# HIGH-POWER, SOLID-STATE AMPLIFIER

*H. Hom, R. McMaster, B. Sanders*
**ITT Gilfillan**
**7821 Orion Ave.**
**Van Nuys, CA 91409**

## ABSTRACT

Because of recent advances in both bipolar and divider/combiner technologies, solid-state amplifiers can now be configured to operate at high power levels through L-, S- and C-band frequencies. This paper describes both module and divider/combiner technology developments that are required to achieve amplifier peak powers of 200 kW at L-band, 70 kW at S-band, and 30 kW at C-band. The feasibility of this performance throughout these frequency ranges has been demonstrated in the Antenna/Microwave Lab at ITT Gilfillan.

## INTRODUCTION

Advances in high-power RF transistor technology are ushering in a new era of high-power, solid-state transmitters which offer higher reliability, ruggedness, and provide high average power over broad instantaneous bandwidths with higher efficiencies than tube-type counterparts. Availability is improved because of the inherent fail-soft operation and the ease of added redundancy associated with multiple module usage. Further, personnel hazards, high maintenance costs, and larger sizes associated with the tube-type, high-voltage power supplies and modulators are eliminated.

The performance advantages of microwave solid-state transmitters over tube counterparts have long since been recognized, but earlier high acquisition costs discouraged widespread usage of this technology. During the last several years, the technology has advanced to a point where completely solid-state, high-power transmitters are practical at a lower overall cost than tube counterparts. The basic reasons for this are threefold. First, evolving technology has increased the output power of microwave transistors by roughly a factor of eight in the last five years; second, the cost of producing this power has concurrently decreased by a factor of six; and third, significant advances in RF combiner technology have helped to increase overall transmitter efficiency to a point that is acceptable to the majority of users. These factors are particularly true for pulse applications in the 400-MHz to 6,000-MHz region. Since this band covers many of the prime search radar frequencies, much of the development effort in pulsed microwave solid-state source development has been concentrated on radar transmitters.

While the technology discussed herein is applicable throughout the microwave frequency region where fundamental solid-state sources are available, this paper will address those accomplishments made (1) on L-band high-power solid-state transmitter for MAR (Minimally Attended Radar) applications, (2) an S-band first-stage for a Military Air Defense shipboard radar, and (3) a C-band developmental module.

## L-BAND MODULE TECHNOLOGY

One-kilowatt, L-band solid-state modules have been a reality here at ITT Giffillan for several years, and have demonstrated excellent performance in a 20-kW scaled-model demonstrational transmitter. Each basic module used in this application consists of 15 100-watt transistors of which 12 are used in the output section to produce the required power output, and the remaining three are used as drivers (see Figure 1).

