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ANALYSIS OF DIFFERENT ANTENNA TYPES FOR WIRELESS COMMUNICATIONS USING A LABORATORY TESTBED [1]

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Abstract: *Antennas are integral parts of every radio-communication device. Throughout the years, the antennas have evolved in size and functionality and have found their place in many different applications. Examples range from personal devices, like mobile phones and tablets, trough RFID tags and wireless printers, to defence applications, such as the phased array antennas for aircraft radar systems or the satellite-based systems, where the antennas are integrated in the ground based communication systems. To decide whether a specific antenna is suitable for a given application, its basic parameters have to be measured and then compared to the results obtained from similar evaluations with different other antenna types. In this paper, we present a laboratory testbed for antenna analysis and a discussion on the obtained measurements from real experiments with different antenna types using only the free-space propagation model. To evaluate the antenna parameters we use the RadPat software, which is connected to an Agilent N9912A FieldFox RF analyser and detector. The testbed is completed by two specialized platforms for antenna mounting. The receiver platform allows for the automated rotation of the receiver module antenna and by this, the antenna angular position and other measurements can be collected. Based on this evaluation testbed we have evaluated several different types of antennas and we have provided analysis on the received results.*

Keywords: *Antennas, RadPad software, RF analyser, free-space propagation.*

INTRODUCTION

The antenna is an essential part of every radio system. It is defined as a device, which can radiate and receive electromagnetic energy in an efficient and desired manner. It is normally made of metal, but other materials may also be used. For example, ceramic materials have been employed to make dielectric resonator antennas (DRAs). Antenna design is an interesting and difficult subject. Depending on the different applications, the requirements for the used antennas may be very different, even for the same frequency bands (Huang, Y., Boyle, K., 2008).

In this paper, we present a laboratory testbed for evaluation of different antenna parameters. The testbed can be used by university students and can help them easily learn how to measure and evaluate the basic antenna parameters. All experiments, which are presented in the paper, are conducted in the "Radio communications and wireless technologies" laboratory of the Department of Telecommunications at the University of Ruse "Angel Kanchev".

The general characteristics of the antennas are one of the main concerns when choosing the right antenna for a specific application. Every antenna has several basic parameters - its gain, beamwidth and bandwidth. The radiation pattern of the antenna is also important and represents a plot of the radiated power as a function of the angle at a fixed distance. The gain is defined as the ratio of the radiation intensity in a given direction from the antenna to the total input power accepted by the antenna divided by 4π. If the direction is not specified, the direction of maximum radiation is implied. Many antenna parameters are functions of its frequency. When the frequency

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is changed, the radiation pattern may also vary, which may result in changes to the directivity, gain, half-power beamwidth and other parameters. Thus, it is important to ensure that the right parameters are chosen when the antenna bandwidth is considered. Once the antenna is designed, it should be manufactured and tested. The construction of an antenna may be a complex process since the antenna has to meet the electrical and mechanical specifications as well as some other requirements (such as costs) (Huang, Y., Boyle, K., 2008).

The analysis of the different antenna types for wireless communications is important part of the design process for every wireless device or system. For this reason, it is vital for the students to become familiar with the different antennas types and to know how to test them properly. The students can do the evaluation of the antennas, using the presented laboratory testbed and the developed laboratory exercises and manuals. They can also use the obtained experience to further test additional types of antennas, which are not investigated here, like water antennas for example.

The types of antennas that are evaluated and presented in this paper include a dipole, Yagi-Uda and microstrip patch antennas. The dipole antennas are very common practical wire antennas (Balanis, C. A., 2016) used in many home appliances, like TVs and Radios. The Yagi-Uda antennas (also known as Yagi antennas) are another popular type of end-fire antennas widely used in the VHF and UHF bands (30 MHz to 3 GHz) because of their simplicity, low cost and relatively high gain. They are most noticeable used for home TV reception and they can be found on the rooftops of many houses (Huang, Y., Boyle, K., 2008). The microstrip patch antennas have attracted a lot of interest and are used for many applications, including satellite communications, aerospace systems, radars, etc. The microstrip patch antennas are low cost, low profile, lightweight, mechanically robust, easy to fabricate and analyse (Hanumante, V., Roy S., 2013). The presented laboratory testbed can also be used for evaluation of other types of antennas, like the monopole antennas, which are nowadays commonly used for wideband and UWB applications, because of their low cost, simple structure and low weight characteristics (Sim, et al. 2004), (Huang, et al. 2008), (Azarmanesh, et al. 2011).

