AN IMPROVED TRAPATT OSCILLATOR CIRCUIT

R. Davies, P.L. Booth and B.H. Newton
Philips Research Laboratories, Redhill, Surrey, RH1 5HA, U.K.

The interaction between TRAPATT diodes and circuits is reconsidered and a new TRAPATT oscillator circuit based on the resulting design criteria is proposed and evaluated; the new circuit exhibits improved characteristics over conventional TRAPATT oscillators.

Introduction

This paper introduces a simple, new and reproducible TRAPATT Oscillator circuit that results from a re-assessment of the interaction between TRAPATT diodes and circuits.

While diode theories have provided appropriate design criteria for the TRAPATT diode, circuit theories have not established the criteria necessary for the design of circuits for stable TRAPATT oscillations without the need for critical circuit adjustments i.e. TRAPATT circuits have been empirically aligned to produce a coherent TRAPATT oscillation into broadband matched loads even without a closely defined frequency requirement.

Thus despite reports over several years of useful peak and mean output power levels at frequencies between 1 GHz and4 GHz from TRAPATT oscillators two factors that have prevented their use in systems are:

i) The frequency coherence has been a critical function of the r.f. load presented to the oscillator, and

ii) Each oscillator had to be individually and critically aligned to produce a coherent oscillation into a broadband matched load.

This contribution will describe how both of these problems have been overcome by including an additional component in the output circuit and by modifying the 'trigger circuit' of the TRAPATT oscillator to take account of the 'transient-phase' of TRAPATT oscillation. The 'transient-phase' referred to here is the time period between the first trapped-plasma cycle and the cycle at which coherence is established. This mechanism has been ignored hitherto in the design of TRAPATT circuits.

Existing TRAPATT circuits and design criteria

To date the following criteria have been generally applied.

i) Provide a circuit to support the small-signal oscillations that grow to trigger the first TRAPATT cycle.

ii) Provide enough locally stored charge to charge the plasma generation process.

iii) Provide a circuit to reflect the subsequent trigger-pulses that maintain the TRAPATT oscillation.

The first criterion has received little attention. However while such attention could possibly minimise leading edge jitter and delay it would appear from the ease with which the collapse of the voltage occurs that it is adequately satisfied in practical circuits which fulfil the second and third criteria.

The second criterion has been used to explain the improved oscillator performance resulting from increased local circuit capacitance due to lumped strays and a reduced trigger-line impedance near the diode.

The third criterion has been widely interpreted by TRAPATT circuit designers as demanding two circuit elements; a delay-line, that is slightly shorter (-10% at S-Band) than a half-wavelength at the TRAPATT frequency, to define the period of the trigger pulse; a filter terminating the delay line that provides an appropriate resistive termination at the output frequency (which is usually the fundamental TRAPATT frequency but might be at a higher harmonic frequency) and a short-circuit at other frequencies harmonically related to the fundamental TRAPATT frequency. To date, while we have explained satisfactorily the circuit load demanded by the diode for efficient coherent operation the actual loading has been optimised experimentally.

The most commonly used circuits for TRAPATT oscillators are based on a configuration due to Evans[1] comprising,

a) Parasitic reactances local to the diode.
b) Trigger-line with stepped impedance.
c) Multi-element output matching filter.
d) Bias filter.
e) Bias decoupling capacitor.
f) Output line and connector.

Figure 1 illustrates a typical microstrip version of the Evans configuration.

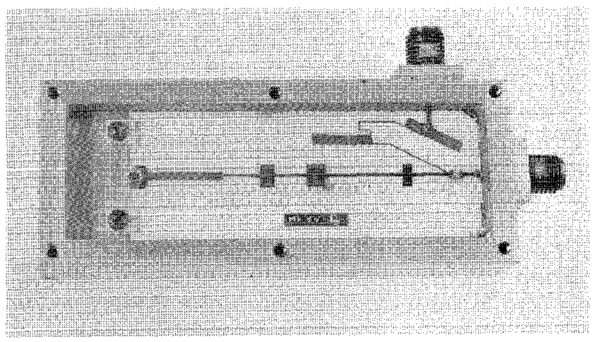

Figure 1. Microstrip TRAPATT oscillator based on the Evans configuration

Two disadvantages of such circuits are that alignment is completely empirical and having aligned the oscillator into a broadband matched load, its operation into practical loads (e.g. isolators, band-pass filters etc) is in general incoherent and a further alignment is necessary.

Measurements of the impedance presented to the TRAPATT diode at the fundamental and harmonically related frequencies of a coherent S-Band TRAPATT oscillator have been made. The results of measurements on a coaxial oscillator are summarised in Table 1.

