UWB ANTENNA USING INDIUM TIN OXIDE (ITO)

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PERPUSTAKAAN TUNKU TUN AMINAH

Especially for my beloved mother who has supported, encouraged and inspired me all the way since the beginning of my studies.

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In the name of Allah, the Most Gracious and the Most Merciful. Alhamdulillah, all praises to Allah for the strengths and His blessing in completing my project report. First and foremost, I want to thank my mother for her love, prayers and support throughout my life.

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ABSTRACT

Recently, the need of high data rate communication, enormously fast speed and shorter distance, the engineers and scientists had have decided to work in the larger scale of frequency resulted in the usage of ultra wide band (UWB) frequency which ranged from 3.1 GHz to 10.6 GHz. The patch antennas offer a potential solution for narrowband and with some modifications and researches done before, it does applicable for the ultra-wide band applications. It cost, light weight, easy to feed and their attractive radiation characteristics. In this project, the performance of the UWB antenna characteristics using Indium Tin Oxide (ITO) and AgHT were investigated. Parametric studies were performed to quantify the effect of the ITO and AgHT characteristics as well as the PET (plastic polymer) coating. All those parametric studies are conducted and simulated using CST Microwave Studio. The reflection coefficient, radiation pattern, VSWR and gain values were compared and contrast between the two antennas. It can be concluded that the AgHT coated antenna works better than ITO in terms of the gain and radiation pattern while work as good as ITO in reflection coefficient and VSWR

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ABSTRAK

Baru-baru ini , keperluan kepada komunikasi kadar data yang tinggi , sangat laju dan jarak yang lebih pendek , para jurutera dan saintis telah memutuskan untuk bekerja dalam skala frekuensi yang lebih besar menyebabkan penggunaan jalur lebar ultra (UWB) di antara 3.1 GHz sehingga 10.6 GHz. *Antena patch* menawarkan satu penyelesaian berpotensi untuk jalur sempit dan dengan sedikit pengubahsuaian dan penyelidikan dilakukan sebelum ini, ia terpakai bagi permohonan band ultra- lebar. Faktor kos , ringan , *feeding* dan corak radiasi menarik mereka. Dalam projek ini , prestasi ciri-ciri antena UWB menggunakan Indium Timah Oksida (ITO) dan AgHT telah dilihat . Kajian parametrik telah dijalankan untuk melihat kesan ITO dan AgHT ciri-ciri dan juga lapisan PET (polimer plastik). Kajian parametrik dijalankan dan simulasi menggunakan CST Microwave Studio. Pekali pantulan, corak sinaran , VSWR dan gandaan dibandingkan di antara kedua-dua antena. Akhirnya dapat disimpulkan bahawa antena AgHT adalah lebih baik daripada ITO dari segi nilai gandaan dan corak radiasi manakala mempunyai prestasi sama seperti ITO dari segi pekali pantulan dan VSWR

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LIST OF SYMBOLS AND ABBREVIATIONS

W	-	Width
L	-	Length
h	-	Substrate Thickness
ε_r	-	Permittivity
λ_o	-	Wavelength in free space
t	-	Patch Thickness
Γ	-	Reflection Coefficient
RL	-	Return Loss
P_{in}	-	Incident Power
P_{ref}	-	Reflected Power
ZL	-	Load Impedance
Z_o	-	Characteristics Impedance
G	-	Gain
η	-	Efficiency
D	-	Directivity
f_H	-	Upper frequency
f_L	-	Lower frequency
f_C	-	Center frequency
ε_{eff}	-	Effective dielectric constant
L_{eff}	-	Effective Length
fr	-	Resonance Frequency
ΔL	-	Length extension
BW	-	Bandwidth
c	-	Speef of Light
φ	-	Electromagnetic Field Elevation Angle
θ	-	Electromagnetic Field Azimuth Angle

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Nowadays the communication technology vastly while the antenna is the most essential components involved. When the need of high data rate communication, enormously fast speed and shorter distance, the engineers and scientists decided to work in the larger scale of frequency. Finally the ultra wide band (UWB) frequency has been chosen with unlicensed use ranged from 3.1 GHz to 10.6 GHz [1, 2]. The allocation of unlicensed spectrum to UWB technology generated a lot of interest in industry and opened the doors for development of numerous daily life applications based on UWB technology [3].