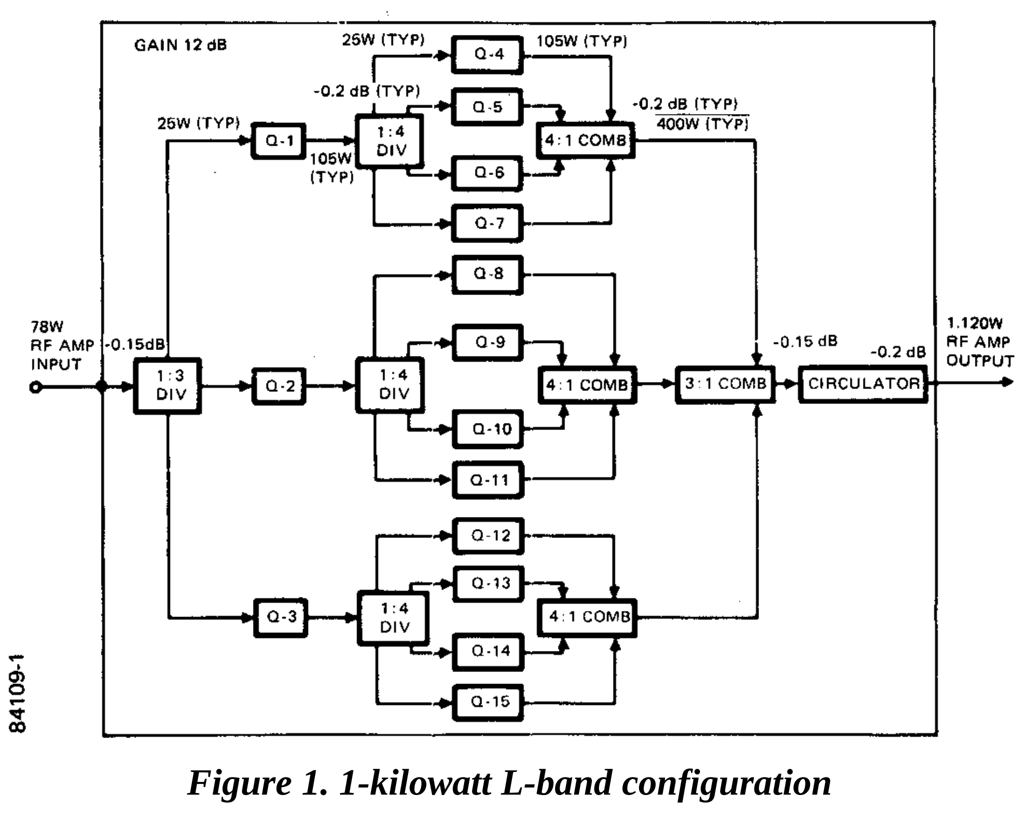


*Figure 1. 1-kilowatt L-band configuration*

## L-BAND MICROWAVE TRANSISTOR

A typical silicon multicell, high-power microwave transistor is shown in Figure 2. These transistors feature internal impedance matching, gold metallization, and diffused ballast resistors for added reliability, as well as high and efficiency over broad signal bandwidths. Other features that add to long life and high performance include a design optimized to minimize thermal stresses and current densities, high integrity silicon and junction passivation, a rugged metallization that prevents electrochemical corrosion, silicon dissolution oxide reduction and electromigration effects, and a package design that provides a hermetic, low parasitic, and maximum heat dissipation environment. Extensive vendor surveys, in-house evaluation efforts, and company-funded transistor developments have ensured that microwave transistors used in these modules are the finest that are available in the industry.

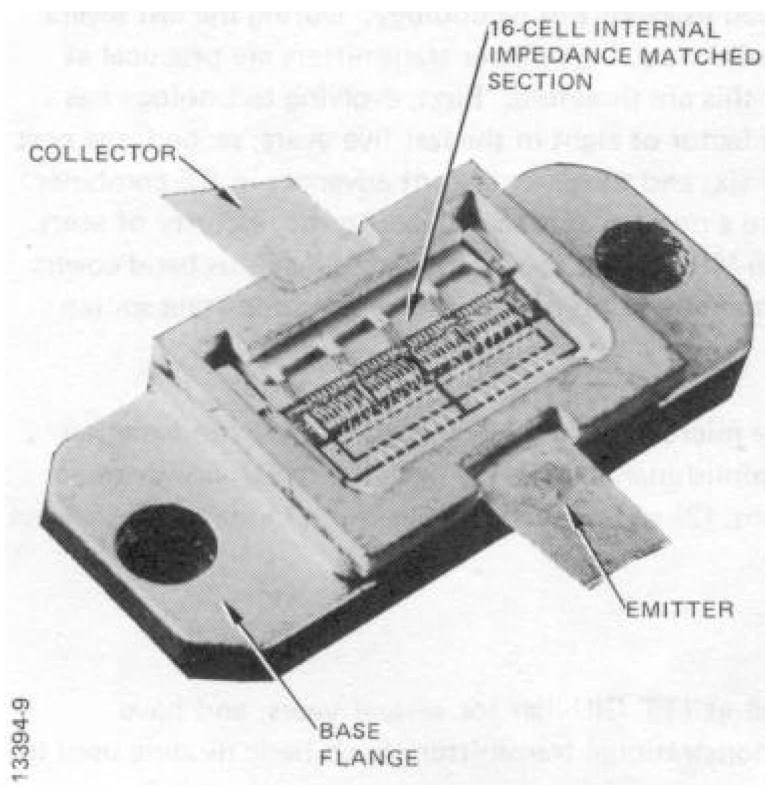


***Figure 2. Cutaway view of a typical solid-state power transistor***

At the outset of module development in late 1977, an 85-watt, 125-µsec transistor with 50-percent efficiency represented the state of the art. One year later, reliable, high performance, 110-watt devices were available from several sources, and shortly thereafter, new breakthroughs in technology began to produce 250-watt, pulsed L-band transistors. This new development is a direct result of company-funded transistor development contract awards to two of the leading transistor manufacturers in the industry to develop high-performance, 300-watt, L-band transistors. The overall impact of this remarkable progress over the past several years is to significantly lower the cost of the L-band pulsed power, while improving both the performance and reliability.

