A Portable and Low-cost RF Measurement System for Instructional Use

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Abstract

In this work, we develop a RF measurement system that consists of portable transmitter and receiver modules operating at the 2.4GHz band using Wi-Fi technologies. Originally designed as a hands-on lab tool for antenna radiation pattern measurements, this system can be a viable tool for multiple instructional tasks such as providing demos in lectures and serving as a measurement tool in labs for various Electrical Engineering (EE) and Electronic Engineering Technology (EET) courses. Relevant courses include those that cover antenna theory, RF signal propagation modeling, and communication systems which are fundamental in upper-division EE/EET curriculum. The system renders several promising features: portable, low-cost, simple, and compact in size, to name a few. In this paper, we first introduce the components and the mechanism of the RF measurement system. We then present a laboratory exercise that designed for an antenna radiation pattern study using the developed system. Detailed lab procedures and results collected from a recent upper-division communication systems course in an EET program are provided. The lab results demonstrate the effectiveness of the developed system. Additional assessment data from students’ feedback further show that the lab experience using the measurement system has been engaging. The proposed system provides a feasible solution for programs which are not equipped with complex and expensive lab facilities and resources for RF and antenna measurements instructional needs.

I. INTRODUCTION

Antenna theory together with RF signal propagation modeling, fundamental in electronic/RF communication curriculum in Electrical Engineering (EE) and Electronic Engineering Technology (EET) programs, are often perceived as abstract and difficult topics [1]. An effective and commonly used teaching technique to facilitate students’ understanding of these topics is the use of hands-on lab exercises to complement lectures. For instance, antenna measurements can
be taken to obtain antenna radiation patterns for different types of antennas through laboratory measurements [2], [3], [4], [5], [6]. Conventionally, antenna and RF signal propagation measurements require complex lab facilities and instruments such as Antenna Test Chambers (e.g., [2], [6]), network analyzers (e.g., [3], [5]), or field strength meters. The cost of equipping such facilities and instruments might be prohibitive and impractical for smaller EET/EE programs that do not have a special focus in these areas. Moreover, some instruments are not closely related to students’ everyday experience and real-life examples. Another common practice for antenna lab measurements is to use wireless transceivers to send a RF signal through a transmitter unit and capture the received signal strength at the receiver. For instance, in [4], the authors described an antenna radiation pattern lab measurement system utilizing the Ritron DTX-450 transceiver and an Icom communications receiver that both operate at 450M Hz. Their system provides a more hands-on approach with the selected practical wireless transceivers modules. The cost of the entire lab system, however, is still relatively high (over $600 including the expenses on major hardware components such as the transceiver, the receiver, and a rotator).

At present, our EET program offers introductory courses that emphasize fundamentals in broad subject areas such as communications, controls, DSP, and power systems. However, we do not have a concentration on some specific fields such as antenna or EM theory which usually demands expensive and complex research and lab facilities and test instruments. In this work, to best cope with our available budget and resources and to meet our pedagogical needs, we have developed a low-cost, simple, and portable RF measurement system. It can be a viable instructional tool for topics such as antenna theory, antenna measurements, and RF signal propagation modeling. Besides the cost savings (below $150 per system), compared to other existing systems, its transceiver modules adopt the popular 2.4G Hz Wi-Fi technologies and consist of off-the-shelf wireless routers and wireless network cards as the transmitter and receiver units. The Wi-Fi enabled devices are more accessible and familiar to students and are excellent real-life examples of RF communication systems. As such, the developed system renders students a great learning opportunity that connects abstract theories learned in classrooms to real-world examples.

In this paper, we will also present a successful laboratory exercise designed for antenna radiation pattern measurements using this system. The experiment data collected from a recent
communication system class in an EET program and students feedback demonstrate that the developed lab setup and the measurement system are efficient and effective to achieve the teaching outcomes.

In summary, the developed RF measurement system can serve a variety of lab activities and instructional tasks for antenna, EM wave propagation, communication systems, and other related topics. Both the measurement system and the laboratory exercise can be readily adapted to courses that cover similar topics in other institutions.

II. RF Measurement System

In this section, we present the components and features of the proposed system. As depicted in Fig. 1, the transmitting module include a transmitting antenna, a modified wireless Wi-Fi router, cable, and an antenna rotator. The receiving module consists of a computer, a wireless network card, and a received signal strength acquisition software. A photo of the actual transmitter unit is provided in Fig. 2.