Any system which has an absolute bandwidth of over 500 MHz or relative bandwidth of greater than 25% is said to be an UWB system. Ultra Wideband Radio (UWB) is a potentially revolutionary approach to wireless communication in that it transmits and receives pulse based waveforms compressed in time rather than sinusoidal waveforms compressed in frequency [2]. This is contrary to the traditional convention transmitting over a very narrow bandwidth of frequency, typical of standard narrowband systems such as 802.11a, b, and Bluetooth. This enables transmission over a wide swath

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of frequencies such that a very low power spectral density can be successfully received [2]. The recent allocation of the 3.1 - 10.6 GHz frequency spectrum by the Federal Communications Commission (FCC) for Ultra Wideband radio applications has presented a myriad of exciting opportunities and challenges for antenna designers [2].

Indium-tin oxide (ITO) is a most popular transparent semiconducting oxide thin film related to the high optical transmittance in the visible and near infrared regions, and also high reflectance in the infrared region, it has been widely applied in various electronic devices, infrared reflectors, and display devices. Because of its low electrical resistivity and its wide electrochemical window, it has also been extensively used as transparent electrodes. Indium tin oxide products include display electrodes for paper-thin LCD, plasma, and organic electroluminescence (EL) televisions, touch screen monitors on ATMS, ticket vending machines, handheld game consoles and mobile phones. Besides, oxide thin films also has stable characteristics for electrical conductivity and electrical transmissions. Moreover, tin oxide also are applied in AgHT. AgHT basic structure is a 3- layered film made of a Silver (Ag) layer sandwiched between two-layers of tin oxide .AgHT played as a conductive coated film developed for use in EMI/RFI shielding and infrared heat rejection applications. AgHT has less resistivity than ITO which is 4 Ωm and 8 Ωm while ITO resistivity not less than 50 Ω-m on a flexible polymer substrates as the ITO layer which is fragile at a low resistivity he advantage The usage of polymer substrate give AgHT benefits which are conformable, lightweight and easy to replace on window glass and providing easy maintenance at a lower cost. AgHT antenna may provide a double impact as a solar module integrated antenna for green technology and a 3-in-1 solution of sun shielding, wireless communication, and solar energy harvesting for energy provision and storage. AgHT also played a potential use as rectennas on glass windows and panels no matter how the size of the antenna design is as well as in large scale antenna arrays. [1]

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1.2 Objective

The objectives of the research are as follows:

1.2.1 Design and simulate the UWB antenna using ITO and AgHT.

1.2.2 Investigate the performance of the UWB in terms of return loss, VSWR, gain and radiation pattern.

1.3 Scope

The scopes of the research are stated below:

1.3.1 Design and simulate the UWB antenna using ITO and AgHT operating at 3.1 up to 10.6 GHz using CST Microwave Studio.

1.3.2 Investigate and observe the performance of these antennas through several parametric studies.

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CHAPTER 2

LITERATURE REVIEW

2.1 Basic Concept of Microstrip Patch Antenna

A microstrip patch antenna has been one of the most innovative topics in antenna theory and design. Microstrip antennas are designed to have many geometrical shapes and dimensions but rectangular and circular microstrip patches have been used in many application. They are used in wide range of modern microwave applications because of their simplicity and compatibility with printed-circuit technology.

