Tajchai PUMPOUNG[1], Pitchanun WONGSIRITORN[2]

Rajamangala University of Technology Isan, Faculty of Engineering and Architecture (1), Rajamangala University of Technology Rattanakosin, Faculty of Engineering (2)

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Accurate Measurement Techniques for 75 Ohms Antenna with 50 Ohms Vector Network Analyzer

***Abstract**. This paper described accurate measurement techniques of a 75 ohms antenna with 50 ohms vector network analyzer (VNA). The antenna under test (AUT) was a commercial antenna (SP-073 DTV antenna). The analysis techniques used three basic principles namely the return loss, Friis formula and absolute gain Eq.s to solve the differences of characteristics impedance (Z_o). The experimental results showed that although the Z_o of AUT was different from the VNA it could also measure the impedance, radiation pattern and gain without the 50 to 75 Ohms converter. While the use of converter led to unacceptable results.*

Streszczenie.** W pracy opisano metodę dokładnego badania anteny 75-ohms przy pomocy analizatora wektorowego sieci VNA. Badania przeprowadzono na przykładzie anteny SP-073-DTV. |Metoda analizy wykorzystuje trzy główne zasady: straty powotnre, formułę Friis i równanie wzmocnienia.* ***Metoda dokładnego badania 75-omowej anteny przy pomocy wektorowego analizatora sieci.

Keywords: Absolute gain; Characteristics impedance; Friis formula; Refection coefficient; VNA.
Słowa kluczowe: antena 75-omowa, badania anteny, wektorowy analizator sieci.

Introduction

The evolution of transmission line use with radio frequency (RF) systems has been continuously developing along with the telecommunications technology. Hence, there are many types of cables available nowadays. The transmission line used with antenna can be classified into three main categories: 50, 75 and 300 ohms. The 300 ohms transmission line is currently used in the smallest group, followed by 75 ohms and the most popular is 50 ohms. The current popularity of the 50 ohms transmission line can be explained by the evolution development and experimentation of scientists leading to recognition that the 50 ohms transmission line has features better than the previous transmission lines [1, 2]. For several years, antenna researchers have focused on design of antenna to support 50 ohms transmission lines resulting in less research on the 75 and 300 ohms.

Typically, the suitable instruments for measuring the main electrical characteristics of antennae such as return loss (*RL*), radiation pattern and gain are vector network analyzer (VNA). In measurement, the calibration kit has to be used together with the VNA to achieve accurate results. The VNA and calibration kit is considered a costly tool [3]. Thus, a small antenna laboratory or a newly established laboratory which has less funding support, is unable to obtain the VNA and calibration kit to support the testing for the three antenna systems at the same time. The 50 ohms VNA and calibration kit are appropriate for a small antenna laboratory, it is a suitable investment and they can be used frequently and are more valuable than other systems.

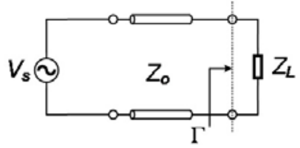
Later problems occurred when there was related research on the topic of 75 ohms antenna such as in the case of digital television DTV [4, 5]. Many researchers still mistakenly use the 50 ohms VNA and calibration kit for measurement of the 75 ohms antenna. They incorrectly presume that the 50 to 75 ohms converter [6] can transform the characteristics impedance (Zo) of 50 ohms VNA to 75 ohms and the measured results such as *RL*, will be based on Z_o = 75 ohms, which is not the case. When used in real practice, the performance will not be as good as the measured results. This highlights the importance of problem statement of this paper that other researchers can apply to correct principles.

The paper is organized as follows, Section 2 describes the principle of measurement consisting of *RL* (dB), radiation pattern and gain. The measured correct results of commercial DTV antennae from the principle described in Section 2 are shown in Section 3. Section 4 studies the effects of measurement by using 50 to 75 ohms converter with 50 ohms VNA. Finally, a conclusion is described in Section 5.

