

A BROADBAND FREQUENCY TRIPLER FOR SIS RECEIVERS

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ABSTRACT

Considerable success has recently been gained in the design and production of high powered frequency triplers incorporating Schottky varactor diodes. The design approach that was used for this goal has now been turned to the design of fixed tuned, broadband frequency triplers specifically intended for use in SIS receivers.

The tripler reported here makes use of a Heterostructure Barrier Varactor or HBV. A waveguide circuit has been designed that provides more than $50\mu\text{W}$ of output power for an input power of 10mW over a frequency range of 250 - 300GHz completely fixed tuned and without the need for bias.

Further modification of the waveguide circuit should extend the useful fixed tuned bandwidth to greater than 100GHz centred at 300GHz.

INTRODUCTION

Future space missions such as FIRST have a requirement for fixed tuned frequency multipliers. Also, there are now a number of large millimetre and submillimetre astronomical arrays both planned and under construction. These will not be able to rely on tuneable frequency multipliers as the receiver local oscillator source because of the increased system complexity that would result. Consequently the requirement for fixed tuned, ultra broadband sources is now becoming urgent.

When considering the design of broadband frequency sources intended for use with SIS receivers it is important to note that high levels of local oscillator power are not required even though most of the available power is dumped via a 20dB beamsplitter. A design study for a broadband Schottky varactor tripler shows that the idler termination of the second harmonic provides the limitation to bandwidth. This is where the HBV has a considerable advantage. HBV frequency triplers have been demonstrated and are now showing performance levels [1, 2] that are very respectable compared with conventional varactor triplers. Possessing an anti-symmetric capacitance versus voltage (CV) characteristic ensures that only odd order harmonics are produced. In addition, unlike an antiseriess arrangement of varactor diodes, a HBV tripler does not even require a particular configuration of the external RF circuit to cancel out unwanted harmonic products, as is the case for a balanced doubler or quadrupler. Cancellation of unwanted harmonics for a HBV is carried out within the intrinsic device.

In many ways therefore the design of a tripler based on a HBV is similar to that of a fundamental mixer with the added complication of providing a broadband input circuit. This paper discusses the design of a fixed tuned unbiased HBV tripler that has been specifically targeted as an LO source for a fixed tuned SIS receiver operating in the frequency range 250 -300GHz.

TRIPLER DESIGN

The tripler has been designed to provide a minimum of 20 μ W for an input power of 10mW over a frequency range of 250-300GHz. This amount is perceived to be adequate for a well designed SIS receiver, however, in the event this specification was easily surpassed.

As no available custom made tripler mount was available for this work an obsolete varactor waveguide doubler block, NB-6, was used. This doubler was originally designed (in 1978) to operate in a tuned manner from 180-220GHz and so includes both E and H plane tuners on the input but only an E-plane tuner on the output. In addition, the waveguide is standard size (reduced height) for the band below that at which the HBV tripler was intended to work. This choice of block was therefore by no means ideal but was the only one available at the time.

For the design of the block a modified version of the Eisenhart and Khan [3] analysis was used [4]. The Eisenhart and Khan (E & K) analysis models the waveguide configuration shown in figure 1.

The analysis allows the waveguide arms to be terminated in any complex reflection coefficient, the position of which is again arbitrary. In this way it can be used to model the output circuit of the proposed HBV tripler. The code has been modified to take into account the effect of placing a contacting probe across the gap between the end of the post and waveguide wall. This structure is realised in practice by the use of a flat $2\mu\text{m}$ thick gold probe integrated with the quartz microstrip filter. The probe is suspended in air, spanning the waveguide.

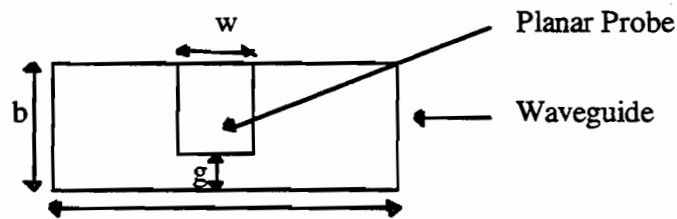


Figure 1: *The Eisenhart and Khan geometry*

The HBV device is then soldered between the end of the probe and the waveguide wall which is formed by the end of the now redundant whisker post. A schematic of this arrangement is shown in figure 2 with a photograph of the inside of the NB-6 doubler block and an SEM of a planar HBV diode chip (UVA-NRL-1174-17).

