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RECENT ADVANCES IN HIGH-POWER MICROWAVE AMPLIFIERS*

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ABSTRACT

Recent advances in microwave amplifiers have increased efficiencies and power levels at frequencies from 0.3 to 150 GHz. These improvements have occurred in both solid-state and vacuum-tube systems. Of special note is the very high power device where power levels of 1 GW are routinely generated. This paper will review the latest results of these R&D efforts.

INTRODUCTION

Recent military requirements for high-power microwave amplifiers have driven the development of these systems to new levels of output power and efficiency at frequencies from 0.3 to 150 GHz. These [illegible]er remarkable improvements have occurred in solid-state and tube type amplifiers.

Significant progress has been made in the power [illegible] capability of solid-state amplifiers and in their e[illegible]cy. In the last few years, GaAs has begun to repl[illegible] silicon as a basic wafer material because of its increased electron mobility that gives it the capability to operate at higher frequencies. Below 3 GHz, silicon bipolar or field-effect transistor (FET) configurations are the device of choice for rf power amplification. Above 3 GHz and especially above 10 GHz, an FET configuration built with GaAs is the device of choice.

Below 10 GHz, not much has happened in the way of power output from tube amplifiers. Most of the improvement has been achieved in the area of efficiency. Klystrons with 60% beam efficiency are now common-place. It has been shown that this efficiency can be improved to about 75% using a depressed collector. Two new devices have been introduced in the past two years, the Klystrode and the lasertron. Great strides have been made in the super power area where vacuum-tube devices are now capable of generating 1 GW of rf power at short pulse lengths.

SOLID-STATE AMPLIFIERS

The SDIO requirements for megawatts of rf power at UHF frequencies have resulted in solid-state specific weight (g/W) improvements as shown in Fig. 1. These data are for a complete amplifier including driver stages, output combiner, and power conditioning. These improvements occur because single device output power levels have improved from 150 peak W per single-ended device to over 700 peak W. At the same time, efficien-cies have improved from about 60% to over 70%. Considerable from about 60% to over 70%. Considerable advances in amplifier packaging technology have also contributed substantially to the amplifier weight reduction.

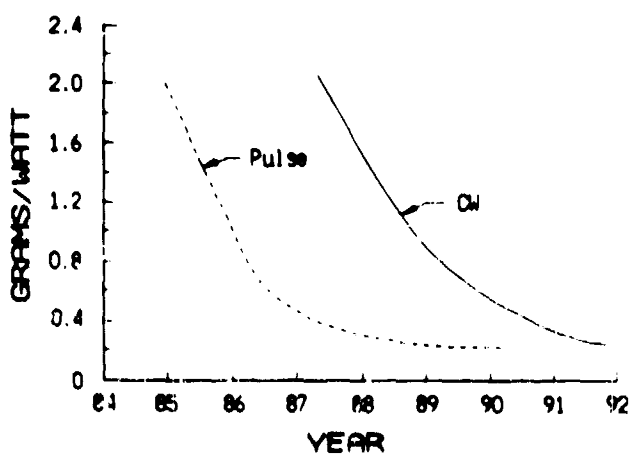

Fig. 1. Specific weight improvements for solid-state amplifiers

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A very recent advance in the state of the art at UHF frequencies is the static induction transistor (SIT).[1] A SIT in both double-ended and single-ended configurations is shown in Fig. 2. The single-ended device has delivered 280 W of cw power with 7.0 dB of gain and 73% efficiency.

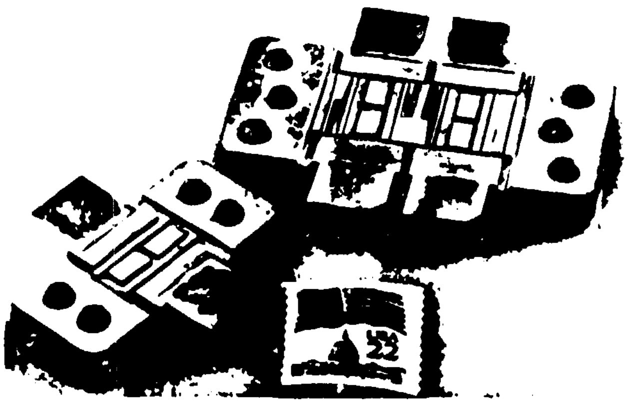

Fig. 2. Static Induction Transistor (SIT) configurations.

As the frequency increases, the output power of the bipolar transistor decreases according to the curve shown in Fig. 3. The search for a solid-state rf device at 10 GHz and above has led to the use of GaAs as a transistor material in place of the conventional silicon. Although the field is new, solid-state

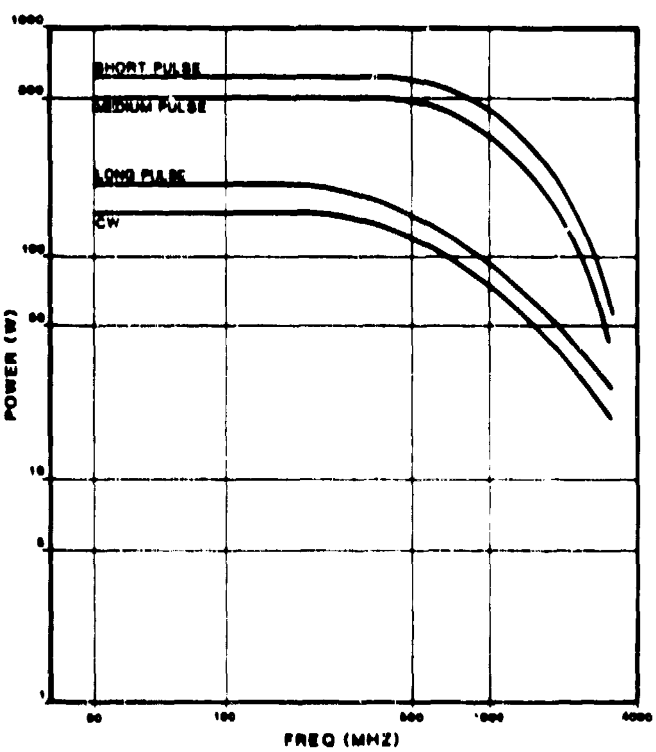

Fig. 3. Bipolar transistor output power vs frequency

amplifiers are being built from 3 to 30 GHz. The GaAs transistors are typically built in the FET configuration and produce a few watts per device at 10 GHz to of the order of 0.5 W at 30 GHz.