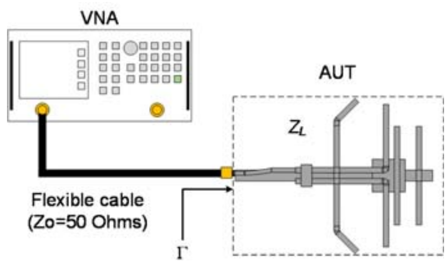
Principle of measurement

This section describes the principle of measuring the electrical characteristics of an antenna which has a different feature impedance from the VNA. It consists of three electrical characteristics namely *RL*, radiation pattern and gain.

Return loss



(a)



(b)

Fig.1. The connection model of *RL* measurement: (a) equivalent circuit of the antenna connected to the signal source and (b) the scheme of AUT.

The definition of *RL* (dB) is described in many books such as Pozar D. M. [7]. *RL* (dB) is defined by Eq. (1) as

(1) $$RL = -20\log\left|\Gamma\right|(\text{dB}).$$

RL (dB) is related to the reflection coefficient (Γ). Γ is defined by Eq. (2) as

(2) $$\Gamma = \frac{Z_L - Z_o}{Z_L + Z_o}.$$

Where Z_L is the load impedance of the antenna. While Z_o is the characteristic impedance of the transmission line (which in this context means the VNA transmission line). Z_o of VNA has been defined since the design and production. In the case of 50 ohms VNA, Z_o is equal to 50 ohms. Then, *RL* (dB) has appeared on the VNA screen, which is the suitable result of *RL* (dB) to use with 50 ohms transmission line only as shown the connection model for *RL* (dB) measurement of AUT with VNA in Fig. 1.

However, while measuring *RL* (dB), Z_L can be known at the same time. Therefore, if *RL* (dB) which is suitable for each transmission line system such as 75 ohms is proposed to be evaluated, it can be achieved by replacing Z_o = 75 ohms into Eq. (2) and (1), respectively. The measured results will be suitable *RL* (dB) for 75 ohms transmission lines.

Radiation pattern

There are two techniques for measuring radiation pattern. The first technique is to measure with a frequency generator along with a spectrum analyzer [8, 9]. The second technique is the measurement with a network analyzer [10, 11]. Normally, both measurement techniques use the transmission line which has Z_o same with an antenna designed. But that is not a fixed rule. Because in real situations, the radiation pattern measurement can be done. Although the transmission line system has different characteristics impedance the shape of the radiation pattern remains unchanged [12, 13].

In this paper, the second technique of measurement by VNA was chosen. The radiation pattern was measured with a VNA and expressed as either $|S_{12}|$ (dB), $|S_{21}|$ (dB) as shown in the scheme in Fig. 2.

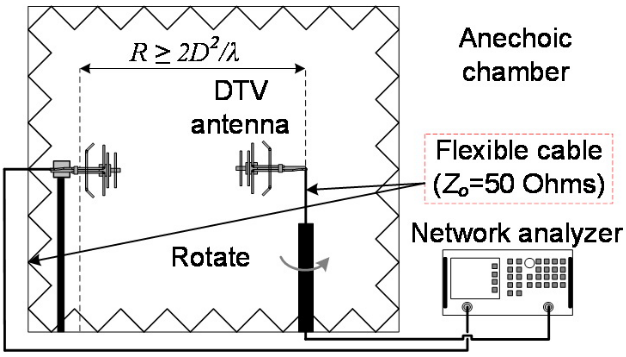


Fig.2. The scheme of radiation pattern and gain measurement.

Gain

The measured gain can be obtained by using the relation from the calculation with two equations [11] which are the Friis formula as given by:

(3) $$G_{abs} = \frac{\left(20\log_{10}\left(\frac{4\pi R}{\lambda}\right) + |S_{21}|(\text{dB})\right)}{2},$$

where the AUT on both sides as shown in Fig.2 has the same characteristics and absolute gain in Eq. (4) as given by:

(4) $$G_{abs} = (1 - |\Gamma|^2)e_{cd}D(\theta,\varphi).$$

The intensive measurement steps of *RL* (dB), radiation pattern and gain will be shown in the next section.

