KA-BAND SOLID STATE POWER AMPLIFIER

Franklin J. Bayuk and Jorg E. Raue
TRW Defense and Space Systems Group
One Space Park
Redondo Beach, California 90278

Abstract

A technology development is described which has clearly advanced the state-of-the-art in high power, high performance solid state amplifiers. Five watts of output power at 37 GHz were achieved with a five-stage amplifier. Three stages operate in the negative resistance mode with 2 GHz of bandwidth, the final two stages are injection locked. The total amplifier gain is 33 dB. High efficiency power combining is used in the two power stages. Extensive use has been made of computer aided design, both in the negative resistance amplifier development and in the modeling and optimization of the multiple diode power combining structures. Novel broadband circulators couple the individual stages and provide interstage isolation with insertion loss levels of 0.1 dB per path. The entire amplifier, including diode current regulators, is enclosed in a housing 6 x 8 x 3 inches in size, and weighs 9 pounds.

Circuit Configuration

The five-stage amplifier design is shown in Figure 1. The three-stage driver module provides 500 mW of output power with 23 dB of gain over a 1 dB bandwidth of 2 GHz. Half watt GaAs lo-hi-lo profile diodes are used in each driver stage. The performance of this amplifier, as well as the low loss broadband circulators, were described previously.[1,2] The power stages are configured as coaxial cavity combiners and constitute the first successful high efficiency power combining effort above 30 GHz. One watt silicon double drift diodes are used in the combiner stages.

The combining scheme is similar to that previously reported at X-band,[3] however, the technique of achieving high combining efficiency and good bandwidth at a specified frequency at upper Ka-band required detailed modeling and a computer aided design approach.

Although devices available were capable of producing 1 watt above 30 GHz, trial and error efforts in various combiner circuits were not successful in producing high power, high efficiency combining results above 30 GHz. The following discussion will briefly outline the approach that led to successful controlled Impatt diode power accumulation at upper Ka-band. For example, 3.6 watts of output power were realized utilizing four one-watt diodes, with total design control over the output frequency. No adjustable tuning elements of any kind were employed in the combiner structure.

The basic combining structure is shown in Figure 2. The power summation is accomplished via the RF magnetic field which couples the individual coaxial circuits to the combiner cavity. The coaxial circuits contain the active devices and the necessary circuit impedance transformation elements required for efficient power transfer from the diode to the cavity. A coaxial probe couples to the RF electric field in the combiner circuit for final transformation to the input/output waveguide port.

The equivalent circuit used for computer modeling of a complex coaxial line structure is shown in Figure 3. The principal coaxial circuit dimensional parameters are identified. The single quantity of primary interest for effective operation of this circuit is the composite circuit impedance presented to the diode, labeled $Z_{circuit}$ in Figure 3. The validity of this equivalent circuit was verified by calculating the impedance seen at the plane of the diode for a given set of parameters representing physically realizable circuit dimensions, and subsequently comparing the predicted circuit impedance with the corresponding directly measured impedance. Employing widely varying sets of parameters, the calculated and measured impedances were determined over a wide but continuous frequency range. Good agreement between predicted and measured values was estabilshed in all cases. In view of the dimensional problems encountered at 35 to 40 GHz, this is considered to be a substantial accomplishment. For example, the total diameter of the combining cavity is about 1/4 inch, the diameters of the individual lines less than 0.08 inch.

The experiments described above established the feasibility of predicting and controlling circuit impedance which is compatible with the device terminal impedance.

Using a broadband coaxial diode circuit in conjunction with an integrated broadband waveguide-to-coaxial transition, the device terminal impedance was ascertained as a function of bias and drive level, and frequency. The various combiner circuit **parameters** were then iterated over physically realistic ranges to satisfy the condition

$$Z_{diode} = -Z_{circuit}$$

at the center frequency. With reasonable care in diode selection, the identical matching circuitry was then utilized in all coupling lines with good results. No additional tuning was used.

The gain-bandwidth characteristics of the amplifier are shown in Figure 4. An attractively low value of external Q of less than 20 was achieved for the 8-diode 5-watt combiner.

A summary of the performance of a number of amplifiers fabricated for the final power stages is listed in Table 1. A photograph of the final integrated amplifier is shown in Figure 5. The input port is on the far left hand side, the output waveguide port is visible at the front of the unit. The 5-junction circulator module coupling the 3 driver stages is clearly identifiable, as are the two cylindrical combining structures. The individual current conditioners are also clearly visible. The entire amplifier is about cigar box size and weighs 9 pounds.