VACUUM-TUBE AMPLIFIERS

Although the Klystrode, an old idea from the 1930s, has now been developed, it has only recently been introduced for television service at 60 kW cw.[2] The Klystrode depends on a grided cathode for its operation. The grid is driven with rf power at the appropriate frequency. This has the effect of bunching the beam as it leaves the cathode. A strong dc voltage is applied between the grid and the anode or body of the tube to supply energy to the prebunched electron beam. The beam then transits a standard klystron output cavity where its dc energy is extracted as rf power.

The use of a grid to prebunch the beam makes the Klystrode much smaller than a conventional klystron at similar frequencies. It also typically has over 70% beam efficiency. A program is presently being conducted at EIMAC to develop a tube capable of 500-kW peak power at 425 MHz and 70% beam efficiency. The tube and magnet will weigh less than 110 lb. An artist's concept of what the tube will look like is shown in Fig. 4.

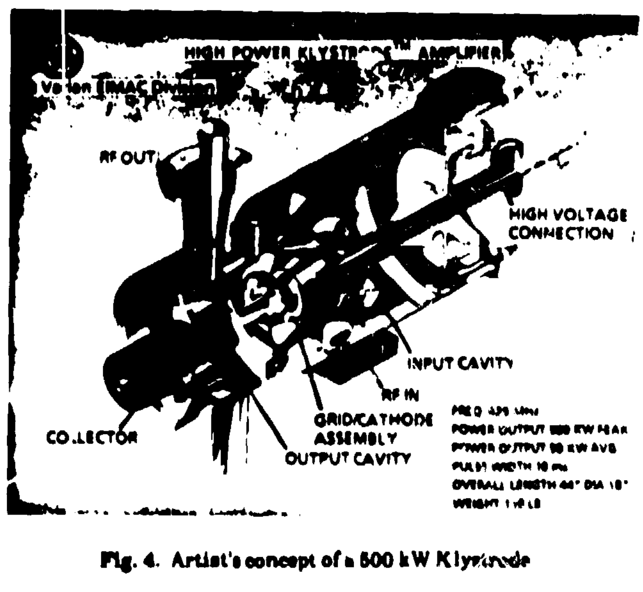

Fig. 4. Artist's concept of a 500 kW Klystrode

Another vacuum-tube device that relies on the concept of a prebunched or emission gated beam is the lasertron. This device was patented by Los Alamos National Laboratory in 1982[3] and has recently been worked on at several laboratories internationally. It operates in exactly the same fashion as the Klystrode except that a laser pulsed at the desired frequency causes a photoemissive cathode to emit. This generates a prebunched beam that passes through the dc field and into the output cavity. Computer simulations show that the lasertron has the capability of achieving greater than 80% beam efficiency at UHF frequencies.

MILLIMETER WAVE AMPLIFICATION

If relatively high powers are desired at millimeter wave frequencies, one usually turns to a traveling-wave tube (TWT) or a crossed-field amplifier (CFA) for amplification of the microwave power. For example, TWTs are available in cw power levels of 40 W at 20 GHz and 100 W at 30 GHz. A CFA is available at 34 GHz and has a peak output power of 3 kW. Efficiencies range from 20% at 20 GHz to 18% at 30 GHz for TWTs and 30% efficiency at 34 GHz for a reflection-amplification mode CFA.

One of the more exciting developments in rf amplifier technology over the past few years has been the gyrotron. The device has been built as both an amplifier and as an oscillator. Originally developed for use as a plasma-heating rf amplifier in the fusion energy program, it is now seen as a potential for several high-frequency applications. Gyrotrons have been built at 28 GHz to deliver 340 kW of cw power at 50% beam efficiency. At 60 GHz, the output power is 200-kW cw at about 40% efficiency. One of the truly remarkable achievements is at 140 GHz, where output powers of 100-kW cw and 300-kW pulse have been measured at efficiencies of about 25%. An R&D program is presently being implemented at Varian to achieve 1-MW peak power at 140 GHz.

VERY HIGH POWER VACUUM TUBES

The possibility of using microwaves as a battlefield weapon has sparked a great deal of interest in very high power rf oscillators at generally short pulse lengths. Powers are typically of the gigawatt level and pulse lengths are between 50 and 100 ns; although one device, the large orbit gyrotron, has the capability of running cw. Two prominent devices in this arena are the relativistic magnetron and the virtual cathode oscillator or Vircator. To date, the highest power relativistic magnetron has achieved 1 GW at an efficiency of about 10% at 3 GHz with a pulse length of 60 ns. The Vircator has achieved greater than 40 GW at an efficiency of 5%. Pulse lengths are 100 to 150 ns and the devices operate over very wide frequency ranges of the order of 1 to 40 GHz. The large orbit gyrotron has delivered 1 GW at about 40% efficiency and shows evidence of operating from 2 to 35 GHz. This will prove to be an exciting field with many measurement and field breakdown challenges to be solved.

ACKNOWLEDGMENTS

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