MAIN PARAMETERS FOR ANALYSIS AND EVALUATION OF THE ANTENNAS

The gain of the antenna is defined as the ratio of the power produced by the antenna from a far-field source on the antenna's beam axis to the power produced by a hypothetical lossless isotropic antenna, which is equally sensitive to signals from all directions. For an isotropic antenna, the gain can be obtained by the following equation, where R is the distance between both antennas:

$$G^2 = \frac{P_r}{P_t}\left(\frac{4\pi R}{\lambda_o}\right)^2 \tag{1}$$

For non-identical antennas, the gain of the antenna can be obtained by measuring the power of the evaluated antenna according to a known reference received power (P_{ref}) and a known reference gain (G_{ref}) from two identical antennas:

$$G_{AUT(dB)} = G_{ref(dB)} + \Delta_{(dB)} \tag{2}$$

where

$$\Delta_{(dB)} = P_{AUT(dB)} - P_{ref(dB)} \tag{3}$$

The beamwidth is described as the concentration of the power of a directional antenna. It is the angle between the half-power (-3 dB) of the main lobe of the antenna pattern.

The bandwidth of an antenna is defined as the range of frequencies where the performance of the antenna conforms to a specified standard. It can be considered as the range of frequencies on either side of the centre frequency, where the antenna characteristics are within acceptable levels. Normally, it is expressed as a fraction of the centre frequency.

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STRUCTURE AND COMPONENTS OF THE LABORATORY TESTBED FOR EVALUATION OF THE DIFFERENT ANTENNA TYPES

The setup of the laboratory testbed for evaluation of the different antenna types is shown in Figure 1. In all of the conducted experiments, a set of two identical antennas is used for the measurements. The first antenna, which represents the transmission antenna, is mounted on the top connector of the fixed antenna holder of the transmitter module (TX). The other antenna is mounted on the top connector of the rotatable antenna holder on the receiver module (RX). This is the antenna, which is being evaluated. Both antennas must be orientated broadside to each other. The distance between the antennas must be at least 50 cm and the transmitted power (P_T) should be at least 5 dBm. In the case of the presented laboratory testbed, an Agilent N9912A FieldFox RF analyser is connected directly to the transmitter module and is used for the generation of the RF signal, but any other RF signal generator can be used as well. Once the signal is generated, it is transmitted over the radio channel to the receiver module. The Agilent N9912A FieldFox RF analyser has also an embedded RF signal detector, so the output of the receiver module is directly connected back to the detector part of the analyser. The information about the transmitted and the received signals is then transferred to the computer and the evaluation of the antennas is done in the RadPat software. The computer is directly connected and communicates with the RF analyser, so that it can collect and the process the data about the transmitted and received signals, but is also connected, using an USB cable, to the receiver module, so that it can control the mechanical rotation of the receiver antenna. In this way, the RadPat software is also capable of displaying the antenna angular position and can be used for configuration of the serial communications or for detection of serial communication errors. Once the obtained experimental data is processed, the measurements are displayed in a table and in a list and the RadPat software can plot the antenna radiation pattern on a polar chart.

