

# High Accuracy Optoelectronic Device Measurement

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## Introduction

As the use of commercial test and measurement equipment for high speed optoelectronic devices becomes more widespread, the need for accurate calibration facilities, traceable to international standards, has become apparent. Two national standards laboratories have responded to the requirement by offering measurement services for optoelectronic devices, in order to give the greatest confidence in the accuracy of these services, they have to be compared in an intercomparison, using a photodiode as the transfer standard. In this paper we discuss the results from two previous measurement intercomparisons and review the major sources of uncertainty in optoelectronic device measurements.

## International Industrial Intercomparison.

The need for accurate standards was shown in the results of an international intercomparison made between 1989 and 1990. Two photodiodes were measured by ten laboratories in Japan, the UK and the USA using, in total, sixteen measurement systems<sup>1</sup>. The scatter in the measurement of the 3 dB point (the frequency at which the RF output from the device is reduced by 3 dB from the DC response) varied by up  $\pm 6.6$  and  $\pm 5.9$  GHz for the two devices. These variations can be largely attributed to errors in the RF power measurements, however certain types of measurement system exhibited observable systematic effects. Many of the measurements were made using systems still under development but three contributors used very similar commercial testgear. Their measurements showed a spread of over 1 dB at 20 GHz. These contributions to the intercomparison in particular, demonstrate the need for traceability.

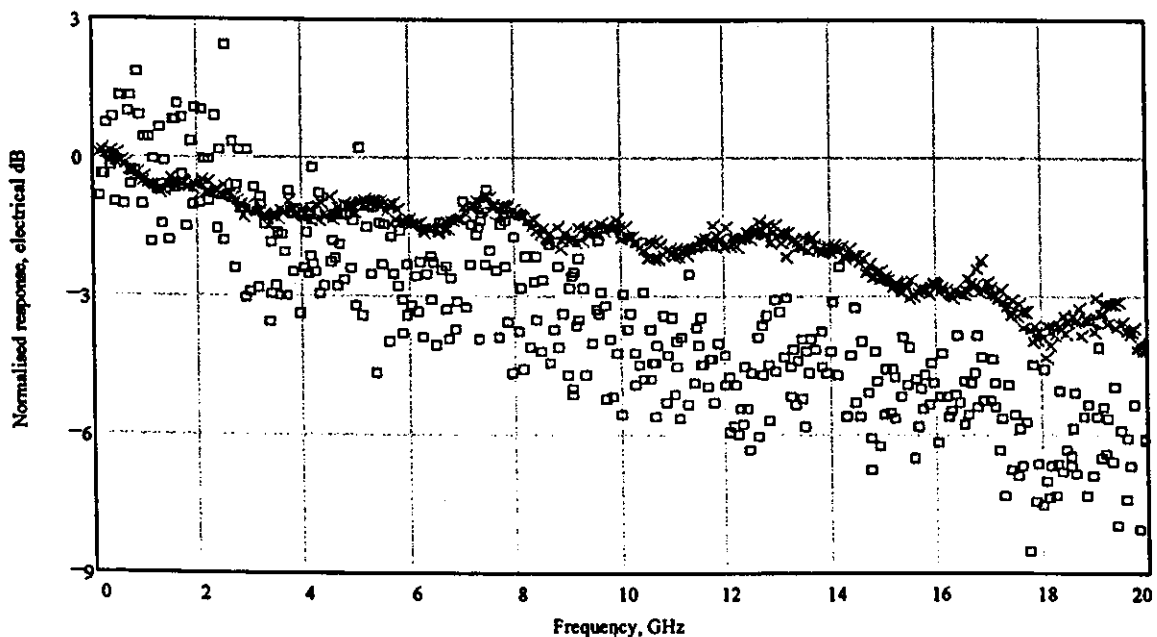


Figure 1 Results from two different commercial measurement systems

## NIST - NPL Intercomparison

The accurate characterisation of optoelectronic devices can be ensured by making measurements which are traceable to national standard facilities. These systems, in turn, should be directly traceable to the primary standards (e.g. microwave power, DC current, electrical rise-time, optical power, etc.). International intercomparisons form the basis for acceptance of national measurement systems. Commercial high-speed photodiodes have been successfully used as transfer standards. Commercial measurement laboratories can have access to the national standard by the same method. Because of the frequent re-measurement of the transfer device, these intercomparisons also yield important information on the stability of the transfer device itself. This is important when the principal traceability route is via a transfer standard, rather than by the direct calibration of the measurement system components.

NIST and NPL have made such a comparison by measuring the frequency response of a high speed photodiode up to 40 GHz operating in both the 1.3  $\mu\text{m}$  and 1.5  $\mu\text{m}$  bands<sup>2</sup>. The average scatter of the combined results was  $\pm 0.15$  dB ( $2\sigma$ ) below 20 GHz and the agreement up to 33 GHz is covered by the combined uncertainties of the measurement.