## DESCRIPTION OF L-BAND AMPLIFIER MODULE

The solid-state amplifier module that was developed for MAR transmitter systems is shown in Figure 3. This module consists basically of an RF section, a rectifier/regulator assembly, a fault-monitor/BITE assembly, and a chassis assembly designed to transfer heat from the microwave transistors efficiently.

The RF section, configured in a high-dielectric, microstrip transmission medium to minimize area, weight and costs, consists of three submodule assemblies and two 3-way divider/combiner networks to produce the rated output power. A typical submodule assembly is shown in Figure 4. The submodule circuitry is mounted on a single substrate of flexible laminate that is preattached to a metal baseplate. Transistor flanges are deleted to reduce the junction-to-baseplate thermal resistance, and the transistors are soldered directly to the baseplate. During the development, some of the transistors were constructed with sapphire lids to permit direct measurement of junction temperature under actual operating conditions. Four RF transistors provide

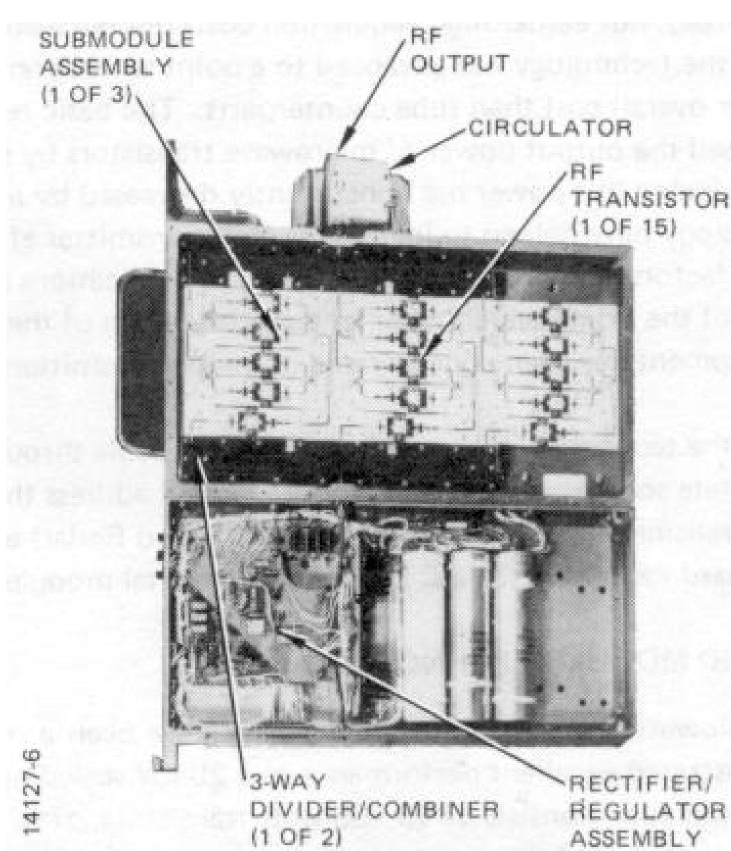


*Figure 3. 1 kilowatt RF power amplifier module*

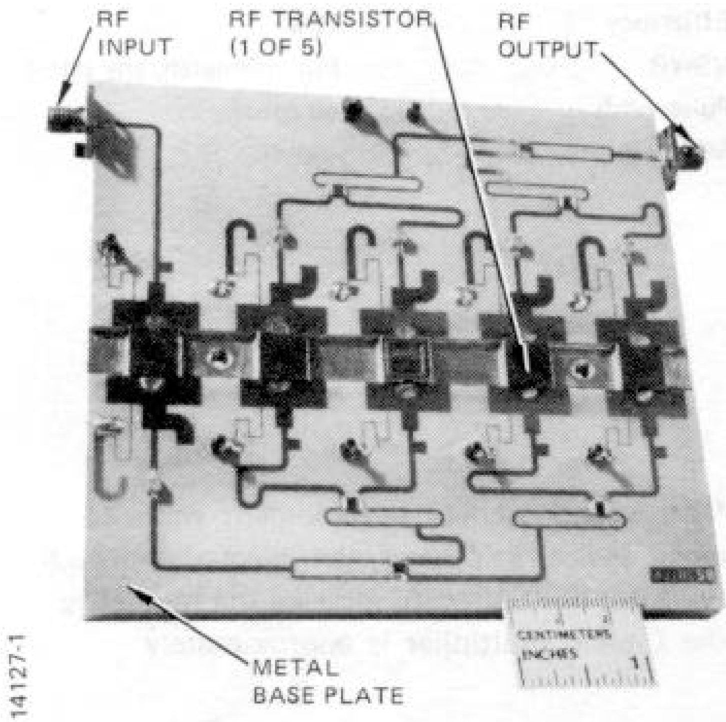


***Figure 4. 400-Watt L-bank, solid-state submodule assembly***

the rated submodule power, while the fifth serves as a driver. When the submodule outputs are combined with the three-way divider/combiner network and directed through the circulator, a module output power in excess of 1,100-watts peak is obtained. Table I shows a summary of the measured RF performance of the module.

***Table I. Comparison of Measured Performance of L-Band Solid-State Amplifier Module with Design Goals***

| Parameter | Measured Performance |
|---|---|
| Frequency | 1200 MHz - 1400 MHz |
| Peak Power Out | 1130 Watts |
| Pulsewidth | 122 µsec |
| Duty Factor | 6% |
| VSWR (Load) | α:1 |
| Gain | 12 dB |
| Efficiency | 38% |
| Pulse Droop | 0.3 dB |
| Amplitude Stability | 0.25 dB/V |
| Phase Stability | 3 deg/V |
| Operating Temperature | -54°C-+70°C |

In addition to the RF section, each power amplifier module contains a power supply series regulator and BITE circuitry mounted in a separate compartment. These designs provide ripple-free collector voltage to the RF transistors, as well as continuous fault monitoring and status indication. Large storage capacitors are used to provide nearly constant energy to the RF transistors during pulse time, thereby preventing excessive pulse droop. The voltage regulation is better than ±0.01 volt to maintain good phase and amplitude stability. The BITE (Built-in Test and Evaluation) circuitry automatically detects faults within the module and relays this information to a centralized fault-monitor network. It also activates lights on the module status panel to allow the operator, with only a cursory glance, to determine whether a given module is functioning correctly or incorrectly.

The module chassis has been designed as a plug-in unit to facilitate rapid maintenance, as this feature is vital in arctic regions where the environment is normally severe. The module is cooled by blowing air across the fin structure located on the rear of the chassis. All calculated temperature gradients in the module were verified with measurements, and the heat-exchange mechanisms designed accordingly. This ensures that heat generated by the RF transistors is efficiently removed from the unit and undesired heat buildups that would compromise the integrity of the transistors are avoided. Thirty RF amplifier modules were built and tested to satisfy MAR feasibility equipment requirements.

## S-BAND MODULE DEVELOPMENT

At S-band, the development of a 610-watt module was successfully completed in 1983. A number of these modules have now been fabricated and combined to form a 4-kW first-stage amplifier for use in a multistage transmitter presently under development here at ITT Gilfillan. Figure 5 shows the first stage amplifier hardware and the attendant Table II shows the measured performance. Phase 2 of this activity will be to fully solid-state both the first- and second-stage S-band amplifiers and achieve a peak-power output of 64 kW.

The present 610-watt S-band module is configured using 16 60-watt transistors and, as similar in the case of the L-band unit, 12 devices are used to generate the module output power. A picture and diagram of the prototype are shown in Figures 6 and 7. ITT Gilfillan is presently engaged in codevelopment efforts with two of the leading microwave transistor manufacturers to produce 120-watt S-band devices. The successful completion of this development will reduce the transistor cost by a factor of two. Another significant achievement that evolved from this S-band exercise was the development of ATE (Automatic Test Equipment) that has been tailored to evaluate high-power amplifiers. This reduces test time by a conservative factor of six. At least 15 modules have been tested using ATE and the test results are repeating with good accuracy. A sample of the module test data is shown in Table III.

