Switched-Coupler High Power Measurement Service*

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Abstract

Beginning in 1999, NIST will be offering power measurement services at power levels from 1 W to 1 kW over the frequency range from 2 MHz to 1 GHz. This new service makes use of a switched-coupler system, and is based on a measurement method described by Kenneth Bramall in 1971. The basic theory of operation and an overview of the system design will be discussed.

NIST is establishing a new measurement service based on a technique originally described by Kenneth Bramall in 1971 [1]. Until now, direct traceability to NIST for high power RF measurements above 500 MHz has not been possible. The new service is being developed in order to improve this situation, and effectively extends the capability of the existing low power microcalorimeter systems by sequentially transferring the calibration down a chain of cascaded directional couplers as shown in Figure 1.

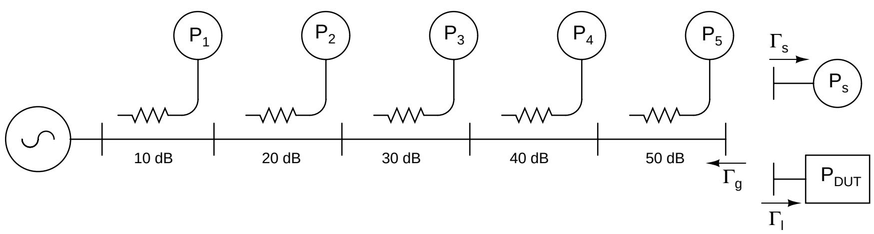

Figure 1: Cascaded Coupler Chain

In the NIST system, the coupling ratios are 10 dB apart to correspond with the dynamic range over which the bolometric sensors provide the lowest operating uncertainty (1 mW to 10 mW). The coupler chain is calibrated by connecting a calibrated bolometer mount to the output port of the coupler chain and adjusting the power until the bolometer reads 10 mW. At this point we take the power ratio between the calibrated mount and the mount on the 10 dB coupler sidearm. The calibrated mount is then removed and replaced with the desired high power load. As long as the system is linear, the ratio of the output power level and the power level on the 10 dB sidearm will remain constant, so

$$\frac{P_s}{P_1} = \frac{P_{l1}}{P_{1x}}, \tag{1}$$

where:

P_s is the power reading on the calibrated bolometer mount,

P_1 is the 10 dB sidearm power reading,

P_{l1} is the power delivered to the high power load,

P_{1x} is the 10 dB sidearm power when P_{1l} is delivered to the load.

Solving this for the output power gives

$$P_{l1} = \frac{P_{1x}}{P_1} P_s. \tag{2}$$

Now if the power is increased until the 10 dB coupler's sidearm power sensor reads 10 mW, the power at the sidearm of the 20 dB coupler should read 1 mW. At this point, the ratio between the output power and the 20 dB coupler sidearm power can be formed, so

$$\frac{P_{l1}}{P_2} = \frac{P_{l2}}{P_{2x}}. \tag{3}$$

Rearranging and substituting equation (2) gives

$$P_{l2} = \frac{P_{2x}}{P_2} \frac{P_{1x}}{P_1} P_s, \tag{4}$$

where:

P_{1x} is the 10 dB coupler sidearm power when P_2 is read,

P_2 is the 20 dB coupler sidearm power when the 10 dB sidearm reads P_{1x},

P_{l2} is the power delivered to the high power load,

P_{2x} is the 20 dB coupler sidearm power when P_{l2} is delivered to the load.

This assumes that both the calibrated bolometer and the high power load are perfectly matched to the coupler chain. In general this may not be true, and a mismatch correction would need to be added to this derivation. Continuing the process until we reach the last coupler in the chain and including the effects of impedance mismatch between the coupler chain, the calibrated bolometer, and the final load, results in

$$P_{l5} = \frac{P_{5x}}{P_5} \frac{P_{4x}}{P_4} \frac{P_{3x}}{P_3} \frac{P_{2x}}{P_2} \frac{P_{1x}}{P_1} P_s \frac{1 - |\Gamma_g|^2}{1 - |\Gamma_s|^2} \left| \frac{1 - \Gamma_g \Gamma_s}{1 - \Gamma_g \Gamma_l} \right|^2. \tag{5}$$

The reflection coefficient terms are defined as:

Γ_g The equivalent generator reflection coefficient of the coupler chain as a source,

Γ_s The reflection coefficient of the calibrated bolometer,

Γ_l The reflection coefficient of the final load.

As the calibration cascades to subsequent couplers in the chain, the powers on the sidearms of any preceding couplers continue to rise. It is therefore necessary to protect the detectors on these sidearms from overloading. We simply remove the coupler from the chain once the power calibration has been passed on to the next higher coupler. As long as the load attached to the coupler chain during the first step of the calibration is not changed, this can be done without modifying equation (5), because the equivalent generator reflection coefficient of the coupler is independent of anything preceding the coupler. As the equation

$$\Gamma_g = S_{22} - \frac{S_{21} S_{32}}{S_{31}} \tag{6}$$

shows, Γ_g only depends on the S-parameters of the coupler[2, pages 43–44]. Replacing a coupler with the signal generator has no effect as long as the calibration is transferred to the next coupler in the chain before removing it.