The 5-stage amplifier delivers 5 watts with 33 dB gain at 37.3 GHz. The power variation over a bandwidth of 700 MHz is less than 1 dB. There were no discernible spurious outputs within the operating band or the waveguide band (26.5 to 40 GHz) and harmonic output levels were at least 20 dB and typically 30 dB below the carrier.

Table 1. Summary of Amplifier Performance of Several Power Combiners

Type of Combiner	Center Frequency (GHz)	Output Power (Watts)	Gain (dB)	Bandwidth (MHz)	Q_{ext}
4-diode	37.3	3.6	10.0	260	50
4-diode	37.3	3.6	28.0	30	50
8-diode	37.3	5.0	7.0	700	20
8-diode	37.3	5.0	29.0	75	20

Summary

This paper described the development of a state-of-the-art high power solid state communications amplifier at 37 GHz. Power combining at the multiple watt level was achieved above 30 GHz for the first time. Solid state power at the 5-10 watt level should prove to be very attractive for millimeter wave satellite communications applications.

Acknowledgement

The authors wish to thank A. Grote and W. Piotrowski for their significant technical contributions in this work, as well as T. Leisher, F. Garcia and N. Yoshiba for their technical support. The GaAs diodes were fabricated by M. G. Adlerstein of Raytheon, the silicon diodes were fabricated by R. S. Ying of the Hughes Aircraft Company. This work was supported by the Air Force Avionics Laboratory, Wright-Patterson AFB, Ohio, under contract F33615-74-C1051, which provided the Impatt diodes.

References

1. J. E. Raue, F. J. Bayuk and A. J. Grote, "Large Signal Device Characterization for Broadband Impatt Amplifier Design", 1976 IEEE-MTT International Symposium Digest, pp. 210-212.
2. W. S. Piotrowski and J. E. Raue, "Low Loss Broadband EHF Circulator", 1976 IEEE-MTT International Symposium Digest, pp. 263-265.
3. R. S. Harp and H. L. Stover, "Power Combining of X-Band Impatt Circuit Modules", Digest of Technical Papers, 1973 IEEE International Solid State Circuits Conference, pp. 118-119.