Measurement results

All the experiment results presented in this paper were conducted in an anechoic chamber. The instrument for measurement used a ROHDE & SCHWARZ 50 ohms VNA: a model of ZVRE while the AUT that uses digital terrestrial television antenna (DTV): model SP-073 (75 ohms antenna).

Impedance and RL* (dB) *measurement results

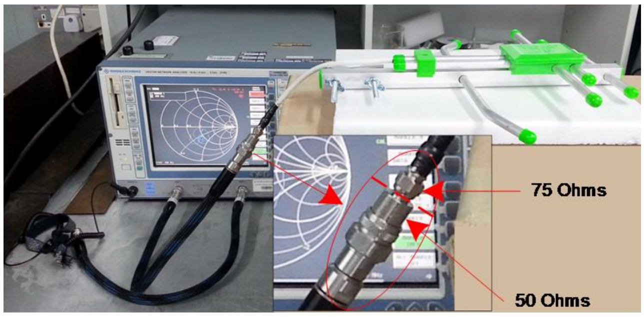


Fig.3. Impedance and *RL* (dB) experimentation environment of the AUT.

Fig. 3 shows the environment of impedance experimentation. The measured results were done without an impedance converter (50 to 75 ohms). After, the transmission line and VNA was calibrated with the 50 ohms calibration kit already. AUT is connected similar to Fig. 1. Then, the results of AUT impedance at the frequency band of 450-850 MHz; which is the frequency band of UHF TV in the universal standard (470-890 MHz) [6], and the frequency band of terrestrial DTV of Thailand (470-790 MHZ) [14] were measured as shown in Fig. 4. It can be seen that the impedance has the lowest and highest resistances of 20.08 ohms (@ 830 MHz) and 109.40 ohms (@460 MHz) respectively. While the lowest and highest reactances are -*j* 54.47 ohms (@ 480 MHz) and +*j*13.13 ohms (@450 MHz), respectively. The impedance of AUT as shown in Fig.4 is the same impedance that appears on the VNA.

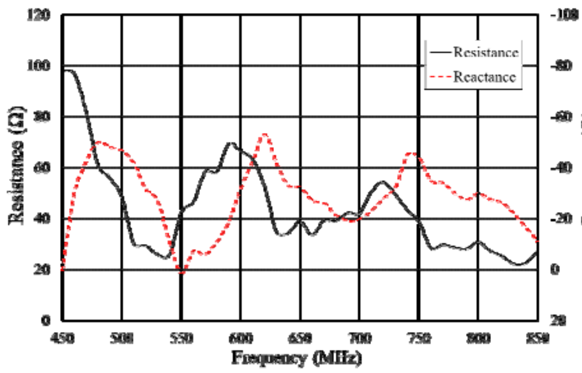


Fig.4. The impedance measurement result of the AUT.

At the same time, when considering *RL* (dB), it was found that RL_{50} (dB) as lower than 10 dB that cover two frequency bands are 532-597 MHz and 662-732 MHz as shown in Fig. 5 at the dashed line. However, it is the *RL* (dB) of Z_o = 50 ohms. The set-top box of DTV terrestrial has Z_o = 75 ohms. Thus, the antenna design has to match with 75 ohms transmission line system such as RG6 or RG11 cable. Thus, *RL* (dB) has to consider with Z_o=75 ohms. It can be applied to the measured impedance result of AUT and replace it to Z_L at Eq. (2). Then, instead of characteristic impedance as must be used in Z_o (in this case Z_o=75 ohms), Γ_{75} will be suitable for the 75 ohms transmission line. The final step takes the Γ_{75} instead of the *RL* (dB) Eq. (1). RL_{75} (dB) can be achieved by using the 75 ohms transmission line system as shown in Fig.5 with the solid line, that covers two frequency bands of 450-471 MHz and 843-604 MHz. It can be seen that the different values of Z_o has affected the meaning in consideration *RL* (dB) that changed.

