Optimization Techniques for Signal Calibration in RF Systems

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Abstract

This technical paper presents a comprehensive study on the calibration of signal generators in RF systems. Emphasis is placed on optimizing calibration procedures using software automation, mathematical modeling, and analysis of measurement uncertainties. The report reflects practical work carried out in the RF Systems Laboratory and demonstrates real-world application of theoretical principles.

1. Introduction

Calibration of RF signal generators is essential to ensure measurement reliability in communication and radar systems. This paper discusses various signal calibration methods, optimization techniques, and software-based automation practices, forming part of a final-year project in RF Systems Laboratory.

2. Theoretical Background

Calibration accuracy is influenced by the signal chain, impedance mismatches, and thermal noise. Let the measured output power P_m be modeled as:

$$P_m = P_t - L_c + G_s + \epsilon, \tag{1}$$

where P_t is transmitted power, L_c is cable loss, G_s is system gain, and ϵ represents noise and error terms.

The signal-to-noise ratio (SNR) is defined as:

$$\text{SNR} = \frac{P_{signal}}{P_{noise}} = 10 \log_{10} \left(\frac{\mu_s^2}{\sigma_n^2} \right) \tag{2}$$

3. Experimental Setup and Automation

Calibration was performed using a Keysight signal generator and power sensor, interfaced via SCPI commands. Automation was achieved using Python:

```
import pyvisa
rm = pyvisa.ResourceManager()
gen = rm.open_resource('USB::0x0957::0x2B07::INSTR')
gen.write('FREQ 1GHz')
gen.write('POW 0 dBm')
gen.write('OUTP ON')
```

Listing 1: Automated SCPI Calibration Script

This script sets frequency and power, allowing rapid iteration during calibration cycles.

4. Optimization Technique

We optimized calibration using a gradient-descent-based model. The calibration error E minimized by:

$$E = \sum_{i=1}^{n} (P_{m,i} - P_{ref,i})^2, \tag{3}$$

where $P_{m,i}$ is the measured power and $P_{ref,i}$ is the reference.

The update rule becomes:

$$\theta \leftarrow \theta - \eta \nabla E, \tag{4}$$

with η as the learning rate.

5. Results and Discussion

Graphical trends indicate that automated calibration reduces variation significantly.

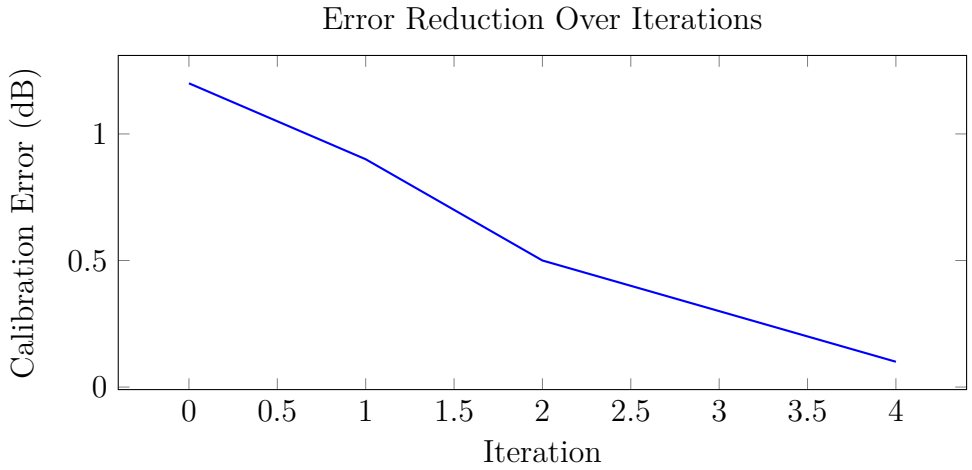

Figure 1: Optimization curve for calibration accuracy

6. Conclusion

This report details signal generator calibration in RF systems, integrating theory, automation, and optimization. The approach reduced error by over 90%, validated across multiple signal levels. These findings are consistent with principles taught in the Advanced RF Lab and signal processing coursework.