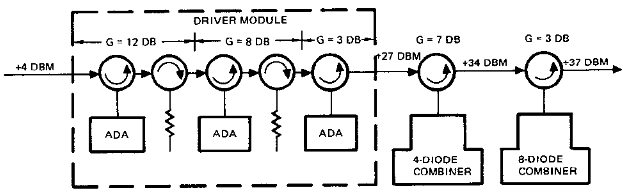

Figure 1. Schematic Presentation of the Amplifier Design

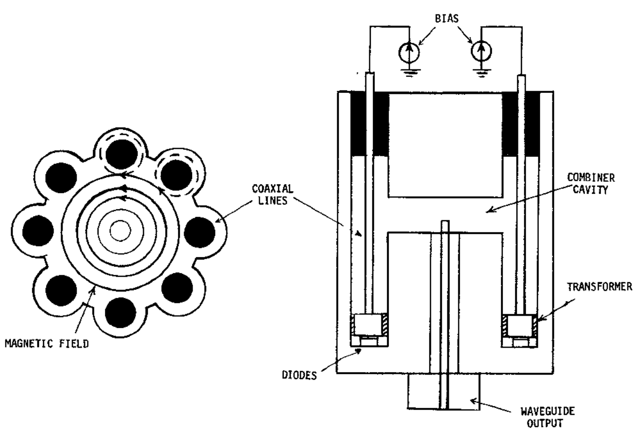

Figure 2. Top View and Cross Section of 8-Diode Combiner

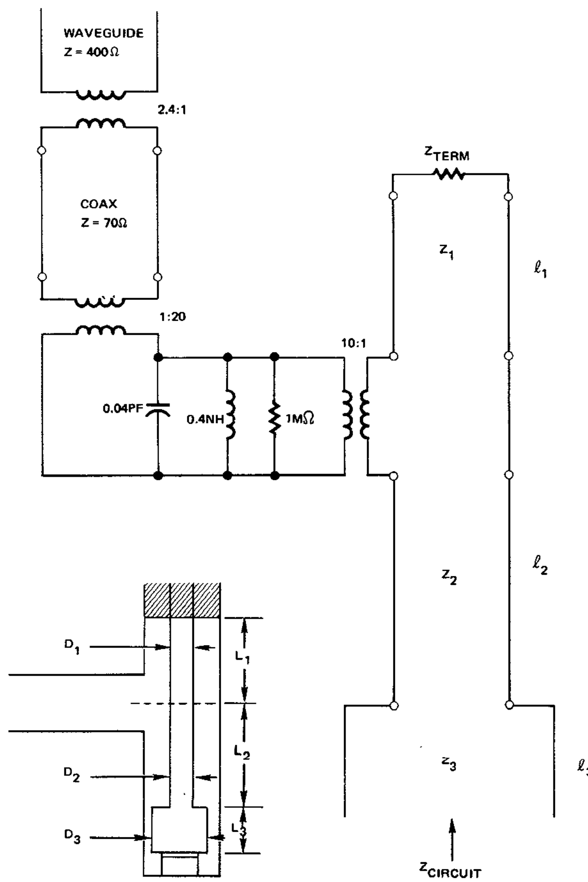

Figure 3. Equivalent Circuit and Parameters Utilized on Model

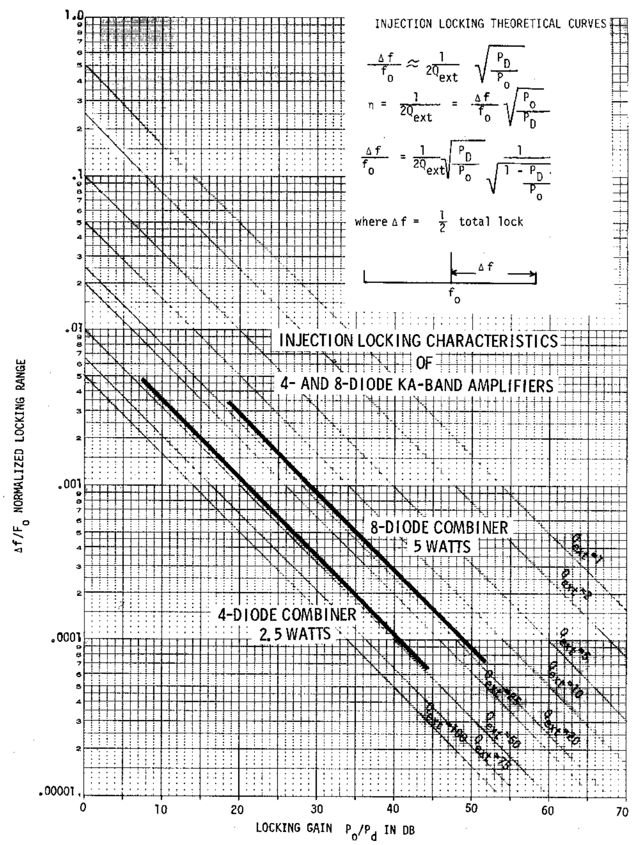

Figure 4. Injection Locking Characteristics of 4- and 8-Diode Ka-Band Amplifiers

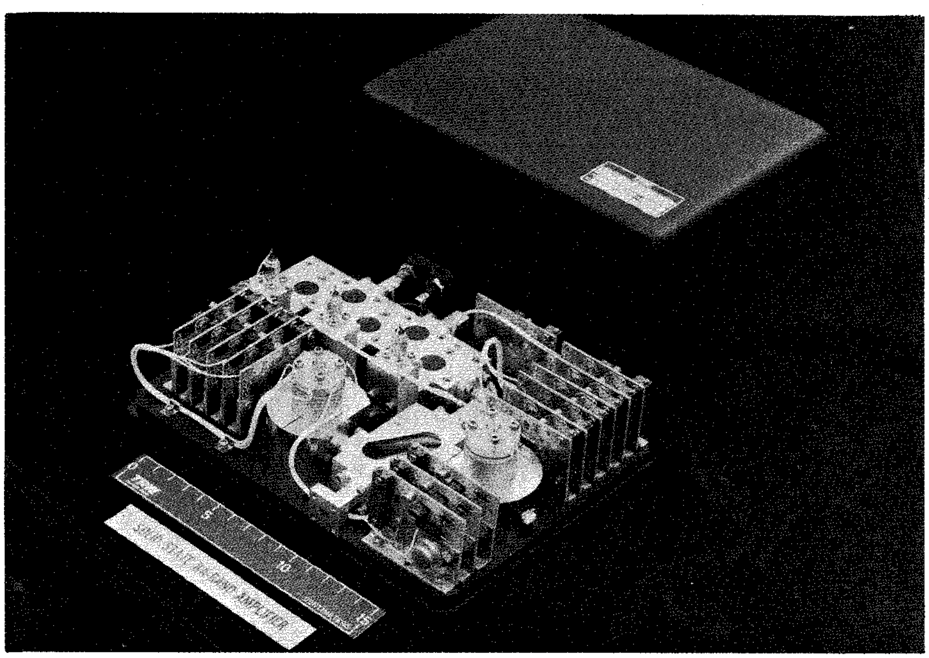

Figure 5. Final 5-Stage, 5 Watt Amplifier Configuration