### Measurement Uncertainties

Some of the important points and commonly encountered problems to consider are detailed as follows:

- Unlike purely optical or electrical measurements, an optoelectronic device frequency response is not the ratio of two similar signals eg. External Quantum Efficiency is the ratio of the measured RF power and the equivalent RF power calculated from the optical power and the wavelength.
- Low RF measured power, typically -50 dBm: National standard RF power calibrations are normally conducted at 0 dBm and the uncertainty increases at low level.
- Poor microwave match of optoelectronic components to the microwave system: photodiodes have a high impedance, laser diodes have a low RF impedance and the stripline construction of optical modulators gives them an impedance typically between 20 and 50  $\Omega$ .
- Optical signal is a modulated carrier, the output is an RF signal - the relative phase of these signals can be made by modelling the diode or optical modulator or by oscilloscope/pulse measurements.

In high accuracy measurements the variation of the absorption coefficient of the photodiode material with wavelength must be considered. Modelling of a commercial photodiode response gives up to 0.3 dB variation between 1.285 and 1.531  $\mu\text{m}$  at 25 GHz.

- Optical and electrical decibels are not the same! 1 dB (optical) is equal to 2 dB (electrical) - working with currents, voltages and Voltage-Reflection-Coefficients is generally safer.

**Table 1: NPL Measurement Capabilities**

| Service                                       | Wavelength              | Measurement Limit * | Typical Uncertainty + |
|-----------------------------------------------|-------------------------|---------------------|-----------------------|
| Photodiode frequency response                 | 1.53 $\mu\text{m}$      | 40 GHz              | $\pm 0.4$ dB          |
| Photodiode frequency response                 | 1.29 $\mu\text{m}$      | 25 GHz              | $\pm 0.24$ dB         |
| Photodiode frequency response                 | 0.85 $\mu\text{m}$      | 26.5 GHz            | $\pm 0.5$ dB          |
| Photodiode frequency response FWHM            | 1.3 $\mu\text{m}$       | 35 ps               | $\pm 10$ ps           |
| Photodiode frequency response FWHM            | 0.85 $\mu\text{m}$      | 15 ps               | $\pm 3$ ps            |
| Integrated Optic Modulator frequency response | 1.53 $\mu\text{m}$      | 26.5 GHz            | $\pm 0.5$ dB          |
| Calibrated transfer photodiodes               | 1.3 / 1.5 $\mu\text{m}$ | 25 / 40 GHz         | as above              |

\* measurements may be possible outside this range, please contact NPL for information

+ uncertainties quoted to 95% confidence

### Conclusions

- An assessment of the uncertainties shows that RF power and impedance mismatch are the major contributions.
- Intercomparisons are valuable to both industry and national standards laboratories to give confidence in the measurement systems that they use.
- Previous intercomparisons have demonstrated the suitability of commercial photodiodes for use as transfer standards.

### References

1. D A Humphreys, T Lynch, D Wake, D Parker, C A Park, S Kawanishi, M McClendon, P Hernday, J Schlafer, A H Gnauck, G Raybon, R T Hawkins II, M D Jones, J H Goll, "Summary of results from an international high-speed photodiode bandwidth measurement intercomparison." Digest, Optical Fibre Measurements Conference, York, U.K. pp. 69-72, 1991.
2. P D Hale, D A Humphreys, A D Gifford, "Photodetector frequency response measurements at NIST, US, and NPL, UK: preliminary results of a standards laboratory comparison." SPIE Proc. vol. 2149, pp. 345-356, 1994.

