

An Automated Oscillator Tuning System for Gunn Oscillator Characterisation at MM-wavelengths

C.P.Unsworth*⁺, J.C.G. Lesurf⁺

* Department of Engineering Science, The University of Auckland,
70 Symond Street, Auckland 1003, New Zealand.

Email : c.unsworth@auckland.ac.nz

⁺ The MM-Wave & High Field ESR group, School of Physics & Astronomy,
The University of St.Andrews, Fife, Scotland, KY16 9AJ, U.K.

Email : jcgl@st-and.ac.uk

Abstract

This article presents an 'Automated Oscillator Tuning System' (AOTS) that together with mechanical motorized fixtures can be used to automatically adjust the frequency and backshort tuners of a coaxial cavity, resonant cap mm-wave oscillator via a computer program. Here we demonstrate how the AOTS can be used to quickly and accurately characterise a coaxial cavity, resonant cap mm-wave oscillator with frequency increments of 100MHz. The oscillator characterisation took 10 minutes with the AOTS as compared to 1hr+ minutes if performed manually and with larger frequency increments. By writing an appropriate computer control program, the AOTS can be adapted to many types of application. Thus, the AOTS has the potential to be versatile with wide functionality.

1. Introduction

The Gunn oscillator exploits the Gunn Effect [1] which occurs in n-type Gallium Arsenide(GaAs) and Indium Phosphide(InP) type III-V semiconductors [2]. Gunn diodes made from these materials produce operating frequencies up to 115GHz for GaAs and around 70-140GHz for InP. This type of diode is a low power and low noise diode as compared to the high power IMPATT diode which also operates by the same effect. The differences between the two are detailed in [3]. This article is concerned with the automatic characterization of the Gunn oscillator that is of the coaxial cavity, resonant cap design [4] that employs the Gunn diode. Such oscillators are designed to perform over the W-band region centered around 94GHz using second harmonic mode generation [4]. A schematic of coaxial cavity, resonant cap oscillator block is shown in Figure 1.

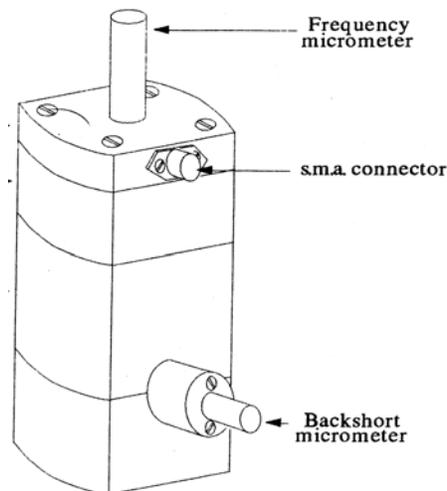


Figure 1 : Schematic of a Coaxial Cavity Gunn Oscillator Block

Figure 1, identifies two micrometers that are located on the outside of the oscillator block. The micrometer located on the top of the block is used to tune

the frequency of millimeter wave oscillations that the oscillator produces. The micrometer that is on the side of the block, known as the backshort, is used to optimize the power output from the block. The SMA connector supplies a DC bias to the Gunn diode that is housed within the block. On the opposite face of the backshort is a WG27 aperture that allows the millimeter wave radiation generated by the diode to propagate from the cavity inside the block into freespace [5] It is not in the scope of the article to describe the detailed workings of the oscillator, however, reference to such can be found in [4,6,7].

2. Manual characterisation of an oscillator.

After a mm-wave oscillator has been constructed, it is necessary to determine its performance. This is termed as 'Characterising' the oscillator block. This involves determining the mm-wave frequencies that occur for different frequency micrometer positions. In addition, the characterisation involves determining what the maximum power output is for the corresponding frequency of interest by adjustment of the backshort micrometer. Figure 2, shows characterisation curves from a typical oscillator block. The upper plot of Figure 2, is the position of the frequency micrometer, in mm, versus the frequency produced, in GHz. As one moves through the dynamic range of the frequency micrometer (3.4 -5mm), one can observe the oscillator reduces its output frequency from 110GHz to around 82.5GHz. In the two regions, (100.2-107.5GHz) and (91-95GHz) one observes oscillator frequency jumps. These occur because of physical imperfections that exist due to the machining of the resonant cap structure. Other frequency jumps

can also occur. However, these are not due to the oscillator but rather miscounts made by the frequency counter used.

