Standalone Antenna Measurement System

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***Abstract*— We propose an affordable antenna measurement system designed for educational purposes. The system is scalable and easy to implement in both hardware and software. The integrated single-board computer (SBC) and the radio frequency printed circuit boards (RF PCBs) provide full independence from bulk microwave measurement devices and personal computers. The pattern measurement done with the system has been compared with the numerically obtained radiation pattern from ANSYS HFSS software. ±1dB detection capability is verified for a single lobe antenna.**

Keywords*— *Antenna measurement; RFIC; RF PCB design; single board computer; web based user interface design;

I. Introduction

The antennas are one of the core elements of telecommunication systems, and high-performance antennas integrated with consumer products are increasing demand. To provide proper communication, a designed antenna must satisfy system requirements. To be sure of the antenna characteristics, test procedures cover an important part of the antenna design process.

In this study, we present the design of a flexible antenna measurement system for educational or small business purposes where high-end performance measurement equipment is not affordable. The system's primary goal is to alleviate the need for complex measurement setups that include network or spectrum analyzers, while providing an easily comprehensible, stand alone, modular, and portable hardware setup and user interface. Since the dependence on professional laboratory equipment will affect the portability of the system, undoubtedly, we try to avoid anything that is not available off-the-shelf or not accessible to the engineering students at low costs.

Similar designs have been reported in the literature with various alterations [2] [8] [9], but these setups mostly lack portability due to dependence on a personal computer to visualize the measured antenna parameters. There are also measurement systems that are represented as standalone - without dependence on any spectrum and network analyzers [3] [4]. In another approach, the received power data processing and control unit is based on field-programmable gate arrays (FPGA) [5]. The usage of the FPGA unit therein provides flexibility for the measurement system. However, the FPGA requires a particular skill set that complicates future improvements by the students.

Our system relays on single board computers, abundantly available in the market, instead of an FPGA based processing unit. The modularity of the proposed system is satisfied by designing the system blocks with distinct PCBs that can be replaced on demand.

The radiation characteristics determine the suitability of the antennas for a system in which they will be integrated utilizing the radiation pattern, polarization, and gain [1]. The proposed antenna measurement system characterizes an antenna by calculating the radiated power pattern, the gain, the directivity, and the beamwidth of the antenna under test (AUT). An IC RF power detector pinpoints the received power through 360° in the co-polarization plane. After detecting the received power, the system utilizes the FRIIS equation to calculate the antenna gain. The directivity and the beamwidth are derived from the observed data. In the calculation of directivity, the Kraus formula is employed since the test antenna's beamwidth is high to use the Tai-Pereira formula [1].

II. System Overview

The designed antenna measurement system operates in the 400MHz - 2.1GHz frequency range. The prominent properties of the system are:

- The electronic system blocks are designed by taking into account modularity.
- The modular system blocks are planned to provide no dependence on bulk microwave laboratory equipment.
- The extensive design makes the most of system properties such as detection of the RF power within the user-defined angle of incidence interval.
- The web browser-based control panel and the user interface makes the system independent from a personal computer, and they allow a multiuser view of the measurement results, especially suitable for the classroom demonstrations.

III. Hardware

A. Transmitter

The transmitter unit in Fig. 1 consists of two subblocks: a frequency synthesizer and a variable gain amplifier.

1) Frequency Synthesizer

This block is responsible for generating the high-frequency signal to drive the antenna amplifier from the reference 64 MHz signal. The production of the RF signal is based on phase locked loop (PLL) IC LTC6946 by Analog Devices^{TM}. The frequency range of the oscillation is 400 MHz to 2.1 GHz. This frequency range can be swept through by using internal frequency dividers. The power of the output signal can be changed from minimum - 9dBm to a maximum of 0 dBm with a resolution of 3dB with the programmable IC output. The circuit schematic for LTC6946 has been designed according to the suggestions given in its datasheet [7]. The alterations were made in order to satisfy the system requirements, which is seen in Fig. 2. The reference oscillator, the PLL loop filter, and the DC blockage capacitors at RF outputs have been chosen accordingly.