Building a system based on these principles requires relatively little hardware. That is part of the reason that we chose this approach. Outside of the couplers needed to create the coupler chain, only a high power signal source and some means for reading the DC substituted power from the bolometer mounts are needed.

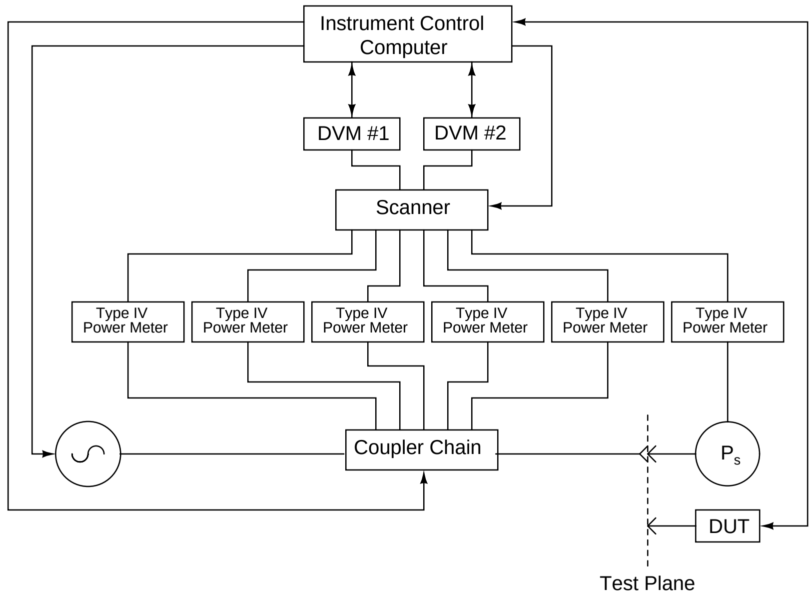

Figure 2: Measurement System Block Diagram

Some of this inherent simplicity was sacrificed in the construction of the NIST system, in order to provide computer automation and control. Figure 2 shows a block diagram of the overall system. The use of NIST Type IV power meters and commercial digital voltmeters (DVM's) forms the mechanism for obtaining power readings from the bolometer mounts. A commercial scanner, or computer controlled switch box, allows us to use just two DVM's for measuring the bias voltage on the Type IV power meters.

Computer automation of the coupler chain was the more interesting challenge. In order to accomplish this, the 10 dB, 20 dB, 30 dB, and 40 dB couplers in the chain were connected in a switching matrix as diagramed in Figure 3.

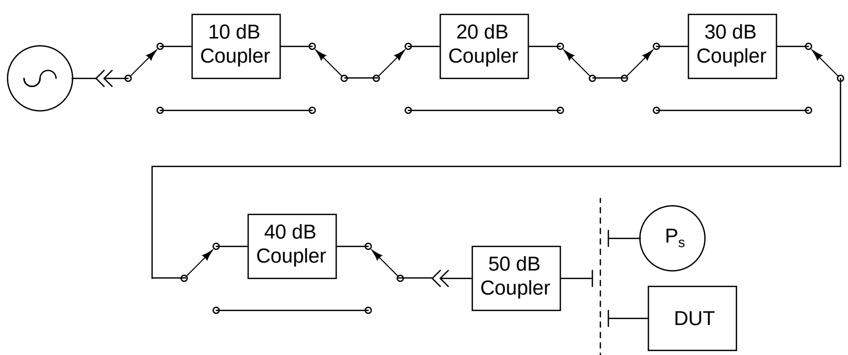

Figure 3: Switched-Coupler Chain

The 50 dB coupler is not included in the computer-controlled matrix, and must be manually connected to the output port of the 40 dB coupler for the initial calibration of the coupler chain. It is directly connected to the generator when power levels greater than 100 W are needed. This was necessary since the cumulative insertion loss of the switches in the coupler chain is approximately 2 dB. Bypassing the switching for the final high power stage keeps the power requirements of the signal source down and reduces RF heating of the switching matrix. Minimization of the heat load on the system is important since thermal expansion in the couplers can cause a shift in the coupling ratios. Water cooling of the mounting plate for the switches and all of the couplers gives added stability.

With this arrangement, our tests show the uncertainty due to coupler nonlinearity to be on the order of 0.05% per coupler. In fact, the uncertainty added by each coupling stage is only on the order of 0.16% resulting in a total Type B uncertainty around 0.8%. With the Type A uncertainty somewhere around 0.5%, and a coverage factor of 2, the expanded uncertainty is approximately 1.9%, a result close to the original design goal of 2%. The new service should be available early in 1999.

References

[1] Kenneth E. Bramall. Accurate microwave high power measurements using a cascaded coupler method. *Journal of Research of the National Bureau of Standards*, 75C, Nos. 3 and 4:185 – 192, July-December 1971.

[2] Glenn F. Engen. *Microwave Circuit Theory and Foundations of Microwave Metrology.* IEEE Electrical Measurement Series 9. Peter Peregrinus Ltd., London, United Kingdom, 1992.