High Power S-band Solid-state Amplifiers for Surveillance and Traffic Control Radars

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Abstract **This paper describes development of a 1.8kW solid-state amplifier operating over 2.7 to 2.9GHz, for surveillance and traffic control radars. A 1.8kW peak power with a pulse width of 100μs and 10% duty cycle is achieved by combining four 550W solid-state power amplifiers. Modular configuration of the 1.8kW amplifier can realize improvement of maintainability, productivity, and low cost. This paper also describes development of a 180W output power with 40dB gain, linear amplifier using GaAs MMICs to realize the temperature compensation, short pulse (1μs) generation, high gain, and precise gain control for the 1.8KW amplifier. The 180W GaAs MMIC amplifier has capability of driving up to twelve 1.8KW amplifiers, and drastically simplifies solid-state transmitter configuration.**

I. Introduction

Because of inherent low noise characteristic, low voltage operation, and high reliability, solid-state amplifiers have become substantial device for the TWT or Klystron based tube transmitters [1], [2]. High power amplifier (HPA) is the most important device for a solid-state transmitter because in its multiplicity, it represents the major cost item, and it affects reliability as well as stable operation. In detail, to realize low cost, reliable cooling system, and effective power combine, this paper proposes an appropriate configuration of the HPAs. The proposed configuration is shown as follows.

1) A 1.8KW HPA panel consists of four 550W amplifiers with ultra low-loss power divider/combiner.
2) The 550W amplifier consists of a 150W output power Si-BJT driving four 150W output power Si-BJTs.
3) Power combining and dividing are realized by two-level of 3dB coupled line method using a low loss dielectric substrate.
4) For the driving purpose, high gain and high power GaAs MMIC based linear amplifiers are used. The GaAs MMIC amplifier realizes the steepest RF pulse shape and temperature compensation function, and simplifies the transmitter configuration.

As a result of the above methods, the 1.8KW HPA achieves more than 80% power combining efficiency, 0.3dB output power droop in 10% duty operation. The GaAs MMIC amplifier also achieves less than 0.1 dB output power droop, 10nSec pulse fall/rise time, and 12-bit digital gain control capability operating in 30dB dynamic range.

II. Power amplifier configuration

A. GaAs MMIC 180W linear amplifier

The output power of a class-C amplifier is sensitive to the input power variation; therefore, to control the output power level, gain of the driver amplifier should be controlled precisely. We developed a 180W linear amplifier using GaAs MMICs [3] for a driver application.

Fig. 1 and Fig. 2 show the photograph and the block diagram of the 180W linear amplifier respectively. The 180W linear amplifier consists of a 20W output GaAs MMICs amplifier driving four paralleled 50W output GaAs MMIC amplifiers.

The GaAs MMIC achieves 47dBm output power and the small signal gain of 22dB. The control of the 180W linear amplifier gain is utilized with a GaAs MMIC attenuator. Fig. 3 shows the measurement characteristics of the GaAs MMIC attenuator. The dynamic range of the gain control is about 30dB, and the attenuation level is precisely controlled by a 12-bit analog to digital converter.

High speed switching of the drain current is necessary to achieve the high efficiency and pulsed RF operation. To minimize the voltage drop and due to the resistance in a drain switch, twenty HEXFETs are connected in parallel, and a bus bar is designed in the input/output of the drain switch. The drain switch achieved the voltage drop less than 0.5V operating in a 120A current condition.

90-degree difference was achieved by using the two levels

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of 3dB coupled line power divider/combiners. A metal wall is installed between amplifiers to minimize mutual coupling. EMI filters are installed to gate terminals of the GaAs MMIC amplifiers to reduce the RF signal interference through the DC voltage line. As result stated above, the 180W linear amplifier achieved better than 90% power combining efficiency and stable operation under –30 to 60 temperature range.

Fig. 4 shows frequency dependency of measured output power (Po) at 2dB gain compression point ,small signal gain (Gain) and Power added efficiency. The linear amplifier achieved better than 52.5dBm output power with 39.9dB small signal gain over the 2.7 to 2.9 GHz frequency-range. In respect of the linearity of the 180W amplifier, excellent linearity was achieved up to the 49dBm output power level.