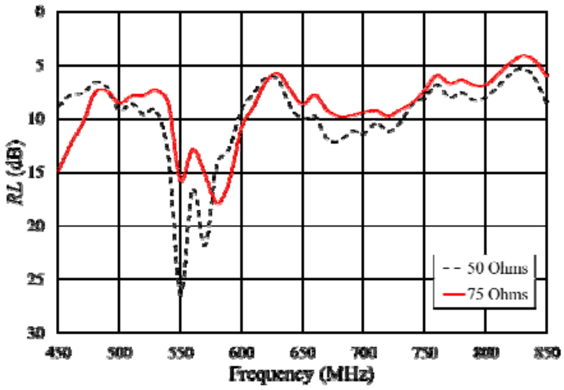


Fig.5. The *RL* (dB) measurement result of the AUT.

Radiation pattern and gain measurement results

In impedance and *RL* (dB) measurement results, the results showed that the VNA can be used to measure RL (dB) of an antenna despite having different antenna impedance. At the same time, the radiation pattern of each antenna was also unique.

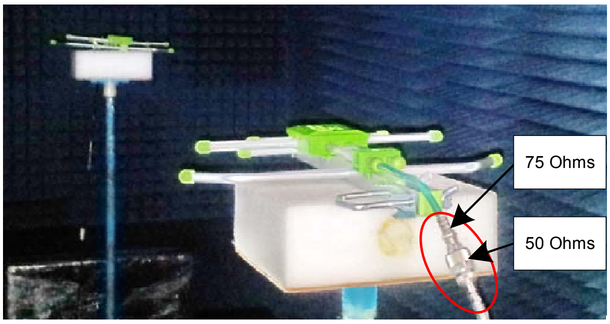


Fig.6. Experimentation environment of AUT: the radiation pattern and gain measurement.

This section shows the results of the radiation pattern and gain of AUT from 50 ohms VNA as shown in the experimentation environment of AUT in Fig. 6. The radiation pattern was measured with a VNA following the scheme described in the section of the principle of measurement. It can be divided into three steps [13]. The first is the calibration of 50 ohms transmission line with VNA. In the second step, the transmission lines are connected to AUT on both sides. The third step is measurement $|S_{21}|$ (dB) or $|S_{12}|$ (dB) (depending on the set up or function of VNA). While AUT rotated on azimuth and elevation planes at the frequency band of 470 MHz 510 MHz and 790 MHz, respectively. Then, the normalized radiation patterns are performed as shown in Fig. 7. It can be seen that both radiation patterns of AUT based on of Yagi-Uda antenna structure on azimuth and elevation planes have the unidirectional beam with the HPBW (half-power beamwidth) in the azimuth and elevation planes of 85° and 140° at 470 MHz, 75° and 150° at 510 MHz and 65° and 105° at 790 MHz, respectively.

The gain measurement was conducted by using the principles of equations 3 and 4, respectively. The step was divided into three steps. First is the measurement of the absolute gain of AUT in a condition of using 50 ohms transmission line by applying Eq. (3). That is calculated via the Friis formula as given by:

