POWER AMPLIFICATION AT 55-65 GHz WITH 18 GHz GAIN-BANDWIDTH PRODUCT

Jorg E. Raue

Systems Group of TRW, Inc.
Redondo Beach, California

Abstract

A high efficiency silicon avalanche diode power amplifier with 100-200 mW output power is described. Typical single stage gain of 20-22 dB with bandwidths exceeding 1 GHz has been achieved in production quantities. Best performance showed an 18 GHz voltage gain-bandwidth product.

Wideband high efficiency amplification has been achieved in two modes: the negative resistance mode and the injection locked mode. The latter case, to be described first in this paper, allows extremely low Q operation by double resonant tuning. The double tuning is routinely accomplished in a waveguide cap-type circuit by placing an additional variable tuning element such as an EH tuner close to the diode circuit. In this fashion voltage gain-bandwidth products much larger than those typical for conventional single tuned circuits have been obtained. The conventional single tuned mode is shown in the lower portion of Fig. 1, where three typical millimeter wave injection locked oscillators are described; these oscillator circuits are of the coaxial type[1] with moderately high external Q's. The double-tuned mode, first observed by the author at X-band, and readily identifiable when observing the swept amplifier response, has the characteristics of a conventional injection-locked oscillator at low injection levels, levels typically corresponding to injection gains of 25 to 30 dB and higher. For these gain levels the gain-bandwidth product is constant - the locking bandwidth decreases one order of magnitude for each 20 dB decrease in drive level. However, as drive is increased, the characteristics change dramatically, and the oscillator departs from the normal 20 dB/decade locking curve response in an initially monotonic fashion. As seen in Fig. 1, the bandwidth increases continuously with increased drive level, but at a rate exceeding that predicted by conventional locking theory, i.e. the gain-bandwidth product is no longer constant but increases with drive level. As drive level is increased further to 15-25 dB injection gain, a point is reached where the bandwidth tends to increase quite rapidly. Beyond this point it is found that (1) extremely stable wideband injection locked operation is achieved, (2) the bandwidth continues to increase with increased drive level, but at a slower rate. The external Q's corresponding to maximum gain-bandwidth products are typically 5 to 10, with Q_{ext} near 3 the lowest value.

Qualitatively, the broadbanding of the amplifier can be described using the concept of double tuned circuits with one of the circuits containing a device sensitive active element which affects the circuit admittance and Q. Quantitatively, the amplifier behavior can be described using the double tuned concept large signal locking stability criteria; it can be shown that the presence of an impedance loop, provided by the second tuned circuit, permits the oscillator to lock around this loop, accounting for the greatly increased locking bandwidth observed. This will be discussed briefly.

More than twenty 55-65 GHz single stage amplifiers have been built and tested to date, each with at least 5% efficiency and 100 mW output power, at least 20 dB of gain and 1 GHz of bandwidth. Best performance achieved shows an 18 GHz gain-bandwidth product with a locking bandwidth of 1.3 GHz with 23 dB gain. Typical junction temperatures for 5% efficiency and 100 mW rf output power are 200-230°C.

Best results achieved with conventional amplifiers are shown in Fig. 2. Single stage power gain of 12 dB was measured, with 140 mW power added by the amplifier, corresponding to 6.4% efficiency and junction temperature rise of 210°C. To the author's knowledge this is the highest level of amplifier efficiency achieved at this frequency, using single drift diodes.

A single stage wideband injection locked amplifier is shown in Fig. 3; a two-stage negative resistance amplifier is shown in Fig. 4.

Details of the diode, diode package and mounting structure are shown in Fig. 5. The threaded chuck (slotted) holding the diode pin (Fig. 5A) is mounted in the amplifier as shown in Figs. 3 and 4.

The fully electroformed circulator, visible in Figs. 3 and 4, is shown in detail in Fig. 6, along with some typical circulator performance data. (Best insertion loss is 0.3 dB over 3 GHz). The close-up photograph shows the Y-junction aluminum mandrel prior to electroforming with the ferrite cylinder in place.

The results of early diode life and burnout tests are highlighted in Tables I and II. These initial results point to device stability and potentially reliable operation at junction temperatures below 225°C.

