ECE 451

Automated Microwave Measurements Laboratory

Experiment 01 - RF Power detection

1 Introduction

This (and the next few) laboratory experiment explores the beginnings of microwave measurements, those performed in the mid twentieth century. The purpose of using these now-obsolete methods is to teach the student the fundamentals that are otherwise invisible to the user of the modern measurement systems.

This experiment has two components. The first part consists of generating a response curve of a basic microwave measurement tool: the square-law detector. In the process of generating this curve, the student comes across a few crucial concepts. The first is that an engineer must know the exact conditions under which a measurement tool provides reliable data. As will be discussed, a square-law detector is only useful over a specific range of input power levels and a specific range of frequencies. Second, the material properties of a device often motivate why that device is used for a specific task. For example, a crystal detector rectifies a radio signal, converting it from alternating current to a pulsing direct current.

Experiment design is undoubtedly the most difficult aspect of an engineering project. However, after an engineer successfully establishes an experimental procedure, he or she often has to run this experiment under many different conditions or many different times. Often, the economy of scale in doing so is such that it is very worthwhile for the engineer to automate the measurement. Automation not only speeds up the measurement process, but it also can significantly decrease the likelihood of operators' error in a measurement. The second part of this lab is to use LabVIEW to automate your measurements of the crystal detector in the first part.

LabVIEW is a graphical language based on C that is incredibly useful for controlling external hardware. Lab-VIEW has all of the same programming constructs (conditionals, loops, variables, etc.) that you would use in any other languages. Often times, unless you work as an automation software engineers, these automation files should be available to you. However, writing your own program to automate a simple task like one in this lab would give you insights into how to go and what to expect about building programs automating more complicated apparatuses that you might come across in your career.

The LabVIEW tutorial with step-by-step procedure is provided separately. If you are brand new to LabVIEW, it is very important that you follow the directions as closely as possible in order for you to learn some of the nuances of the language.

You will use ADS (Advanced Design System) to plot the data obtained by automation process to get to know about ADS since it is intensively used not only later in this course but in your career as an RF engineer as well.

The background section of this lab provides you information on why crystal detectors are used and how they function. Do not be concerned with having a full understanding of this section. They are merely included to be used as a reference for when questions arise during laboratory work and to help you make conclusions when you write your report.

Useful links

1. LabVIEW tutorial videos on NI `http://www.ni.com/academic/students/learn-labview/`

2. LabVIEW Basics `http://www.ni.com/white-paper/7466/en/`

3. LabVIEW VISA Overview `http://www.ni.com/support/visa/vintro.pdf`

2 Background

Square-law detectors

All experimental measurements made in the microwave region depend upon the ability to detect the presence of RF power. By far, the bulk of these measurements are made by two common detection systems, "square-law

detectors" and heterodyne systems. The latter are considered to be linear detectors since the useable output signal is proportional to the electric field, or RF voltage, applied to this detector. Our present concern is with the square-law detectors. These devices find the widest use because of their extreme simplicity of instrumentation.

The square-law devices used for the detection of low-level RF power include the crystal diodes and thermally sensitive devices such as bolometers, barretters and thermistors. They derive their name from the fact that the output, a voltage or a current, is approximately proportional to the square of the input RF voltage or current. Thus, this output is proportional to the applied input power.

Figure 1 shows a typical response of an RF detector in which the square-law region is clearly indicated.
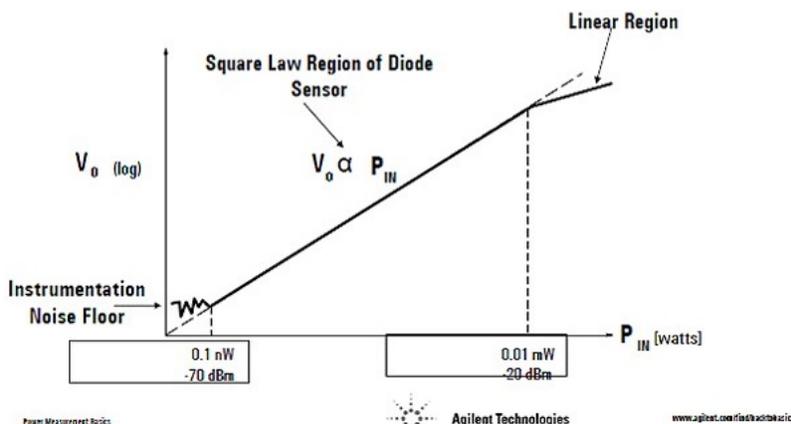