A microstrip patch antenna in its simplest form consists of a radiating patch on one side of a dielectric substrate and a ground plane on the other side as shown in Figure 2.1. The bottom surface of a thin dielectric substrate is completely covered with metallization that serves as a ground plane. The rectangular microstrip patch antenna is made of a rectangular patch with dimensions width (W) and length (L) over a ground plane with a substrate thickness (h) and permittivity (εr). The length (L) of the patch is usually $\lambda_O/3 < L < \lambda_O/2$ and the thick of the patch is very thin ($t \ll \lambda_O$).

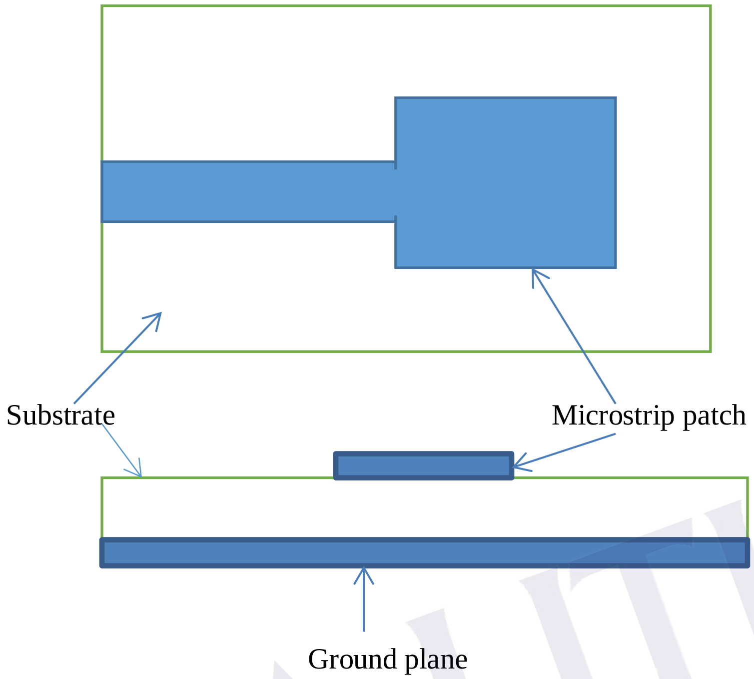

Figure 2.1: The simplest microstrip patch antenna.[2]

The patch is generally made of a conducting material like gold or copper. The radiating patch and the feed lines are commonly photo etched on the dielectric substrate. Microstrip patch antennas radiate primarily because of the fringing fields between the patch edges by variety of methods. The patch is in fact electrically a bit larger than its physical dimensions due to its fringing fields.

Although rectangular microstrip has a very simple geometric structure, the electromagnetic fields involved are actually complex. Accurate and thorough analysis requires mathematical treatment. Some of the disadvantages of microstrip antenna configurations include narrow bandwidth, spurious feed radiation, and poor polarization purity, excitation of surface waves, limited power capacity, and tolerance problem.

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2.2 Types of Microstrip Patch Antenna

There are different types of microstrip patch antennas which can be classified based on their physical parameters. The patch may be square, rectangular, dipole, circular, triangular, circular ring, elliptical or any other configuration. These are illustrated in Figure 2.2.

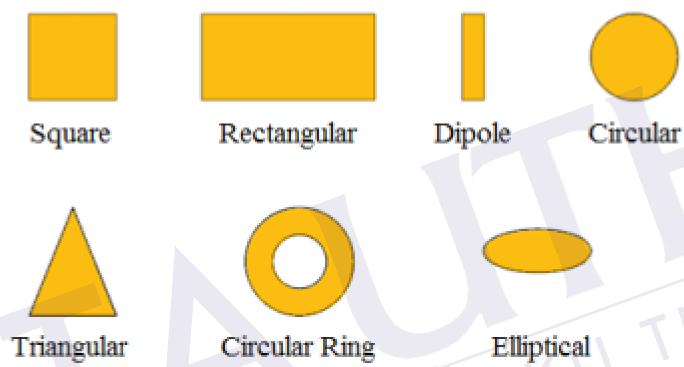

Figure 2.2: Common shapes of microstrip patch antenna.[2]

The rectangular microstrip patch antenna is widely used because of ease of fabrication and analysis. This type is also robust design and very eases to handle.