A close-up view of the rugged diode package mounted on the 1/8" diameter copper pin is seen in Fig. 4B. Easily identified is the flat square plated-on copper heat sink, situated between two quartz blocks. The quality ribbon bond to the Au top contacting area of the diode (n-side) is seen in (C) while the diode is visible in (D). The avalanche diode, fabricated by Texas Instruments, Inc., is a single drift diffused silicon diode. The diode diameter at the mesa base is typically 0.9 to 1.1 mil, the corresponding heat flow resistance 75 to 95°C/C and the junction capacitance at breakdown 0.14 to 0.18 pf.

Reference:

1. N.D. Kenyon, "A Circuit for MM-Wave IMPATT Oscillator", Digest of Technical papers, 1970 International Microwave Symposium (G-MTT) pp. 300-303.

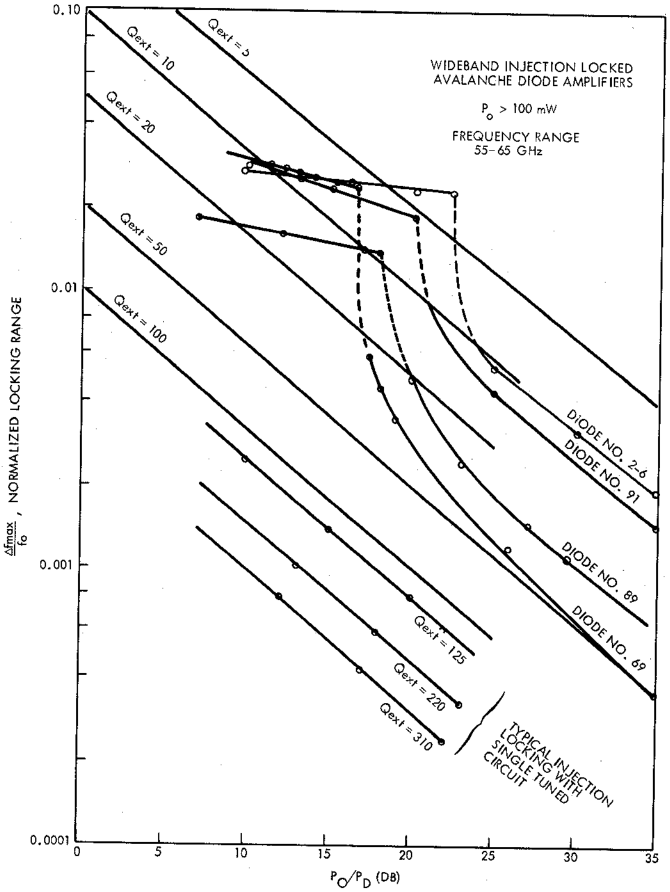


FIG. 1. INJECTION LOCKED AMPLIFIER CHARACTERISTICS, BOTH DOUBLE TUNED AND SINGLE TUNED MODE.

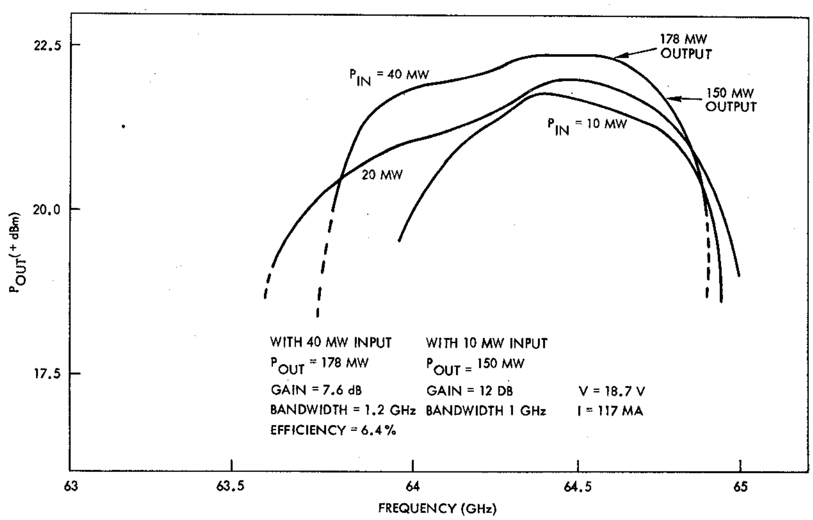


FIG. 2. AVALANCHE DIODE AMPLIFIER OUTPUT POWER AND BANDWIDTH FOR SEVERAL DRIVE LEVELS.