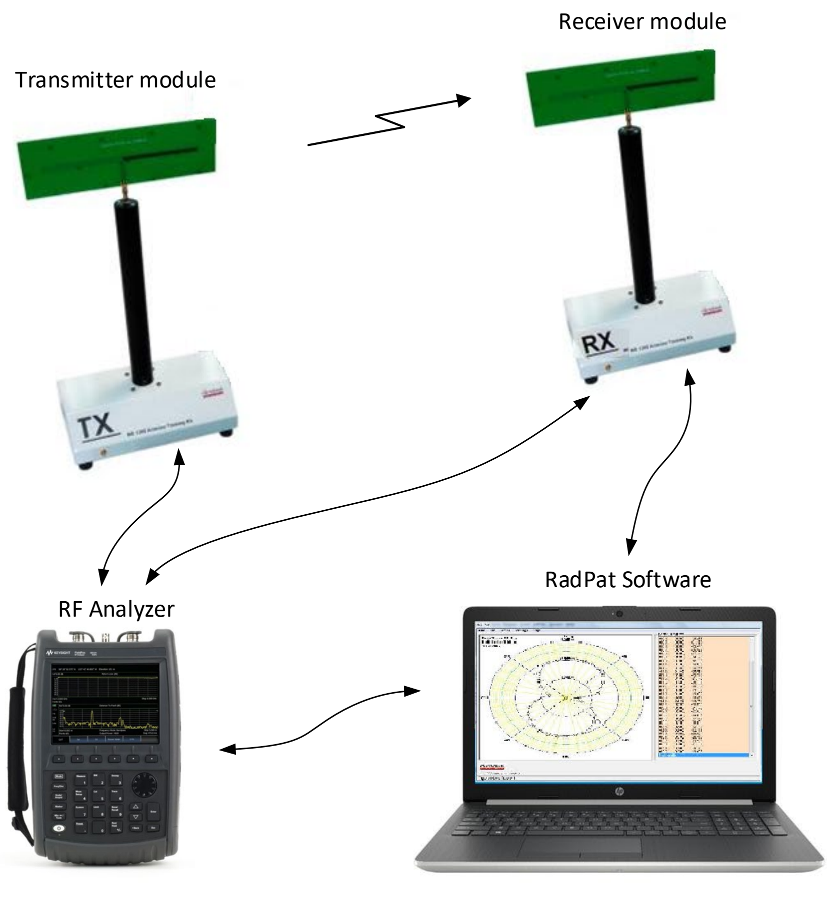

Fig. 1. Laboratory testbed for evaluation of the different antenna types

EVALUATION AND ANALYSIS OF THE PARAMETERS OF THE DIFFERENT ANTENNA TYPES FOR WIRELESS COMMUNICATIONS

In order to present the capabilities and the functionality of the discussed laboratory testbed, we have performed several series of evaluation experiments, which were conducted with a 2.4 GHz λ/2 dipole antenna, a 2.4 GHz Yagi-Uda and a 2.4 GHz microstrip patch antenna. In all experiments, we have measured the gain, the beamwidth and the bandwidth of the antennas.

Measurements and evaluation of the 2.4 GHz λ/2 dipole antenna

To measure the gain of the antenna, we use the following values: frequency of the antenna $f = 2.4$ GHz, wavelength $\lambda = 0.125$ m, distance between the TX and the RX modules $r = 0.5$ m and dimension length of the antenna $D = 0.048$ m.

Based on this, the relation between the received power (P_R) at the receiving antenna and the transmitted power (P_T) at the transmitting antenna can be calculated, as follows:

$$\frac{P_R}{P_T} = -39.75(Max)\,dB \; = 5.888\times 10^{-4}\,(ratio) \tag{4}$$

where P_T = +5 dBm = 3.1623 mW and P_R = -34.75(Max) dBm = 3.35×10^-4 mW.

The path-gain factor F for the free-space propagation model is equal to one, so gain can be calculated as follows:

$$G = \left(\frac{4\pi r}{\lambda F}\right)\sqrt{\frac{P_R}{P_T}} = \left(\frac{4\times 3.14\times 0,5}{0,125}\right)\sqrt{5.888\times 10^{-4}} = 1.219\;(ratio) \;=\; 0.86\;dB \tag{5}$$

We can use the data collected and processed by the RadPat software to evaluate the beamwidth measurements. The results are presented in Table 1. The last column in Table 1 is calculated using the equation: Normalized (dB) = P_R (dBm) - max P_R (dBm)

Table 1. Measurements from the RadPat software for the 2.4 GHz λ/2 dipole antenna

Angle (Degree)	P_R/P_T (dB)	P_R (dBm)	Normalized (dB)	Angle (Degree)	P_R/P_T (dB)	P_R (dBm)	Normalized (dB)
10	-32.3	-27.3	0	190	-33.15	-28.15	-0.85
20	-32.4	-27.4	-0.1	200	-33.09	-28.09	-0.79
30	-32.71	-27.71	-0.41	210	-33.35	-28.35	-1.05
40	-34.06	-29.06	-1.76	220	-34.18	-29.18	-1.88
50	-35.6	-30.6	-3.3	230	-35.34	-30.34	-3.04
60	-37.15	-32.15	-4.85	240	-36.65	-31.65	-4.35
70	-39.92	-34.92	-7.62	250	-39.8	-34.8	-7.5
80	-41.8	-36.8	-9.5	260	-43.76	-38.76	-11.46
90	-46.73	-41.73	-14.43	270	-53.32	-48.32	-21.02
100	-59.57	-54.57	-27.27	280	-62.12	-57.12	-29.82
110	-51.62	-46.62	-19.32	290	-46.18	-41.18	-13.88
120	-45.12	-40.12	-12.82	300	-40.44	-35.44	-8.14
130	-42.03	-37.03	-9.73	310	-37.72	-32.72	-5.42
140	-39.07	-34.07	-6.77	320	-37.01	-32.01	-4.71
150	-37.18	-32.18	-4.88	330	-34.24	-29.24	-1.94
160	-35.44	-30.44	-3.14	340	-33.6	-28.6	-1.3
170	-34.59	-29.59	-2.29	350	-32.6	-27.6	-0.3
180	-33.76	-28.76	-1.46	360	-32.47	-27.47	-0.17