<u>Table I</u>
<u>Power-impedance characteristics of Coaxial Oscillator (1 ∿ 4A)</u>

Power (Wpk)	f		2f		3f		4f	
	R	X	R	X	R	X	R	X
35 (15%)	1.5	-1.3	10	-10	200	30	5.3	46
40 (20%)	1.8	-0.5	2	0	142	23.6	96	68
45 (23%)	2.1	-0.7	4	-8	138	69	58	107
50 (25%)	2.8	-3.2	15	-0.2	4.6	40.5	29	163
60 (27%)	3.2	-1.9	2.5	-7	4.6	-12.4	92	42
70 (29%)	3.9	-3.1	20	-30	7	40	1.2	27
85 (32%)	5.3	-2.7	2.5	-9	20	-30	2.9	38.3

N.B. Impedances are referred to the short-circuit plane of the coaxial mount.

The results suggest that:

i) The impedance termination at the fundamental frequency should be complex; the resistive component should be less than a critical value above which value the output becomes incoherent (or the current drive must be reduced); the reactive component is small and capacitive but not critical.

ii) The impedance terminations at the harmonically related frequencies are larger mis-matches in a 50 ohm system but the value of the impedance is again not critical.

These observations suggest non-critical circuit requirements for coherent TRAPATT oscillation. Experience indicates however that this is not so; the circuit loading defined above is thus a necessary but insufficient condition for coherence and it is necessary to critically adjust the load defining elements. In order to resolve this anomaly the circuit-device interaction was reassessed. For this purpose attention was focussed on the time domain since it is only when coherence has been established that it is appropriate to consider only the terminations at harmonically related frequencies.

Extended design criteria and the new oscillator circuit

The results of recent studies of TRAPATT circuits, isolators and band-pass-filters in the time domain has lead to a reassessment of the circuit design criteria.

Time-domain-reflectometer (T.D.R.) measurements were made on Evans type matching filters, isolators and band-pass filters and these components were found to have similar responses; Figure 2 illustrates typical results.

It was proposed that should the Evans matching filter be terminated in an isolator or filter then the diode would be excited by two trigger-pulses - the required one from the Evans matching filter and a spurious impulse from the isolator or filter. The oscillator would thus only become coherent if the trigger pulses arrived at the diode simultaneously or if one was dominant. This suggested that a broad-band resistive load was required to avoid spurious reflections. The travelling-wave-directional filter TWDF[2] has such a property and its use has enabled coherent operation into practical loads to be obtained.

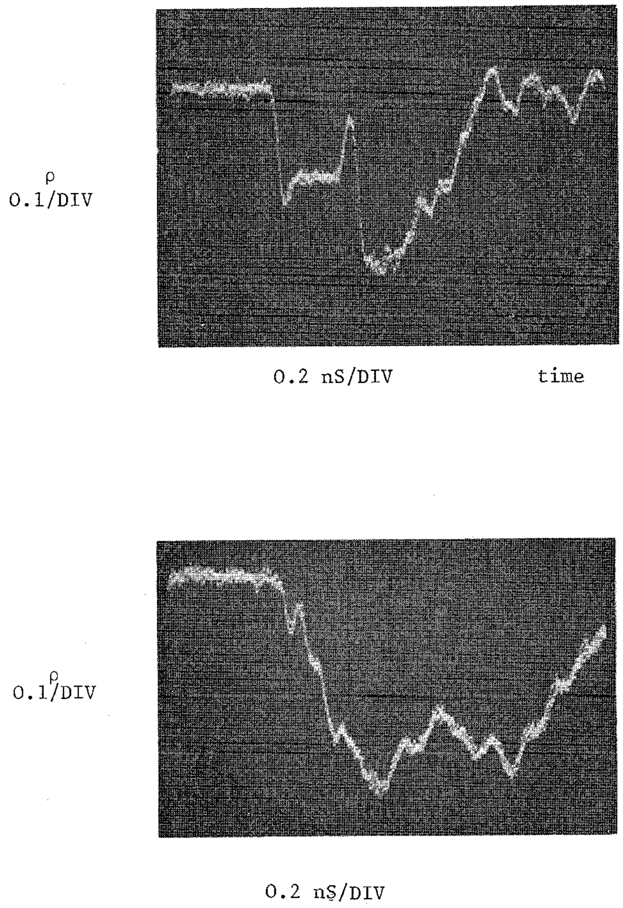

Figure 2. Time-Domain response of
a) The oscillator matching filter
b) Isolator

The role of the impedance change in the trigger-line was also considered in the time-domain. The change from about 30 ohm to 50 ohm approximately two-thirds along the trigger-line as shown in Figure 1 is proposed to be helpful in preventing the device voltage exceeding breakdown during the recovery period in the transient phase. A new circuit design based on this proposal is introduced in Figure 3.