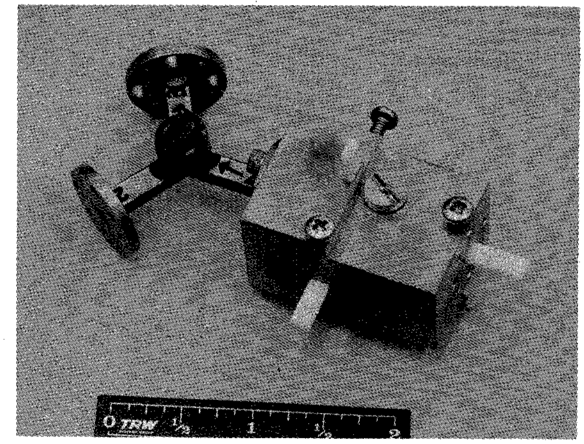


FIG. 3. SINGLE STAGE AVALANCHE DIODE AMPLIFIER.

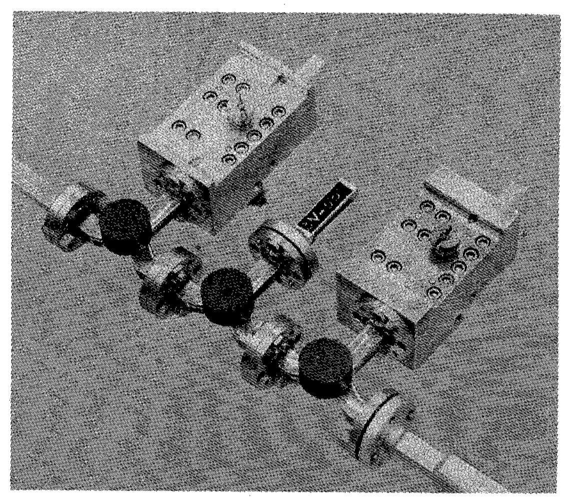


FIG. 4. TWO-STAGE AVALANCHE DIODE AMPLIFIER; CIRCULATORS ELECTROFORMED.

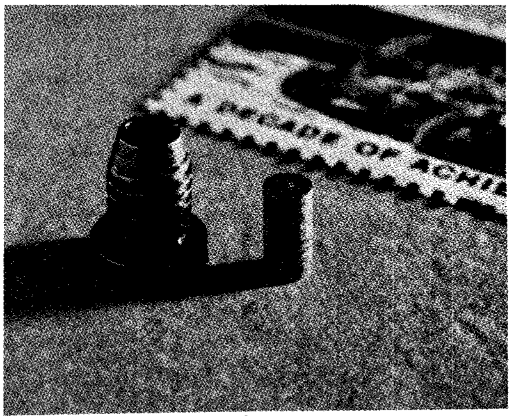
Table I. Extended-Life Tests on Oscillators

Diode No.	Lot No.	T_j	Hr	Results
30*	AR14-2	175	3870	No change
108*	AR56-1	210	3560	No change
43	AD15-1	250	600	Diode shorted
51	AD20-1	250	2260	No change, but diode failed near T_j = 300° during subsequent amplifier tests
60	AD15-1	250	3000	No change

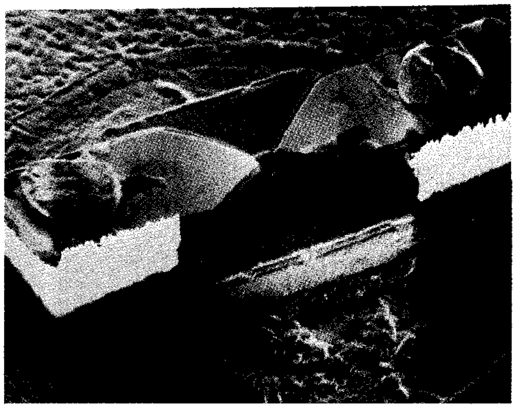
*Diodes previously used in irradiation tests

Table II. Controlled Burnout Tests on Avalanche Oscillator Diodes (Lot AD20-1)

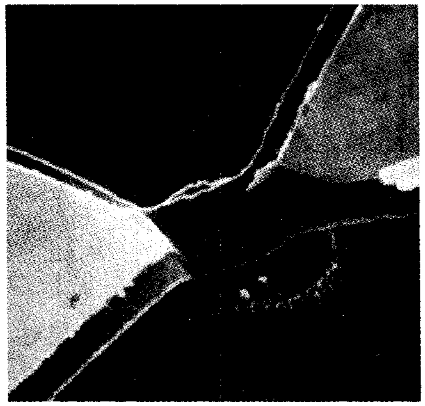
Diode No.	C_o pF	P_{in} Watts	R_θ °C/watt	T_j at Burnout, °C
97	0.637	3.7	97	380
98	1.14	7.2	53	410
99	0.85	6.1	75	475
102	0.741	5.2	80	435
104	0.976	6.1	70	450



