

THE UK NATIONAL STANDARDS OF RF AND MICROWAVE ATTENUATION – A REVIEW

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Abstract

The National Physical Laboratory has, for over 30 years, developed and maintained the UK's primary RF and Microwave attenuation facility. Over this time there have been dramatic changes in the requirements for RF and Microwave Standards. This paper summarises the current facility and discusses the different measurement techniques that have been employed.

Introduction

Attenuation, together with Power, Impedance and Noise, is one of the key measurement quantities required for underpinning almost every aspect of precise microwave metrology. It is over twenty years since the capability of the National Attenuation facility was last fully described [1] and considerable development has taken place since that report. The most noticeable change in this time has been the shift from waveguide to wide band coaxial measurements.

The Definition of Attenuation and the NPL Measurement Philosophy

Consider a source and a load directly connected and then connected via a 2-port network, the attenuation of the 2-port network is defined as the ratio of powers absorbed by the load in the two cases, when both the source and load are matched to the transmission line impedance.

Almost uniquely amongst primary standard laboratories, the NPL systems are designed for single frequency measurements with the measurement ports being impedance matched to the line impedance. This means that attenuation is measured directly, in terms of the definition, and almost the only calculation required being the estimation of uncertainties. While this approach increases the measurement time it offers the lowest possible uncertainty.

Measurement Techniques

There are many methods of measuring attenuation [2], the principal techniques that are used to offer the UK National Measurement facility are detailed below.

Power Ratio. Power from an impedance matched source is passed either directly into, or through, the device under test, into an impedance matched power sensor. The change of indicated power is the attenuation of the device under test. Prior to measurement the detector is assessed for linearity [3]. Our systems use thermistor sensors over a very limited range of about 6 dB, with measurement uncertainties of $\pm 0.001 - 0.002$ dB. The principle advantage of this method is that since only DC cables are moved during

the measurement it is well suited for measuring devices with complicated connector geometries.

AF Series Substitution. This is the simplest 'frequency conversion' system to implement and the most accurate. Power from a stable RF impedance matched source is passed either directly or through the device under test via an impedance matching element into a mixer. There the signal is mixed with that from a local oscillator and converted to the operating frequency of the reference device. In our systems the reference is an Inductive Voltage Divider operating at 10 or 50 kHz. The amplified signal is then detected, either by an AC voltmeter, AC to DC converter or Phase Sensitive Detector. On inserting the unknown attenuation to be measured into the circuit, the reference device is adjusted so that the detector indication is restored to its original value. The measurement range of the systems may exceed 100 dB (depending on frequency) with uncertainties as low as ± 0.004 dB for a 60 dB measurement.

Parallel Substitution. Parallel substitution systems are generally preferred when the reference attenuator has an appreciable insertion loss which would severely limit the dynamic range of any series connected system, for example the NPL-developed waveguide beyond cut off attenuator [4]. Parallel systems normally have two separate measurement channels each incorporating a frequency and amplitude stable RF or microwave source, isolation and impedance matching components. A reference attenuator is incorporated into one channel and the unknown attenuator in the other. If the attenuators are operated at different frequencies then one channel will additionally incorporate a frequency conversion element. The output from the channels are alternately switched into a common receiver (or detector). With the device under test (DUT) at the 'datum' setting the calibrated attenuator is adjusted for equality in signals from the two channels, the reference attenuator is then reset to balance with the DUT at the 'attenuation' setting. The DUT attenuation is the difference in the two settings of the reference attenuator.

Voltage Ratio. In some respects this can be considered as an extension of the AF substitution method, and most of the NPL systems can be used in either Voltage Ratio or series substitution modes. In these systems the RF or microwave signal is passed through a gauge block attenuator and the device under test before being down converted to a low frequency. In our systems this lower frequency is either 10 kHz or 50 kHz. It is measured by a commercial AC digital voltmeter, previously calibrated for *voltage steps* using a stable low frequency source and an Inductive Voltage Divider, the latter providing traceability. Typically the

voltmeter is characterised over a range corresponding to 23 dB.

This technique has the advantages of being easy to automate and has a wide dynamic range. It requires a stable detector and, as a large number of individual components are required, screening and signal isolation becomes problematic for very high attenuation measurements. Ultimately the dynamic range is limited by isolation / leakage and mixer noise constraints, but a range of over 130 dB can be obtained at 30 MHz.

Modulated Sub-Carrier. In its simplest form this type of system can be likened to an AC bridge. One arm of the bridge comprises a pair of inductive voltage dividers fed from an audio frequency source (traditionally 1 kHz). The voltage in this arm is nulled against a low frequency signal output from a balanced mixer. The mixer is fed with two microwave signals, both originating from a common source. One signal is unmodulated, but passes through a phase shifter, the second which passes through the device under test is amplitude modulated (usually with a p-i-n modulator) with a signal derived from the audio generator which 'feeds' the other arm of the bridge.

This type of system has the considerable advantage of only requiring a single RF source and so is popular at short millimetre wavelengths where sources are expensive and difficult to frequency lock.

Receiver Systems. This can be considered to be a variation on the Voltage Ratio technique, where the AF amplifier and AC voltmeter are replaced by an RF receiver operating in the MHz region. Our receiver systems were developed to replace the aging modulated sub carrier systems covering 50 to 110 GHz. A commercial measurement receiver is used for both RF amplification and detection. The receiver is operated at a fixed frequency of 10.7 MHz and harmonic mixers are used to down convert the microwave signal [5]. Traceability for the attenuation measurement is provided by calibrating the receiver with coaxial switched attenuators measured on a Voltage Ratio system. Typical measurement uncertainties are ± 0.02 dB for a 50 dB measurement at 60 GHz and ± 0.1 dB for a 30 dB measurement at 95 GHz, comparable with the modulated sub-carrier systems.

Mixers

The majority of the measurement systems employ a frequency conversion process, and the performance of the mixer is vital to the correct measurement of attenuation. We have developed dedicated systems to evaluate the performance of the mixers. Uncertainties of the order of $\pm 0.0001 / 10$ dB can be obtained by measuring highly repeatable attenuators at differing power levels [3].

Confidence in the Systems

Confidence in the correct operation of the various systems has been established through the continual measurement of 'check standard attenuators'. These

devices have a long calibration history and are measured each time a system is prepared for use. NPL also has a long history of participation in National and International attenuation comparisons.

Limits and Challenges for the Future

The current generation of standards facilities have uncertainties which either match or slightly exceed the repeatability of the best transfer devices and commercial receivers. Any improvements in RF connectors, attenuators and receiver technology will require considerable investment in the primary facilities before such improvements can be exploited.

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References

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