Extending the traceability to UK national standards for complex reflection parameters at lower RF

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Abstract

This paper gives details of a research and development programme currently being undertaken by the UK's National Physical Laboratory to provide a service to industry for traceability to national standards for complex reflection parameters at lower RF. The service will provide traceability for items fitted with 50 ohm type-N connectors in the frequency range 100 kHz to 100 MHz. This paper gives an outline of the work programme and reports on progress to date.

BACKGROUND

In recent years, the state-of-the-art of impedance standardisation at RF in the UK has improved significantly due to several key developments made to both the hardware and software aspects of the measurement systems [1]. The hardware improvements have been based around developing new primary impedance standards [2] whereas the software improvements have concentrated on applying more detailed models of the standards and in-depth studies of the uncertainty of measurement for the overall systems [3].

This work was recently extended downwards in frequency to address the lower RF frequency band [4]. These advances were made exclusively for the top echelon metrology-grade connector types (i.e., GR900 and GPC-7). However, it was also recognised that subsequent developments would be needed to address the connector types used more frequently by industrial calibration facilities, e.g., the type-N connector and, to a lesser extent, the GPC-3.5 connector.

This has led to the launch of the present programme of work which is aimed at developing such an impedance measurement facility suitable for devices fitted with type-N connectors. The developed system will subsequently be further extended to include GPC-3.5 devices and, in principle, other connector types, as and when these are required by UK industry.

THE APPROACH

As with the earlier systems, the present system utilises an automatic network analyser (ANA) as the measuring instrument operating as a one-port vector reflectometer. Minimum assumptions are made about the performance of the ANA (i.e., only that the instrument gives linear responses) and this is achieved by writing external calibration and measurement algorithms to process the raw uncorrected vectors generated by the ANA for both the calibration and measurement items.

It was soon realised, however, that the specialised hardware developed for the top echelon connector types was not easily adapted to suit the type-N and GPC-3.5 connector types or, indeed, for other connector types to be addressed in the future. It was decided therefore to complement the existing specialised 'calculable' standards with a generalised approach to characterising standards whereby, in principle, any stable artefact could act as a calibration item for the reflectometer system.

The generalised approach is based on interpolating values for the calibration standards from frequency regions where the items can be measured satisfactorily. Specifically, by interpolating between a certified (traceable) value at DC and values obtained at RF (i.e., 50 MHz and above), the characteristics for the given artefact can be determined at the intermediate frequency region. Care must be taken, however, to select only devices whose characteristics are sufficiently well-behaved over this frequency region.

An example of data collected for a type-N dielectric-plugged open-circuit is shown in Figure 1. (Such an item could be used as a calibration standard for the new system.) This shows measurements, made from 50 MHz to 100 MHz in 5 MHz intervals, of the imaginary component of the complex voltage reflection coefficient. Note that the DC value of the imaginary component of the notional 'DC reflection coefficient' is zero, by definition (since both susceptance and reactance are zero at DC).