2.3 Feeding Techniques

Microstrip patch antennas can be fed by a variety of methods. These methods can be classified into two categories, contacting and non-contacting. To obtain a desirable return loss at the resonant frequency, a microstrip patch antenna must be matched to the transmission line feeding it.

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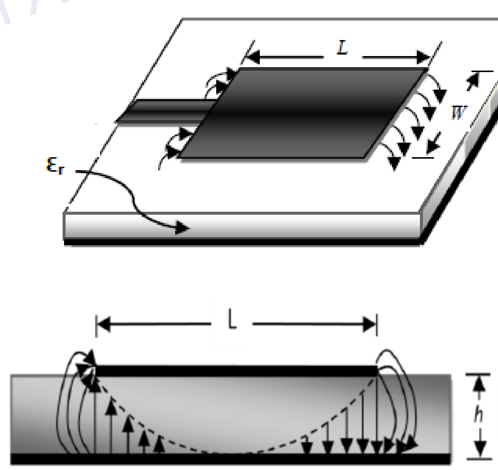
The microstrip line is also a conducting strip. It is easy to fabricate and simple to match by controlling the feed position and rather simple to model. This conducting strip is directly connected to the edge of the microstrip patch. The conducting strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure. This conducting strip and the patch are also made from the same material [2].

2.4 Fringing Effects

Fringing fields have a great effect on the performance of a microstrip antenna. In microstrip patch antennas, the electric field in the center of the patch is zero. The radiation is due to the fringing field between the periphery of the patch and the ground plane. Figure 2.3 shows there is no field variation along the width and thickness. The amount of the fringing field is a function of the dimensions of the patch and the height of the substrate. Higher the substrate, the greater is the fringing field [7] [2].



(a) Electric field lines (top view) (b) Electric field lines (side view)

Figure 2.3: Electric field lines for rectangular microstrip patch antenna. [2]

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Due to the fringing effect, the microstrip patch antenna looks greater than its physical dimension. Thus, an effective dielectric constant is to be introduced. The effective dielectric contstant takes in account both the fringing and the propagation in the line. Hence, when designing a patch antenna it is typically trimmed by 2-4% to achieve at the desired resonance frequency.

2.5 Radiation Pattern

The power radiated or received by an antenna is a function of the angular position and radial distance from the antenna. The radiation pattern is good represented in the form of a three dimensional graph of power versus elevation and azimuth angles but more commonly represented by E-plane or H-plane where one angle is held fixed while the other is varied [2]

The microstrip patch antenna has radiation pattern that can be calculated easily. The source of the radiation of the electric field at the gap of the edge of the microstrip element and the ground plane is the key factor to the accurate calculation of the patch antenna.

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2.6 Return Loss

Return loss is an important parameter when connecting an antenna. It is a way to characterize the input and output of signal sources. The return loss is related to impedance matching and the maximum transfer of power theory. When the load is mismatched, not all the available power from generator is delivered to the load. This return loss is also a measure of the effectiveness of an antenna to deliver power from the source to the antenna [2].

The return loss, RL shows the level of the reflected signal with respect to the incident signal in dB. It is defined by the ratio of the incident power of the antenna P_{in} to the power reflected back from the antenna of the source P_{ref}. The mathematical expression is:

$$RL = -20\log_{10}|\Gamma|(dB) \qquad (2.1)$$

Where $|\Gamma|$ is determined by:

$$|\Gamma| = \frac{P_{in}}{P_{ref}} = \frac{Z_L - Z_O}{Z_L + Z_O} \qquad (2.2)$$

The Z_L and Z_O are the load and characteristic impedance.