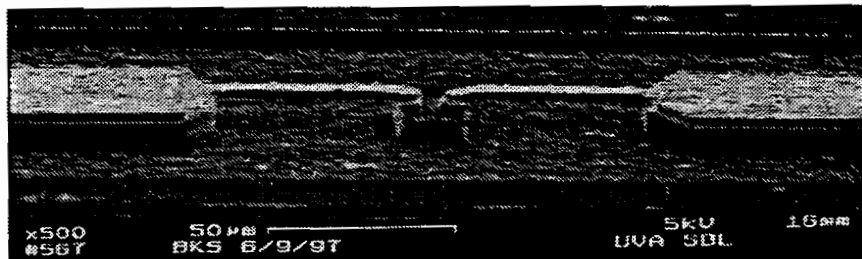
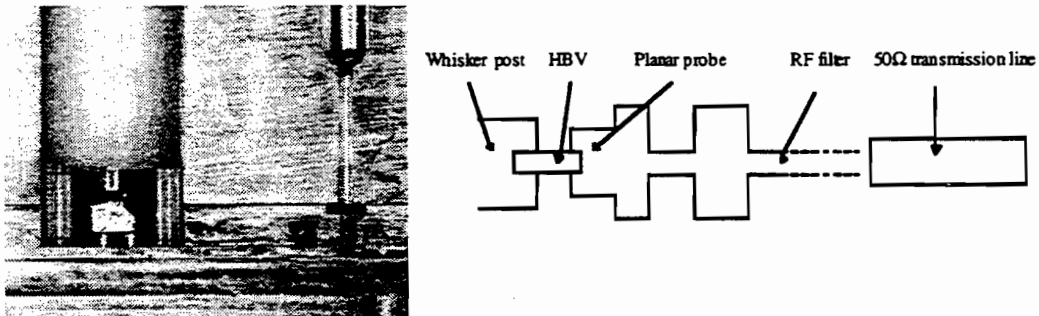


Figure 2: *A schematic of the HBV assembly, and the inside of the NB-6 doubler block*

In order for the tripler mount to be designed accurately (that is the dimensions of the waveguide probe and the microstrip RF filter), a target impedance is required.

An analytical model for a HBV device has been derived [5] and used to produce a two dimensional map of predicted performance (efficiency) as a function of output impedance. This is then plotted on a Smith chart. Two such plots are shown below in figure 3 for $6\mu\text{m}$ and $8\mu\text{m}$ diameter HBVs operating under the conditions indicated.

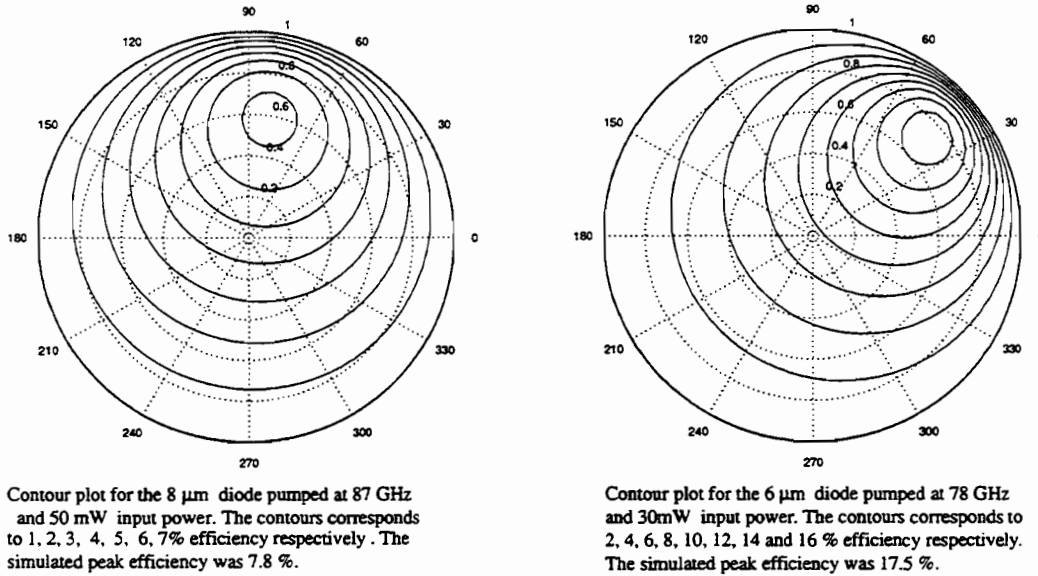


Figure 3: Predicted efficiency as a function of output embedding impedance for a HBV tripler.