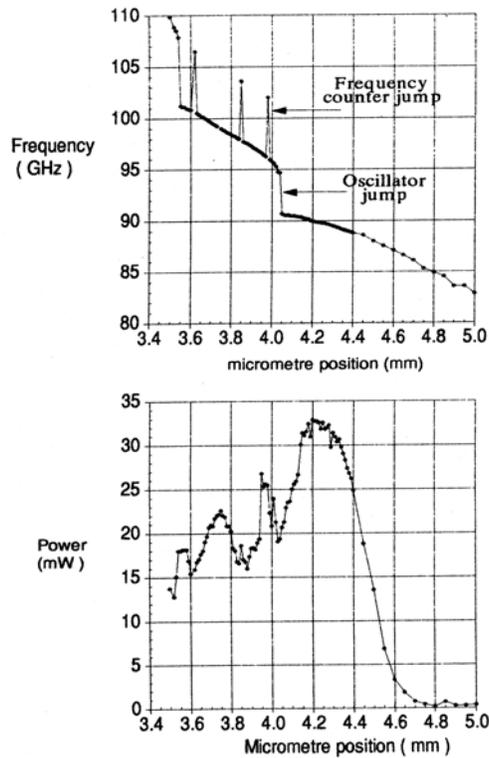


Figure 2 : Characterisation curves produced from manual tuning

All frequency measurements presented in this article, were performed using an EIP Microwave frequency counter [8] which is prone to frequency jumps. Such jumps are highlighted, in Figure 2, at frequencies of 96, 98 and 101GHz. The lower plot of Figure 1 is the position of the frequency micrometer, in mm, versus the maximum power (mW) produced by the backshort. As one can see the largest power of the oscillator is achieved at around 90GHz. All power measurements presented in this article were measured using a Boonton RF Power Meter [9].

It is necessary for the manual characterisation of an oscillator to be performed before an oscillator can be used. In addition, if an oscillator is to be sold the characterisation should be performed over very small frequency micrometer increments in order to obtain accurate characterisation curves. This coupled with the tuning of the backshort to obtain optimum power is a tedious, time consuming task. Sometimes because of physical frequency jumps that are observed in the characterisation process, the resonant cap has to re-machined and the characterisation process repeated. Thus, the manual characterisation of an oscillator can last 1hr+, depending on the experience of the researcher. This was one motivation for the development of the 'Automatic oscillator tuning system' (AOTS) presented here.

3. Characterisation by Bias Tuning

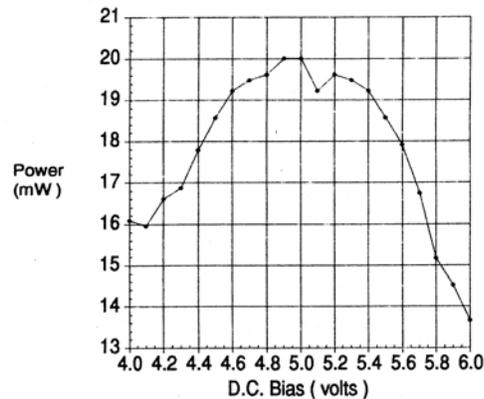
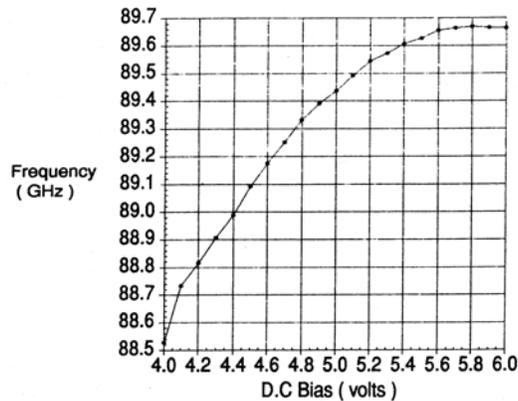


Figure 3 : Characterisation curves from bias tuning

An oscillator can also be characterised by adjusting the DC bias of the power supply instead of adjusting the frequency micrometer. An automated version of bias tuning was developed by [7]. Figure 3, depicts the characterisation curves of such a process. One drawback of this method is that the DC bias can only be swept over the oscillator's operating voltage range. Thus, it is not possible to obtain the full dynamic range of frequencies that the oscillator produces when tuned by such a method. Rather, a small range of frequencies is obtained in the order of 1-2GHz with this method as opposed to a range of approximately 30GHz from manual frequency tuning, described in section 2.