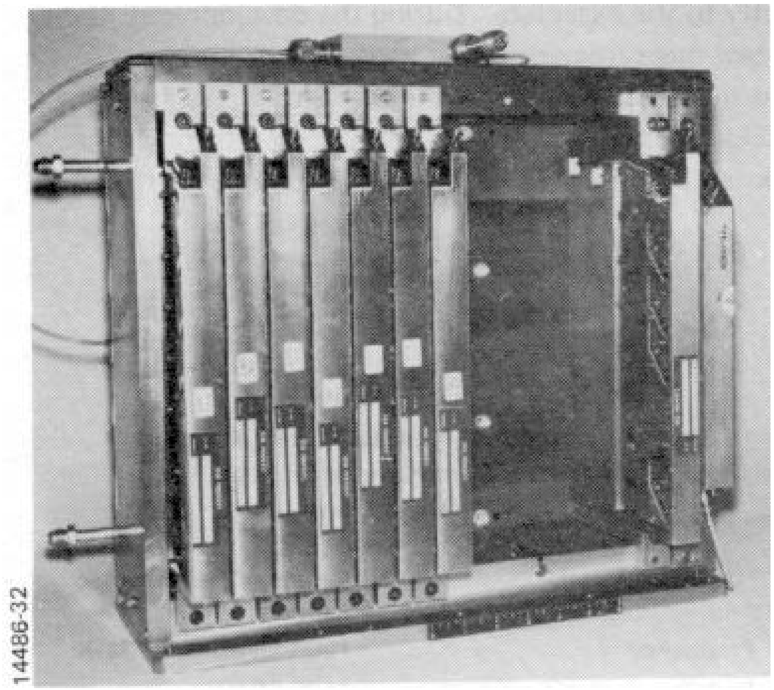


***Figure 5. 4-kilowatt amplifier***

***Table II. 4-Kilowatt Amplifier Measured Performance***

| Parameter | Performance |
|---|---|
| Frequency | 2900 MHz to 3100 MHz |
| Peak Power Output | 4.6 kW |
| Duty Factor | 4% |
| Gain | 40 dB |
| Efficiency | 20% |
| VSWR | Full mismatch, any phase |
| Pulsewidth | 40 µsec |
| MTI Stability | -58 dB |