These plots can then be compared with similar plots of predicted embedding impedance as a function of frequency and backshort position, produced using the E & K analysis. Optimisation of the waveguide probe for the NB-6 block was restricted to the variation of the probe width and gap only, as the waveguide dimensions **a** and **b** were not adjustable. Figure 4 shows a series of embedding impedance plots for a frequency range of 200-300GHz as a function of backshort position. The final circuit parameters that gave the most broadband response for the NB-6 mount are, $w = 0.176\text{ mm}$, $g = 0.111\text{ mm}$. It is important to note that the final frequency response available is limited purely by the choice of waveguide dimensions which are fixed. It will be shown later that once the waveguide dimensions **a** and **b** are adjusted a much more broadband device is obtained.

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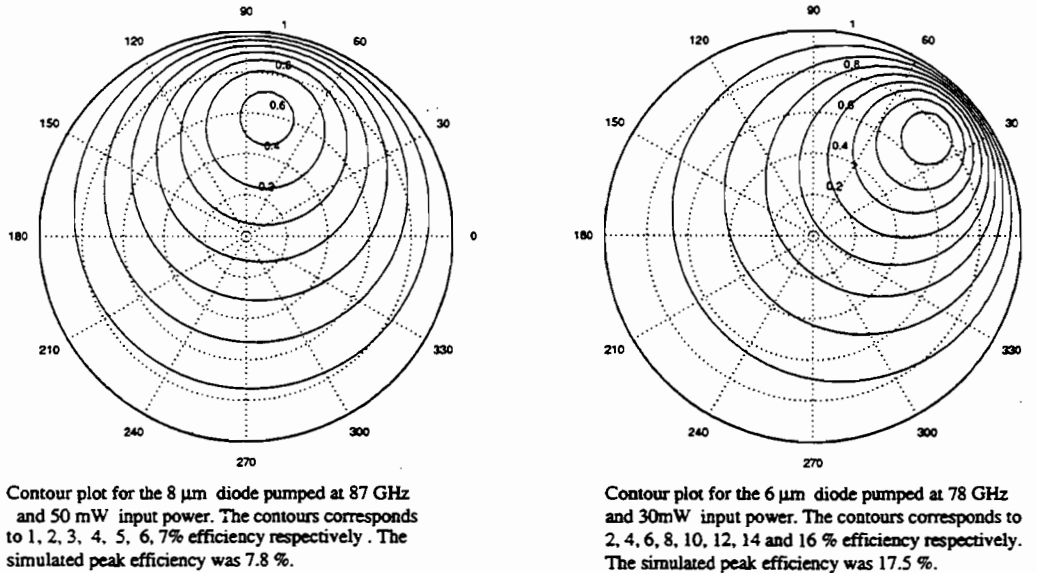