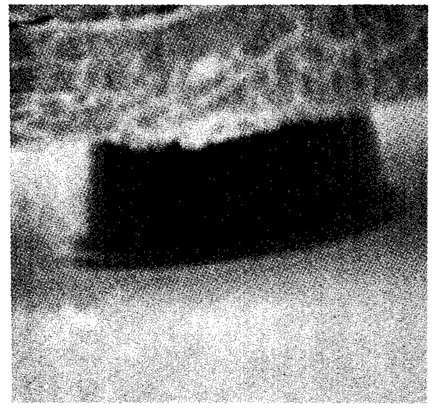
(A)



(B)

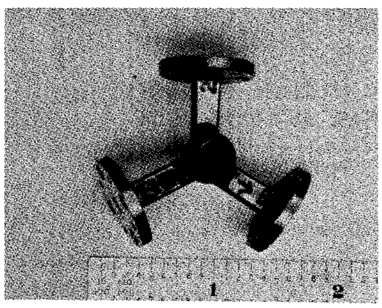


(C)

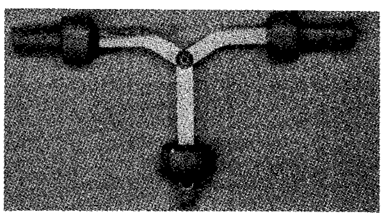


(D)

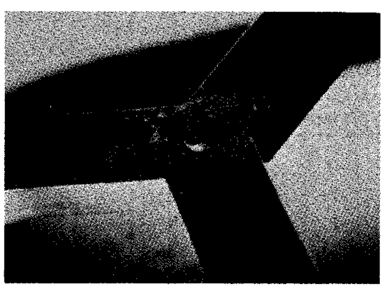
FIG. 5. 55-65 GHz SILICON AVALANCHE DIODE AND PACKAGE - PIN AND COLLET (a), DIODE PACKAGE (b), WEDGE BOND OF ALL RIBBON TO AU PLATING ON TOP OF DIODE (c) AND 0.001 INCH DIAMETER AVALANCHE DIODE (d)



(A)



(B)



(C)

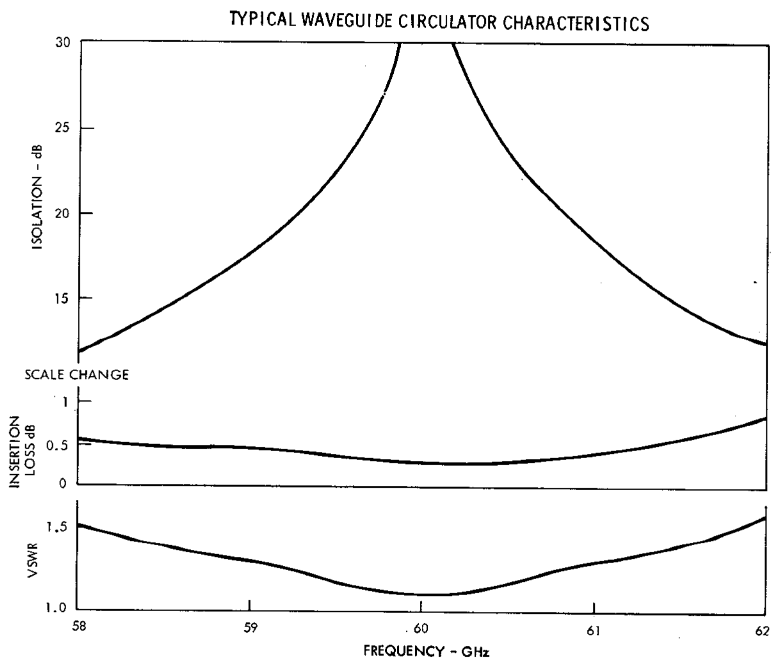


FIG. 6. TYPICAL CIRCULATOR IS SHOWN, TOGETHER WITH PHOTOGRAPHS OF A FINISHED OSCILLATOR (a), AS WELL AS A FINISHED ALUMINUM MANDREL (b) AND CLOSE-UP (c), PRIOR TO ELECTROFORMING.