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The RadPat software can be used also to plot the radiation pattern, according to the data recorded in Table 1. The result is shown in Fig. 2, where in red is presented the 3 dB beamwidth of the antenna. The beamwidth in this case is 85 Deg.

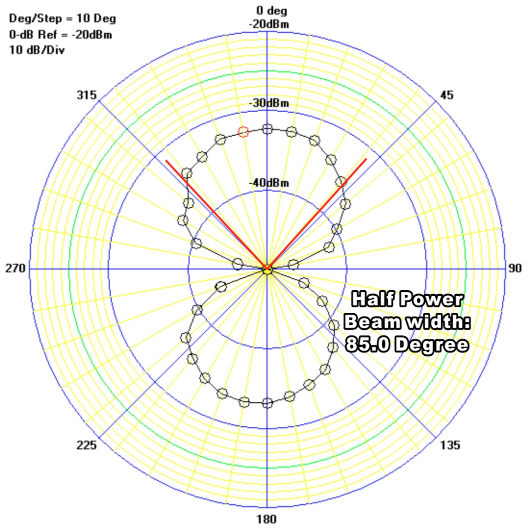

Fig. 2. Radiation pattern of the 2.4 GHz λ/2 dipole antenna

The bandwidth measurements for the 2.4 GHz λ/2 dipole antenna are conducted using the Agilent N9912A FieldFox RF Analyser. The recorded result for the return loss, S_{11} is - 15.35 dB, and the antenna bandwidth is 360 MHz.

Measurements and evaluation of the 2.4 GHz Yagi-Uda antenna

The gain transfer method can be used in this specific case for the proper calculation of the gain of the antenna. This method defines that a set of reference antennas should be set and used to measure the received power. The obtained power level will be used as the reference power (P_{ref}) with a known gain (G_{ref}). Following this, another receiving antenna should be used to replace the reference antenna. The replacement antenna will be treated as the antenna-under-test (AUT). The received power (P_{AUT}) of the antenna-under-test is obtained within identical measurement conditions. The difference between the two received power levels (P_{AUT} and P_{ref}) is the difference between the antenna gains. Following the evaluation experiments with the 2.4 GHz λ/2 dipole antenna (above), we calculated the gain of the antenna and its received power as G (dipole) = 0.86 dB and P_R (dipole) = -27.3 dBm.

The relation between the received power P_R at the receiving antenna and the transmitted power P_T at the transmitting antenna in this case can be calculated:

$$\frac{P_R}{P_T} = -32.3\ dB\ = 5.888 \times 10^{-5} \left(ratio \right) \tag{6}$$

The received power P_R is -26.2 dBm and the ΔGain can be calculated:

$$\Delta Gain\ = P_R \left(AUT \right)\ - P_R \left(dipole \right) = -26.2 + 27.3 =\ 1.1\ dB \tag{7}$$

The gain for 2.4 GHz Yagi-Uda antenna is:

$$G\left(AUT \right)\ = G\left(dipole \right)\ +\ \Delta Gain =\ 0.86 + 1.1 = 1.96\ dB \tag{8}$$

To analyse and present the beamwidth measurements, we use the data obtained using the RadPat software. The results for the received signal strength levels are shown in Table 2.