4. Automatic Oscillator Tuning System (AOTS) overview

This section describes how an 'Automatic Oscillator Tuning System' (AOTS) was developed to control the mechanical movement of the 'frequency' and 'backshort' tuners of a coaxial cavity, resonant cap millimeter wave Gunn oscillator block as described in section 1. This was performed via an electronics unit that was interfaced to mechanical fixtures affixed to the oscillator block. In addition, the electronics unit was interfaced to a computer and thus an oscillator could be completely controlled by the computer. In addition, computer control programs could be developed and tailored specifically to the experiment. Thus, making the AOTS application independent. The application dependence of the AOTS is

highlighted in [6] where the AOTS is employed in a variety of experiments using a 'millimetric rotary polariser quasi-optical system.

4.1 The Mechanically Motorised Oscillator block

Figure 4, shows how two machined mounting brackets were used, one for each tuner, to support a small motor that would drive the tuner, either up or down via a wheeled cog mechanism. A small, linear, high precision, 10 turn potentiometer was also located on each mounting bracket which was connected to the tuner via a small locking collar. Thus, the position of the micrometer could be located by a reference voltage from the potentiometer as the tuner moved. A female seven way pin connector was also housed in the frequency tuner's mounting bracket, into which all the control wires of the motors and potentiometers were connected.

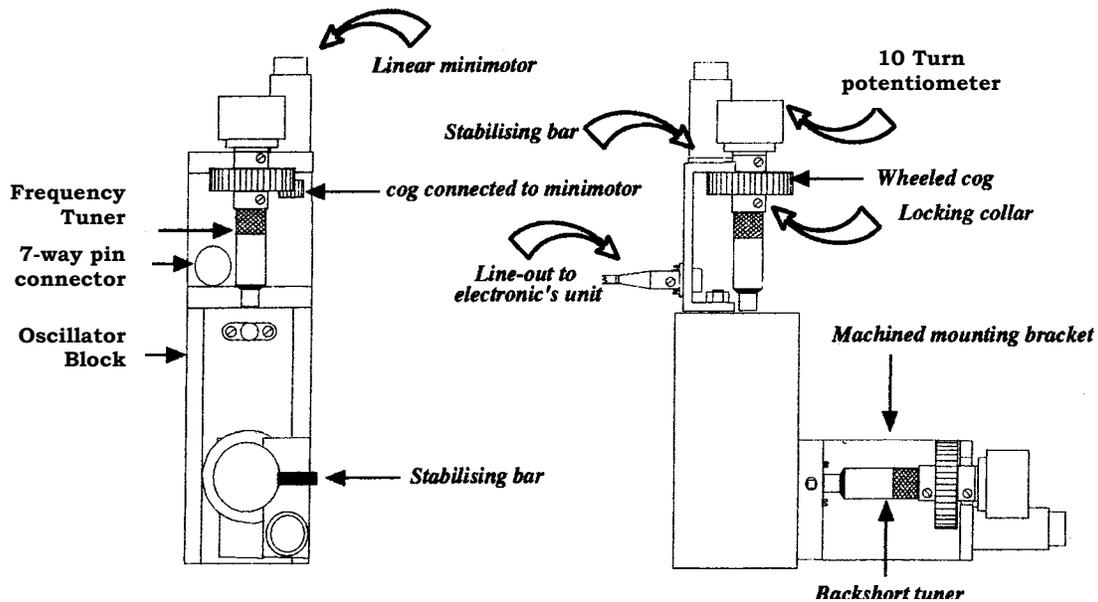


Figure 4 : Motorized Oscillator Block

A male 7-way connector would then connect the oscillator block to the AOTS

electronics unit, to be described shortly. The fixtures had previously been designed by [10] for a similar envisaged system. However, the system was not developed further.