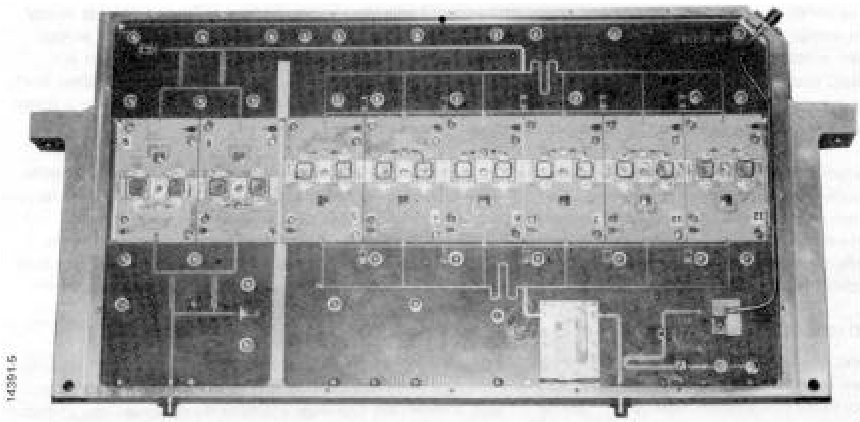

*Figure 6. 610-Watt module amplifier*

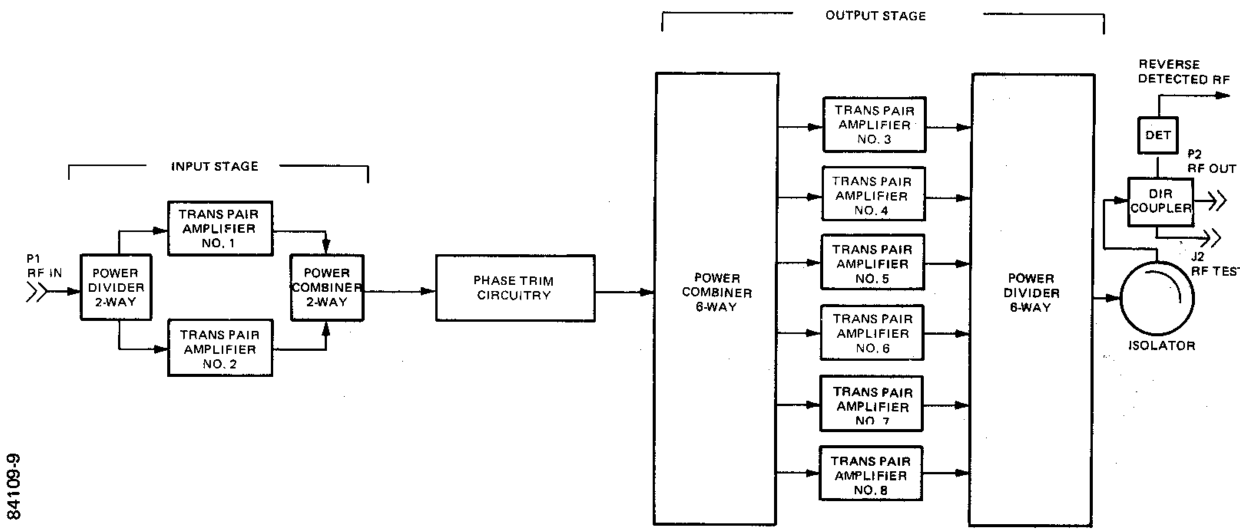


*Figure 7. 610-Watt RF amplifier configuration*

## C-BAND MODULE

A 300-watt C-band module was configured in 1983, and much of the subcomponent development was also accomplished. Because of the nonavailability of fundamental frequency devices at C-band, the selected approach here is to generate fundamental frequency power at S-band, then use varactor multipliers to increase the frequency to C-band. The S-band amplifier work has been completed and the C-band multiplier is approximately 80 percent complete.

A configuration of the 300-watt module is shown in Figure 8. Six sets of multipliers are combined at the output to obtain 300 watts. Each multiplier set is driven by a pair of S-band amplifiers. This amplifier circuit design has been optimized for high efficiency, 50 percent, and medium output of 50 watts. A photograph of a completed S-band pair-amplifier is shown in Figure 9, and the measured performance is shown in Table IV.

## *Table III. ITT Gilfillan Test Report - 610-Watt Amplifier, P/N 168215*

**Serial No. 6 Pass**
**EDM Reference Module**

**Date: March 12, 1984**

| Freq (GHz) | Relative Power 5% | Relative Power 95% | Total Droop (dB) | Pwr Gain (dB) | Pwr Out (Watts) |
|---|---|---|---|---|---|
| 2.9 | 0.1 | -0.1 | 0.20 | 10.0 | 594 |
| 3.0 | 0.1 | -0.2 | 0.30 | 10.5 | 665 |
| 3.1 | 0.2 | -0.1 | 0.30 | 10.3 | 634 |

| Freq (GHz) | VSWR | Insertion Phase 5% (deg) | Insertion Phase 50% (deg) | Insertion Phase 95% (deg) | Phase Droop (deg) |
|---|---|---|---|---|---|
| 2.9 | 1.19:1 | 0.4 | 0.4 | 0.2 | 0.2 |
| 3.0 | 1.11:1 | 0.7 | 0.5 | 1.4 | 1.3 |
| 3.1 | 1.14:1 | 1.2 | 1.1 | 0.7 | 0.5 |

**For 3 GHz: (Peak Values)**

| Collector (Volts) | Collector (Amps) | RF Power (Watts) | Efficiency (%) |
|---|---|---|---|
| 41 | 94.41 | 656 | 22.6 |
| 42 | 96.40 | 671 | 22.1 |
| 43 | 98.19 | 671 | 21.2 |

Amplitude Stability = ±0.2 dB
Phase Stability = ±0.1 degrees
Nominal Current = 0.17 mAmps
RF Test (3 GHz) = -39 dB From Output