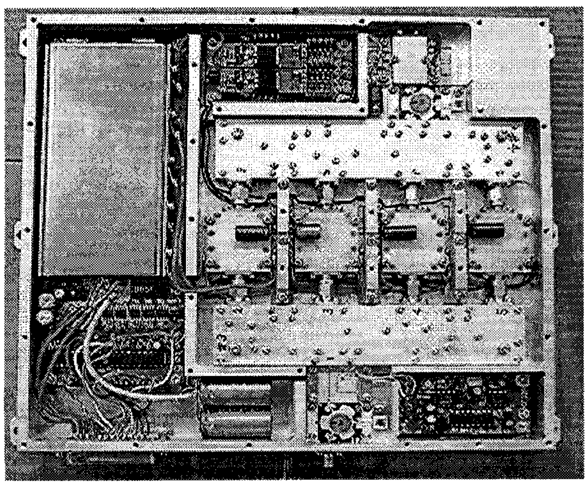

Fig. 1. Photograph of the 180W linear amplifier

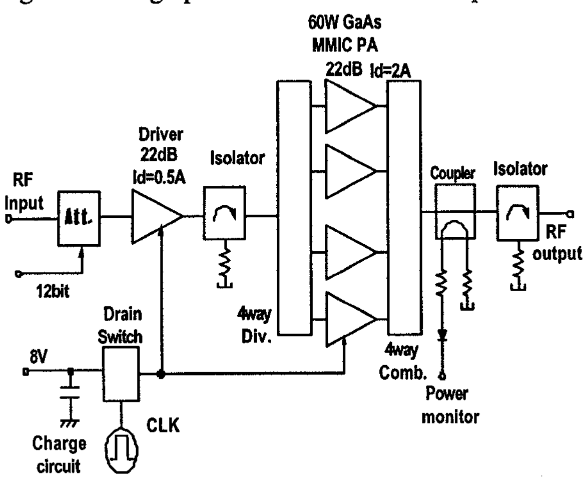

Fig. 2. Block diagram of the 180W linear amplifier

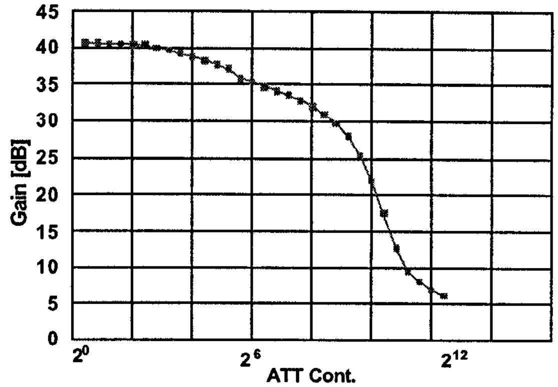

Fig. 3. Characteristics of GaAs MMIC attenuator

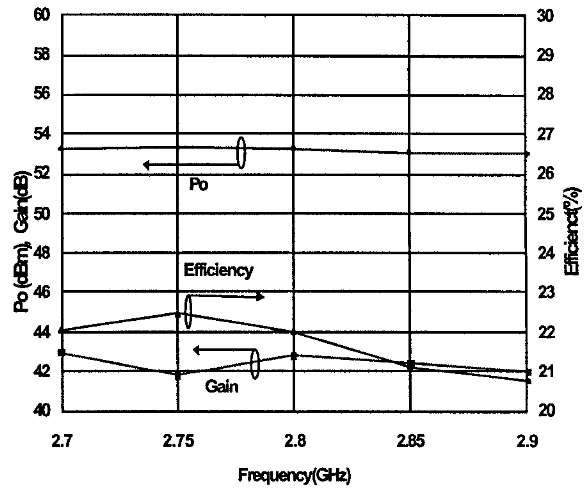

Fig. 4. Frequency dependency of the linear amplifier

B. 1.8KW high power amplifier

The 1.8KW HPA consists of four 550W amplifiers and 4-way power divider/combiners. Fig. 5 and Fig. 6 show the block diagram and the photograph of the 1.8KW HPA.

Power transistors used in the 550W amplifier are 150W output power, 9dB gain Silicon bipolar device (IB2729-M150 from Integra Technologies, Inc. Torrance, CA) in the common base configuration, operating in class C to achieve maximum output power and efficiency. Photograph of the 550W amplifier is shown in Fig. 7.