For good power transfer, the ratio P_{in}/P_{ref} shall be high. If the return loss is low, the standing wave phenomena's or resonances might occur, and it will end up in the frequency ripple or gain. During the process of the design of microstrip patch antenna there is a response taken from the magnitude of S_{11} versus the frequency which known as the return loss. In most practical circuits a return loss value of -10 dB is good enough [2].

2.7 Gain

Gain is a useful measurement describing the antenna performance. Although the gain of the antenna is closely related to directivity, it is a measure that takes into account the efficiency of the antenna as well as its directional capabilities. Antenna gain usually expressed in dB, simply refers to the direction of maximum radiation. Mathematically the maximum gain, G is obtained by using equation 3[2]

$$G = \eta D \qquad (2.3)$$

Where, η = efficiency and D = directivity

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2.8 Directivity

It is desirable to maximize the radiation pattern of the antenna response in a fixed direction to transmit or receive power. Likewise, the directivity is dependent only on the shape of radiation pattern. It is always referenced to an isotropic point source as in Figure 2.5. A quantitative measure of this response is the directive gain of the antenna for a given direction.

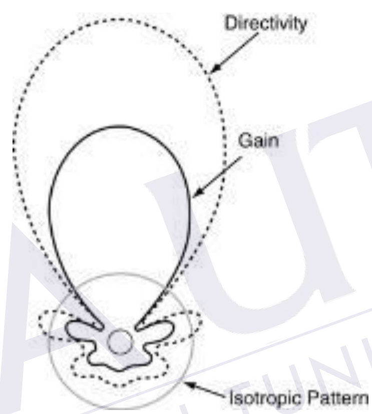

Figure 2.4: Directivity of an antenna [2]

2.9 Bandwidth

The bandwidth of an antenna is defined as the range of usable frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard [1]. The bandwidth can be defined as the ratio of the upper to lower frequencies of acceptable operation. The bandwidth of a narrowband antenna can be defined as the percentage of the frequency difference over the center frequency. The bandwidth is given by the expression:

$$Bandwidth_{narrowband}(\%) = \left[\frac{f_H - f_L}{f_C}\right] \times 100\% \tag{2. 4}$$

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REFERENCES

1. Peter, T.(2012) , *Optically Transparent UWB Antenna for Wireless Application & Energy Harvesting*, Brunel University, PhD Thesis.

2. Balanis Constantine A., *Antenna Theory, Analysis and Design*, 2nd edition. John Wiley & Sons Inc. n. 1997

3. Zehforoosh,Y., Ghobadi, C., and Nourinia,J., (2006) Antenna Design for Ultra Wideband Application Using a New Multilayer Structure *PIERS Online*, 2(6): pp 544-549

4. Sohaib, M. (2010), *Antenna Design for UWB Radar Detection Application,* Chalmers University of Technology : Master's Thesis

5. Guan,N., Furuya, H., Delaune D. & Ito,K., Antennas Made of Transparent Conductive Films, *PIERS online,* 2008. 4(1): 116-120.

6. Chen-Tin Lee, Cheng-Ming Lee, Ching-Hsing Luo, The Transparent Monopole Antenna for WCDMA and WLAN, *IEEE journals*, WAMICON 2006.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

7. Jo M., Lim C. G., & Zimmers E.W., *RFID tags detection on water content using a back propagation learning machine*, KSII Trans. On Internet and Information Systems, Vol. 1, no. 1, pp. 19–32, 2207.

8. Elrashidi. A, Elleithy K.& Bajwa H., *Input Impedance, VSWR and return loss of a Conformal Microstrip Printed Antenna for TM_{01} Mode Using Two Different Substrates*. International Journal of Network and Communications, 2012, 2(2):13-19.

9. Saberin, J.R., Furse, C., Challenges With Optically Transparent Patch Antennas for Small Satellites, *IEEE journal*, 2011,

10. Yasin,T., Baktur, R., and Furse, C., A Study on the Efficiency of Transparent Patch Antennas Designed from Conductive Oxide Films, *IEEE journal*, 2011 pp 3085-3087

11. Nasser-Moghadasi, M. and Koohestani, M., A Simple UWB Microstrip-Fed Planar Rectangular Slot Monopole Antenna, *Loughborough Antenna & Propagation Conference*, 2011. pp1-3.