Table 2. Measurements from the RadPat software for the 2.4 GHz Yagi-Uda antenna

Angle (Degree)	P_R/P_T (dB)	P_R (dBm)	Normalized (dB)	Angle (Degree)	P_R/P_T (dB)	P_R (dBm)	Normalized (dB)
10	-54.39	-49.39	-23.19	190	-49.72	-44.72	-18.52
20	-50.95	-45.95	-19.75	200	-49.42	-44.42	-18.22
30	-49.55	-44.55	-18.35	210	-47.17	-42.17	-15.97
40	-49.34	-44.34	-18.14	220	-46.3	-41.3	-15.1
50	-48.89	-43.89	-17.69	230	-50.96	-45.96	-19.76
60	-44.27	-39.27	-13.07	240	-55.36	-50.36	-24.16
70	-40.41	-35.41	-9.21	250	-53.05	-48.05	-21.85
80	-36.5	-31.5	-5.3	260	-36.1	-31.1	-4.9
90	-34.38	-29.38	-3.18	270	-34.45	-29.45	-3.25
100	-33.34	-28.34	-2.14	280	-32	-27	-0.8
110	-33.42	-28.42	-2.22	290	-31.2	-26.2	0
120	-34.19	-29.19	-2.99	300	-31.85	-26.85	-0.65
130	-35.97	-30.97	-4.77	310	-33.73	-28.73	-2.53
140	-39.06	-34.06	-7.86	320	-39.57	-34.57	-8.37
150	-41.96	-36.96	-10.76	330	-46.67	-41.67	-15.47
160	-44.88	-39.88	-13.68	340	-48.29	-43.29	-17.09
170	-46.45	-41.45	-15.25	350	-48.49	-43.49	-17.29
180	-48.27	-43.27	-17.07	360	-50.35	-45.35	-19.15

The antenna radiation pattern, according to the data presented in the Table 2, is shown on Fig. 3, where the 3 dB beamwidth of the antenna is presented in red. The beamwidth in this case is 40 Deg.

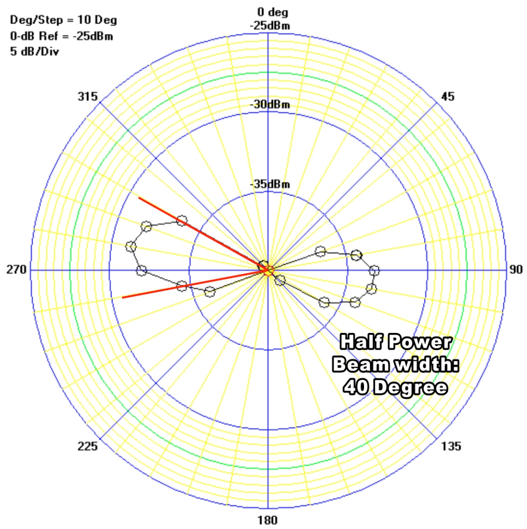

Fig. 3. Radiation pattern of the 2.4 GHz Yagi-Uda antenna

The bandwidth measurements for the 2.4 GHz Yagi-Uda antenna are conducted using the Agilent N9912A FieldFox RF analyser. The recorded result for the return loss, S_{11} is - 20.05 dB, and the antenna bandwidth is 177.5 MHz

Measurements and evaluation of the 2.4 GHz microstrip patch antenna

In a similar fashion to the experiments with the 2.4 GHz Yagi-Uda antenna, the gain transfer method can be used for the calculation of the gain of the 2.4 GHz microstrip patch antenna as well.

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The gain of the dipole antenna and its received power P_R are G (dipole) = 0.86 dB and P_R (dipole) = -27.3 dBm. The received power P_R was -41.8 dBm, so the ΔGain can be calculated as:

$$\Delta Gain \ = P_R\left(AUT\right) \ - P_R\left(dipole\right) = \text{ -41.8+27.3= -14.5 } dB \tag{9}$$

The gain for the 2.4 GHz microstrip patch antenna is calculated as:

$$G\left(AUT\right) \ = G\left(dipole\right) \ + \ \Delta Gain \ = \text{ -14.5+0.86 = -13.64 } dB \tag{10}$$

The beamwidth measurements are again presented using the RadPat software. The results for the received signal strength levels are shown in Table 3.

Table 3. Measurements from the RadPat software for the 2.4 GHz microstrip patch antenna