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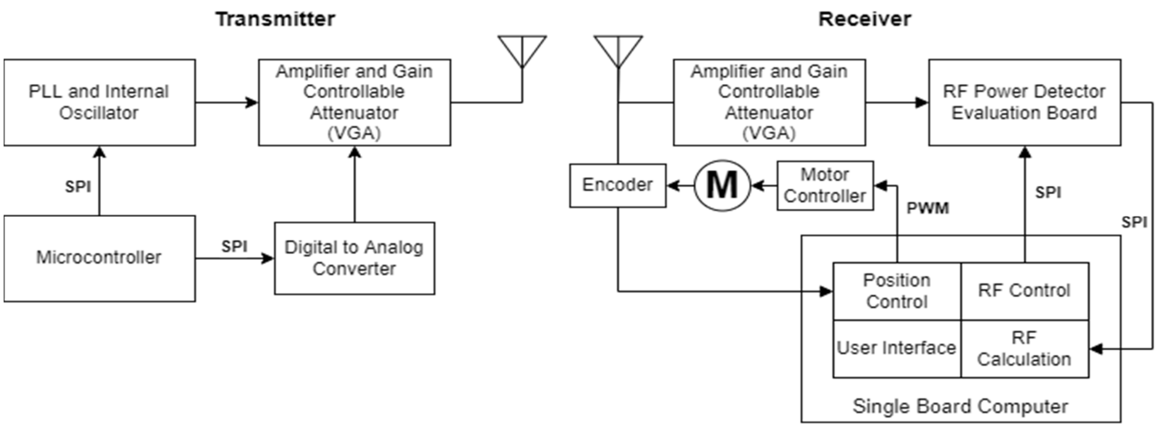

Fig. 1. System block diagram

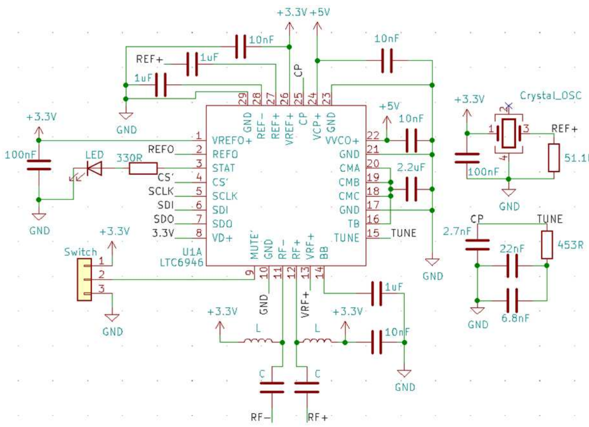

Fig. 2. PLL schematic

In the multi-layer printed circuit board (PCB) design, which is seen in Fig. 3, the high frequency tracks are implemented by using coplanar waveguides (CPW) to reduce electromagnetic loss. The designed prototype is placed inside of the alumina thin wall die-cast enclosure to reduce electromagnetic interference.

Fig. 3. PLL board prototype

2) *Variable-Gain Amplifier (VGA)*

This block is responsible for amplification and tuning the signal level. In order to keep the system expenditure low, a fixed gain amplifier unit and gain controllable attenuator in a single IC block have been used, each accessible externally. The cascade connection of these two blocks provides tuning of the output signal level for the linear region of the RF power detector. Simultaneously, this provides compensating the cable losses and free space loss.

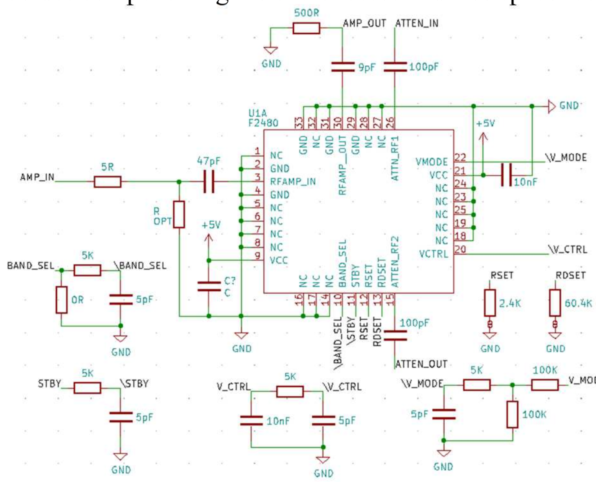

Fig. 4. VGA schematic

The design is based on RFIC F2480 by Renesas^{TM} [14]. The schematic, in Fig. 4, has been designed according to the recommended design of Renesas^{TM}. The designed PCB has been placed inside an alumina box depicted in Fig. 5.

