainability, fail soft operation and "hot replacement" of HPAs and power supplies. This transmitter provides the enhanced performance required for new modern radars and upgrades of existing radar systems using tubes.

Table 2 Measured Performance of the 22 kW Solid-State Transmitter

Frequency (GHz)	2.7	2.8	2.9
Output Power (kW)	24.12	25.24	22.12
Input Power (W)	15.8	15.8	15.8
Pulse Width (μs)	50	50	50
Duty Cycle (%)	5	5	5
Amplitude Droop (dB)	0.36	0.62	0.3
Rise Time (ns)	125	95	127
Fall Time (ns)	14	23	7

ACKNOWLEDGEMENTS

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REFERENCES

1. E.D. Ostroft, et al, "Solid-State Radar Transmitters", Dedham, MA: Artech House, Inc., 1985.

2. M. Hanczor and M. Kumar, "12-kW S-Band Solid-State Transmitter for Modern Radar", 1993 IEEE Transactions on Microwave Theory and Techniques, Nov. 41, No. 12, pp. 2237-2242, December 1993.

3. R. Frey and M. Kane, "Temperature Effects Examined for Microwave Power Transistor Performance and Thermal Design Considerations", Microwave Systems News, Vol. 15, Nov. 1985.