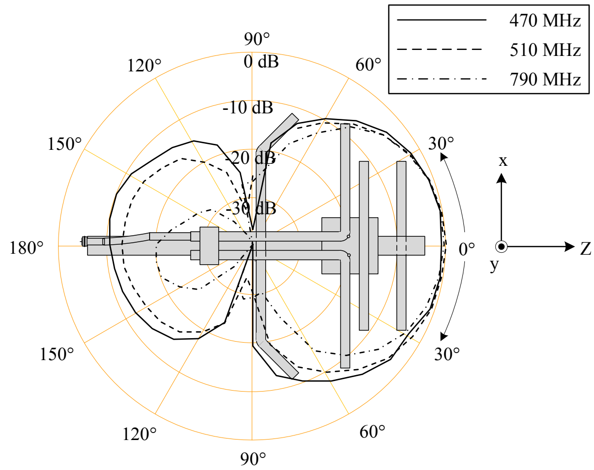
$$G(50\Omega)_{abs} = \frac{\left(20\log_{10}\left(\frac{4\pi R}{\lambda}\right) + |S_{21}|(\text{dB})\right)}{2}. \quad (5)$$

Second is to apply the $G(50\Omega)_{abs}$ to Eq. (4) for calculation of the antenna radiation efficiency (e_{cd}) and directivity ($D(\theta, \varphi)$) of AUT as given by

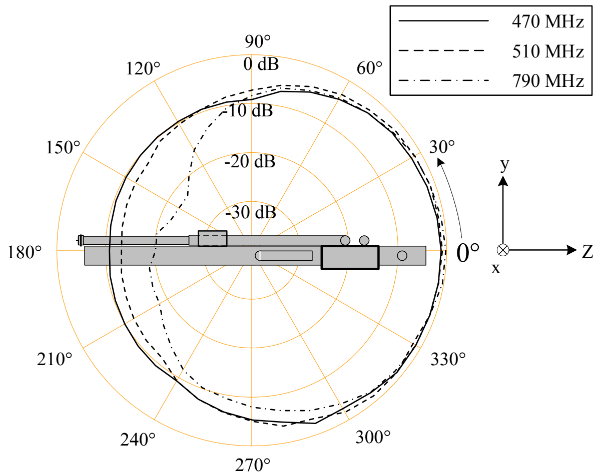
$$G(50\Omega)_{abs} = (1 - |\Gamma_{50\Omega}|^2) e_{cd} D(\theta, \phi). \quad (6)$$

Where the $\Gamma_{50\Omega}$ is derived from the step of impedance measurement with VNA as previous. Then, e_{cd} and $D(\theta, \varphi)$ of AUT are given by

$$e_{cd} D(\theta, \phi) = \frac{G(50\Omega)_{abs}}{(1 - |\Gamma_{50\Omega}|^2)}. \quad (7)$$



(a)



(b)

Fig.7. Radiation pattern from measured: (a) azimuth-plane and (b) elevation-plane.

In the final step, the absolute gain in a condition of using 75 ohms transmission line is calculated by replacing $e_{cd} D(\theta, \phi)$ by Eq. (7) to Eq. (8) as given by:

$$G(75\Omega)_{abs} = (1 - |\Gamma_{75\Omega}|^2) e_{cd} D(\theta, \phi). \quad (8)$$

Where $\Gamma_{75\Omega}$ caused by the previous step of the impedance and *RL* (dB) measurement results.

Fig. 8 shows the gain of AUT in the condition of using 50 ohms and 75 ohms transmission lines. The results showed that both gains had the same trend. The average gains of AUT in condition using 50 ohms and 75 ohms transmission line were 8.86 dBi and 8.80 dBi, respectively. The minimum gains were 7.64 dBi and 7.52 dBi (@ 510 MHz of both impedances) and the maximum gains were 13.50 dBi and 12.89 dBi (@ 850 MHz of both impedances), respectively.