12. Bialkowski, M. E. and Abbosh A.M., "Design of UWB Planar Antenna With Improved Cut-Off at the Out-of-Band Frequencies" *IEEE Antennas and Wireless Propagation Letters*, 2008 Vol 7, pp 408-410.

13. N.M Khusyafan and M.M. El-Nahass, Study of Structure and Electro-Optical Characteristics of Indium Tin Oxide Thin Films, *Advance in Condensed Matter Physics, 2013*, 2013: 1-3

14. Guan, N., Furuya, H., Himeno, K., Goto, K. and Ito, K., A Monopole Antenna Made of A Transparent Conductive Film, *IEEE Journals*, 2007 :263-266

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

15. Gholipur, A., Askarpour, A.N. and Faraji-Dana, R., A Simple Design Approach for Planar UWB Antennas, *IEEE Journals,* 2009: 1973 – 1976

16. Tai, L.C., Chi, W.S., Comb-Shaped Dipole Antenna on Transparent Substrate, *IEEE Journals,* 2005, 610-612

17. Katsunaros, A., Hao,Y., Collings, N., and Crossland W.A., Optically Transparent Antenna for Ultra Wide-Band Apllications, *Electronic Letters,* 2009, Vol 45, No.14

18. Peter, T. and Nilavalan, R., Study on The Performance Deteriorating of Flexible UWB Antennas, *Loughborough Antenna and Propagation Conference*, 2009, pp 699-672.

19. Peter, T., Sun, Y.Y., AbuTarboush H.F., Nilavalan R., and Cheung S.W., Miniature Transparent UWB Antenna With Tunable Notch for Green Wireless Application, *IEEE Journals* 2011, pp 259 – 262

20. Chen, Y., Liu, S., Dai, Z. and Wei, Y., (2010) Broad-Band Space-Filling-Based Slot Antenna, *Proc. Of ICMMT 2010,* pp 291-293

21. Saberin, J.R. and Furse, C.(2012), Challenges With Optically Transparent Patch Antennas, *IEEE Antennas and Propagation Magazine,* 54(3) pp 10-16.

22. Leung, K.W., Pan, Y.M., Fang, X.S., Lim, E.H., Luk, K.M., and Chan, H.P.(2013), Dual-Function Radiating Glass for Antennas and Light-Covers-Part I : Omnidirectional Glass Dielectric Resonator Antennas, *IEEE Transactions On Antenna and Propagation,* 61(2) pp 578- 586

23. Colombel, F., Castel, X., Himdi, M., Legeay. G., Vigneron, S. and Cruz, E.M. (2009), Ultrathin Metal Layer, ITO Film and ITO/Cu/ITO Multilayer Towards Transparent Antenna, *IET Science, Measurement and Technology,* 3(3) pp 229 – 234

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

24. Pakorn Prajuabwan, Porntheeraphat, S., Klamchuen, Annop & Nukeaw, J. (2007). ITO Thin Films prepared by Gas-Timing RF Magnetron Sputtering for Transparent Flexible Antenna. *Nano/Micro Engineered and Molecular Systems, 2007. NEMS '07. 2nd IEEE International Conference*, pp. 647 – 650

25. Bowman, C., Bogorad, A., Brucker, G., Seehra, S. & Lloyd, T. (1990). ITO-coated RE transparent materials for antenna sunshields-space environment effects Nuclear Science. *IEEE Transactions* 37(6)1 pp.2134 – 2137

26. Chi-Fang Huang & Li Chen(2001). Realization of a printed-on-display antenna for mobile terminals *Antennas and Propagation Society International Symposium, 2001 IEEE* 1:pp.140 - 143

