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A comparison between in-waveguide and free space power
measurement standards at 60 and 94 GHz

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ABSTRACT

A description is given of the results of a comparison between a photoacoustic power meter and the UK primary in-waveguide power measurement standards at 60 and 94 GHz.

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Table of Contents

1. INTRODUCTION	1
2. EXPERIMENTAL, RESULTS AND DISCUSSION	1
3. CONCLUSIONS	3
4. REFERENCES	3
5. ACKNOWLEDGEMENTS	3

1. INTRODUCTION

In previous publications⁽¹⁻³⁾ the use of the photoacoustic power meter (PAPM) as both an absolute and a non-absolute device for the determination of power propagating in free space at near millimetre wavelengths has been described. Typically, it has been shown possible to measure power at the 1 mW level with a random uncertainty of about 1% and a response time of 40 ms. These parameters represent significant improvements over previous free space measurement standards⁽⁴⁾. In order to check on possible systematic errors in the performance of the PAPM an intercomparison was carried out at 94 GHz between it and the UK National Standard of in-waveguide power measurement, based on a waveguide-thermistor mount. This gave the result that the PAPM gave a value for received power that was a factor of 1.02 ± 0.018 higher than that of the in-waveguide standard.

Although this factor seemed to indicate a welcome level of agreement and low systematic error between the two power measurement methods, the small offset between them provided concern that all might not be as it seemed. In the present paper the results of further intercomparisons between the PAPM and various in-waveguide thermistor mount standards at both 60 and 94 GHz are presented and discussed. These show that the earlier intercomparison was subject to an unexpected systematic error, possibly associated with the use of lenses in the quasi-optical instrumentation used for the measurement, and that the comparison of values for received power achieved by the two methods is much closer to unity than the previous result at 94 GHz.

2. EXPERIMENTAL, RESULTS AND DISCUSSION

In the intercomparison, initial measurements were made at 60 GHz using a 50 to 75 GHz multistate reflectometer operating in WG25. The PAPM was set up with fused silica windows with spacings optimised for 60 GHz operation. The reflectometer had been converted into a calibrated quasi-optical multistate reflectometer similar to the WG27 one used in the earlier intercomparison at 94 GHz⁽¹⁾. A quasi-optical adaptor consisting of a corrugated feed horn and a lens coupled radiation from the reflectometer into free space to throw the waist of a Gaussian beam at a known position. It could be set up so that the power at the waist was either coupled back into waveguide by a second, reversed quasi-optical adaptor, to be absorbed in a calibrated thermistor mount, or was incident on the PAPM. Three nominally identical quasi-optical adaptors were used. Measurements were made with various combinations of quasi-optical adaptors. The measurement procedure followed the 'three known loads' technique⁽¹⁾, using a short circuit in three positions to obtain three known phase shifts, to ultimately give the efficiency, η , of the PAPM referred to the waveguide thermistor, as the ratio of the power indicated by the PAPM to that delivered to the PAPM.

These 60 GHz measurements were repeatedly made at power levels of 0.45 and 3 mW. In all cases the measured PAPM efficiency, η , was found to be between 1.07 and 1.09, with a typical random uncertainty of ± 0.003 on each individual measurement. Such values were much larger than those found in the original 94 GHz intercomparison (1.02).

In order to check whether these efficiency values were in some way related to multiple beam inter-reflection, the lenses in the three quasi-optical adaptors

were blazed to have very low reflection coefficients at 60 GHz. The measurements were then repeated. These, again, gave very reproducible results showing unchanged measured PAPM efficiencies in the 1.07 to 1.09 range.

A possible explanation for efficiency values in excess of unity would be that the PAPM and the waveguide thermistor were not illuminated by the same power levels during the calibration. If, in particular, the two quasi-optical adaptors used to bring the power out of waveguide, and then back into waveguide to the thermistor mount, were not returning all the power back to waveguide, this could lead to efficiency values in excess of unity. This would not be a problem with the much larger area PAPM.

In order to check on this possibility a simpler measurement procedure was adopted. The function of the multistate reflectometer was unchanged during these measurements. The only difference from the quasi-optical adaptor method was that the waveguide to free space adaptor (ie the corrugated horn) was characterised simply, by ignoring possible multiple reflections occurring within the horn. This was implemented as follows. First, the power at the test port was measured with the thermistor mount connected to the reflectometer. Then the thermistor mount was replaced by a corrugated feed horn which delivered power at normal incidence to the PAPM, which could be positioned almost in contact with the output aperture of the feedhorn, and up to 25 mm away from it. The return loss in the feedhorn was calibrated by covering the aperture of the horn with an aluminium flat, leading to a voltage reflection coefficient of 0.9905 at 60 GHz. This factor, combined with the results of the thermistor measurement gave the power delivered to the PAPM. The PAPM measurement itself, gave the power indicated by the PAPM. Thus, the ratio of the two power levels gave the efficiency of the PAPM. Thermistor mounts must be used with cw power, while the PAPM requires modulated power. Thus, a part of the measurement procedure was to calibrate the modulation efficiency of the waveguide modulator, and to allow for this in the calculation of overall PAPM efficiency.