4.2 The AOTS Electronics Unit

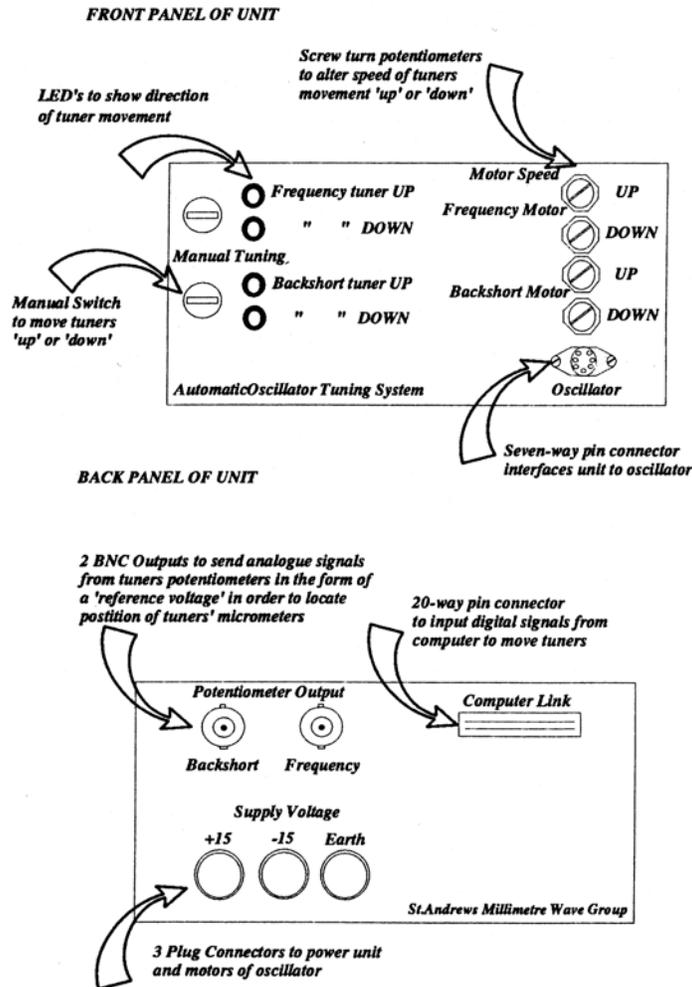


Figure 5 : The AOTS Electronics Unit

An AOTS electronic unit was developed to control the mechanically motorized oscillator block, described in section 4.1. The AOTS electronics unit developed is shown in Figure 5. The unit has the functionality to allow the user to control the motorized oscillator block manually using the front panel switches or via a

computer which can be interfaced to the back panel. The features of the unit, shown in Figure 5, are now discussed.

The front panel of the unit has manual override facilities and consisted of :

- One 7-way pin connector: To interface the electronics unit to the oscillator.
- 4 screw turn potentiometers : To alter the 'up' and 'down' motor speeds of the backshort and frequency tuners.
- 2 Flat lever toggle switches (up-off-down) : To control the up and down movement of the frequency and backshort tuners manually.
- 4 L.E.D's: Two for each tuner to display the tuners direction of travel.

The back panel of the unit consisted of:

- A 20-way pin connector: To receive 'digital signals' from the computer to move the frequency and back short tuners up and down. A ribbon cable interfaced the connector to a 'Computer Card' shown in Figure 7.
- 2 BNC connectors: To send the 'analogue signals' from each of the oscillator's frequency and backshort potentiometers to the computer. This was in the form of a reference voltage which located the micrometer position of each tuner, described in section 4.1. Each of the BNC connectors fed into a breakout box which in turn connected to the analogue to digital converter (ADC) channels of the 'Computer card', as shown in Figure 7.

- +15/-15 & Earth connectors: To power the electronics unit. This in turn powered the linear motors of the oscillators.