Figure 1: Typical characteristic curve of an RF detector. Image courtesy of Agilent Technologies

Although barretters and thermisters are useful in the absolute measurement of power, for most laboratory measurements it is sufficient to determine the relative power or field strength levels. These relative power measurements may be made on unmodulated signals giving a direct current or voltage from the detector. For the utmost sensitivity, the detector should be followed by some signal amplification before the output is presented on an indicator. The problems associated with stable, high gain DC amplifiers can be avoided by using an RF source that is modulated at an audio frequency. The resultant detected, low-level audio signal may be easily amplified in a narrow band, high gain amplifier. As indicated in Figure 2, a crystal detector can be used to detect very small signals by the use of a low-noise amplifier following its low-pass output.
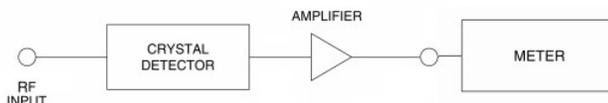

Figure 2: Simplified schematic for RF power detection

The detector must be able to follow the modulation envelope of the RF signal to obtain a useable audio output signal. An audio modulation frequency of 1,000 Hz is a good compromise frequency. It is sufficiently high that the selective circuits in the amplifier can reject ripple voltages from the power supply, and low enough to be compatible with time constants of the barretters and crystals. Thermistors, however, have a time constant of approximately 0.1 second and would require a considerably lower frequency of modulation.

The range of power levels that can be detected or accurately measured is limited at higher power levels by the deviation of the device from the square law characteristic and at the very low power levels by the noise produced by the detector itself and the following amplifying system as depicted in Figure 1.

3   Pre-lab

1. Explain how representing input power and output voltage in log scale might benefit the representation of square-law region? **Hint:** look at Figure 1 and think of the mathematical function relates them, also, look at question 2 below.

2. In the scenario illustrated in Figure 2, if the gain of our detector (i.e. the gain of the amplifier before the output terminal) was made 4 times larger, how would the slope of its output (in log scale) (see Figure 1) change (if at all)?

4 Equipment

- HP Microwave Source (8350 Sweep-Oscillator).
- HP Voltmeter (3457A).
- Keysight 8474B Crystal Detectors.
- N-type, BNC cables.
- Software: National Instruments LabVIEW, Keysight ADS.

5 Procedure

In this lab, you will measure the response of RF detectors to identify some of their characteristics. Characteristics of these RF detectors are important to be identified because we will need to use them to do future measurements. Not knowing their limitations as well as designed operating conditions might lead to malfunctions of them during a measurement setup and hence incorrect collected data.

1. Arrange the lab equipment as shown in Figure 3. The crystal detector can be directly connected to the microwave source to minimize the number of cables you need and eliminating the N-type cable. On some sources, the RF output is on the back of the device (make sure you connect to the one labeled RF, not AUX). Obtain data to plot a curve of RF (600MHz) power -50dBm to 15dBm in 5dBm steps. Plot the data with the RF power (in dBm) on the linear x-axis and the DC voltage (in millivolts) on the y-axis (logarithmic scale).
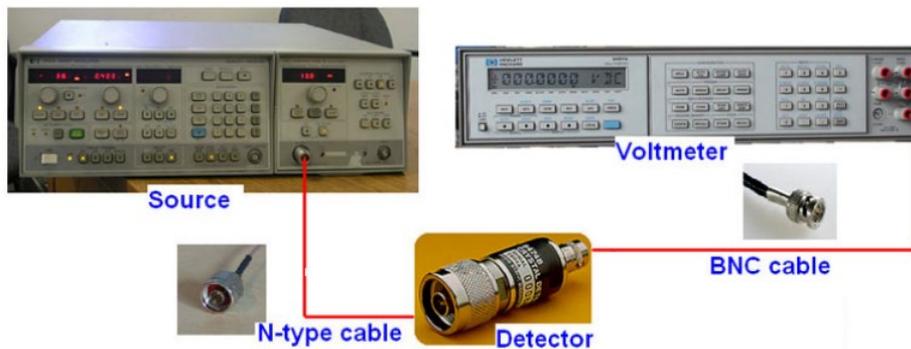

Figure 3: RF power measurement setup

2. From your curve of RF power into the detector vs. DC voltage out of the detector, determine the "square-law" range of your detector (it is recommended that you would perform a best-line-fitting on the data to show its linearity)[1]. Figure 4 shows an example. What is the measured slope of the detector in the square-law region? How does the measured curve compared with what you would expect from a detector (discuss about different ranges of the input power: too low, too high, neither low nor high power regions)? How is it compared to the datasheet [1]?

