THE CIRCUIT/DEVICE INTERFACE IN GUNN AND IMPATT DIODE APPLICATIONS

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Gunn and impatt diodes are now beginning to find wide acceptance in component use for message carrying systems. The purpose of this talk is to briefly acquaint the reader with the various component applications for these devices and their limitations. The limitations that are considered here are a) FM noise properties b) Large FM deviation distortion properties.

Let us first consider the types of devices that are presently available, and compare their properties. Table I provides such a breakdown. These

BULK SEMICONDUCTOR DEVICES
FOR COMMUNICATIONS

	Device	Power	Efficiency	Noise Figure	Stability	Reliability
1)	GUNN	10 mW 500 mW	2% 6%	15 dB 25 dB	DIFFICULT	EXCELLENT
2)	SiIMPATT SINGLE DRIFT	100 mW 1 W	4% 7%	45 dB 55 dB	EASY	VERY GOOD
3)	SiIMPATT DOUBLE DRIFT	1 W 3 W	9% 12%	45 dB 55 dB	EASY	N D Y
4)	GaAs	1 W 4 W	12% 25%	45 dB 55 dB	DIFFICULT	N D Y

devices are all commercially available. Notice that Gunn devices are typically a factor of two behind impatt devices in power and efficiency. However the noise figure of a Gunn device is typically 30 db below that of an impatt device making it ideally suited to applications where noise is critical. Noise figure does not tell the whole story because Gunn devices show strong (1/f) noise at low frequencies. Because (1/f) noise is confined to the region of base band below 100 KHz, this type of noise is rarely a problem in communication systems. Both the thermal and the (1/f) noise of Gunn diodes are subject to certain variabilities. (1/f) noise depends critically on the bulk material impurity properties and surface properties of the device. Certain etches will reduce this noise, other etches will enhance it. Thermal noise is even less well understood at this time. The author has measured noise figures varying between 11 db and 25 db. Generally speaking noise properties are a wafer property. They do, however, correlate with the average electric field inside the diode's active region. High fields produce a low noise figure, low fields produces a high noise figure. Other device and circuit parameters can influence the average electric field, possibly explaining the variation in thermal noise from wafer to wafer. In particular, high chip temperature can cause a reduction in the electric field. This means poor bonding can result in high noise figure devices.

At first glance, the single drift Si impatt would appear to offer few advantages over Gunn devices. However, these devices are now of proven reliability (something that cannot be said for other impatt at this time), and offer medium power and easy stability in amplifier applications. Double drift impatts offer a considerable power and efficiency improvement, and are as simple to work with in terms of circuit design as single drift impatts. However some reliability questions need to be cleared up at this time. The GaAs "Read" structure devices offer the most exciting possibilities at present; with over 4 watts of power at up to 30% efficiency. These diodes are very tricky to work with circuit wise. They have a strong tendency to drop out of the "high efficiency mode" under changes in temperature and circuit tuning. The whole question of reliability has not been addressed at this time.

Oddly, all of the above mentioned impatts seem to exhibit noise figures in the 45 db to 55 db range. No one device is clearly superior to any other. Circuit tuning does have a large affect on the noise properties of these devices. As the oscillator circuit tuning is changed from over coupled to under coupled, the noise figure may increase by 15 db. This is thought to be caused by excessive multiplication within the diode which is brought on by the high RF signal levels the diode experiences when it is under coupled.

Next let us consider component applications for Gunn and impatt devices. A summary is given in Table II.

MESSAGE CARRYING APPLICATIONS
FOR BULK SEMICONDUCTOR DEVICES

	Type	Message Input	Message Output	Noise	Types of Distortions	# of Telephony Channels	Stage Gain
1)	VCO	B B	RF	GUNN-LOW IMPATT HIGH	LINEARITY	GUNN 1200 to 1800 IMPATT UNDER 100	NA
2)	REFLEC TION AMPLIFIER	RF	RF	GUNN LOW IMPATT LOW AT HIGH DRIVE	GROUP DELAY AM/PM	1800 1700	5 dB 10 dB
3)	INJECTION LOCKED OSCILL-ATOR	RF	RF	GUNN-LOW IMPATT LOW AT HIGH DRIVE	GROUP DELAY AM/PM	1800 2700	7 dB 15 dB
4)	PHASE LOCKED OSCILL ATOR	RF	RF	GUNN-LOW IMPATT - LOW AT HIGH LOOP GAIN	GROUP DELAY	1800 2700	20 dB 30 dB

The first component, the local oscillator, is not a message carrier at all, but is a supplier of CW power to other components (a mixer and demodulator) which are message carriers. In order to assure a good signal to noise ratio in the mixer and demodulator, the LO must exhibit low FM noise and a high degree of long term frequency stability. Via a well established relationship, the FM noise of a local oscillator varies as the square root of the noise figure, and inversly with circuit Q. This means that to achieve the same noise level as a Gunn diode, an impatt diode must be operated in a circuit with three times the Q. This is a serious disadvantage which makes impatts very unattractive for this application. At present Gunn local oscillators with Q's of about 1,000 can easily achieve -90 db FM noise relative to 200 KHz in a 3 KHz bandwidth. This kind of performance is superior to any other type of local oscillator presently in use.