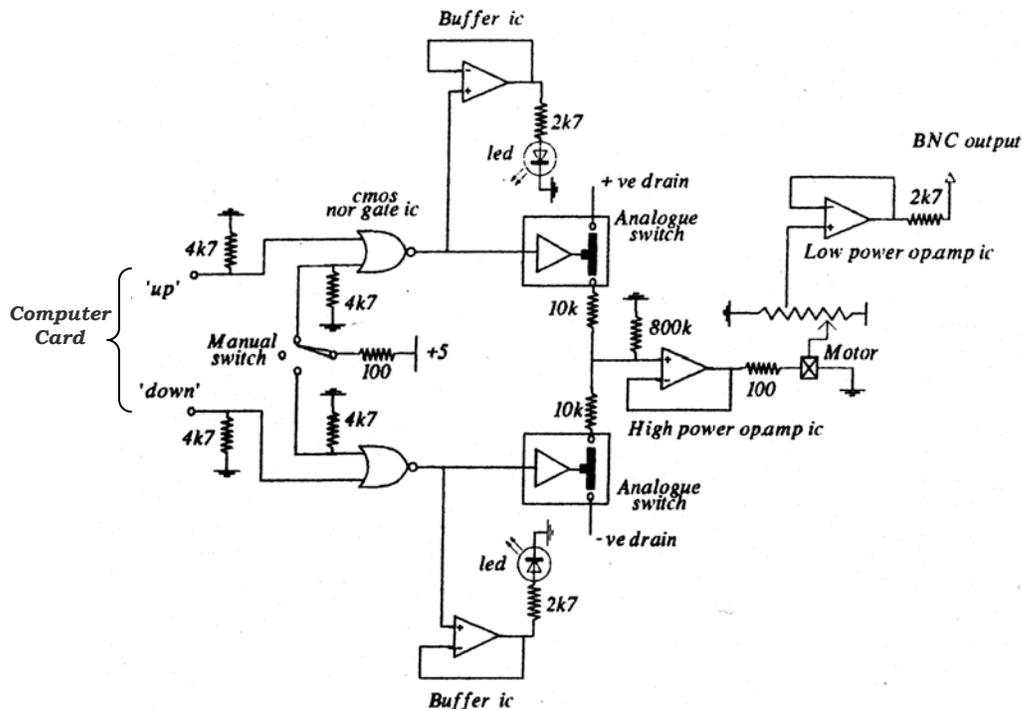


Figure 6 : Electronic circuit required to control a single tuner

Figure 6, depicts the circuit necessary to control the 'up' and 'down' movement of a single tuner. Thus, two of the circuits shown in Figure 6 were necessary for complete control of the oscillator's frequency and backshort tuners.

The circuit shows how the motors could be driven by sending (+5v) signals from the computer, via 2 of the digital I/O of the computer card. Alternatively, the (+5v) signal could be transmitted by the user via a manual switch. The 'NOR' gates would then respond appropriately by sending a (+5v) signal to the Analogue Switch and LED. The LED would light upon receipt of the signal and identify whether the tuner was moving up or down to the user. Depending on whether the

signal from the computer card was to move the tuner 'up' or 'down' a (+ve) or (-ve) bias would be applied respectively to the High Power Operational Amplifier. The High Power Op-Amp in turn would drive the linear motor clockwise or anticlockwise. As the tuner was rotated by the motor, the 10-turn potentiometer affixed to the motor, by the locking collar, would also rotate in the same direction. The potentiometer would thus provide a reference voltage to the BNC output to locate the position of the micrometer anywhere in its travel. The BNC was fed directly to a breakout box which was connected to the ADC card of the computer, shown in Figure 7. In this way, the circuit provided a way of automatically tuning the micrometers of the oscillator whilst monitoring their positions. Two circuits of that shown in Figure 6 were then realised on Printed Circuit Board (PCB). This provided a more robust solution and aided in the future manufacture of such a system.

5. Automated Oscillator Tuning System (AOTS) Characterisation Setup

The electronics unit was interfaced to the computer via a computer card. The computer used was an Acorn Archimedes Computer [11]. The interface from the computer to the AOTS was via a 'Wildvision Card' [11] which contained an 8-way digital I/O channels and 8 ADC channels. All computer programs developed to control the AOTS were written in the BBC Basic V language[11]. Only two digital I/O channels were required for each tuner, in order to move it either up or down. Therefore, a total of four digital channels were necessary for the control of both of the oscillator's tuners. Of the eight ADC channels available on the computer

card, one channel was required to read the analogue voltage of each of the 10-turn potentiometers that would be used to locate the position of the micrometers. Therefore, a total of two ADC channels were necessary. For the automatic characterisation of an oscillator the experimental setup of Figure 7 was required.