Angle (Degree)	P_R/P_T (dB)	P_R (dBm)	Normalized (dB)	Angle (Degree)	P_R/P_T (dB)	P_R (dBm)	Normalized (dB)
10	-44.61	-39.61	-2.81	190	-59.69	-54.69	-17.89
20	-43.25	-38.25	-1.45	200	-57.14	-52.14	-15.34
30	-42.44	-37.44	-0.64	210	-53.57	-48.57	-11.77
40	-41.47	-36.47	0.33	220	-53.09	-48.09	-11.29
50	-41.8	-36.8	0	230	-50.84	-45.84	-9.04
60	-42.14	-37.14	-0.34	240	-48.42	-43.42	-6.62
70	-42.83	-37.83	-1.03	250	-48.31	-43.31	-6.51
80	-43.62	-38.62	-1.82	260	-48.13	-43.13	-6.33
90	-44.86	-39.86	-3.06	270	-48.43	-43.43	-6.63
100	-45.91	-40.91	-4.11	280	-48.77	-43.77	-6.97
110	-46.82	-41.82	-5.02	290	-49.05	-44.05	-7.25
120	-47.78	-42.78	-5.98	300	-50.41	-45.41	-8.61
130	-48.31	-43.31	-6.51	310	-51.62	-46.62	-9.82
140	-49.56	-44.56	-7.76	320	-52.39	-47.39	-10.59
150	-51.87	-46.87	-10.07	330	-51.54	-46.54	-9.74
160	-54.22	-49.22	-12.42	340	-51.25	-46.25	-9.45
170	-57.33	-52.33	-15.53	350	-48.99	-43.99	-7.19
180	-60.79	-55.79	-18.99	360	-48.18	-43.18	-6.38

The radiation pattern, according to the data recorded in Table 3, is presented in the figure below. The 3 dB beamwidth of the antenna is again presented in red and the beamwidth in this case is 85 Deg.

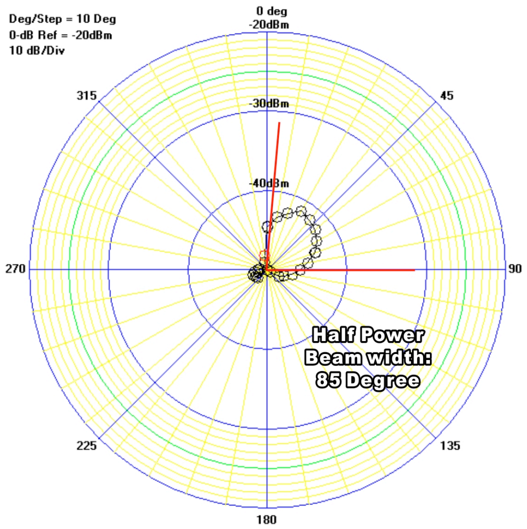

Fig. 4. Radiation pattern of the 2.4 GHz microstrip patch antenna

The bandwidth measurements for the 2.4 GHz microstrip patch antenna are conducted using the Agilent N9912A FieldFox RF analyser. The recorded result for the return loss, S_{11} is - 16 dB. The antenna bandwidth is 62 MHz.

CONCLUSIONS

This paper presents a laboratory testbed for analysis and evaluation of different antennas. In the presented evaluations, we have investigated and used only the free-space propagation model. The antenna with the highest gain is 2.4 GHz Yagi-Uda. It is used in applications where high gain and directionality are required. The antenna with the widest beam width and with the highest bandwidth is the 2.4 GHz λ/2 dipole antenna. The antenna with the lowest gain and the lowest bandwidth is the 2.4 GHz microstrip patch antenna. Nevertheless, these type of antennas are used in many applications, including for mobile and satellite communications, global positioning systems, radio frequency identification and in various WiMax (IEEE 802.16 standard) applications.

The presented laboratory testbed can be used by students for evaluation of different types of antennas and for conducting laboratory exercises within the subject "Radio communication technologies", which is part of the BSc curriculum of the Telecommunications department.

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REFERENCES

Azarmanesh, M., Soltani, S. and Lotfi, P., (2011). Design of an ultra-wideband monopole antenna with WiMAX, C and wireless local area network band notches. *IET Microwaves, Antenna & Propagation*. 5(6): 728-733.

Balanis, C. A., (2016). *Antenna Theory: Analysis and Design*. John Wiley and Sons. 4th Edition. ISBN: 978-1-118-64206-1

Hanumante, V., Roy S., (2013). *Comparative Study of Microstrip Patch Antenna Using Different Dielectric Materials*. 9th International Conference on Microwaves, Antenna, Propagation and Remote Sensing ICMARS-2013, 11th - 14th December, Jodhpur, INDIA.

Huang, C. Y., Jeng, B. M. and Yang, C. F., (2008). Wideband monopole antenna for DVB-T applications. *Electronic Letters*. 44(25): 1448-1450.

Huang, Y., Boyle, K. (2008). *Antennas: from theory to practice*. John Wiley and Sons. ISBN 978-0-470-51028-5

Sim, D. U., Moon, J. I. and Park S. O., (2004). A wideband monopole antenna for PCS/IMT-2000/Bluetooth applications. *IEEE Antenna and Wireless Propagation Letters*. 3: 45-47.

