HEWLETT PACKARD

COMPONENTS

APPLICATION NOTE 959-1

Factors Affecting Silicon IMPATT Diode Reliability and Safe Operation

With careful attention to operating conditions, properly constructed silicon double drift IMPATT diodes have been shown to be extremely reliable and efficient high power sources of pulsed or CW microwave energy. Failures can, in most cases, be avoided by taking into consideration four predominate failure mechanisms:

- Fabrication Defects
- Excessive Junction Temperature
- Bias Circuit Related Burnout
- Tuning Induced Burnout

FABRICATION DEFECTS:

Excessive surface leakage current or metalization overhang in a defective diode can lead to early failure even under normally safe operating conditions. Hewlett Packard effectively eliminates the great majority of these failure-prone devices, both by careful screening and with a high junction temperature burn-in procedure. Where extremely reliable operation in harsh environments is required, an additional screening and preconditioning program is recommended.

EXCESSIVE JUNCTION TEMPERATURE:

The long term intrinsic operating lifetime of a silicon IMPATT diode is directly related to the average junction temperature. For a given junction temperature the failure rate is then critically dependent on the particular metalization scheme used to contact the silicon chip. The metalization system used on HP double drift IMPATT diodes has been shown to result in extremely high reliability under severe stress conditions. For example, median time to failure (MTTF)* at an operating junction temperature of 250°C has been calculated to be 2 million hours.

BIAS CIRCUIT RELATED BURNOUT:

The frequency band of small-signal negative resistance in an IMPATT diode is limited by transit-time effects to approximately 1.5 octaves at microwave frequencies. When operated as a free-running oscillator or amplifier under large-signal conditions, however, an IMPATT diode develops an induced negative resistance at lower frequencies. This effect is an order of magnitude lower in silicon than in GaAs IMPATT diodes. An improperly designed biasing network which resonates with the diode can thus result in bias circuit oscillations and excessive noise. In certain cases the transient current that results from the discharging of any bias circuit capacitance shunting the diode can lead to failure. Shunt capacitance should therefore be kept to an absolute minimum.

Double drift silicon IMPATT diodes are relatively easy to stabilize against bias circuit instabilities. Simple biasing schemes such as those described in HP Application Note AN935[1] have been found to result in reliable low noise operation under proper rf tuning conditions. More complicated bias circuits are described by Brackett[2]. These circuits have been shown to be effective in eliminating tuning-induced burnout and bias-circuit oscillations in GaAs IMPATT oscillators. Brackett's bias circuit stabilizing approach can also be used with silicon double drift IMPATT diode oscillators or amplifiers.

TUNING INDUCED BURNOUT:

Perhaps the most commonly observed and frustrating failure mechanism in silicon double drift IMPATT diodes is that which results from improper rf tuning. Tuning induced burnouts can be easily avoided after understanding the circumstances which result in these failures.

(a) Load Resistance and Safe Operation. The representative curve shown in Figure 1 illustrates the influence of circuit load resistance on output power for either a pulsed or CW IMPATT in a circuit which resonates the diode at a single frequency near the optimum operating frequency f_{oo}. The pulsed or dc operating current is kept fixed at I_O.

*MMTF is defined as the time to failure of 50% of a population of devices.

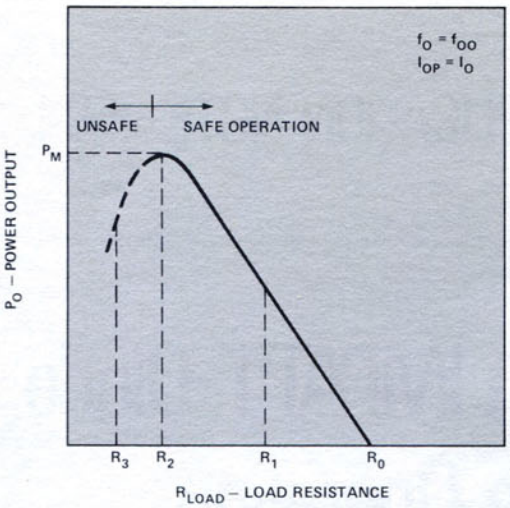

Figure 1

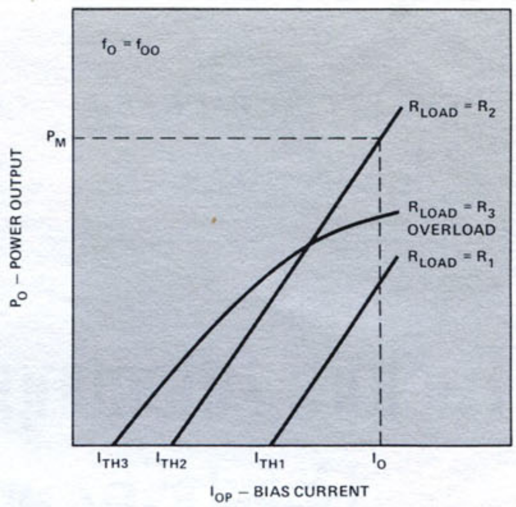

Figure 2

Oscillation does not occur for load resistances greater than R_O, the magnitude of the diode's small-signal negative resistance. Output power increases as R_{LOAD} is reduced below R_O until the maximum obtainable power is achieved for $R_{LOAD} = R_2$. It has been experimentally determined that the onset of power saturation in silicon double drift IMPATT diodes results from large-signal limiting of the rf chip voltage amplitude to a maximum value of approximately 0.35 times the dc bias voltage. In general, R_2 will be between one-half and one-third of the small-signal negative resistance, R_O.