3. The next part of this lab is to automate the process you just went through. Figure 5 illustrates the equipments set up. They will communicate with each other via GPIB connection.

Before you dive in and create your LabVIEW project, you should read this first. In general, no files should not be saved on C:\, instead, they should be saved on U:\ so that your files are still available to you regardless

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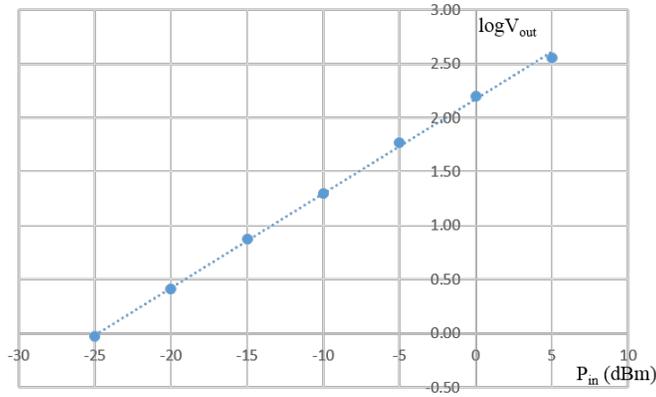[1]Here is a quick way to do it using Excel.

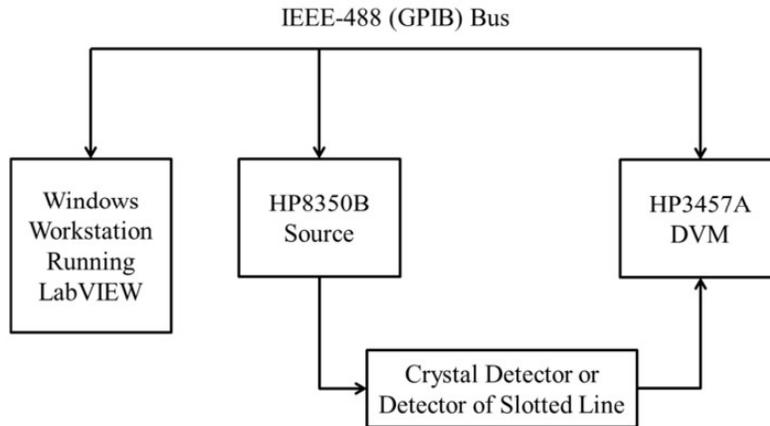Figure 4: An example of best line-fit data to show "square-law" region

Figure 5: Block diagram of automated measurement setup

of which EWS computer you're using and so that they are not erased when the Network Admins do their periodic cleaning or upgrading.

You are now about to write a LabVIEW Virtual Instrument (VI) in which the user defines the minimum power, maximum power, number of power points, and source frequency. The program will communicate with the instruments and collect the detector output voltages and convert them to the logarithmic voltage format, and display both the linear and logarithmic values on the computer screen. The program will then save the data in LVM file format (which is easy to use within LabVIEW, but not compatible with other applications such as Keysight ADS). Thus, you will add functionality to the program so that the user can switch the saved file format from LVM to CITIfile (which can later be imported into ADS). You will be provided with a custom VI to achieve this. This VI will make sure of generation of the .CITIfile in the correct format.

For those familiar with LabVIEW and want to design your own VI, Figure 6 contains the suggested program flow chart for measuring and saving data. There is also a step-by-step guide for creating the VI in the LabVIEW tutorial 1 for those who are not familiar with LabVIEW. Remember to include a printout of your completed Front Panel for your report.

4. Have your LabVIEW program ready then set the source frequency and power range as same as step 1, then perform the automated measurement. Wait until the measurement is done, take a screen shot of your Front Panel for your report.

Notice that there will be some clicking noises from the generator during the measurement. These clicking noises happen corresponding to some "bumps" in the plot. Verify that and try to explain what could cause these clicking noises.

