MAURY MICROWAVE
CORPORATION

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THEORY OF NOISE MEASUREMENT

Introduction

Noise is a natural phenomenon that affects most microwave and RF systems. Because noise masks desired signals, it is important to understand and minimize its effects on the performance of microwave and RF devices. Although there are several types of noise, **thermal noise** is an important consideration for microwave designers because it greatly affects the linear microwave and RF systems they work with. Thermal noise is the focus of this application note.

Noise figure (a measure of the noise generated by two-port devices) can easily be determined by using commercial noise figure meters, but the measurements they provide are limited to **SIMPLE NOISE FIGURE**. Simple noise figure is the noise figure of a device terminated with a particular value of source impedance. The problem with this is that the noise figure of a given device usually varies as the source reflection varies.

To minimize the effects of device noise figure, the relationship between noise figure and source impedance (or source reflection coefficient) must be known. The noise figure depends on the **COMPLETE NOISE PARAMETERS** as shown below.

Equation 1:

$$F = F_{min} + \frac{4\,R_n}{Z_o}\;\frac{|\Gamma_s - \Gamma_{opt}|^2}{|1+\Gamma_{opt}|^2(1-|\Gamma_s|^2)}$$

where

F = Noise figure (linear ratio)

F_{min} = Minimum noise figure (linear ratio)

Γ_{opt} = Optimum complex reflection coefficient

R_n = Noise resistance

Γ_s = Complex source reflection coefficient

Maury Microwave's noise characterization software (MT993A) is designed to find the complete set of noise parameters consisting of F_{min}, Γ_{opt}, and R_n. Since Γ_{opt} is complex, this makes a total of four scalar parameters. Γ_{opt} is the source reflection coefficient which corresponds to F_{min}. R_n is a scale factor which shows how fast F changes with Γ_s. (The software actually displays r_n, which is R_n normalized to 50 ohms.)

To find F_{min}, Γ_{opt}, and R_n, the simple noise figure must be measured at a variety of source impedances. In principle, since four scalar variables are to be found, only four measurements are required. In practice, however, it is much more effective to measure more points, and use a "least means square's" mathematical technique to extract the parameters. The MT993A software requires a minimum of six positions, but more may be used.

Noise Characterization

Noise characterization also requires the parameters of the Device-Under-Test (**DUT**) to be separated from the parameters of the measuring system to which the DUT is connected. To do this, the system must be calibrated to learn the system parameters. The noise contribution of the system (often called the second stage since it follows the DUT) will vary with its source impedance according to equation 1.

Therefore, the complete noise and gain parameters of the system must be known to determine the system noise contribution when a particular DUT is connected.

After the system is calibrated, noise characterization of a DUT can be done. This consists of measuring the total noise figure, F_{total}, with several different source impedances. The noise figure of the DUT for each position, F_{dut}, is then given from the Friis cascade equation as shown in equation 2 (below). G_{dut} is the available gain of the DUT as resolved from the DUT S-parameters and the source reflection coefficient.

Equation 2:

$$F_{dut} = F_{total} - \frac{F_{sys} - 1}{G_{dut}}$$

One practical consideration shown by Equation 2 is that if F_{sys} is high and G_{dut} is low, then F_{dut} will be a small difference between large numbers. This would make it very sensitive to errors. Therefore, if DUTs with low noise figure values are to be measured, it is important to keep F_{sys} as low as practical. That is why a load tuner is important when the DUT has a high output reflection coefficient. The effect of losses in the tuners, bias tees, and the fixture is eliminated in the MT993A software. Since the losses are resistive in nature, they add noise in proportion to the ambient temperature in kelvins (absolute temperature scale). During the setup, the ambient temperature is entered in degrees Celsius and is later read by the program during a calibration. Conversion to kelvins is done automatically.

Another practical consideration is that the reflection coefficient of the noise source usually changes when switched between the hot and cold states. This software takes this rigorously into account by using the noise power function given in Equation 3. The noise power equations allow the source impedance to be independent for each power measurement, and therefore eliminate this traditional source of error.

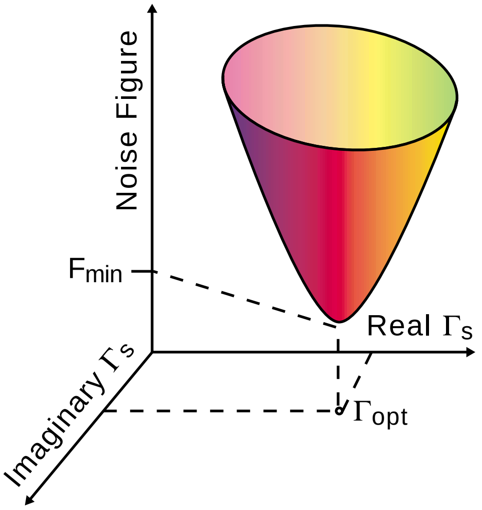
Equation 3:

$$P = kB\{[t_{ns} + t_0(F_1 - 1)]G_{al} + t_0(F_2 - 1)\}G_{t2}$$

where

P = The total measured noise power.
k = Boltzmann's constant.
B = The system bandwidth.
t_o = 290 kelvins.
t_{ns} = Temperature of the noise source in kelvins.
F_1 = The DUT noise figure (function of source impedance).
F_2 = The system noise figure (a function of the DUT output impedance).
G_{a1} = The DUT's available gain (a function of source impedance).
G_{t2} = System transducer gain (function of DUT output impedance).

Figure 1: Noise Characterization



- Determines the Four Noise Parameters
  - Minimum Noise Figure
  - Real Part (Magnitude of Optimum Z, Y, or Γ
  - Imaginary Part (Angle) of Optimum Z, Y, or Γ
  - Equivalent Noise Resistance

$$F = F_{min} + R_n/G_s\,|\,Y_s - Y_{opt}\,|$$

$$F = F_{min} + 4r_n \frac{|\,\Gamma_s - \Gamma_{opt}\,|^2}{|\,1 + \Gamma_{opt}\,|^2\,(1 - |\Gamma_s|^2)}$$

Figure 2: Noise Characterization Block Diagram