A STUDY OF HIGH POWER PULSED CHARACTERISTICS OF LOW-NOISE GaAs MESFETS

L. Dormer and D.S. James
FERRANTI ELECTRONICS,
Microwave Division, First Avenue,
Poynton, Cheshire, SK12 1NE,
England

ABSTRACT

Low-noise GaAs MESFET's have been investigated for catastrophic burn-out ratings when exposed to representative pulses from an X-band transmitter/T-R cell combination. Also reported are failure analyses, non-catastrophic but recoverable effects and longer term tests.

Introduction

This paper describes a study of some important reliability and r.f. performance aspects of GaAs MESFET's in low-noise amplifiers when used in radar receiver applications. In the radar front-end the r.f. pre-amplifier is subjected to pulses from the transmitter/T-R cell combination, with typical spike and flat leakage components of the order of 10 nJ and 100 mW respectively. In comparison with paramps, FET low-noise amplifiers are relatively fragile under such circumstances.

Little has so far been reported on these factors (1, 2), and it is considered important that these aspects be adequately investigated in order that radar system requirements may be properly addressed without prejudice to overall reliability.

Catastrophic Burn-Out Experiments

A number of commercially available devices have been subjected to short term exposure to pulse trains from an X-band transmitter followed by a primed T-R cell which was specially tailored to provide relatively high output levels. The pulse trains were analysed and statistically evaluated by means of a computer driven transient analyser.

Most of the devices are 1μ nom. gate types, of several different design configurations and gate metals. Each device was in hermetically packaged form, installed in a single-stage amplifier test jig with dedicated power supply circuits incorporated. The r.f. input circuit was arranged to provide approximately the minimum noise measure at 9.0-9.5 GHz.

The overall test procedure is outlined in Fig. 1. Prior to subjecting the devices to a programme of controlled r.f. exposure each unit was d.c. tested (reverse leakage, forward i/v, log i/log v). Included in the measurement apparatus was an automatic noise figure meter, with associated manual r.f. switches (Fig. 2) such that the system noise figure could be measured from a period of approximately 3 secs after termination of each 4 min. dose. Doses of increasing energy level were given until failure; the latter is arbitrarily defined as :-

a) a change in drain current of greater than 20%

and/or

b) an increase in overall system noise figure of greater than 3 dB.

For each test the drain current was monitored continually and found to decrease monotonically with r.f. pulse energy. The pulses from the T-R cell each consisted of a relatively narrow spike of high peak power (∿ 3 nsecs half width, up to 100 W), followed by a longer flat leakage component of approximately 150 mW level, 0.4μ secs duration, 1 kHz p.r.f. These pulses were attenuated appropriately for each test dosage (see Figs. 1 and 2).

Burn-Out Results

Electrical

In nearly all cases both failure criteria were met i.e. both noise figure and drain current changed significantly on failure. Failure was seen in all cases but one to be an apparently instantaneous event. In fact, by adjustment of the threshold detector in the transient digitiser it is possible to observe at a conveniently slow rate the behaviour associated with each and every one of these most energetic pulses, and under these conditions it appears that the device indeed seems to fail coincident with one such high energy pulse, as evidenced by a significant change in drain current. Also preliminary, separate CW tests support the tentative conclusion that it is the large r.f. spike component which causes burn-out.

Initial burn-out results are shown in Fig. 3. The different types of device failure are categorised in electronic terms as follows; the percentage of devices tested which fall into the respective category is shown in brackets :-

(a) Gate to source short circuit. (60%)

(b) Low transconductance (G_M). (25%)

(c) Drain to source short circuit. (8%)

(d) Reduction to abnormally low drain current. (5%)

(e) Increase in noise figure. (2%)

Physical examination

Failure analyses have been performed using optical microscope, SEM and EDAX techniques. Certain devices have been sectioned and optically examined, some involving low-angle lap preparation.

It is considered that a small percentage of burn-out failures were due to faulty device manufacture involving some of the following irregularities: (a) untidy packaging, (b) irregular gate definition and (c) misaligned gates.

In a majority of cases, however, it is still not possible to determine a failure mechanism which is common to all devices tested. It is thought that substrate imperfection is a most likely cause, wherein stressing brings about a temperature increase in extremely localised spots; depending upon the depth of the sensitised area the failure mechanism proceeds as either sub-surface metal migration, or an interaction of material at deeper level resulting in the now familiar eruption of the gate-source or gate-drain channel (Fig. 4).

Optical examination of the failed devices is only suitable for pin-pointing the most obvious of surface manifestations due to breakdown. The scanning electron microscope has been the most useful instrument for categorising the different surface defects seen. These are as follows :-

(a) Metal Migration

   (i) Gate channels g/s, g/d.

   (ii) Gate entry adjacent to step.

(b) Gallium arsenide melt down and eruption.

   (i) Full width of channels, g/s or g/d.

   (ii) Localized spots in channels, g/s or g/d.

(c) Step damage.