A VCO is an oscillator which is capable of carrying messages. Varactor tuned Gunn VCO's have been used by several organizations to provide direct conversion of base band information to microwave frequencies. A very interesting signal to noise ratio problem developes with VCO's since both FM noise and electronic tuning bandwidth depend inversely on circuit Q. Since the number of multiplexed channels which can be handled by a VCO depends on the bandwidth, the signal to noise expression contains a 1/Q factor in both the numerator and the denominator. Therefore the Q factor cancells out of the signal to noise ratio leaving only device related parameters. This means two things 1) S/N cannot be increased without bounds by varying the circuit Q. 2) only one critical Q provides peak performance; if the Q is too high distortions suffer; if Q is too low, noise suffers. Of course the Gunn devices have a 30 db advantage over impatts in this kind of application. At 1800 channels capacity, a Gunn VCO can provide 87 db signal to noise ratio, which is quite acceptable. The impatt VCO is 30 db worse off, which is not acceptable for this application.

Any negative conductance device may be used in a reflection amplifier application via embedment in the proper circuit for stability. The signal to noise ratio of such an amplifier is directly proportional to the RF power input and inversely proportional to the noise figure and the number of channels squared. Gunn amplifiers provide acceptable signal to noise ratio under 1800 channels loading at 1 mw input. Impatts, however, require 200 mw input power in order to provide acceptable noise. It is a common practice in reflection amplifiers to use Gunn diodes in the low level stages to achieve low noise, and impatts at high levels (above 200 mw) in order to take advantage of the impatt's high efficiency and greater power generating capabilities.

Due to the Gunn diodes wide band negative conductance, stability is difficult to achieve. Impatts are easier to stabilize, but are subject to several distortion mechanisms which can cripple their message carrying capability. These distortions include:

1. Induced oscillations at one half the fundamental frequency-resulting in high in band group delay.
2. Induced oscillations at 1.5 times the fundamental frequency having the same results as 1.
3. High AM/PM at lower band edge due to the large dynamic inductance of the avalanching zone.

These distortions limit the practical gain-bandwidth product of an impatt device to about 3.0 GHz. Gunn devices seem to be similarly limited. This means a practical reflection amplifier, with a 500 MHz bandwidth is limited to about 8.0 db gain. For this reason, true reflection amplifiers always have the highest number of stages and are therefore the most costly approach to a given application.

In an attempt to reduce the cost of an amplifier by reducing the total number of stages, two types of "false amplifiers" have been developed. A "false amplifier" is an oscillator, masquerading as a reflection amplifier (ie, it performs identically in a system). "False amplifiers" can practically support much higher stage gains than reflection amplifiers can. The two types of "false amplifiers" that are available are 1) injection locked oscillators, 2) electronically phase locked oscillators. Both types of false amplifiers seem to have similar gross operating characteristics. A locking bandwidth exists, wherein the frequency of the input is identical to the frequency of the output. Over this locking band, the phase of the output minus the phase of the input varies by 180°. The power output of a false amplifier is roughly equal to the oscillator's power output. But here the similiarity ends, the distortion and noise properties of the two "false amplifiers", differ considerably.

It can be shown that injection locked oscillators behave noise wise exactly like reflection amplifiers. This means that an impatt oscillator must also be driven at the 200 mw level in order to achieve satisfactory noise performance.

The most exciting of the two "false amplifiers" is the electronic phase locked oscillator. Such a device consists of a high power VCO with a phase locked loop closed around it. If the response of the loop is sufficiently fast, the phase of the VCO signal will be servoed in tune to the phase of the input signal, even at rates exceeding 10 MHz. Best of all, the loop provides noise and distortion suppressing qualities that make it possible for a crude VCO to meet rather demanding specifications. Furthermore, because the open loop gain is determined by a) the phase detector's sensitivity b) the video amplifier's gain c) the VCO's tuning sensitivity; and not by circuit Q's and microwave powers, stage gain between 30 db and 40 db are achievable. Since communications amplifiers usually require in excess of 30 db gain, the phase locked approach can do in one stage what would take five or more reflection stages. Whats more, the noise suppressing properties of the loop eliminate the need for Gunn diodes; thereby reducing cost and complexity and raising efficiency.

Let us see how this works. For example take a 5 Watt impatt VCO and close a phase locked loop around it. The input power is 1 mw. A 50 mw impatt VCO would have a 50 db signal to noise ratio at 1800 channel. By raising the power output to 5 watts a 20 db noise advantage is gained, producing a signal to noise ratio of 70 db. Now suppose the open loop gain of the amplifier is 30 MHz; a very practical number from this author's experience. The noise suppression is equal to 20 log (open loop gain/highest B.B. frequency) or 10 db at 10 MHz base band. This results in a further improvement of the signal to noise ratio, to 80 db, a perfectly acceptable number.

To date, the author has constructed a 3 watt single phase locked oscillator in the 10.7 to 11.7 GHz band which is capable of 32 db of RF gain with acceptable noise and distortion for 1800 channels. The VCO makes use of two Si double drift impatt diodes and a GaAs varactor. A pair of Schottky barrier diodes are employed in the phase detector. A similiar lower power unit has been systems tested at 1800 ch. and has demonstrated NPR's in excess of 60 db.