For R_{LOAD} less than R_2 the output power decreases sharply due to saturation of the rf voltage. Failure is likely to occur when R_{LOAD} is significantly less than R_2.

One possible mechanism which might be responsible for diode burnout under this condition has been described by van Iperan[3] who suggests that the low-frequency negative resistance which is induced by large rf voltage modulation could lead to a transversely non-uniform current density within the diode.

(b) Threshold Current and Optimum Tuning. Tuning induced failure can in general be avoided by paying careful attention to the relationship between power output and bias current for a particular diode. The three curves in Figure 2 illustrate output power versus bias current corresponding to the three values of R_{LOAD} indicated in Figure 1. For single frequency operation at f_{oo} there is an unambiguous one-to-one relationship between the threshold current where oscillation begins and the value of the load resistance.

Once the optimum load resistance has been determined for a particular diode, the corresponding threshold current can be used as an indicator of unsafe circuit loading. Figure 2 shows that the threshold current I_{TH3} for a load resistance of R_3 is considerably less than I_{TH2} which corresponds to the optimum load resistance for the desired operating current of I_O. The observation of a threshold current less than I_{TH2} would thus indicate that an unsafe overload condition would exist if the bias current were increased to I_O.

Although a load resistance of R_3 would be unsafe for operation at a bias current of I_O, it would result in optimum performance at some lower bias current. A rough but useful rule-of-thumb for double drift silicon IMPATT diodes is that for optimum tuning the threshold current will be approximately 1/3 the desired operating current.

The threshold current corresponding to maximum output power at a particular bias current is also a weak function of the fixed frequency of oscillation. In general the optimum threshold current will increase slightly as the operating frequency is increased within a diode's useful frequency range.

For diodes of the same type it is important to realize that the optimum threshold current for operation at a particular output power or operating current may vary as much as ±10% from diode to diode due to differences in the packages or chip negative resistances.

(c) Coaxial and Waveguide Cavities. The curves in Figures 1 and 2 and the concept of an optimum threshold current are only useful for achieving safe operation of diodes which remain resonated at a single frequency approximately independent of bias current and rf voltage amplitude. For this reason single-transformer coaxial cavities are recommended for initial device characterization because they are broadband, well behaved and relatively easy to understand. Noise, stability or resistive power loss considerations may, however, ultimately require the use of a waveguide cavity. Great care should be taken in this event to insure singly resonant operation and avoid tuning-induced failures due to improper loading. Below the waveguide cutoff frequency the IMPATT diode is decoupled from the external load and a short circuit may be presented at the plane of the diode. The use of absorptive material in the bias circuit can be an effective solution to this problem.[4]

The large harmonic voltages that are easily generated in waveguide cavities can also play a part in tuning induced failures. It has been found that these failures can be eliminated if the commonly used sliding short is replaced by a sliding load for the next higher frequency band.

The following scenario is proposed as one of the most common procedures resulting in tuning-induced failures of IMPATT diodes.

- The diode is mounted in a waveguide cavity which is to be tuned by a sliding short and a slide-screw tuner.
- The bias current is increased until oscillation begins.
- The sliding short is adjusted to result in the desired oscillation frequency.
- The bias current is increased slowly and the slide-screw tuner adjusted carefully until the desired output power or operating current is reached.
- At this point it is noticed that the frequency of oscillation has shifted, so the sliding short is adjusted in an attempt to achieve the desired frequency.
- The diode burns out.

From the earlier discussion it should be clear that this failure probably occurred because the change in the position of the sliding short resulted in a load resistance that was less than the optimum value for the fundamental frequency or its harmonics. In almost all cases such tuning-induced failures can be avoided by simply reducing the bias current to slightly above the threshold value before making any tuning changes.

REFERENCES

(1) HP APPLICATION NOTE AN935 – Microwave Power Generation and Amplification Using IMPATT Diodes.

(2) C.A. Brackett, "The Elimination of Tuning-Induced Burnout and Bias-Circuit Oscillations in IMPATT Oscillators", B.S.T.J., 52, pp 271-307, March 1973.

(3) B.B. van Iperan, "Efficiency Limitation by Transverse Instability in Si IMPATT Diodes," Proc IEEE (Lett.), 62, pp 284-285, Feb. 1974.

(4) K. Kurokawa and F. M. Magalnaes, "An X-Band 10 Watt Multiple-IMPATT Oscillator," Proc. IEEE, 59, p. 102, Jan. 1971.

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