(d) Overheating

The technique of taper sectioning has been well known for some time in the carrying out of metallurgical examinations, and Fig. 5a shows how this technique is applied to failed GaAs FETs in order to reveal depth of damage in a channel blow-out. Deep damage has occurred under gate pad metal and in the region of the gate entry. Fig. 5b shows the gate structure before being lapped away.

Fig. 6 shows a SEM photograph of a typical blow-out subsequently examined under EDAX technique. The elements found in this examination are overlayed on the photograph and shows that there has been considerable temperature excursion, as revealed by the disassociation of Ga and As, and of Au and Ge.

Longer Term Pulsed Exposure

About a dozen 1μ devices of type A have been subjected to longer term exposure under conditions which correspond to actual radar use. The amplifiers were exposed to pulses from a representative magnetron T/R-limiter combination for periods of greater than 500 hrs. One failure was experienced after 620 hrs., two others after approximately 100 and 300 hrs. respectively, even though the 6 nJ max. spike energy at the input was around an order of magnitude below the average short term burn-out level recorded. There is thus suspicion of either a cumulative FET wear-out mechanism, or of a greater statistical probability of occasional very high spike energies than thought likely to emanate from the protection unit. Support for either possibility is provided by tests on device A7; although the device survived the normal 4 minutes dosage of 60 nJ max. spike energy, it subsequently failed after approximately 1 hour exposure at this same level. Those devices which did not fail catastrophically exhibited less than 0.15 dB change in gain or noise figure at the end of the test periods.

Non-Catastrophic Effects

In most cases examined so far, there has been observed recoverable degradation of system noise figure after short term (∿4 mins.) dosage. Typical behaviour for one device type is shown in Fig. 7. In all cases the noise figure recovery was associated with a similarly behaved recovery of drain current. In some cases the initial, low energy (10 nJ peak) dosage resulted in an apparently permanent change in noise figure i.e. an annealing effect, usually of the order of 0.1-0.2 dB increase in noise figure.

Some devices exhibited as much as 1 dB increase in system noise figure at the 10 nJ peak energy level, as measured ∿3 secs after termination of the r.f. pulse exposure. It is interesting to note that a reasonable percentage of devices showed a recoverable decrease rather than increase in this figure at this point in time; some of these changes may be due to variations in gain.

It might be thought likely that these recovery effects could be correlated in some way with 1/f noise, since it is probable that the physical mechanism involves various trapping phenomena. Initial measurements of FET 1/f noise, both straight baseband and also close-in oscillator FM noise, show no apparent correlation, however, between device types exhibiting lower system noise figure recovery effects and this measured noise. Indeed, FET devices of the same types as studied in this paper showed essentially no significant variation in 1/f noise.

The recovery effects described above reveal behaviour which is perhaps of less immediate importance to radar receiver design than that of inter-pulse behaviour. To study the latter, a special inter-pulse test set has been commissioned, which permits simultaneous measurement of gain and noise figure over selectable 20 μsec "windows" during the inter-pulse periods. Initial results for inter-pulse noise figure are presented in Fig. 8, including some for a recently developed, improved device.

Conclusions

Catastrophic burn-out energies are reported for several types of commercially available MESFET's. There is wide variation in test results between device types and between different manufacturer's batches. Also non-catastrophic, recoverable effects have been observed, although the overall picture is clouded somewhat by the fact that some devices exhibit permanent noise figure annealing after dosage at relatively low spike energies. Further work is progressing on inter-pulse testing. Preliminary longer term tests suggest some caution in relation to the reliability of the devices in radar receivers, an experience understandably similar to that experience with mixer diodes (3).

Acknowledgements

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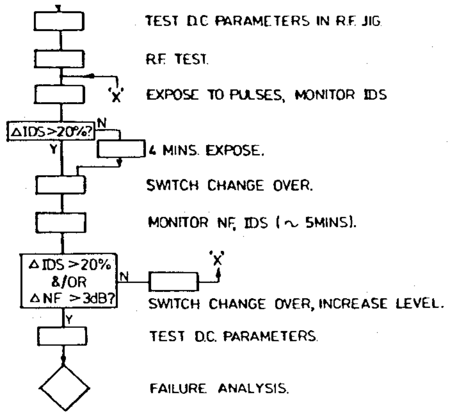

