A BETTER BIASING TECHNIQUE FOR IMPATT DIODES

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ABSTRACT

A new biasing technique is introduced which increases power, bandwidth, and reliability in IMPATT circuits while also eliminating thermal runaway and reducing cold startup times, all done with simpler biasing electronics than before.

INTRODUCTION

This paper describes a new technique called loadline (LL) biasing which enables significant performance improvement from IMPATT diode circuits over those using constant current (CC) biasing. IMPATT amplifiers and oscillator circuits have been around for over 20 years using the CC biasing technique which is that suggested by all of the diode manufacturers. Research was first done at Cornell in 1979 suggesting constant voltage (CV) biasing (1) as an alternate approach because it offered some advantages over CC. Additional effort on CV biasing was discussed in a MTT symposium paper in 1983 (2). CV biasing however also had limitations which kept it from general acceptance. Consequently CC biasing is still the only generally accepted method for biasing IMPATT's.

DISCUSSION

In order to appreciate the differences between the various biasing techniques, consider Figure 1 which plots bias current (I_B) versus bias voltage (V_B). CC, CV and LL bias lines are depicted in the figure and two IMPATT device lines are labeled as 1 and 2. The CC line represents a bias source impedance of ∞ ohms, that is an open circuit. The CV line represents zero ohms or a short circuit. The LL line represents any finite value bias source impedance, determined by the inverse slope of the line. Any of the three biasing techniques could be used to establish the initial operating point (P1) on device line 1 as each of the bias lines is established through that point, resulting in similar performance under steady-state conditions. If for some reason the IMPATT device line were to shift to the position of line number 2 (for example, increase in ambient temperature), and the biasing is not adjusted, the operating points would no longer be coincident and would represent quite different performance. The new CC point would be at a higher voltage than previously, resulting in an increase in bias power ($I_B \cdot V_B$ product). The CV point would be at a much lower current, resulting in a reduction in bias power. However, the shift along the loadline was chosen to follow approximately the $I_B \cdot V_B = K$ (constant) curve; this shift results in a drop in current with a corresponding increase in voltage, so that the bias power ($P_B = I_B \cdot V_B$) remains essentially constant. This is the basis for loadline biasing.

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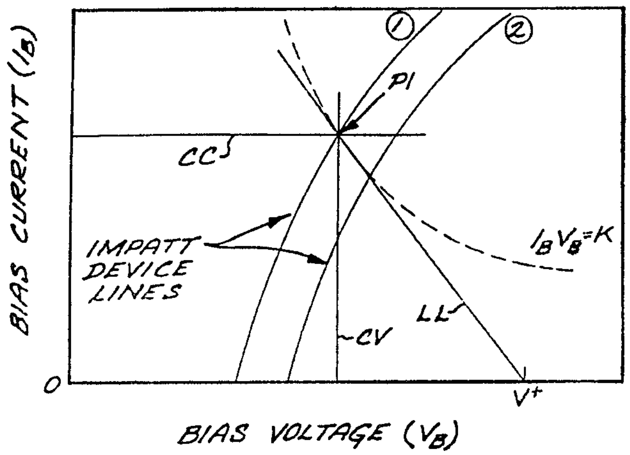

Figure 1. Fundamental concept of loadline biasing. Proper loadline adjustment will minimize the influence of temperature or device changes on RF performance.

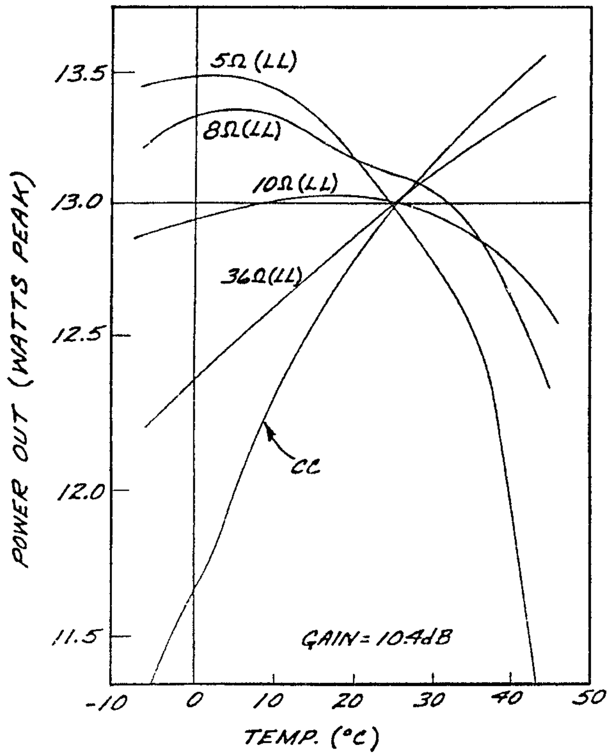

Figure 2. Optimum Loadline selection. Choosing the right loadline (10 ohm) results in essentially constant output power over a wide temperature range.