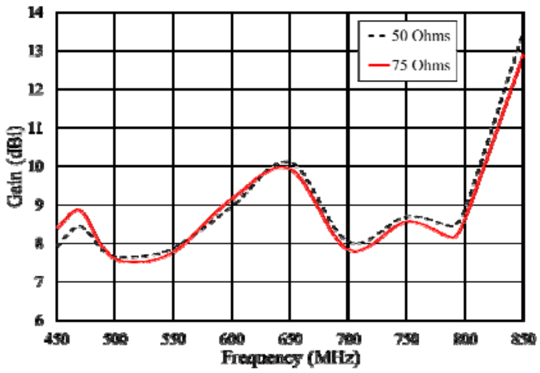


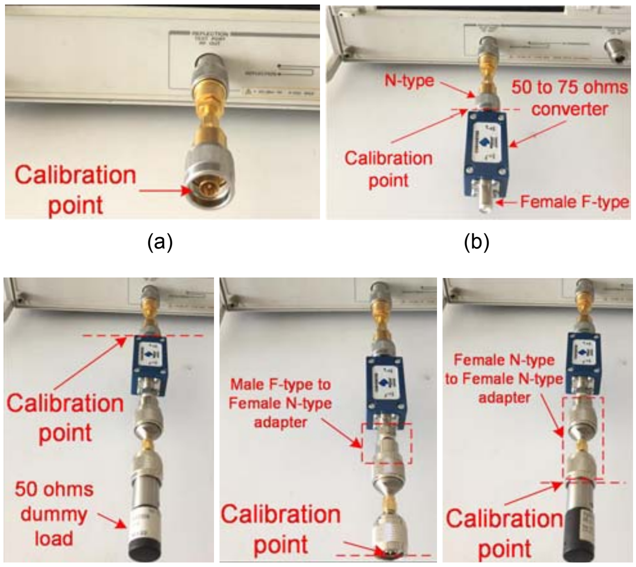
Fig.8. Measured gain of AUT.

Effects of using the converter and estimation for testing

This section describes the effects of measurement by using 50 ohms (female N-Type) to 75 ohms (female F-Type) converter with 50 ohms VNA. A Wilson 50 to 75 ohms converter model of 859955 was the equipment under test (EUT). The experimental instrument and calibration kit are Agilent VNA model of 8753ET and the female N-type calibration kit as shown in Fig. 9.

Fig.9. EUT for experimental the effects of using the converter.

The case studies are classified into five cases. First, the calibration was done at the end of the male N-type connector as shown in Fig. 10. (a). Then measurement the impedance in the case of open circuit (without load) was done as shown in Fig.11 in case 1. The measured results illustrated that the impedance on the Smith chart will approach the right-hand side of the Smith chart, which is the ideal open circuit area. The second case was connecting the converter 50 to 75 ohms after the calibration after step 1. Then the measurement of the impedance in the case of open circuit (without load) was performed as shown in Fig. 10. (b). Fig. 11 in case 2, it can be seen that the impedance has a direction deviating to the left-hand side of the Smith chart. The highest and lowest resistances are respectively 2 ohms and 0 ohms. While, the highest and lowest reactances are +*j*48.15 ohms and -*j*32.28 ohms, respectively. The readable impedance from VNA has changes due to the fact that once any device is brought to be connected in after the calibration, VNA will be considered EUT. The result was shown in the format of impedance and *S* parameters. Therefore, connecting AUT after the converter, in this case, may cause the result to not match the properties of the antenna.



(a) (b)

(c) (d) (e)

Fig.10. Case studies environment: (a) N-type open circuit measured, (b) F-type convertor open circuit measured, (c) add converter and dummy load after for measured, (d) include converter and add male to male F-type adapter before open circuit measured and (e) measured with dummy load after step (e).

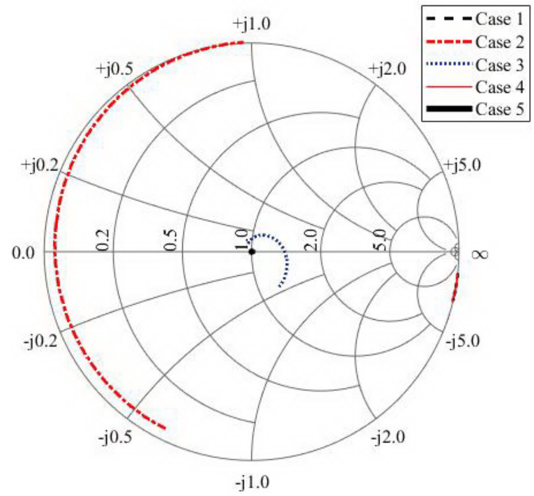


Fig.11. The impedance of case studies.