Detected RF BITE is Normal
Overheat Detection is: Normal

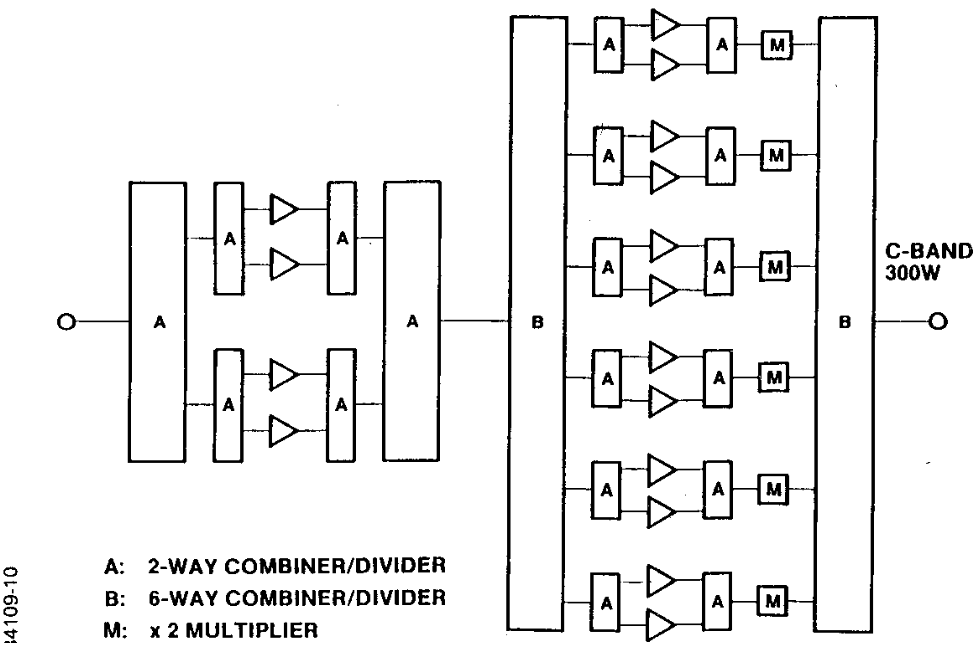


*Figure 8. 300-Watt C-band configuration*

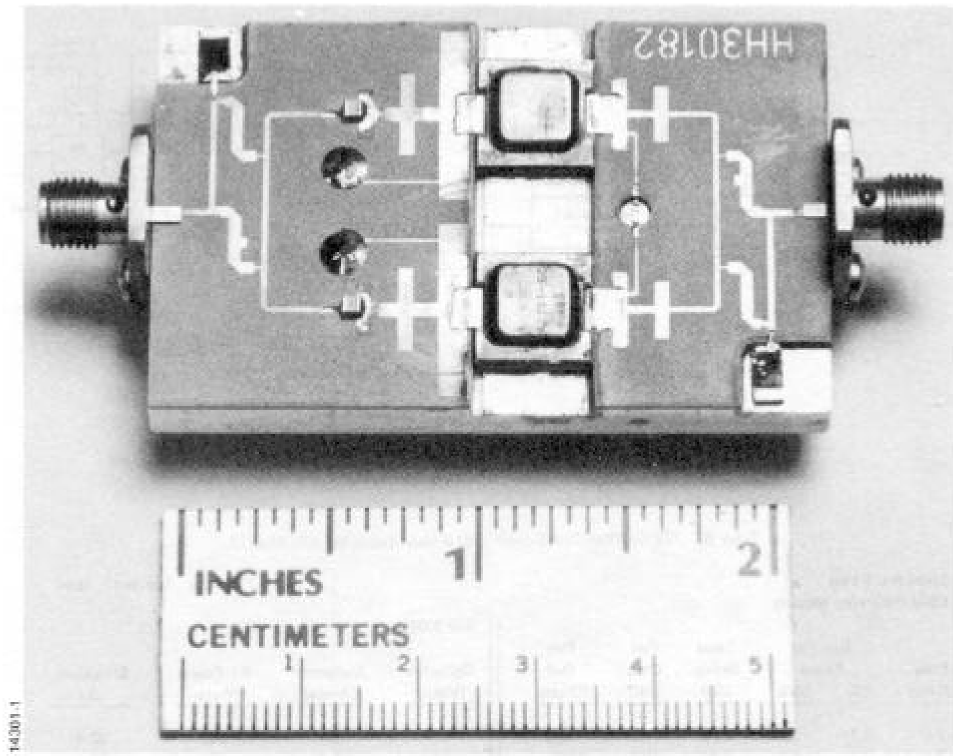


***Figure 9. 100-Watt, S-band, high efficiency amplifier***

***Table IV. High-Efficiency S-Band Amplifier***

Part No. - AMS2731-45
Mfr - MSC (Microwave Semiconductor Corp)