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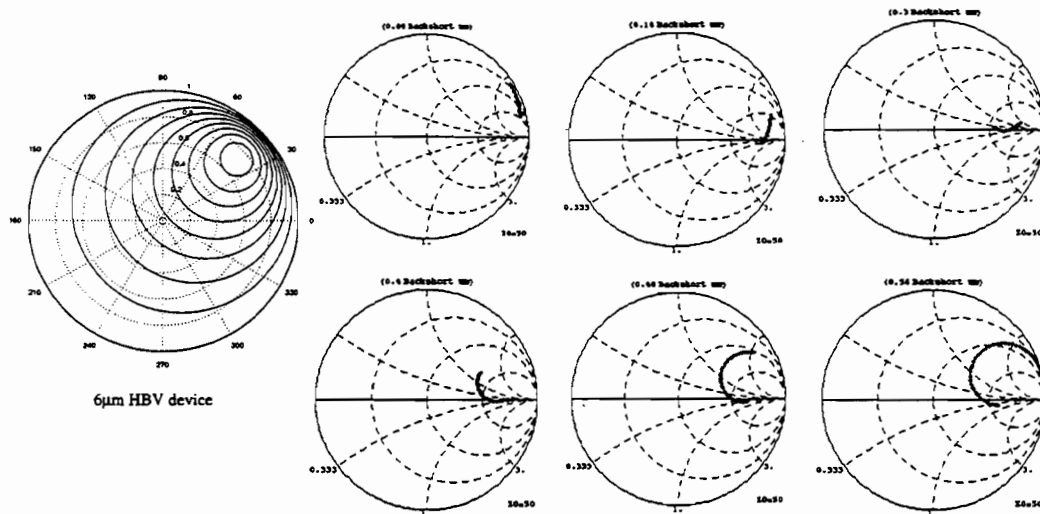


Figure 4: Fixed tuned output embedding impedance as a function of backshort position. For comparison, the efficiency contour plot for a 6 μm HBV is shown on the left.

This series of plots show that for a fixed backshort position it is not possible to provide the optimum embedding impedance over the frequency range 200 - 300GHz. Variation of the probe and HBV position within the waveguide was attempted but a more broadband response could not be obtained. The plots indicate that as the backshort is moved away from the HBV the frequency response would shift. This trend was observed in the real tripler. Further evidence as to the accuracy of the E & K predictions came about by accident when upon insertion into the waveguide the output backshort became trapped at a position of 4.45mm from the HBV instead of a position 0.45mm (the position corresponding to the best broadband response).

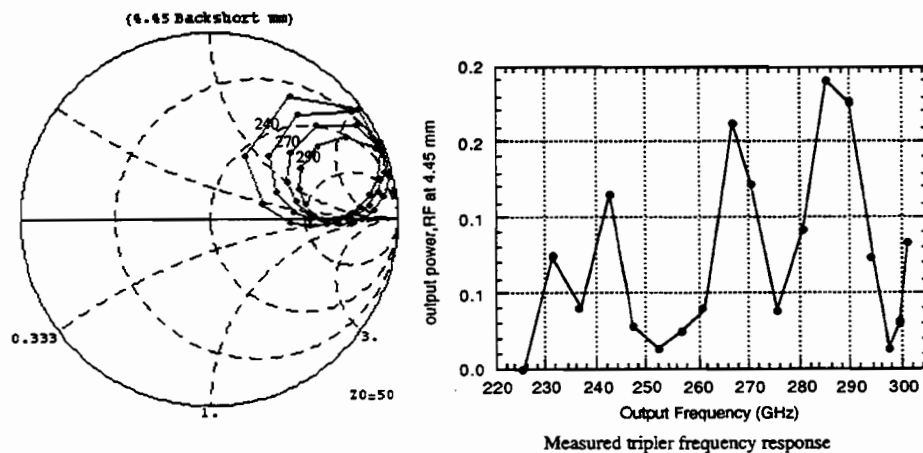
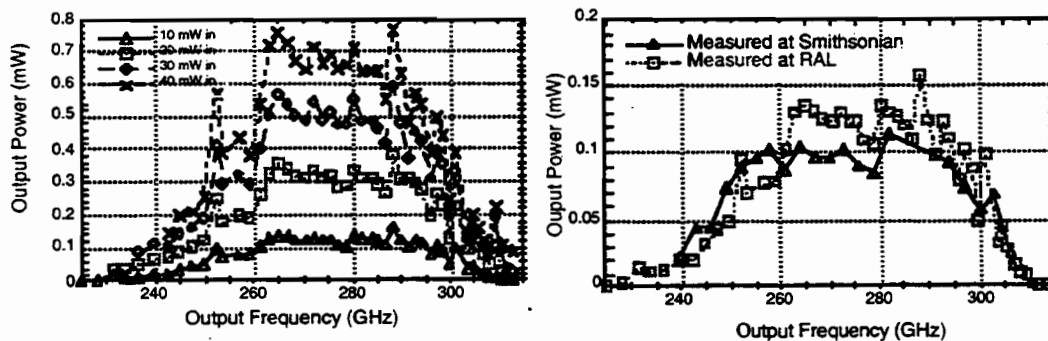


Figure 5: Effect of misplacement of backshort on the broadband frequency response.