In the third case, after adding the convertor, the broadband 50 ohms dummy load was connected at the female F-type connector as shown in Fig. 10. (c). Fig. 11 in the case 3 can be observed that the impedance is at the centre zone of the Smith chart but it is not in the centre point of the Smith chart. If a broadband dummy load is connected, the correct measurement results of the impedance should be at the centre point of the Smith chart. It is shown that the experimental of EUT of this technique is still an incorrect technique. Therefore, it can be concluded from the three cases before that if the converter is connected after the calibration step, the measurement results of AUT will be not correct. Therefore, adjusting the calibration points by connecting the converter to VNA should be done first and then calibrating as in case 4 presented in Fig. 10. (d). Fig. 11 in case 4 show that the tendency of impedance is similar to case 1.

Finally, the fifth case is an extension of case 4 by connecting the 50 ohms dummy as shown in Fig. 10. (e). It can be seen that the overall impedance is at the centre point zone of Smith chart as shown in Fig. 11 in case 5. That means that VNA considered 50 ohms dummy load an ideal load match as the characteristic of them. Therefore, it can be concluded that the measurement should be done by connecting the convertor from VNA first and then calibration as in case 4. It is obvious that in case 5, EUT can be connected from convertor in case 4 and the results showed that it can provide adequate accurate impedance as shown in Fig. 11 (case 5). However, this technique in case 5 is not recommended. From the observation of the calibration in cases 1 and 4, the measurement results after the calibration almost do not differ. Therefore, it can be concluded that if EUT is connected after calibration, the results will be similar.

Nevertheless, connecting the converter, as in case 4 might make the experimental become unwieldy and unnecessary.

However, it might be difficult to observe a *RL* (dB) of lower than 10 dB by 50 ohms VNA with 75 ohms antenna. Then, if the lowest and highest impedances which affect *RL* (dB) of 75 ohms antenna of lower than 10 dB can be known before setting an experiment, it will be helpful to allow an estimation of the rough performance of the antenna before transforming by an equation. The possibility that the antenna is matched with 75 ohms transmission line can be approximately calculated with Eq. (1), as shown in Table 1 by setting the situation into two cases. The first assumes the reactance to be zero or perfectly conjugate match with the 75 ohms transmission line while the resistance is adjusted. Secondly, the resistance of the antenna is assumed to be perfectly matching with the 75 ohms transmission line while the reactance is varied. Table 1 shows that the maximum and minimum resistances of 75 ohms as antenna design should be not higher or lower than 144.38 ohms and 38.96 ohms, respectively. While the maximum and minimum reactances should be not higher or lower than ±*j*50 ohms.

Table 1. Impedance for various *RL* (dB) based on Eq. (2)

Resistance (Ω)		Reactance (Ω)	
Maximum	Minimum	Maximum	Minimum
144.38	38.96	+*j*50	-*j*50

Conclusion

In this paper, the principle of the return loss and the reflection efficiency equations has been presented for application to transform the return loss suitable with the 75 ohms transmission line by measurement with 50 ohms VNA. The radiation pattern can be measured normally with a network analyzer as each antenna has a unique radiation pattern. Although the impedance of the antenna is a mismatch with Z_o of the transmission line, the radiation pattern remains unchanged. However, the caution is that the transmitted energy must be sufficient for the sensitivity of VNA (a high mismatch may lead to a high loss). The proposed technique of a gain measurement with AUT of 75 ohms antenna is successfully achieved by the application of the Friis formula and absolute gain equation.