Fig. 5. VGA board prototype

The amplifier unit can supply fixed 12dB gain through 400 MHz to 3000 MHz frequency range. In order to analyze amplifier characteristics, power gain (GP), available power gain (GA), transducer power gain (GT) data have been derived from the experimentally measured S-parameters via ANSYS Nexxim circuit simulator, which is the used to calibrate the received power at the receiver stage. The resulting waveforms are shown in Fig. 6.

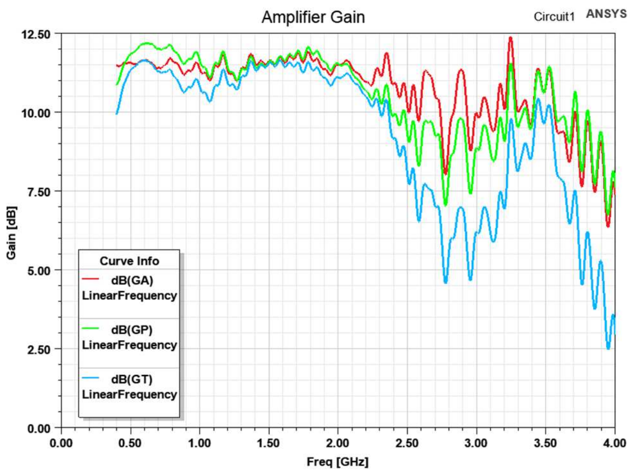

Fig. 6. Gain characteristic of amplifier

The gain control signal has been generated using a digital-to-analog converter (DAC) attached to a microcontroller's SPI port. In Fig. 7, the attenuation characteristic is depicted with respect to the control voltage level for three different frequencies. The power radiated by the AUT in the measurement frequency has also been calibrated with respect to the attenuator characteristic.

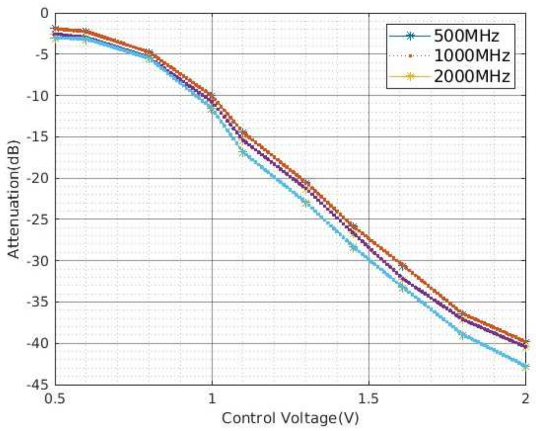

Fig. 7. Attenuation characteristic of the attenuator in linear range

B. Receiver

In the receiver unit, Analog Devices™ RF power detector CN0150 has been utilized. It provides 12-bit resolution RF power level data in decimal format through SPI. The device is capable of detecting RF signals in 1 MHz to 6 GHz with an accuracy of ±1dB over 55 dB range for 50Ω reference, for which the characteristic curve is shown in Fig. 8.

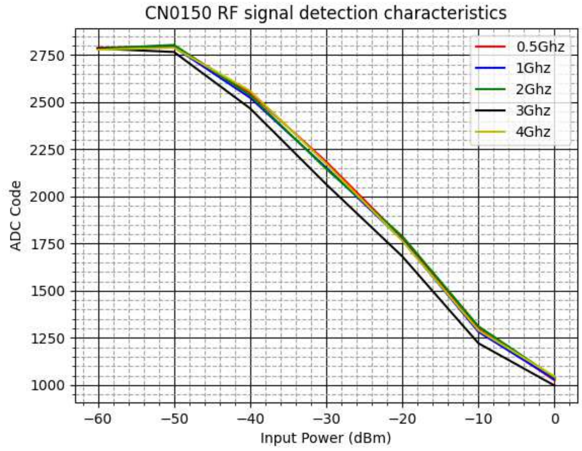

Fig. 8. CN0150 RF signal detection characteristics

C. Control Unit

The hardware blocks in this context are responsible for the excitation of the mechanical part, which changes the angle on incidence, the control of data flow in the system, the calibration and the correction of received data, and the visualization of the processed data.