![RF measurement system diagram](image)

Fig. 1. RF measurement system diagram

Detailed descriptions, function, and cost of each component are outlined in Table I and Table II. We highlight several features as follows:
The Wi-Fi router serves as the transmitter. Depending on the use of the measurement system, the antenna and the router setup might be different. For antenna radiation pattern measurements, the router can be modified such that its pre-packaged antenna might be removed and replaced with one that is designed and built by students. We will discuss such a case in the next section. For RF signal path loss modeling, the router built-in antenna can be used and therefore the router can be kept intact and no need to modify it.

For the current version, the antenna rotator is manually operated. A user controls the tuning knob to rotate the antenna for a certain angle.

The entire receiver unit is a computer equipped with a wireless network card and a free software (the version we have adopted is named as “Network stumbler”) to capture the
received RF signal strength. Most students own laptops which typically are configured with a wireless network card. Therefore, the receiver unit is very cost-effective and accessible to students.

- Compared to other wireless transmitter and receiver modules, the choice of using 2.4G Hz Wi-Fi devices is more appealing due to the fact that these devices are also more accessible and students are in general familiar with these components (e.g., a Wi-Fi wireless router). The 2.4G Hz 802.11 wireless devices are also suitable for other measurement tasks such indoor RF signal propagation modeling [7].

- All of the components except the computer are off-the-shelf parts. The antenna is tuned at 2.4G Hz and can be constructed using appropriate materials. For instance, A dipole antenna can be built using a piece of 16 AWG wire. The support is built by a PVC pipe.

- The measurement system in a whole is portable and easy to relocate to different indoor or outdoor locations.

- The total cost is about $150 per system and is far less expensive than existing systems.

**TABLE I**

<table>
<thead>
<tr>
<th>Component</th>
<th>Function</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>tx antenna</td>
<td>radiate a RF signal</td>
<td>students design and build</td>
</tr>
<tr>
<td>Wi-Fi 2.4G Hz router</td>
<td>generates a 2.4G Hz RF signal</td>
<td>$40</td>
</tr>
<tr>
<td>rotator</td>
<td>rotate the antenna between 0 – 365 degrees</td>
<td>$80</td>
</tr>
<tr>
<td>cable</td>
<td>feeds a signal from the router to the antenna</td>
<td>$5</td>
</tr>
<tr>
<td></td>
<td>total cost: $130</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE II**

<table>
<thead>
<tr>
<th>Component</th>
<th>Function</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>wireless network card</td>
<td>receives the RF signal</td>
<td>$25 or equipped laptop computers</td>
</tr>
<tr>
<td>software “Network stumbler”</td>
<td>acquire Wi-Fi signal strength readings</td>
<td>shareware</td>
</tr>
<tr>
<td>computer</td>
<td>hosts the network card and the software</td>
<td>surplus lab computer or student’s laptop</td>
</tr>
<tr>
<td></td>
<td>total cost: $25</td>
<td></td>
</tr>
</tbody>
</table>
Hands-on laboratory activities have been well acknowledged as an integral part of engineering and engineering Technology curricula and made critical impact in improving teaching efficiency and enhancing students understanding of abstract topics [8]. In this section, we elaborate on a successful laboratory exercise that is designed for antenna radiation pattern measurement using the proposed RF measurement system. Antenna radiation pattern, used to characterize an antenna, plays an important role in understanding antenna principles. Lab objectives and lab procedures are presented below in brief.

A. Lab Objectives and Pedagogical Goals

This lab exercise (a two-hour lab session) aims to provide students a hands-on opportunity to

- enhance understanding in antenna radiation pattern theory.
- accumulate hands-on skills in antenna measurements.
- be familiar with and practice constructing commonly used dipole antennas.

B. Lab Procedures

The lab includes three components: Pre-lab assignment, in-lab measurements, and post-lab analysis.

The pre-lab assignment facilitates students to get familiar with two types of dipole antennas through theoretical studies, specifically:

- Calculate the length of a half-wavelength dipole for 2.4G Hz Wi-Fi applications.
- Calculate the length of a 1.5-wavelength dipole for 2.4G Hz Wi-Fi applications.
• Sketch theoretical 2D radiation patterns of the two selected antennas and observe the features of each radiation pattern.

Prior to the lab session, basic antenna theory on dipole antennas and their radiation patterns were discussed in lectures. Completing the pre-lab assignment requires students to review lecture material and prepares them for the lab tasks.