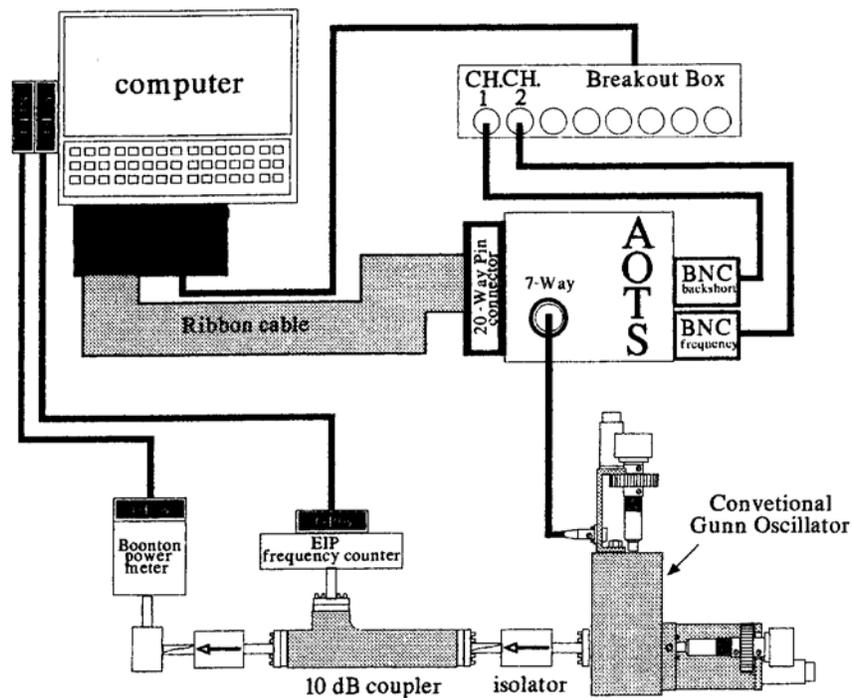


Figure 7 : Schematic of the AOTS required for oscillator characterisation

The mm-wave output of the oscillator was fed into an mm-wave isolator then to a 10dB coupler which split the radiation. From the coupler 10% of the radiation was directed to the EIP frequency counter [8] and 90% directed to the Boonton power meter via another isolator [9]. Both the EIP and Boonton were 'General Purpose Interface Bus' (GPIB) compatible [12]. Thus, they were interfaced to the GPIB ports of the computer. Connected in this manner it was now possible for the computer to measure the frequency and power of the mm-wave radiation that the

oscillator generated. Thus, Figure 7 depicts how a computer could be used to control the oscillator's micrometers and measure the instantaneous frequency and power of the oscillator. A series of general computer procedures was developed which could be combined to operate the AOTS in many ways and communicate with the EIP frequency and Boonton power meter. The procedures and computer code are fully detailed in [Unsworth 1997].

6. Technical Considerations

When characterising an oscillator manually, there are obviously critical limits which one should not tune the micrometer beyond. In the case of the frequency tuner, one does not want to wind the micrometer too low else there is a risk of crushing the oscillator's diode. Similarly, one does not want to move the micrometer to far up else one would needlessly tune the oscillator below the cutoff of the waveguide. Similar limits exist for the backshort tuner. In the case of the AOTS, the above mentioned limits could be specified as voltages. These voltages are specific to each oscillator. For the oscillator block (D4), the critical frequency tuner limits were found to be 3.00-4.38 volts. Similarly, the critical limits for the backshort were found to be 4.29- 4.46 volts. The critical voltages could be located quickly using the manual over-ride facility of the AOTS system.

Another consideration was in the accurate reading of the voltage from the potentiometers of the frequency and backshort tuners. It was found that single readings could produce different voltages this was due to the quantisation error of the ADC. For a 12 bit ADC, 4096 discrete steps existed over its 10 volt range.

Thus the quantisation error, in the specified range was ($=10/4096 = 2.5\text{mV}$). It was found by averaging 20 samples at the same micrometer position the quantisation error could be sufficiently reduced to make an accurate measure of the voltage.

7. Characterisation Procedure

The program to characterize the oscillator would initially move the frequency tuner to the lowest critical limit which corresponded highest frequency the oscillator could obtain without damage to the diode occurring. The program would then stop the frequency tuner at this limit move up slightly to a start position which was slightly lower in frequency. The start position for oscillator block D4 was chosen to be at 4.28volts. The reason for winding the frequency micrometer all the way down and then up slightly was to avoid the frequency hysteresis that occurs in these oscillators and is dependent on the direction of tuning. Thus, it is always necessary to be consistent with the direction one chooses to tune the oscillator. The program continued by incrementing the frequency micrometer in small distances. It was found that voltages of 0.01volts could be accurately incremented which corresponded to a frequency resolution of 100MHz. However, any resolution could be chosen depending on the requirements of the experiment to be performed. After the frequency tuner had been incremented the EIP frequency counter would be read by the computer via the GPIB. The backshort tuner was then scanned across its voltage range and the Boonton power meter read. This process would continue until the highest

critical limit of the frequency tuner was reached which corresponded to the lowest frequency of the oscillator.