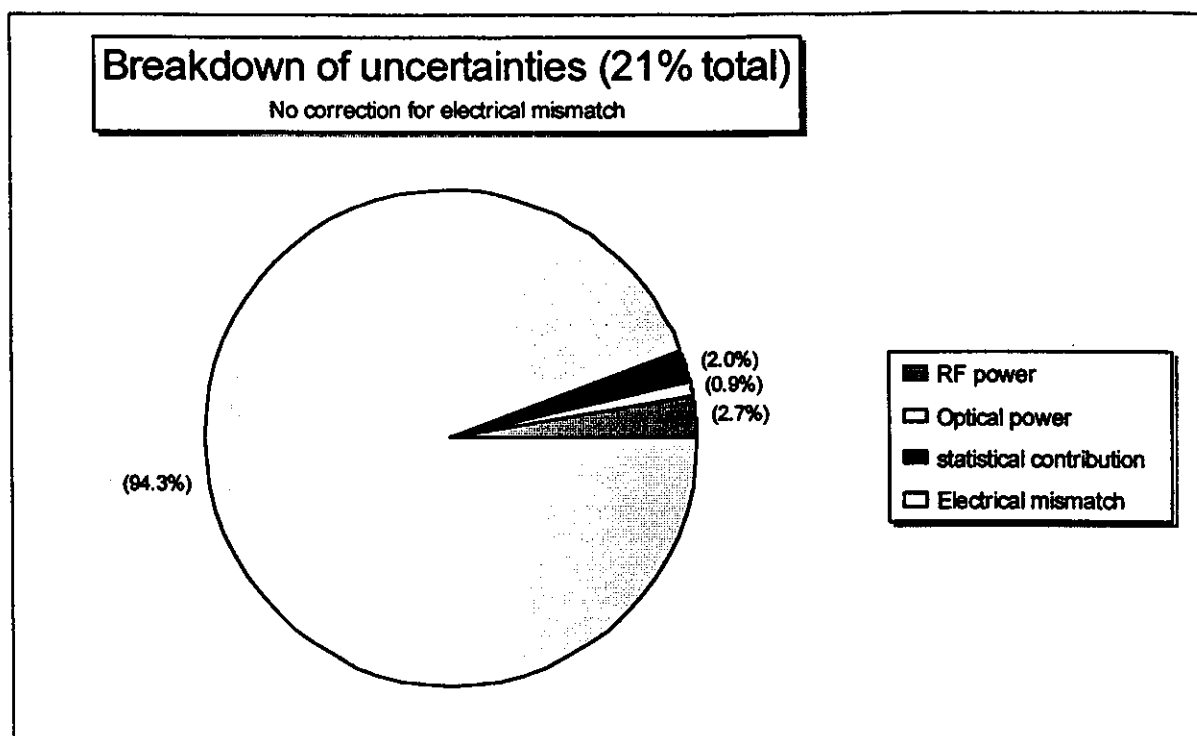


**Figure 2** Uncertainty contributions - no impedance mismatch correction

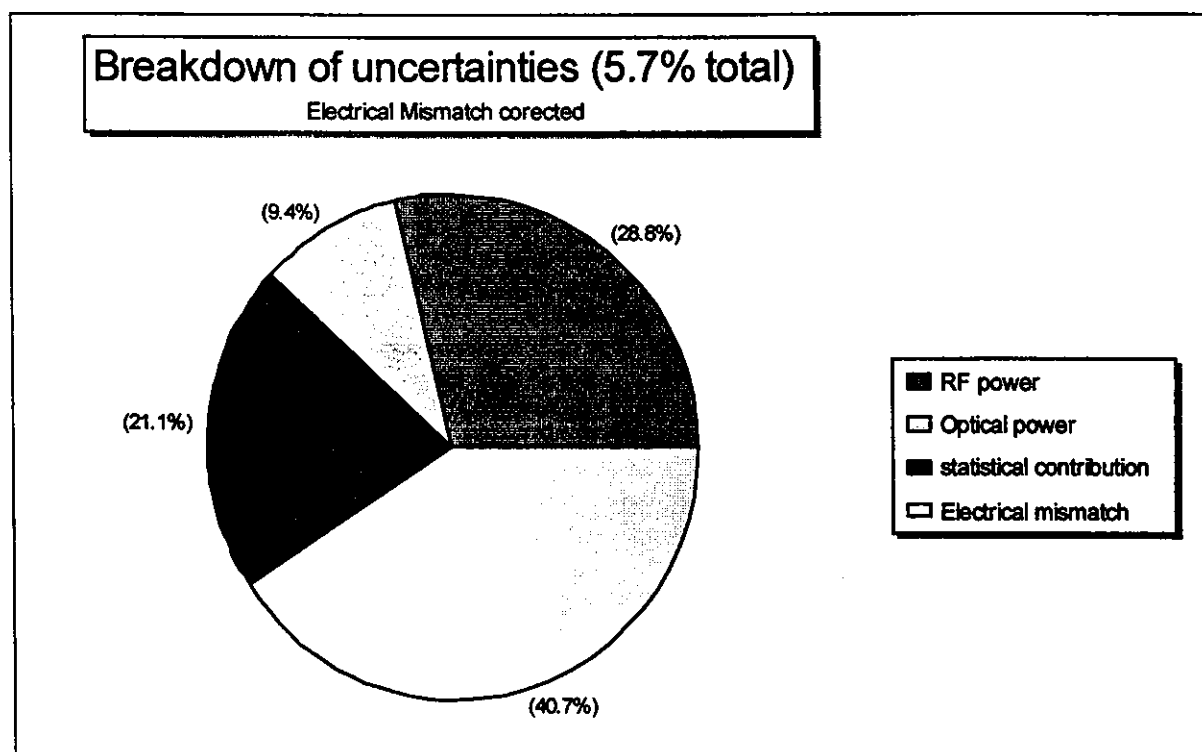


**Figure 3** Uncertainty contributions - impedance mismatch corrected

Figures 2 and 3 show the principal contributions to the overall uncertainties in a typical photodiode measurement. In both cases the quadrature sum of the uncertainty contributions is used to obtain the overall estimate.