Design of a Low Cost Vector Network Analyser

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This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of the author's knowledge, it contains no material previously published or written by another person, except where due reference is made in the text.

Josh Johnson

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Abstract

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Glossary

COTS - Commercial Off-The-Shelf

DUT - Device Under Test. With reference to a VNA, the device connected to VNA's ports being measured.

ISM - Industrial Scientific Medical

PCB - Printed Circuit Board.

PCBA - Printed Circuit Board Assembly.

RF - Radio Frequency.

S-parameters - Scattering Parameters. Elements of a scattering matrix which describe the behaviour of linear electrical networks.

S_{MN} - S-paramater describing the relationship between ports M and N in an electrical system. Common s-parameters are S_{11} which represents the reflected power incident on port one, and S_{21}, which represents the gain of a DUT between ports 2 and 1.

VNA - Vector Network Analyser. Electronic test and measurement instrument which measures s-parameters of electrical networks.

1 Introduction

1.1 Background

A Vector Network Analyser is a radio frequency test and measurement instrument which measures the s-parameters of a device under test. VNAs are used extensively in the design of RF devices as they allow the gain and phase response of RF components such as antennas, filters, amplifiers, and mixers to be characterised over the their operating frequencies, which is crucial for successful design and manufacturing of RF devices.

Given that VNAs are intricate pieces of engineering and are sold in low volume to engineering firms, their price represents this high level of performance and niche market, with VNAs typically ranging from tens of thousands to millions of dollars. Given this pricing is prohibitively expensive for teaching in educational institutions and far more than most electronics hobbyists have to spend, this limits the scope of projects and learning experiences which can be accessed outside of professional engineering environments.

1.2 Aim

The aim of this thesis is design and build a VNA which is significantly cheaper than the commercial offerings, as this will lower the barrier of entry to RF engineering and enable more hobbyists and educators to build or purchase a VNA which fits their needs. Whilst this VNA will not have the frequency and dynamic range, accuracy, UI, or speed of a commercial VNA, it will still be able to provide indicative measurements which are sufficiently accurate for home or educational use, along with providing an interesting learning exercise in the areas of radio frequency and embedded engineering.

1.3 Overview

Chapter 2 - Requirements, Constraints, and Specifications details the requirements and constraints of the VNA, and will enable the design scope and device specifications to be determined.

Chapter 3 - Design covers design of the VNA. Resulting from theory of operation and research of other low cost VNAs, the high level architecture along with detailed design was undergone and though testing candidate components were validated and selected.

Chapter 4 - Implementation and Assembly details printed circuit board layout along with assembly of the PCB. Furthermore, mechanical design of an enclosure along with firmware and software implementation is discussed.

Chapter 5 - Calibration and Testing covers calibration of the VNA, comparison of measurements to commercial VNAs, along with a discussion of the results and proposes future avenues for improvement of the VNAs.

2 Requirements, Constraints and Specifications

2.1 Requirements

At a high level, to be useful the VNA must be able to measure the gain and phase response of a DUT over a given frequency range, and have industry standard features including plotting and file handling which would allow it to replace a commercial VNA in certain situations.

2.2 Constraints

There are an number of constraints acting upon the project which will constrain the design and function of the device. The desire of the project is to build the most performant VNA that can be designed within the below constraints.

- **Cost -** as outlined in the introduction, the major goal of this project is to build a VNA at a significantly lower price than commercial offerings. As such, there will be a large number of trade-offs required to bring the price down, and as a result the accuracy, dynamic range, bandwidth, and numerous other performance characteristics will be traded off in an attempt to reach the desired price point.
- **Component Selection -** in an attempt to decrease the cost of low volume manufacture, along with the engineering time and resources required, all components in the design must be commercial off-the-shelf, as this will reduce the cost and time required during development and manufacturing.
- **Resources -** due to a number of factors including skill level of the designer, limited time frame, monetary resources available, and the lack to access to test gear and industry specific tools such as Keysight's Advanced Design System and CST Microwave Studio, the complexity of the project needs to be limited to ensure that a minimum viable product is able to be produced within the given time frame.

2.3 Specifications

Taking the above outlined requirements and constraints into consideration, specifications for the VNA can be determined. Given that there are no hard numbers specified, and that the goal for the VNA is one which is as performant and feature complete as possible given the constraints, many of the exact specifications of the VNA will be determined during the design process. This allows cost to be a key factor during the architecture design and components selection, as small decreases in performance are able to be made to save significant cost, which would not be possible if the system requirements were highly specified. In saying this, there are some key minimum specifications and high level architectural choices which will help narrow the design scope:

- **Bandwidth -** the VNA should have at least 1GHz of bandwidth, as this will allow both the 433MHz and 915 MHz ISM bands to be within the frequency span, and as such enable testing of components which can be utilised without a amateur radio licence.

- **Interface -** controlling the VNA from a computer will not only remove the need for a display on device which will lower cost, but also significantly reduce the embedded compute power required whilst allowing for use of tools such as Python's NumPy and scikit-rf for data processing and VNA calibration, along with Qt and Matplotlib to provide a user interface with a much lower time investment than developing the required functionality from scratch on embedded hardware.
- **Licencing -** the VNA should be able to be designed, manufactured, programmed, and operated using solely free tools, and where practicable open source tools. This ensures the VNA is able to be operated without any expenses other than the cost of hardware, whilst also ensuring that the hardware, firmware, and software is able to be viewed and modified by anyone without having to purchase proprietary tools, which may be prohibitively expensive and become obsolete, preventing access to the source files used during design.

3 Design

4 Implementation and Assembly

5 Calibration and Testing

6 References

7 Appendix