This occurred during the first iteration of RF testing. Disappointingly, the tripler showed a far from broadband response, rather a series of resonances. However, once the error with the output backshort was found the E & K analysis was re-run for this backshort position. The results are shown in figure 5. From the E & K analysis a series of resonances is predicted for a backshort fixed this far back from the HBV. Due to dispersion, the frequency response follows a series of loops. As the loops move inside the Smith chart a sharp improvement would be observed followed by a rapid degradation as the output impedance moves towards the open circuit position. Whilst initially a source of some disappointment this exercise did, however, give some indication as to the validity of the design approach.

Once the correct backshort position was obtained the tripler produced a smooth broadband response as expected. The optimisation process was then simply to move the backshort in small increments and measure the frequency response. This was carried out iteratively until the desired response was obtained. The most flat frequency response was obtained for a backshort position of 0.45mm.

The final frequency response, after the backshorts had been locked is displayed in figure 6. For comparison purposes the triplers performance has been measured at the Smithsonian Institute. The output levels measured at both establishments agree well. In addition, the harmonic frequency response of the tripler has been investigated using a Fourier Transform Spectrometer at RAL and no unwanted second or fourth harmonics were observed measured to within the sensitivity of the system.



Final measured frequency response as a function of input power (Backshort fixed at 0.45mm)

Final fixed performance for 10 mW input. Comparison of measures made at RAL and the Smithsonian Institute

Figure 6: Final fixed tuned frequency response for the NB-6 'tripler'.

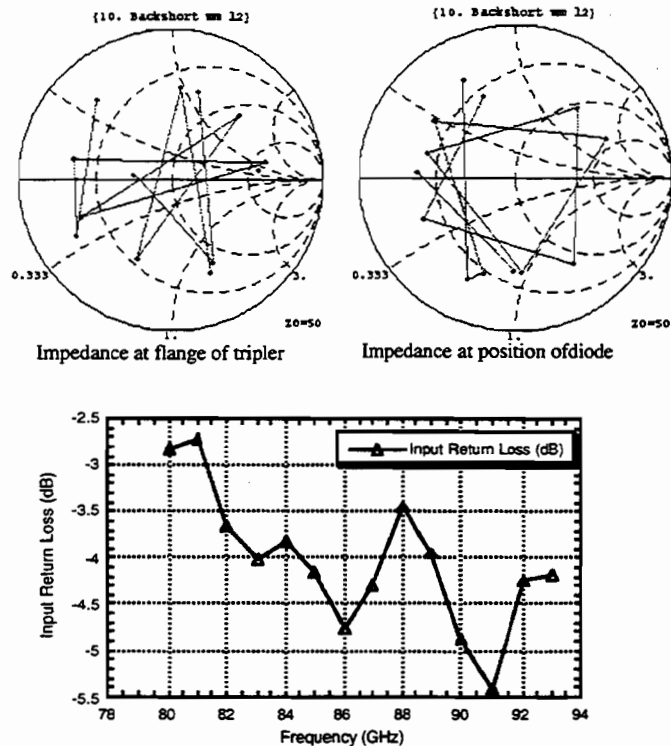


Figure 7: Measured and de-embedded reflection coefficients for the finished tripler.