The proposed effects of using the converter 50 ohms to 75 ohms were concluded to be an unsuitable technique for measuring the impedance, *RL* (dB), and refection coefficient of 75 ohms antennae. Likewise, the gain measurement of 75 ohms antenna, if the obtained reflection coefficient is an incorrect value, the antenna gain will be an inaccurate value causing errors in actual use. Nevertheless, it can be used for measuring the radiation pattern as the radiation pattern measurement does not depend on the impedance of AUT. The convertor impedance may be suitable to transform the impedance from one impedance system to another impedance system. However, it is unsuitable for measuring the electrical characteristics of AUT. Furthermore, all proposed techniques in this paper show that no matter what the Zo system of the antenna is; such as 25 ohms, 75 ohms or 300 ohms, the proposed measurement techniques in this paper can be used and provide adequate accurate values.

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***Authors**: Tajchai Pumpoung, Department of Telecommunications Engineering, Faculty of Engineering and Architecture, Rajamangala University of Technology Isan, Nakhon Ratchasima, 30000, Thailand, E-mail: tajchai.pu@rmuti.ac.th; Pitchanun Wongsiritorn, Department of Telecommunications Engineering, Faculty of Engineering, Rajamangala University of Technology Rattanakosin, Nakhon Pathom, 73170, Thailand, E-mail: pitchanun.won@rmutr.ac.th.*

REFERENCES

[1] Breed G., There's Nothing Magic About 50 Ohms, *High Frequency Electronics*, 6 (2007), 6-7
[2] Breed G., Why 50 Ohms? The Readers Respond!, *High Frequency Electronics*, 6 (2007), 63-67
[3] Keysight Technologies 2000-2019, "Network Analyzers," Available at: https://www.keysight.com/en/pcx-x2015001/network-analyzers?nid=-32503.0&cc=TH&lc=eng
[4] Wong. L., Chi Y. W., Brian C., Yang S., Internal DTV antenna for folder-type mobile phone, *Microwave Optical Technology Letter*, 48 (2006), 1015-1019
[5] Piotr J.-M., Grzegorz T., Mariusz W., Flexible antenna design for semi-passive HF RFID transponder in ink-jet technology, *Przegląd Elektrotechniczny*, 4 (2015), 1-5
[6] 2019 WilsonAmplifiers.com, "ANTENNAS & PARTS: Wilson Electronics 50 ohm to 75ohm Converter – 859955." Available at: https://www.wilsonamplifiers.com
[7] Pozar D. M., Microwave Engineering, John Wiley & Sons, 2012
[8] Farzaneh S., Ozturk A. K., Sebak A. R., Paknys R., Antenna-Pattern Measurement Using Spectrum Analyzer for Systems with Frequency Translation, *IEEE Antennas and Propagation Magazine*, 51 (2009), No. 3, 126–131
[9] Varnoosfaderani, M. V., Thiel, D. V., Junwei Lu., External Parasitic Elements on Clothing for Improved Performance of Wearable Antennas. *IEEE Sensors Journal*, 15 (2015), No. 1, 307-315
[10] Sun, L., Zhang, G., Sun, B., Tang, W., Yuan, J., A Single Patch Antenna with Broadside and Conical Radiation Patterns for 3G/4G Pattern Diversity. *IEEE Antennas and Wireless Propagation Letters*, 15 (2016), 433–436
[11] Bhardwaj, S., Nahar, N. K., Volakis, J. L., A Cost-Effective Phase less Pattern Measurement Method for a CP Antenna in a Submillimetre-Wave Band. *IEEE Antennas and Wireless Propagation Letters*, 16 (2017), 1683–1686
[12] Balanis C. A., Antenna Theory Analysis and Design John Wiley & Sons, 2005
[13] Pumpoung T., Phongcharoenpanich C., Design of wideband tag antenna for UHF RFID system using modified T-match and meander-line techniques, *Electromagnetics J*, 35 (2015), No.5, 340-354
[14] NBTC, "Spectrum Management Master Plan No. 3 (B.E. 2560) (2017)", Available at: https://www.nbtc.go.th/spectrum_management/