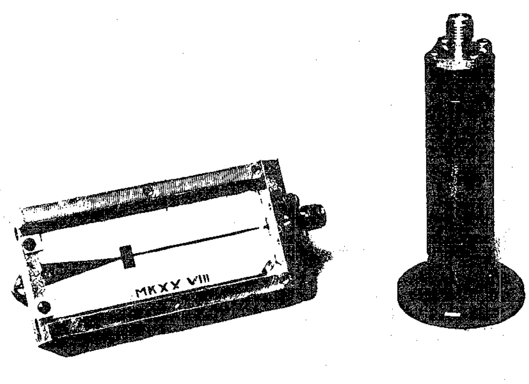

Figure 3. A simple TRAPATT oscillator

3.1 Summary of characteristics of coaxial S-Band TRAPATT oscillator

Devices: Planar diffused flip-chip diodes with junction area 4.10^{-4} cm^2.

Reproducibility: 14 diodes from a batch were tested in a fixed S-Band coaxial oscillator.

At ~ 4.5 amps and 0.1% duty the results were:

Total spread of output powers ±5%
Total spread of frequency ±23 MHz

Tunability: Coherence was maintained over a 700MHz frequency range using single variable mechanical tuning at fixed basis.

Current pushing at 0.1% duty

$\hat{I}$ (Amps)	$P(\hat{W})$	ΔF (MHz)	Efficiency (%)
3.5	60	-15	27.7
3.6	64	-12	28.7
3.8	70	-7	30
4	78	0	30.5
4.2	82	+3	30.5
4.4	88	+9	31.2
4.6	90	+11	30.6
4.8	96	+15	31.2
5	103	+20	32.7

Frequency/temperature (20°C to +125°C)

$$\frac{df}{dT} \sim -400 \text{ kHz}/^{\circ}\text{C}$$

$$Q_{ext} \sim 30$$

Frequency variations with duty-cycle

Duty(%)	ΔF(MHz)
0.1	-1
0.2	-2
1	-6
2	-20

Device thermal resistance ~ 15° C/W

Frequency and Power setting

Power and frequency are adjusted by the length (P_p) and position (P_f) respectively of the low impedance trigger slug.

i) Maximising the power by varying P_p at 4A drive

$\hat{P}$-Watts	P_p(m.m.)
56	7.5
70	6.75
75	6.25
80	6

ii) Setting frequency by varying P_f

11 diodes were tested in the circuit and P_f varied to increase the operating frequency by approximately 30 MHz at S-Band. The results are summarised overleaf, where for convenience the frequencies are referred to that of a reference diode (≠ 815)

Diode	f_1(MHz)	f_2(MHz)	Δf (MHz)
815	0	+28	+28
816	-2	+26	+28
817	-13	+12	+25
819	-32	-7	+25
820	-3	+21	+24
821	-1	+26	+27
823	-22	+2	+24
824	-24	0	+24
825	-6	+21	+27
826	-12	+13	+25
827	-26	0	+26

Harmonic content including isolator and T.W.D.F. in output circuit

$2f < -35\ dB_c$

$3f < -26\ dB_c$

$4f < -35\ dB_c$

$5f < -35\ dB_c$

These results demonstrate improved coherence, reproducibility, tunability, current pushing and load tolerance together with a defined alignment procedure while maintaining high efficiency. A microstrip realisation at S-Band has also been made.

The results and considerations have been interpreted as requiring modifications to the design criteria to read as follows:

i) Provide a circuit to support the small signal oscillations that grow to trigger the first TRAPATT cycle.

ii) Provide a local circuit and trigger-line geometry to generate the optimum voltage-time response and to provide the local stored charge necessary to drive the diode charging process. The local circuit should also provide the recovery-voltage suppression in the transient phase essential to establish coherence.

iii) Provide a circuit to reflect subsequent trigger pulses that maintain the TRAPATT oscillation without introducing spurious trigger pulses.

Conclusions

This contribution describes an improved TRAPATT oscillator circuit and discusses a technique whereby coherence is maintained into practical loads, thereby removing two obstacles to the implementation of TRAPATT oscillators in microwave systems.

Acknowledgements

This work has been carried out with the support of Procurement Executive, Ministry of Defence, sponsored by DCVD. The authors wish to thank their colleagues at Philips Research Laboratories, Redhill, Surrey and Mullard Ltd., Hazel Grove, Cheshire, England for their helpful discussions and for the supply of diodes; in particular Messrs. S. Jones, M. Pierrepont, P.L. Sugar and J.G. Summers.

References

1. W.J. Evans: IEEE Trans. MTT-17, 1060, 1969.
2. S.B. Cohn & F.S. Coale: Proc. IRE, August 1956, pp 1018-1024.