DISCUSSION

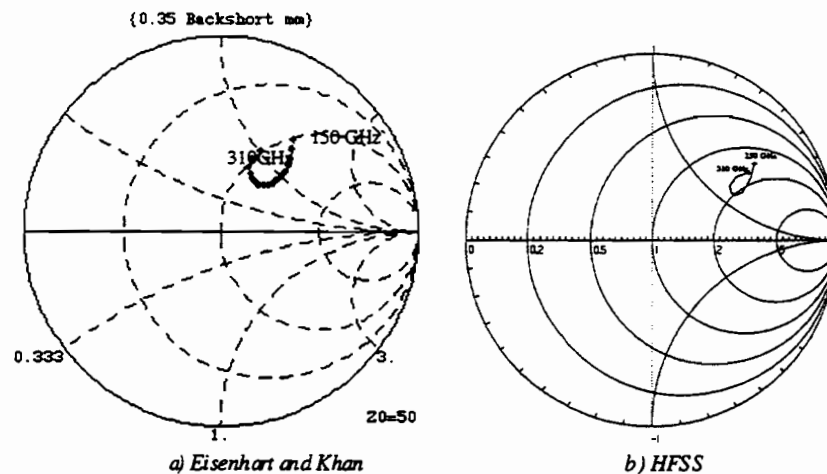
The HBV tripler provides a minimum of 50 μ W for a frequency range of 250 - 350GHz, however, the efficiency is very low, only \approx 1% over most of the band. The efficiency improves slightly for harder pump power which would imply that this diode is too large in area for the intended 10mW input power available for this application. Another design parameter that could be improved is the input circuit impedance. No attempt has been made to optimise this aspect of the design. The input return loss and reflection coefficients have been measured at the Smithsonian Institute. The results are displayed in figure 7. It can be seen that there are substantial gains to be made with regard to this aspect of the device.

However, the area in which most gains are likely to be made involve the complete redesign of the waveguide mount this time including the waveguide dimensions **a** and **b**.

FUTURE POTENTIAL FOR THIS WORK

Before the waveguide mount was completely redesigned a comparison between HFSS and the E & K analysis was first carried out in order to determine the level of

agreement attainable. A simple waveguide structure was modelled for both cases and then compared. Figure 8 shows how the two approaches both predict the same trend. However, the absolute values for the embedding impedances differ but because of the speed advantages (5 seconds for the E & K verses \approx 1 day for HFSS) it was decided that the E & K analysis would be used to obtain the approximate dimensions for the mount and HFSS to be used for final verification.



HFSS and Eisenhart and Khan results for the same waveguide structure i.e. $a = 1.35$ mm; $b = 0.1$ mm; $g = 0.035$ mm; backshort at 0.35 mm; width = 0.2 mm frequency range: (150 - 310 GHz)

Figure 8: A comparison between Eisenhart and Khan and HFSS

A complete sweep of the waveguide circuit was then carried out to determine the most optimum values for the variable parameters, a , b , w , g and the optimum backshort position. The following figures show the embedding impedance as a function of two of these parameters over a fixed tuned frequency range of 150Ghz -350Ghz.

Similar plots could be shown for the variation of a and b .

Finally the optimised waveguide configuration is shown in figure 10 overlaid on the efficiency contour plot for a $6\mu\text{m}$ HBV and the RF backshort fixed at a distance of 0.35mm. It can be seen from this figure that the output impedance of a fixed tuned waveguide cavity can provide the optimum embedding impedance over a frequency range of 150 - 310 GHz .