The mechanical parts are produced with 3D printing as much as possible to make the mechanical system more modular and reduce electromagnetic interference. The mechanical part consists of 2-gear-mechanism to transfer torque and increase rotational accuracy. Step motor and L298N dual H bridge motor driver rotates the AUT without any positional feedback. Nevertheless, an encoder is added to detect any anomaly due to mechanical defects such as gear gaps. A 10 to 1 gear mechanism is used to increase the rotation precision. Thus, the angular accuracy of the step motor, which is 1.8°, is reduced to 0.18°. In addition, the angular accuracy has been checked with a 500 ppr encoder attached to the shaft.

The receiver unit is controlled by a Raspberry Pi 3+ single-board computer (SBC). The SBC manages the user interface, controls the antenna position, and processes the data from the RF power detector. An additional Raspberry Pi 3+ cape provides error free wiring with the help of the connectors in the PCB. Moreover, the SBC communicates with an STM32 Nucleo-G431RB unit in the transmitter through an IrDA-based UART interface over which the frequency and attenuation level inputs are adjusted. The STM32 Nucleo-G431RB microcontroller commands the PLL board to set the frequency that the user typed in the interface in the transmitter unit. Also, the attenuation level, which is determined through the calibration process, is passed to the DAC unit by which the corresponding analog control signal for the VGA unit is generated.

The receiver is supplied by a GS-R405 step-down regulator, and the RF power detector is supplied through a linear regulator utilizing an LM317 IC to eliminate switching ripples. The electronic parts are supplied by using a 10W AC/DC converter with output voltage of 5V and suitable filtering in the receiver unit.

IV. Software

A. STM-Raspberry Pi

Debian-based Raspberry Pi OS is used on Raspberry Pi, which is open source and is easy to use. In order to minimize the possibility of encountering any problems from future updates, a virtual environment has been created to separate the libraries used by the antenna measurement system from the main libraries used by the system. The SBC is the main control unit of the system, and the STM32 is used to control the transmitter. Therefore, STM32 configures the PLL and VGA according to the frequency and DAC values sent by the Raspberry Pi over the UART interface.

B. User Interface

The user interface is based on a web server running on the SBC. In this way, future updates can be integrated easily, and several devices on the same network can control and display the results upon user request. The ability to demonstrate the results through network broadcasts is especially suitable for education-oriented applications. Python, HTML, Javascript, and CSS programming languages are used to develop the GUI. The user interface consists of two main parts. The user makes antenna measurements in the first part. In addition to antenna measurement, one can make separate measurements for the free space and the cable losses. The previous measurement results are accessed and displayed in the second part. Flask is used as the main development framework for the web interface of the system [10]. All input and output data are stored in an SQLAlchemy-based SQLite database, allowing the measurements to be used in further analysis [11]. In order to generate the graphical outputs, Plotly library is used, which provides online graphing tools and scientific graphing libraries. The Jinja templating engine creates a common interface for the web pages. The user interface are seen in Fig. 9 [12] [13].

V. Results

We have carried out the measurements with two identical microstrip patch antennas at transmitter and receiver sites operating at 1.8 GHz to demonstrate the proposed system. The radiation pattern of the designed antenna obtained by ANSYS HFSS and the measured pattern has been compared in Figure 10. The numerical results obtained by characterizing the antenna are shown in Table I. The calculation of the gain is carried out using the (1).

$$P_r = P_o G_{0t} G_{0r} \left(\frac{\lambda}{4\pi R}\right)^2 \quad (1)$$

where P_r is received power, which is measured with the help of RF power detector. P_o is the power fed to the transmitter antenna, measured after calibration. G_{0t} and G_{0r} are the same since the transmitter and receiver antennas are identical. The free-space loss term is calculated with the input's wavelength, λ, and far-field distance, R.