Looking at the temperature influence in greater detail, we plotted measurements of output power versus ambient temperature for a single diode injection locked oscillator using a variety of LL values (different source impedances). Figure 2 shows that for CC and high LL values, the output increases with temperature. At 10 ohms the response is quite flat, whereas for lower values, the output falls off. This particular circuit would not operate over the temperature range at CV. Selecting a 10 ohm LL would eliminate the need for external temperature compensation in this circuit since this biasing builds compensation in.

Experimental observation can easily show that the proper selection of the loadline can result in maximum injection locking bandwidth. Tests were run on a 16 diode power combiner to demonstrate the advantages of loadline biasing. In particular consider Figure 3a which shows the average RF output power versus frequency for a power combiner. The different curves indicate the performance shift as the heat sink temperature is altered. The biasing is constant current. As the temperature increases, the frequency is lowered and the average output power increases. Using a 40 w circuit requirement for comparison purposes, the bandwidth at 12 °C is about 33 MHz with a maximum power at 43 w, increasing to about 85 MHz and 50 watt at 55 °C. Notice particularily that there are no common frequencies at which the circuit operates over the entire temperature range.

In comparison, the results represented by the curves in Figure 3b show the output of the same 16 diode combiner (with some slight retuning) except that the biasing has been changed to LL. Using the same 40 w criterion, the bandwidth is about 75 to 80 MHz for all four temperature conditions. Also, the maximum power is quite constant at about 50 w. The most important aspect however is that there is about 50 MHz of common bandwidth over the temperature range, making this design much more useful than the CC circuit.

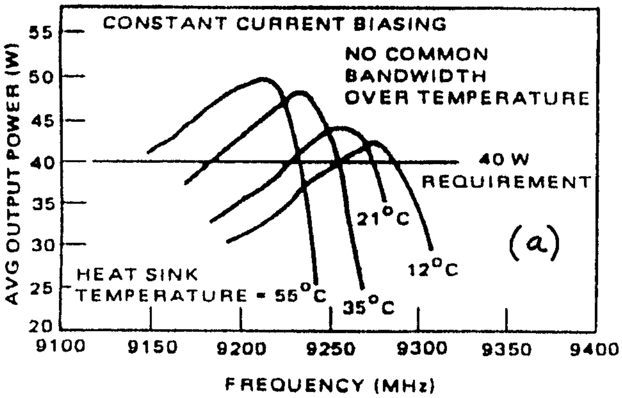

Figure 3a. Effect of heat sink temperature on a 16 diode combiner. Constant Current Biasing The bandwidth shifts noticeably as the temperature changes with no common frequencies over the temperature range.

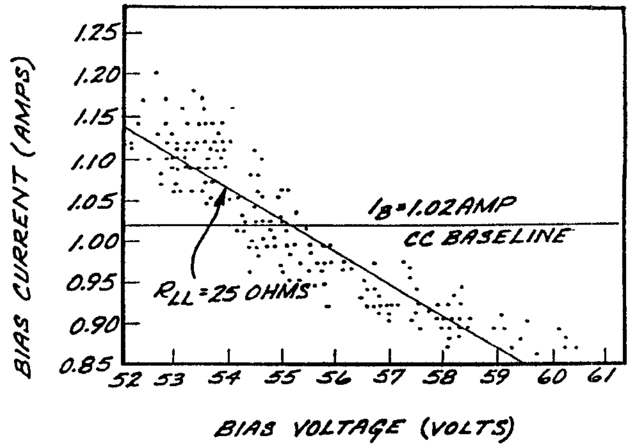

Figure 4. Bias data for a 150 diode set. Choosing a 25 ohm LL results in better matched performance whether in a multidiode combiner or a single diode circuit.

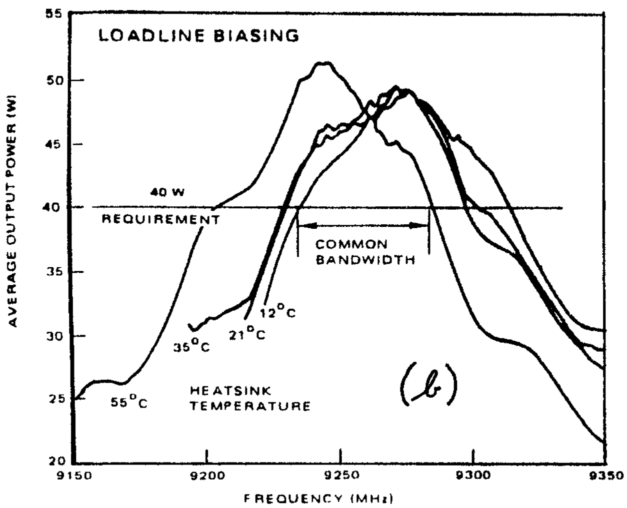

Figure 3b. Effect of heat sink temperature on a 16 diode combiner. Loadline Biasing The bandwidth is relatively unaffected by the temperature changes, providing a wide common operating bandwidth.