8. Oscillator Characterisation Results using AOTS

The Gunn oscillator block (D4) was characterised using the AOTS using the experimental setup shown in Figure 7.

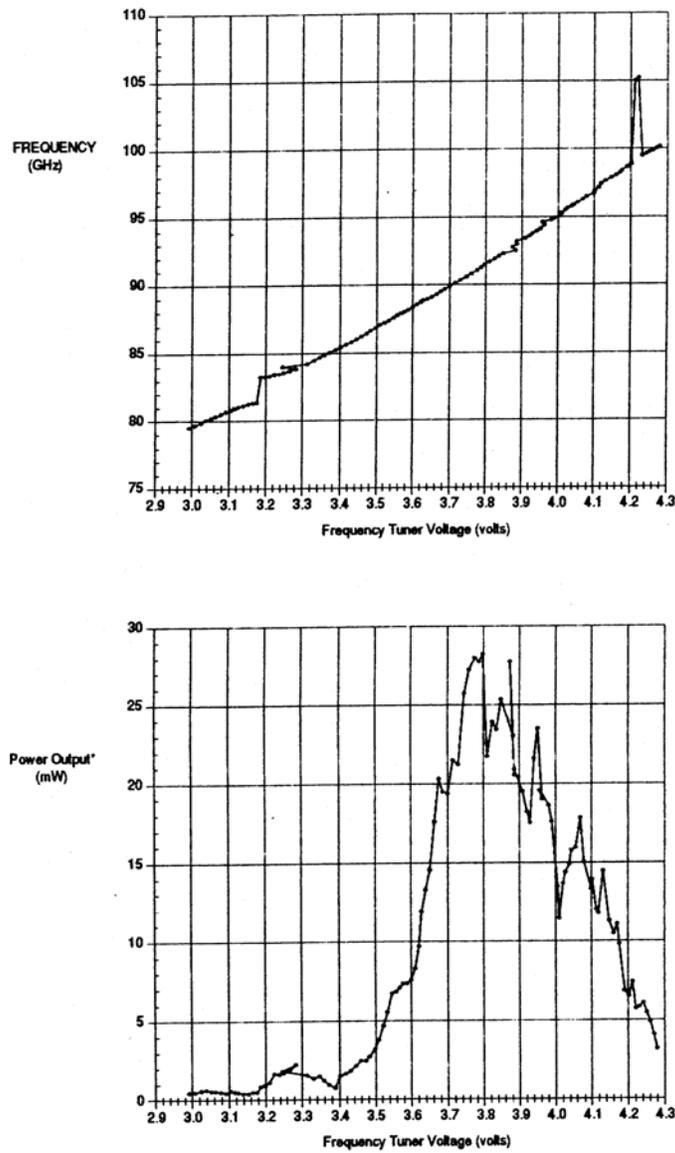


Figure 8 : Characterisation curves of oscillator D4 using the AOTS

The characterisation curves of the frequencies and maximum power obtained were plotted against the voltage of the frequency micrometer as shown in Figure 8. These results were performed with frequency micrometer being incremented at its highest resolution of (~100MHz). As can be seen from the uppermost figure, only one true frequency jump occurs with oscillator block (D4) at around 83GHz. This is the only frequency jump that occurs over the operating range of the oscillator (89-100GHz) and spans ~2GHz. The other jump that can be seen is due to the EIP miscounting. It was found that the number of EIP frequency miscounts could be greatly reduced using high resolution of stepping.

The whole automated characterisation procedure took approximately 10 minutes to perform at the highest frequency resolution. This proved to be a significant as compared to manual characterisation of at least 1hr+ (performed at a much lower frequency resolution). A photograph of the AOTS system is shown in Figure 9.