Remember to save measurement data into a .CITIfile when the program pops up a window and ask you.
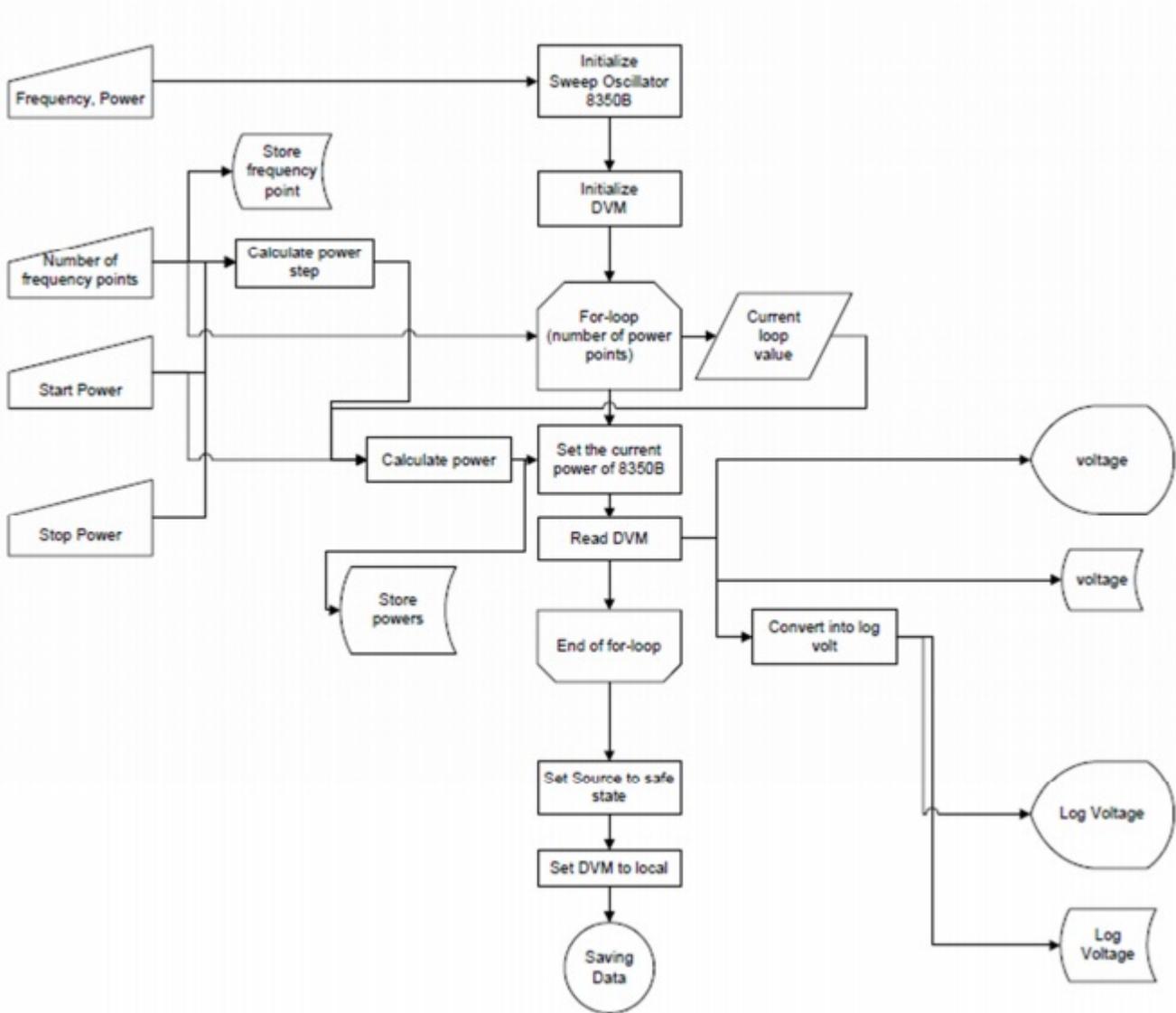
4

Figure 6: Suggested Program Flow Chart for Measuring and Saving Measured Values

5. Import and plot the data in ADS. Find the "square-law" region in your plot by placing makers on the limits of this region. Compute the slope of the response. Compare it with the result in step 1. Explain any discrepancies (if any) between them.

6 Conclusion

1. Write down the slope and the intersect to help you plot the "square-law" region of the 8474B detector, similar to Figure 4. Why is it important to determine the "square-law" region for the detector?

2. Comment on the use of LabVIEW in this experiment. What would be pros and cons using LabVIEW to automate your measurement?

References

[1] Datasheet, Keysight 8474B/C/E Planar-doped Barrier Diode Detectors 0.01 to 50 GHz.