| Serial No. | Frequency | Peak Power Out (W) | Pulsewidth (μsec) | Gain (dB) | Efficiency (Peak) (%) | Efficiency (Average) (%) |
|---|---|---|---|---|---|---|
| 424 | $F_1$ | 111.3 | 307 | 6.7 | 49.8 | |
| | $F_2$ | 109.4 | 307 | 6.6 | 48.2 | 48.83 |
| | $F_3$ | 104.5 | 307 | 6.4 | 48.4 | |

**Divider/Combiner Technology**

Our divider/combiner technology over the past several years is highlighted by the successful development of a 110-way, parallel-plate divider/combiner network that is particularly well suited for combining modules of high-power levels in excess of 500 kW, and provides a phenomenally low loss of 0.23 dB. Conventional networks with comparable combining ratios would typically have insertion losses on the order of 2 to 3 dB. A photograph of the construction is shown in Figure 10, and the performance is shown in Table V.

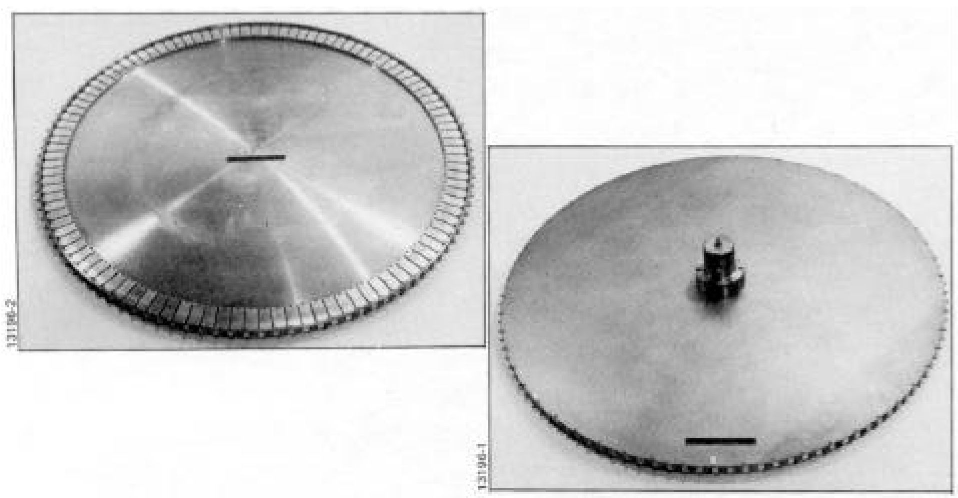


***Figure10. 110-way parallel-plate divider/combiner network***

***Table V. Measured Performance of 110-way RF Divider/Combiner***

| Parameter | Measured Performance |
| --- | --- |
| Frequency | 1200 MHz - 1400 MHz |
| Average Coupling | -20.64 dB |
| Average Insertion Loss | 0.23 dB |
| Interport Isolation | |
| Adjacent Port | 15.1 dB |
| All Others | 22 dB |
| Peak Phase Error | ±4.45 degrees |
| rms Phase Error | 2.31 degrees |
| VSWR | 1.35:1 |
| Peak Power | 200 kW (Limit of Test) |
| Average Power | 13 kW (Limit of Test) |

A new linear waveguide divider/combiner network was developed in 1983 to accommodate the form-factor requirements of a Navy solid-state transmitter development. A 20-way network was successfully developed that demonstrated an insertion loss of 0.25 dB and a peak-power handling capability of 70 kW.

The development of planar stripline and microstrip divider/combiner networks continued to advance with the realization of a high-power (10 kW), 7-way network at S-band and a moderate-power, 6-way network at C-band. These planar networks are best suited for combining transistors within a module, but can also be used to combine modules in low-power transmitter applications.

## CONCLUSION

The technology has advanced to a point where high-power, solid-state transmitters have been reduced to state-of-the-art practices at frequencies ranging from UHF through C-band. ITT Gilfillan has demonstrated capabilities from L-band through C-band for developing solid-state transmitters with peak-power outputs from 30 kW to 200 kW