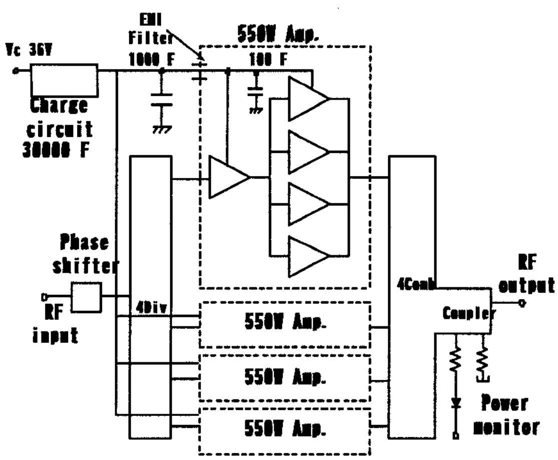

Fig. 5. Block diagram of the 1.8kW HPA

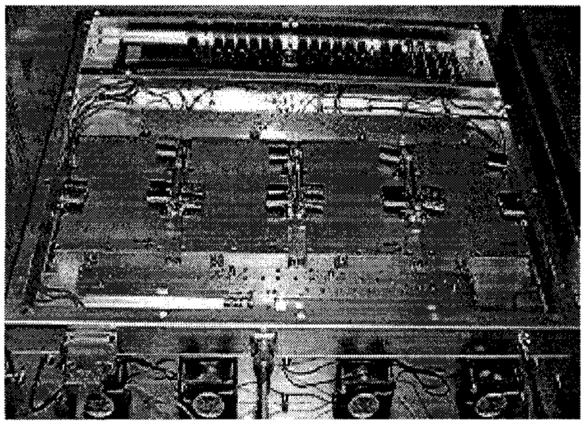

Fig. 6 Photograph of the 1.8KW HPA

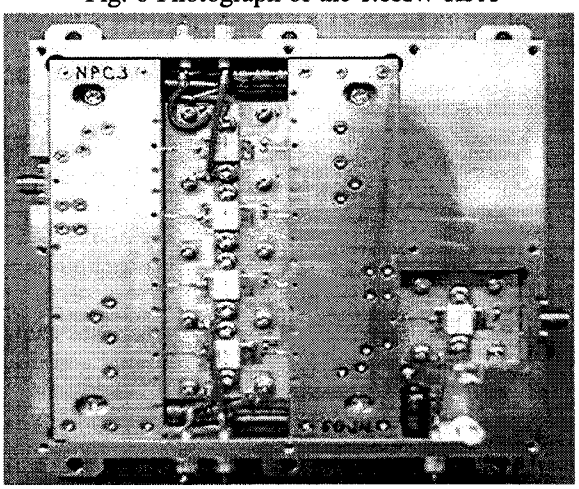

Fig. 7. Photograph of the 550W amplifier

A thickness of the power divider/combiner was selected as a manner equal to the depth of the 550W amplifier case to prevent an RF signal feedback between a driver and final stage Si-BJTs. EMI filters and ceramic capacitors prevent an RF signal leak to the DC voltage line. Due to the fact that EMI filter deteriorates the RF pulse rise time, a 100μF capacitor is connected to the individual collector terminals to improve the RF pulse rise time.

Four-way power divide and combine are performed using low loss 3dB coupled lines. The insertion loss of the four-way divider/combiner was less than 0.5 dB. Port to port isolation and port return loss were more than 20dB respectively in the 2.7 to 2.9 GHz frequency range. By using the 3dB coupled line power divider/combiner, phase difference of the transistors is 90-degrees. This feature minimized odd mode oscillation. To realize excellent gain flatness, a frequency equalizer using a resistor and an open stub is inserted to an input matching circuit for the Si-BJT. The frequency equalizer improves the stability of operation, because the equalizer reduces quality factor of the input matching circuit and compensates the gain flatness in the lowest operational frequency range. An output matching circuit topology was optimized to minimize the Si-BJT's collector-voltage drop. These design guarantee the high efficiency and highly stable operation of the 550W amplifier.

Fig. 7 shows the frequency dependency of the gain and output power. The output power was measured in the condition that the individual Si-BJT's collector current of 10A. This is 10% lowered condition of the nominal corrector current value to increase the transistor's reliability. From Fig. 8, the output power of the 550W amplifier is better than 57.5dBm, with better than 16dB gain.