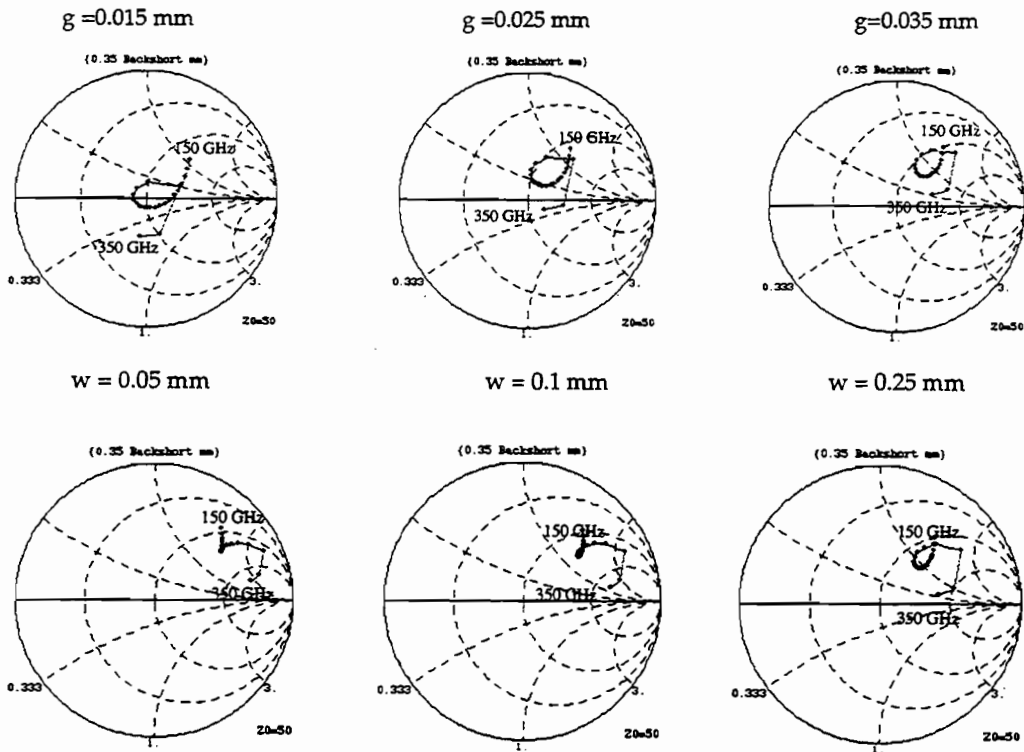


Figure 9: Embedding impedance as a function of g and w is shown.

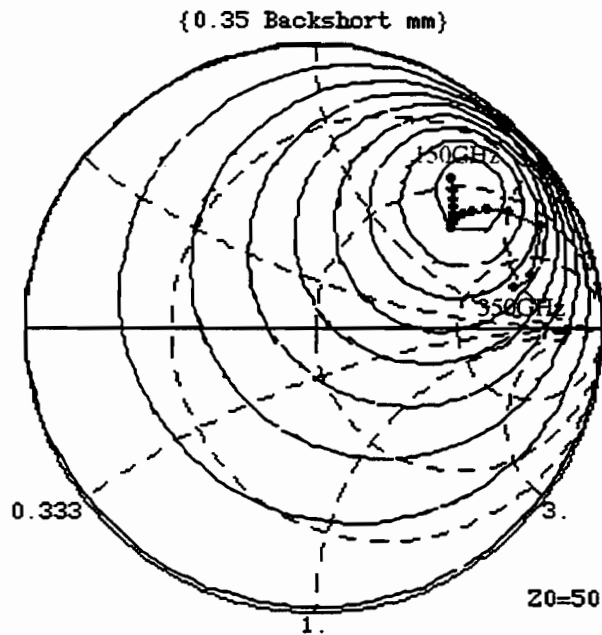


Figure 10: View of the contour plot for the $6 \mu\text{m}$ diode together with the E & K simulated response, for $a = 1.35 \text{ mm}$, $b = 0.1 \text{ mm}$, $g = 0.035 \text{ mm}$ and $w = 0.1 \text{ mm}$.

CONCLUSION

An obsolete doubler block has been turned into a very useful HBV frequency tripler that has broadband performance completely fixed tuned and unbiased. This has been achieved via the use of accurate analytical models and a planar HBV diode. The tripling behaviour makes the HBV an ideal device for ultra broadband frequency triplers particularly where high powers and efficiency are not the ultimate driver.

REFERENCES

- [1] 'A High Power 270 GHz Frequency Tripler Featuring A Schottky Diode Parallel Pair', J.Thornton, C.M.Mann, P.de Maagt, IEEE-MTT Conference, Denver, 1997.
- [2] 'Design of 100-900GHz GaAs/Al/GaAs/GaAs Planar Heterostructure Barrier Varactor Frequency Triplers', J.Stake, L.Dillner, S.H.Jones, T.O'brien, C.M.Mann. E.Kollberg, 9th International Conference on Space Terahertz Technology, JPL, Pasadena, 1998.
- [3] 'Theoretical and Experimental Analysis of a Waveguide Mounting Structure', R.L.Eisenhart, P.J.Khan , IEEE Transactions on Microwave Theory and Techniques VOL. MTT-19 no.8 August 1971, pp706 - 719.
- [4] 'A Design Approach For Planar Waveguide Launching Structures', J. Thornton, C. M. Mann, 7th Int. Symposium. Space THz Technology, Charlottesville, March 96.
- [5] 'Analysis of Carrier Transport in a Heterostructure Barrier Varactor Diode Tripler', J Stake , S H Jones, J R Jones, L Dillner, Proceedings. of the 1997 International Semiconductor Device Research Symposium, Charlottesville, December, 1997