Typical results of doing this at 60 GHz are shown in figure 1 for various positions of the PAPM with respect to the feedhorn, and for an incident power level of 2.6 mW. Each point shown represents the mean of five independent determinations, with the error bars indicating $\pm$ one standard deviation. At separations greater than 15 mm the measured efficiency falls off with increasing separation in a reproducible manner. It seems reasonable to assume that at those displacements the geometry was such that the power delivered to the PAPM was smaller than at closer separations. At separations less than 15 mm the three efficiency values agree within the limits imposed by their random uncertainties, leading to a mean value of 0.9995 ± 0.0016 for the PAPM efficiency at 60 GHz, as shown by the horizontal line in the figure.

The repeat of the previous 94 GHz intercomparison⁽¹⁾ used a WG27, 75 to 110 GHz, multistate reflectometer in a similar, simplified return loss, quasi-optical configuration to that used for the 60 GHz results in this work. Intercomparisons were made using three different standard thermistor mounts, with a calibrated corrugated feedhorn used to couple the radiation to the PAPM. At a power level of 0.9 mW, and for horn-PAPM distances less than 10 mm, these gave a value for the PAPM efficiency at 94 GHz of 0.9965 ± 0.0022 .

The efficiency values determined at 60 and 94 GHz agree with each other within

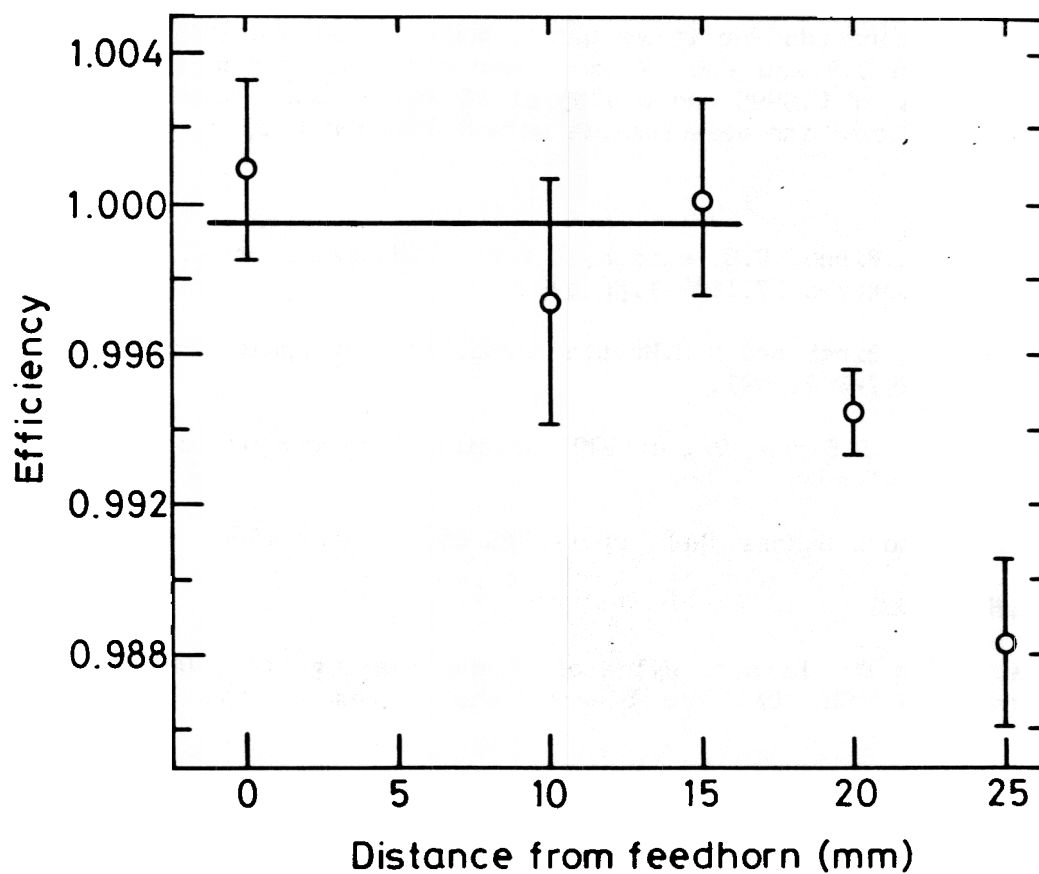


Figure 1. The measured efficiency of the PAPM at 60 GHz as a function of the distance between the feedhorn of the reflectometer and the PAPM. The horizontal line indicates the mean of the values at 0, 10 and 15 mm separations.

the limits imposed by the random uncertainties in their measurement. Furthermore, that at 94 GHz is now shown to be less than both unity and the value of 1.02 ± 0.018 previously assigned. It is interesting to note that, throughout the use of this simplified return loss method, measured efficiencies less than unity always resulted when horns alone were used to couple the radiation to the PAPM. Larger than unity values always resulted when a lens was involved in the coupling. Under such conditions at 60 GHz, power overspill was detected at the aperture of the corrugated horn of the quasi-optical adaptor. This may explain the slightly larger than unity values previously found for the 94 GHz efficiency.

3. CONCLUSIONS

A photoacoustic power meter designed to determine accurate values for near millimetre wave power levels propagating in free space has been compared with the UK primary standards for in-waveguide power at 60 and 94 GHz. At power levels of between 0.9 and 2.6 mW the power meter was found to have power efficiency values of 0.9995 and 0.9965 at 60 and 94 GHz, respectively. The standard deviations of the measurements were 0.0016 and 0.0022, respectively.

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5. ACKNOWLEDGEMENTS

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