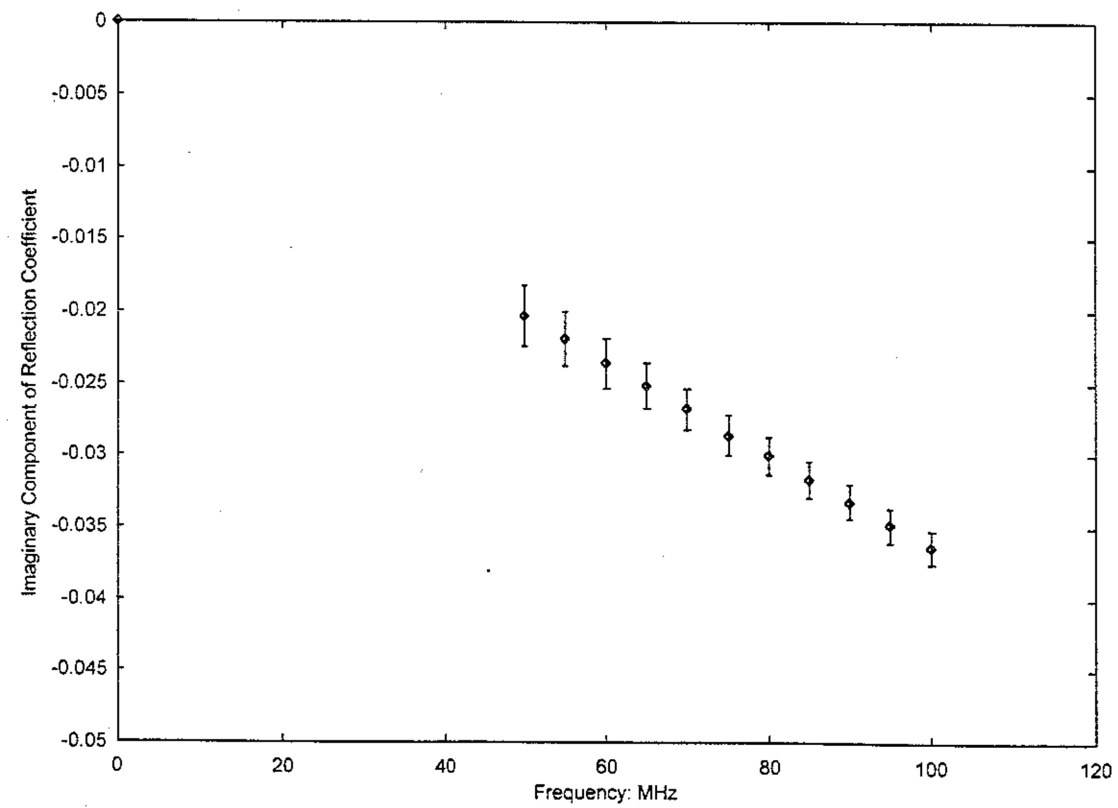

Figure 1: Graph showing typical measurement data to be used by the interpolation routines to predict performance for the calibration standards over the intermediate frequency region.

This new approach of characterising the calibration standards using interpolation routines will be combined with more conventional techniques (used on the earlier system [3]) to evaluate the size of other components to the overall uncertainty for the system.

REFLECTOMETER SIMULATOR

It was decided, at the start of the development programme, to implement a reflectometer simulator [5] to predict the system performance for any given three-standard calibration routine. By exploiting the invariance of the cross ratio of four complex numbers under the bilinear transform the true values of the reflection coefficients can be related to those of the theoretical values given to the calibration standards. Then, by expanding for small uncertainties, an expression relating the measurement uncertainty for a given termination to those of the calibration standards can be obtained [6,7]. By plotting the uncertainty over the complex plane of true values, uncertainty profiles are obtained indicating the measurement uncertainty due to a given calibration.

Figure 2 shows a typical uncertainty profile for a short-open-load calibration. We notice that the uncertainty is smallest along the real axis, indicating that this form of calibration is best used for terminations with small reactive components. This is generally the case at lower RF where the reflection coefficient degenerates to the real axis. It was therefore decided that the short-open-load calibration technique, would form the basis for the RF development programme.