27. Bourry, M., Sarret, M., Drissi, M. (2005). Novel ITO alloy for microwave and optical applications Circuits and Systems, 2005. *48th Midwest Symposium*

28. Leung, K.W., Pan, Y.M., Fang, X.S., Lim, E.H., Kwai-Man Luk, Chan, H.P. (2013). Dual-Function Radiating Glass for Antennas and Light Covers—Part I: Omnidirectional Glass Dielectric Resonator Antennas *Antennas and Propagation, IEEE Transactions 61(2*) :pp.578 - 586

29. Balki, O., Elsayed-Ali, Hani E (2009). Fabrication of Passive Wireless Sensor by Pulsed Laser Scribing of Indium Tin Oxide. *New Technologies, Mobility and Security (NTMS), 2009 3rd International Conference*, pp.1 - 3

30. Ito, Y., Ameya, M., Yamamoto, M., Nojima, T. (2008). Unidirectional uwb array antenna using leaf-shaped bowtie elements and flat reflector .*Electronics Letters*, 44(1) :pp.9 - 11

31. Kazuhisa Sano, Kazuhiro Ito(2008). Dielectric waveguide slot antenna with integrated filter for automotive UWB radar applications. *Microwave Symposium Digest, 2008 IEEE MTT-S International* , pp.113 - 116

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

32. Chahat, N., Zhadobov, M., Sauleau, R., Ito, K.(2010). Design and characterization of an UWB wearable antenna. *Antennas and Propagation Conference (LAPC).* pp. 461 - 464

33. Ameya, M., Ito, Y., Yamamoto, M., Nojima, T. (2007). 2-Element UWB array antenna using leaf-shaped bowtie element. *Antennas and Propagation Society International Symposium, 2007 IEEE* pp. 1961 - 1964

34. Schantz, H.G (2012). Three centuries of UWB antenna development *Ultra-Wideband (ICUWB), 2012 IEEE International Conference* pp. 506 - 512

35. Pancera, E. (2010). UWB antennas and channel characteristics. *Wireless Information Technology and Systems (ICWITS), 2010 IEEE International Conference,* pp. 1

36. Kishk, A.A.,Xuan Hui Wu, Ryu, K.S. (2012). UWB antenna for wireless communication and detection applications Ultra-Wideband (ICUWB*). 2012 IEEE International Conference,* pp. 72 - 76

37. Kumar, K. ; Gunasekaran, N (2011). A new novel compact planar UWB antenna. *Signal Processing, Communication, Computing and Networking Technologies (ICSCCN), 2011 International Conference*, pp. 41 - 45

38. Zhining Chen (2008). Miniaturization of ultra-wideband antennas. *Microwave Conference APMC 2008 Asia-Pacific*, pp. 1 - 2

39. Yilin Chen, Yonggang Zhoun(2009).Design of a filter-antenna subsystem for UWB communications. *Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications, 2009 3rd IEEE International Symposium*, pp.593 - 595

40. Hyok Jae Song, Tsung Yuan Hsu, Sievenpiper, D.F., Hui Pin Hsu, Schaffner, J.,Yasan, E.(2008). A Method for Improving the Efficiency of Transparent Film Antennas . *Antennas and Wireless Propagation Letters, IEEE,*7 pp.753-756

41. Levin, B.M., Rechels, T.R (2013). Experimental study of a transparent antenna. *Direct and Inverse Problems of Electromagnetic and Acoustic Wave*

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

Theory (DIPED), 2013 XVIIIth International Seminar/Workshop pp. 101 – 103

42. Mias, C., Tsakonas, C., Prountzos, N., Koutsogeorgis, D.C., Liew, S.C., Oswald, C., Ranson, R., Cranton, W.M. & Thomas, C.B. (2000). Optically transparent microstrip antennas *Antennas for Automotives (Ref. No. 2000/002*) IEE Colloquium pp. 8/1 - 8/6

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