Loadline biasing also has the property of reducing the performance variation (power and frequency) within a given set of diodes. Figure 4 is a bias plot, showing the current and voltage operating points for roughly 150 different diodes, all operating in the identical RF circuit with a power output of 9 watts peak. The circuit tuning was fixed but the bias varied to set the 9 w level. We see that a definite trend exists in the data. These individually preferred biasing conditions can be represented by the best-fit linear approximation shown by the loadline R_{LL} = 25 ohms. Using this LL value will minimize the performance variation for this set of diodes when all are operated in the same fixed tuning circuit environment with a single fixed bias condition.

The alternative CC approach is represented by the horizontal line at 1.02 amps. We can see that generally the diodes requiring greater than 1.02 amps for 9 watts peak will produce less power when forced to operate in at 1.02 amps in a CC mode. Similarly, those diodes not requiring 1.02 amps for 9 watts will produce more power with 1.02 amps bias. Therefore, CC biasing of this set of diodes will create a spread in power that is greater than the spread associated with the 25 ohm loadline.

We also studied the biasing effects on pulsed oscillators in coaxial circuits. We particularly were interested in the injection locking bandwidth where the efficiency, and consequently the lower dissipation and temperature vary over the band. The gain, bandwidth and power tradeoffs of an injection locked oscillator operating with both CC and LL biasing are compared in Figure 5. The arch-shaped lines represent operation at a particular gain level for CC as a function of bias current between 0.4 and 1.2 amps. The maximum bandwidth occurs around 0.8 amps and maximum power near 1.0 amps. Therefore, to get the peak power available from the diode, there is a sacrifice in bandwidth.

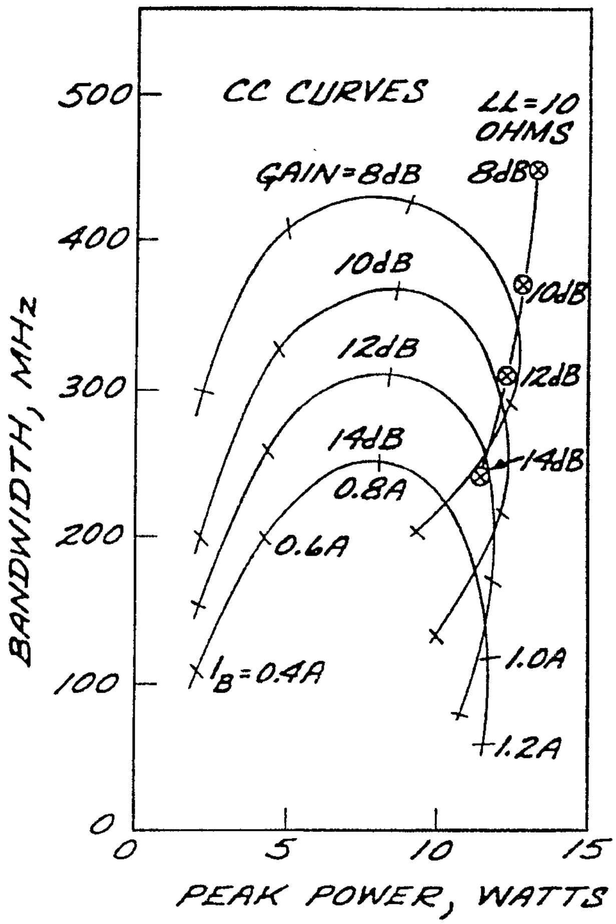

Figure 5. Bandwidth Power relationship for CC biasing compared with LL biasing at 10 ohms. Choosing the proper LL value gives the maximum gain simultaneously with maximum bandwidth.

The determined optimum loadline value of 10 ohms was also used at the same four gain levels. Each gain level in the figure is compared with the corresponding CC curve. In all four cases there is substantial improvement in performance, essentially realizing the maximum power simultaneously at the maximum bandwidth.

The advantage that LL biasing has over the traditional CC biasing is that it compensates actively, through biasing changes directly at the junction, for changes in junction temperature or diode operating point (ie. unmatched devices).

SUMMARY

Loadline biasing will bring to IMPATT circuit operation (1) increased power, (2) increased bandwidth, (3) increased reliability through elimination of thermal runaway, (4) reduced temperature sensitivity, and (5) reduced startup time (coldstart) to steady state conditions. RF combiner performance is improved in addition to these parameters because of reduced sensitivity to diode mismatch. On the basis of this, the development of loadline biasing represents a significant breakthrough for IMPATT circuit operation.

ACKNOWLEDGEMENT

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(1) J.W. McClymonds, G.C. Dalman, and C.A. Lee, "Linear High Power IMPATT Amplifiers Using Constant Voltage Bias", Proceedings of the Seventh Biennial Cornell Device Conference, pp 349-359: 1979.

(2) J.L. Chan, "Constant Voltage Biasing of IMPATT Injection-Locked Oscillators", 1983 IEEE MTT-S Symposium Digest, pp 218-220.