The in-lab measurements consist of the following tasks:

• Step I: build a half-wavelength dipole and a 1.5-wavelength dipole using the 16 AWG wire as tx antennas, respectively. Note that the transmitter is a wireless router. For the half-wavelength dipole antenna, it will be connected to the router through a piece of cable using the center feed method. Therefore, the antenna consists of two identical sections each with a length slightly > \( L/2 \) and with \( L \) representing the wavelength.
• Step II: for each antenna, place the transmitter and receiver unit at a certain distance \( d \). Obtain measurements of the received signal field intensity through “Network stumbler” readings and sketch the actual radiation pattern plot. For each angle, take multiple readings and use the average value as the final result to combat possible noisy data.
• Step III: move the receiver unit to a farther distance, repeat step II.

After accomplishing these measurement tasks, students were asked to analyze and summarize their lab results through post-lab analysis, which are outlined as follows.

• Comment on the actual radiation pattern plot for each type of antenna that is under test.
• Compare the theoretical radiation pattern with the actual ones obtained through lab measurements. Specify whether these patterns are consistent. If not, explain why the difference exist.
• Specify the difference observed from the radiation pattern plots when the distance between the transmitter and the receiver increases. Explain the difference.
• Sketch the voltage and current distributions (i.e., standing waves) of the two antennas.
• (optional) Suggest any improvements or other methods or tools for obtaining more accurate
In this section, we will discuss some assessment results to validate that the proposed measurement tool and the developed laboratory activity are effective. The assessment data consist of both lab measurement data and student survey feedback collected from students who took a recent communication system course in our EET program in winter 2013.

A. Lab experiment Data

To gauge the effectiveness and the performance of the proposed RF measurement system, we provide an actual radiation pattern based on lab measurement for a half-wavelength dipole (designed and constructed by the students) in Fig. 3. Note that the antenna set up is rather simple without using a sleeve Balun, yet, the measurement results are comparable to those obtained by other more expensive and complex measurement tools. Some performance comparisons are provided as follows.

First, as a comparison with the ideal theoretical half-wavelength dipole antenna radiation pattern illustrated in Fig. 4, the actual pattern plot of Fig. 3 overall assumes the number 8 shape. It clearly demonstrates the characteristics of the E-field strength of a half-wavelength dipole antenna: the null regions along the 0 and 180 degree angles are clearly present. There are minor deviations from the theoretical pattern, which are expected given factors such as the noisy setting of the lab room and the accuracy of the received signal strength readings provided by the free software. The overall actual pattern plot renders a reasonable approximation of the theoretical pattern.

Comparing with the results obtained from other existing measurement methods, e.g., the measurement set up using an anechoic chamber in [6], the resulting radiation pattern of the
The proposed measurement system is comparable to the one obtained in [6] (refer to Fig. 10 in this reference).

In addition, the measurement accuracy of the radiation pattern can be improved through the following effort:

- Sleeve Baluns can be used to achieve impedance matching between the router and the antenna feed point. This will further improve the 0 degree angle null region, as noted in [6].
- Note that the theoretical radiation pattern is obtained assuming the free-space environment which is hardly available in normal laboratory rooms. The actual measurements were taken in a typical EET lab room which happens to have computers and other instruments and reflecting table tops and metal furniture, conduit and wiring, and poles support the ceiling. This uncontrolled environment may impact the measurement accuracy. One effective solution is to conduct the lab measurements in a large space without interfering objects, e.g., an empty gym or a sports court.

B. Student Feedback

Next, we present student feedback regarding the developed measurement system and the lab exercise. A questionnaire was disseminated to a group of twenty-two students who took a communication system class in winter 2013. Students were unanimously positive (100%) about the lab experience and felt that the lab was fun and engaging. All students indicated that they enjoyed the hands-on activities of constructing and testing dipole antennas, taking measurements, and analyzing the lab results. The measurement system is convenient to use and requires minimal training or troubleshooting. The impact of having a real hands-on lab on their understanding of antenna-related concepts is far profound than that from lecturing-only or lecturing with software simulations.

Moreover, a few students also provided insightful and useful suggestions on how the lab might
be improved. For instance, one pointed out that “I’d suggest in the future some other extended tasks could be explored such as studying the impact of walls and floor orientations”. Another commented that the measurement data looked quite noisy at times and there is a need for more efficient ways of conducting the lab measurements.

V. CONCLUSIONS

In this paper, we present a simple, portable, and low-cost RF measurement system that is suitable for instructional uses for topics related to antenna theory, RF signal propagation modeling, and communication systems. Moreover, we also introduce a laboratory exercise for antenna radiation measurement using the proposed system. Lab experiment data from students in a communication system course have validated the effectiveness of the system. In addition, students’ feedback show that the designed lab tool and lab exercise have been successful. The
proposed system might be a viable low-budget option for similar courses in EE and EET programs in other institutions to meet their instructional needs.

REFERENCES