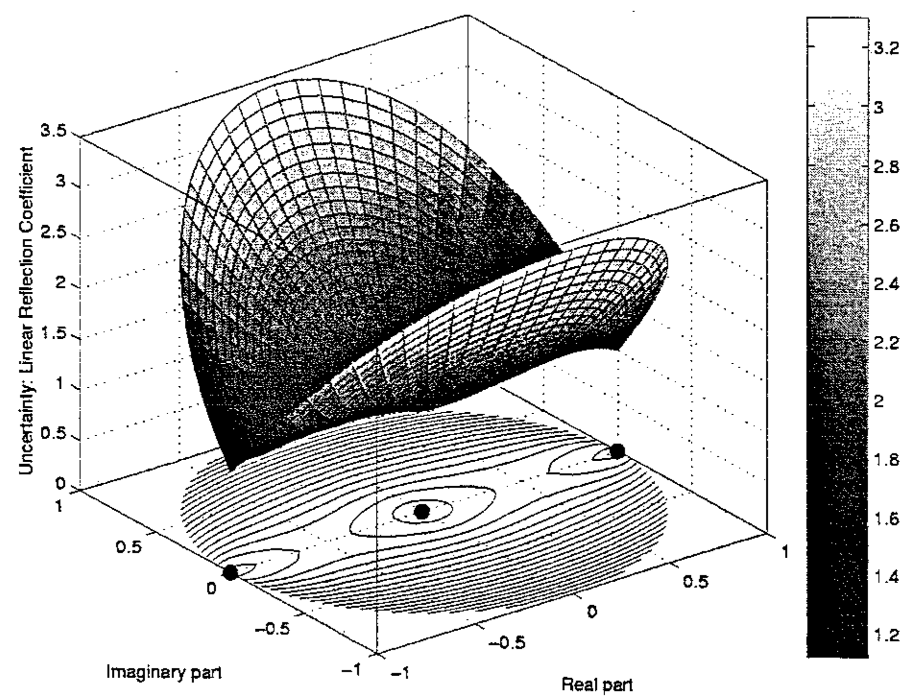

Figure 2: Uncertainty profile over the complex plane, predicted by the reflectometer simulator, for a network analyser calibrated using a short-circuit, an open-circuit and a near-matched load. All uncertainties are in milli-units.

ERROR STRUCTURE CONSIDERATIONS

An additional consideration with the use of the new interpolation approach to characterising the calibration standards is the need for a detailed re-examination of the contributions to the uncertainty of measurement for the system. Specifically, applying fitting algorithms simultaneously to the two components of the complex reflection parameter data will require an in-depth study of the error structure for the vector, two-component, data.

Such a study will be based around extending existing techniques, given in the literature [8], for evaluating uncertainty in measurement. Uncertainties for the input quantities to the measurement process will be represented in terms of covariance matrices, and these matrices will be propagated through the measurement model (i.e., the calibration and measurement algorithms) to give uncertainties in the measurement results also in terms of covariance matrices. Such an approach will take full account of any correlation between components of each complex vector and, indeed, also any correlation between the individual vectors themselves.

Finally, consideration will also be given to develop suitable methods for expressing the evaluated uncertainty of measurement in a concise, and easy to interpret, manner. This will enable customers for the measurement system to readily interpret the measurement results appropriately for their own application.

COMPUTING ENVIRONMENT

With such a radical new approach to this measurement problem, it was deemed appropriate also to up-date the computer hardware and software used to drive the system. It was decided to implement the software on a Pentium PC running under the Windows 95 operating system. Operator, and network analyser, interfaces with the computer will be developed using the Visual Basic programming language whereas the numerical algorithms (for the calibration routines and uncertainty calculations) will be implemented in Fortran accessible from Visual Basic via Dynamic Link Libraries (DLLs).

PERFORMANCE PREDICTIONS

The performance of the completed system can be summarised in terms of the quality of the measurements (i.e., the size of the uncertainties) and the cost to the customer for such a calibration service.

Clearly, from the uncertainty profiles generated by the reflectometer simulator, it will be difficult to give a single figure to represent the likely uncertainty of measurement for the system for all measured reflection coefficients. However, the uncertainties for customer artefacts will not be smaller than the uncertainty inherent in the calibration standards which, will themselves be closely related to the uncertainties in the measurement data used by the interpolation routines. Existing RF measurement data currently being utilised to characterise the calibration standards includes standard uncertainties of the order of 0.0013 in terms of magnitude reflection coefficient values. This figure therefore could be used as a predicted performance indicator for the completed system.

Performance in terms of the customer cost of the measurements is also likely to be improved significantly. This will be achieved by using computer-intensive (rather than operator-intensive) methods to reduce the time taken to perform the measurements for the customer calibrations. Where possible, and where appropriate, uncertainty contributions will be assessed using prior knowledge of the system performance.

SUMMARY

This paper has reviewed a programme of work, currently being undertaken by the UK's National Physical Laboratory, to extend traceability to national standards, for complex reflection parameters at lower RF. The programme of work includes implementing a new, generalised, approach based on using efficient interpolating routines to characterise the calibration standards. The paper has also discussed some of the specialised aspects of this measurement problem, e.g., the treatment of the intricate, and correlated, error structure inherent in applying such a technique. Finally, predictions concerning the likely performance of the completed system have been given.

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