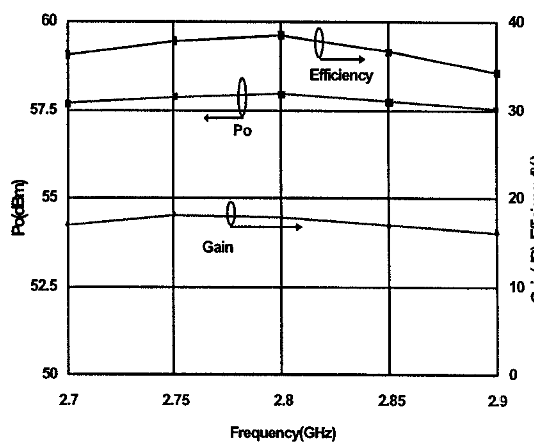

Fig. 8. Frequency dependency of 550W amplifier

Next, we describe the 1.8KW HPA. As shown in Fig.5, 1000μF capacitors are connected to the individual 550W amplifiers to compensate the voltage drop between the charge circuit and the 550W amplifiers. A phase shifter is placed in the input of the 1.8KW HPA. Thermal design using the air-cooling technique of the 1.8KW HPA is such that the maximum junction temperature is less than 170 at ambient temperature of 60 .

Power combiner for the 1.8KW HPA need more than 1.8KW peak power handling capability. We used low loss, high peak power tolerance substrate. The thickness of the dielectric substrate is twice as the substrate used in the 180W and 550W amplifiers. When the substrate thickness is doubled, the conductor width is doubled too; therefore, the conductor loss and a heat from the conductor can be reduced. The peak power tolerance of a strip-line is approximated to the co-axial line peak power tolerance [4],

$$P = (0.124)E^2 a^2 \sqrt{\varepsilon} \log_{10}(a/b) \qquad (1)$$

where, P =peak power , E =voltage gradient at the surface of the center conductor, =relative dielectric constant, a =strip-line width, and b =substrate thickness. Fig. 9 shows the characteristic of the peak power handling for the 50Ω strip-line calculated by equation (1). From Fig. 9, more than 10kW peak power tolerance is achieved when a 5.08mm thickness substrate is used. Measured combiner insertion loss was less than 0.6dB. The power combiner implements a directional coupler to detect the output power level.

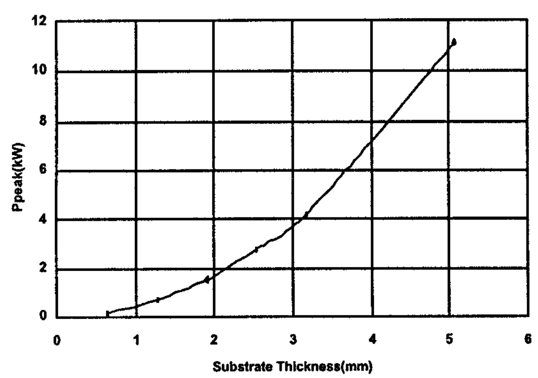

Fig. 9. Peak power handling characteristic for a $\varepsilon_r = 2.2$ material.

Fig. 10 show s the measured frequency dependency of the gain, output power of the 1.8KW HPA. From Fig. 10, better than 62.55dBm (1.8KW) and about 14dB gain was achieved.

There are gain unbalance among the four 550W amplifiers (1dB max), lower gain amplifier can not operate at the compression point so the power output is lower than expected.

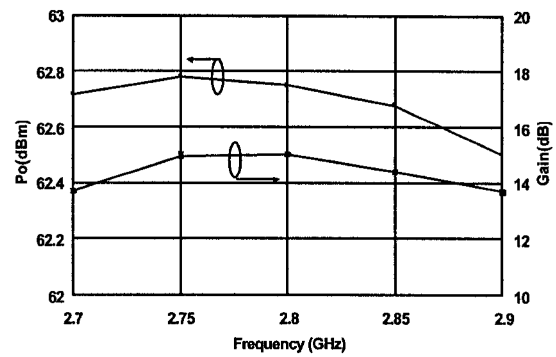

Fig. 10 Frequency dependency of 1.8KW amplifier

III. Conclusion

We have described the design and performance of the amplifier family for the next generation of the air surveillance and traffic control radars in the 2.7 to 2.9GHz band.

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