The numerical and experimental radiation patterns given in Fig. 10 are in agreement and within the acceptable tolerance limit of the RF power detector as can be confirmed from Table I.

Since RF PCBs do not contain an additional matching network, there is a slight mismatch between the microstrip patch antenna and the VGA board in the operating frequency, reflecting in the difference between numerical and experimental peak gain results.

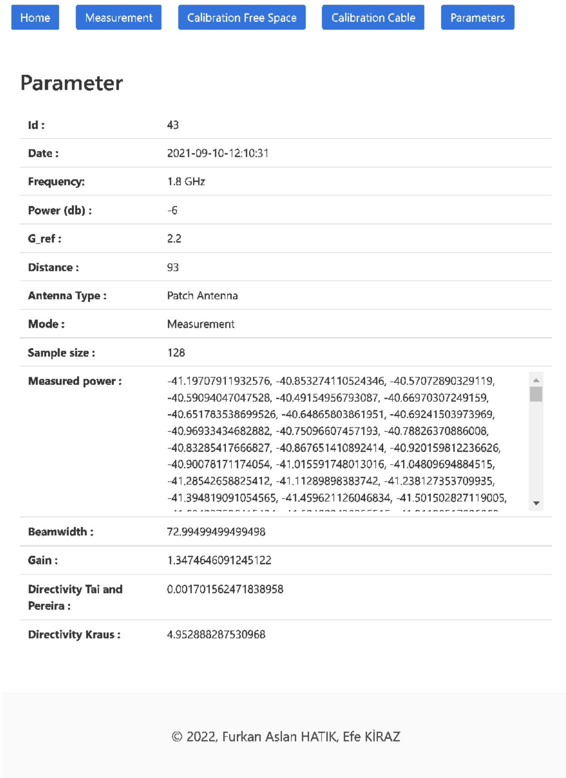

Fig. 9. Result Page

TABLE I. 1.8 GHZ MICROSTRIP PATCH ANTENNA PROPERTIES

Antenna Parameters	Results	
	Numerical	*Experimental*
Peak Gain	1.678154	1.3474
Peak Directivity	4.914148	4.9528
Beamwidth	80°	72.9°

In addition, the designed microstrip patch antenna is not perfectly matched to 50Ω as in simulation due to the manufacturing tolerances of the antenna. An isolator could be used in the transmitter and receiver to avoid the effects of such mismatches at an expanse of the cost.

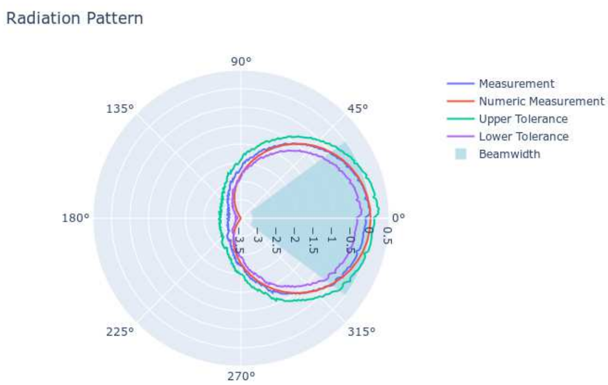

Fig. 10. Numerical and experimental radiation patterns

VI. Conclusion & Future Work

We present an antenna measurement system that serves as an educational instrument and an industrial product for start-ups in this study. The system costs well under 1000$ with acceptable accuracy yet can be improved easily due to the modular design. Multi-layer RF PCB design and flexible, SBC based user interface, which provides independence from a personal computer, are the prominent features of the measurement system. In order to increase the performance of the system, many improvements can be implemented to suit further requirements. For instance, the antenna impedance shall also be measured to fully characterize the AUT. Since the impedance measurement requires excitation of the AUT at the currently passive receiver site, another PLL and a wide-band circulator could also be placed in receiver unit, all of which to be controlled digitally. Besides, the transmitter antenna may be connected with a directional coupler, and an additional power detector can detect the power transmitted to the antenna directly. As a result, the measurement and the calibration time can be reduced and accuracy can be improved significantly, at the expense of additional cost.

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