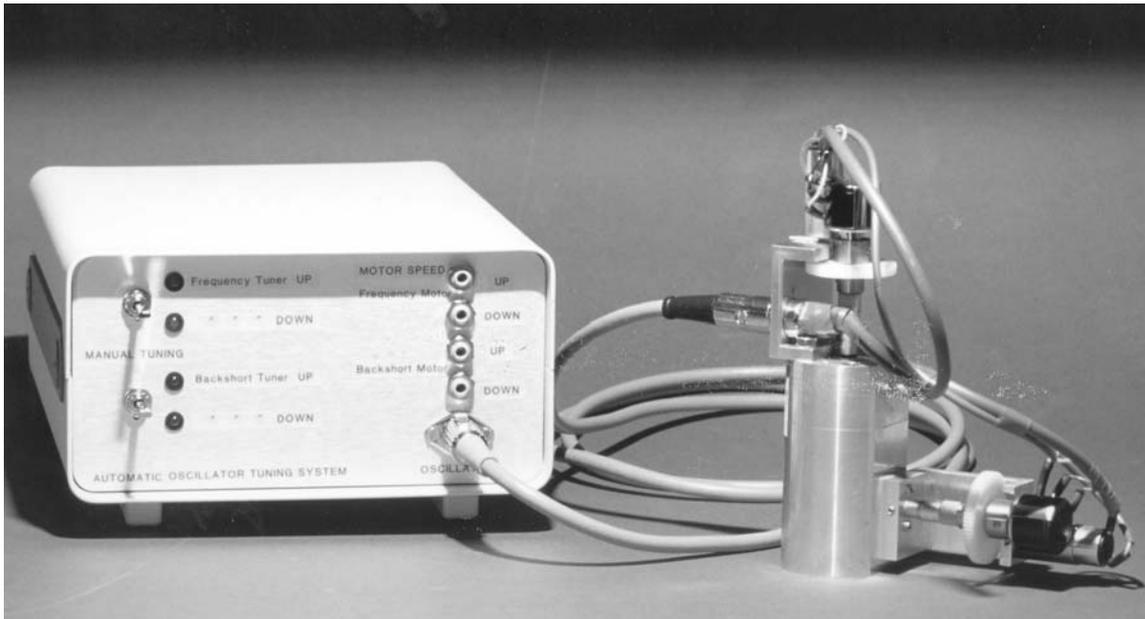


Figure 9 : The Automatic Oscillator Tuning System (AOTS)

Conclusions

The article has presented an 'Automated Oscillator Tuning System' (AOTS) that together with mechanical motorized fixtures can be used to automatically adjust the frequency and backshort tuners of a coaxial cavity, resonant cap mm-wave oscillator via a computer program. The AOTS has wide functionality and by writing an appropriate computer control program could be adapted for many different types of application. Here we have demonstrated how the AOTS can be used to quickly and accurately characterise a coaxial cavity, resonant cap mm-wave oscillator with a high frequency resolution of 100MHz, over an operating region of 11GHz. In addition, the characterisation took 10 minutes as compared to 1hr+ (at a lower frequency resolution) if performed manually.

Acknowledgements

The authors would like to thank Dr. D.A. Robertston and Dr. G.M. Smith from the MM-Wave & High Field ESR group at the University of St.Andrews, Scotland, for their help and advice during this work.

References

- [1] Kroemer H.: 'Theory of the Gunn Effect', Proceedings of the IEEE, 1964, 52,12, pp 1736.
- [2] Gunn J.B.: 'Microwave oscillations of current in III-V semi-conductors', 1963, Solid State Communications, Vol. 1, pp 88-91.

- [3] Brookbanks D.M.: 'Millimeter wave solid state sources', Allen Clark Research Centre, Annual Review, 1981.
- [4] G.M. Smith.: 'Transferred Electron Oscillators at MM Wave Frequencies and their Characterisation using Quasi-Optical Techniques', PhD Thesis, The University of St.Andrews, 1990.
- [5] Carlstrom J.E, Plambeck R.L, Thornton D.D.: 'A continuously tunable 65-115GHz Gunn oscillator',1985, IEEE Transactions in Microwave Theory & Techniques, Vol. 33, issue 7, pp. 610 – 619.
- [6] C. P. Unsworth.: 'A Fully Automated Millimetric Rotary Polariser Quasi-Optical System', PhD Thesis, The University of St.Andrews,1997.
- [7] D.A. Robertson.: Millimetre Wave Quasi-Optical Signal Processing and Spread Spectrum Techniques, PhD Thesis, The University of St.Andrews,1994.
- [8] EIP Microwave Inc. 575 & 578 Source Locking Microwave Counters Manual, Sect. 10, pp.06-1 to 06-7.
- [9] Boonton Electronics Corporation Instruction Manual for Model 4220 RF Power Meter, pp. 4-13 to 4-23.
- [10] A.R. Harvey.: 'A Millimetre Wave Quasi-Optical Complex Impedance Bridge', PhD Thesis, The University of St.Andrews, 1990.
- [11] <http://www.acorncomputers.co.uk/>, accessed June 2006.
- [12] <http://www.ni.com/gpib/>, accessed June 2006.