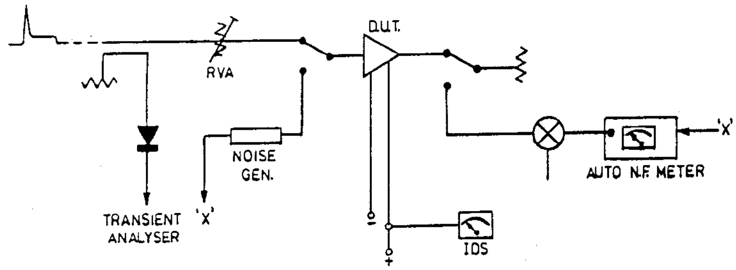

Fig.2. Test Arrangement for Catastrophic Burn-Out

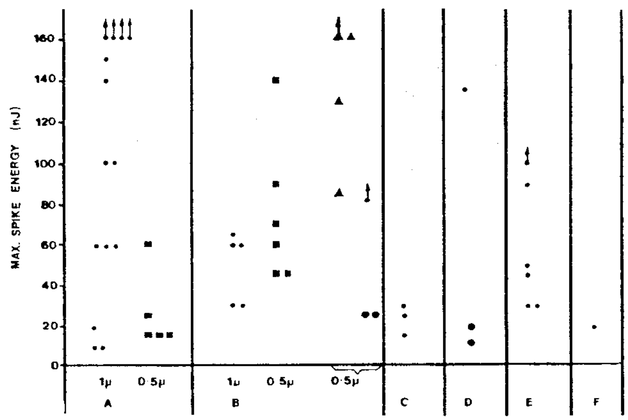

Fig.3. Initial Burn-Out Levels Measured

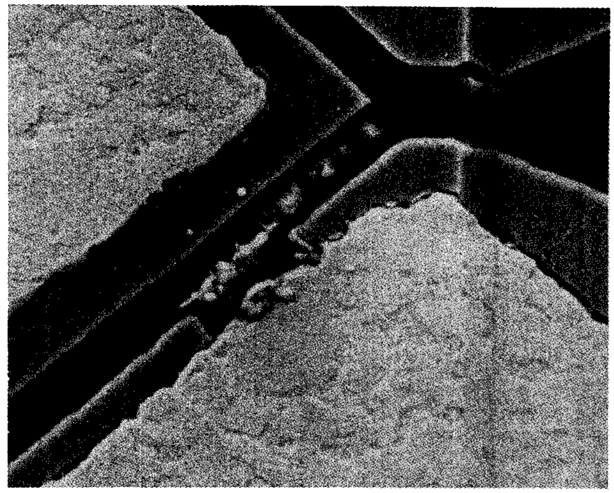

Fig.4. G/S Short, Predominant Failure Mode

a) Channel blow-out

b) Gate of failed device before lapping

Fig.5. Angle-lap Examination

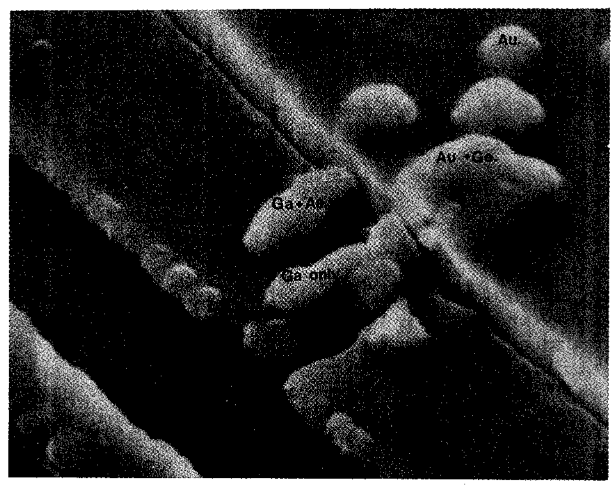

Fig.6. EDAX Examination of Failed Device

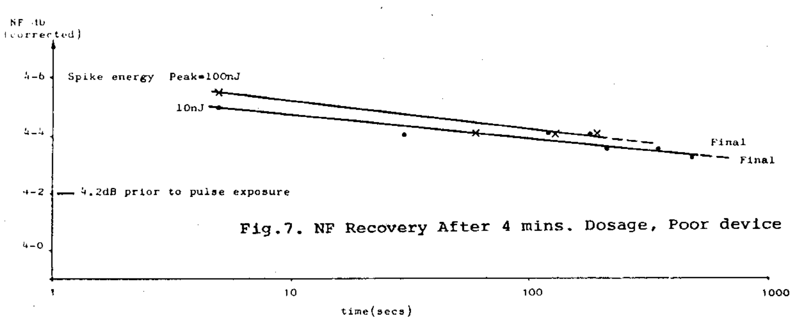

Fig.7. NF Recovery After 4 mins. Dosage, Poor device

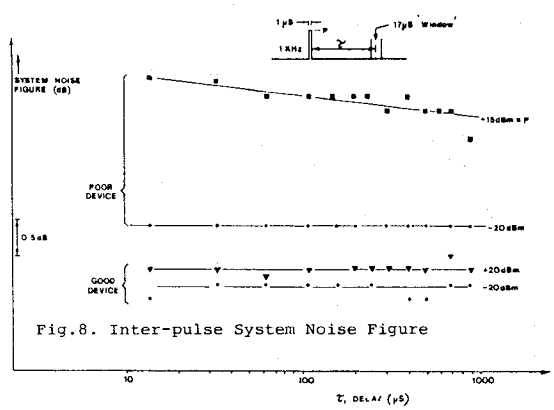

Fig.8. Inter-pulse System Noise Figure