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Rainfall Measurements Due to Radio Frequency Signal Attenuation at 2 GHz

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Abstract

In this paper we present an experimental validated system for measuring rainfall due to radio frequency (RF) signal attenuation at 2 GHz. Measurements took place in Ioannina, NW Greece, starting in April 2015 and lasting for twelve months. The primary acquired extensive results have shown reliable and accurate measurements for rainfall amounts smaller than 1 mm for 5 min periods. The very important innovation is that this paper presents significant earth-to-earth measurements due to rainfall attenuation (at 2 GHz) in order to act as a map for future investigation and as a prior knowledge for the behavior of other systems operating at frequencies around S-band.

Keywords

Remote Sensing, Rain, Attenuation, S-Band, Measurements

1. Introduction

Extreme precipitation is one of the most significant research subjects in climatology during the last decades [1] and it is associated with the ongoing climatic change [2]. During extreme precipitation events, accumulated rainfall is often characterized by high spatial variability [3]. Although conventional rain-gauges provide accurate temporal rainfall measurements, their spatial accuracy is limited to the spot of measurement. Epirus, NW Greece, is a mountainous area with very complicated relief and it is characterized by high spatial variability of precipitation [4], which cannot be satisfactorily analyzed by using the measurements of the existent rain-gauge network. In contrast to the small density of the rain-gauge network over Epirus, man-made generated radio waves, with wavelengths greater than 3 cm, are abundant, especially in the urban environments of the region. The question arises as to whether or not we can improve precipitation's spatial precision of conventional rain gauges by using radio frequency (RF) signals data attenuation due to precipitation. To answer this question we must first prove that it is possible to measure rainfall precipitation for wavelengths greater than 3 cm.

Measuring RF signal attenuation through the atmosphere is a complex process that depends on a variety of parameters such as rain, temperature, humidity, multipath propagation, noise and interference. Especially for frequencies below 10 GHz, very few studies have provided measurements and reporting implementation outcomes [5]. The difficulty in such kind of measurements lies particularly in the fact that signal attenuation due to rainfall is very small at such frequencies demanding customized and high accurate measurement setup. A research team from Korea has used commercial available GSM mobile phones on the 1.8 GHz band to measure received signal strength under dry and rainy weather conditions [6]. Results of a nationwide experiment that uses 5 GHz fixed wireless network as a rain alarm system through monitoring the changes in received signal levels are presented by two research teams from Philipines [7]. A link of path length 200 m was set up in Johor Bahru, Malaysia. Rain rate was measured for one year over 6 GHz frequency [8]. The aforementioned works are primarily based on received signal strength indicator from commercially available fixed or mobile terminals and for extreme rain events. This fact limits the accuracy of the measurements in particular for small rainfall events and short distances. The experimental customized system presented in this work, overcomes hardware limitations of commercial systems. The 10^{-4} dBm accuracy in combination with 24-bit resolution provides efficient signal detection even for small rainfall events.

There are earth to earth measurements that primarily use microwave links operating at frequencies above 10 GHz which estimate path average precipitation [9] [10] [11] [12]. Microwave links occasionally lie few to several tens of meters above the ground while link's distance is a few km. A major drawback of data by commercial microwave links is the limited or nonexistent availability of commercial microwave link data by network operators [13]. Additionally there are errors due to wind jitter on the antenna and due to wet antenna attenuation. Furthermore, there is a data latency of 1-day and coarse resolution with three modes *i.e.* every 15 min, 1 h, and 24 hours [14].

In this paper we present a system for measuring rainfall due to 2 GHz RF signal attenuation. The proposed system has a temporal resolution of 12 secs and data latency in real time. The system consists of 1) a pair of antennas-two meters above the ground- and a transmitter-receiver module on a line of sight of several meters giving the advantage of uniform rainfall along the path at any time and 2) the conventional rain gauge at the meteorological station of the University of Ioannina. Additionally, as the antennas are inside two adjacent buildings, there is neither wet antenna attenuation nor wind jitter errors. The sensitivity of the conventional rain-gauge is 0.2 mm per tip.

The antennas, as well as the associated electronics for the receiver were designed and implemented in the Electronics-Telecommunications and Applications Laboratory of the University of Ioannina. Parts of the system have already been pre-validated for a small range of measurements in order to be certain for the proper principle of operation [15]. Specifically, the final version of the system is located in the area of the University Campus (20˚50'48"W, 39˚37'11"N, 490 m), at a distance of 4 km from Ioannina, a city of 120,000 habitants which is the capital of Epirus.

The paper is organized as follows: In the next section we present a detailed description of the experimental setup. In Section 3 we discuss preliminary measurement results that confirm system’s operability. The final section contains concluding remarks and future work.

2. Experimental Setup

The experimental setup consists of two subsystems shown in **Figure 1**. Subsystem A consists of the transmitter (A1) and the receiver module (A2). Transmitter module consists of a microwave signal generator and the transmitting antenna while receiver module comprises of the filter, the power detector, the A/D and the microcontroller. Subsystem B is a tipping bucket rain gauge with programmable rainfall measurement time intervals. The transmitter as well as the receiver use two identical waveguide antennas located between two adjacent buildings. Each waveguide antenna occupies a small volume; it is light weight and has a resonant frequency of 2 GHz. The distance between the front edges of the waveguide antennas is 21.5 m. The elevation angle is zero degrees and the two antennas are at a height of 2 meters above the ground surface. Since the antennas are within the buildings we eliminate additional errors in our measurements due to influences such as ice and moisture in the antenna surface and jitter phenomenon due to wind. The transmitter module consists of a signal generator which emits an un-modulated carrier at 2 GHz.

The system of the receiver is consisted of various subunits. These subunits range from the microcontroller stage to the constructed antenna. Also a Band Pass Filter (BPF), with lower and upper cutoff frequencies of 1960 MHz and 2360 MHz respectively, is included in the system. Other also important subunits should not omitted which are the Analog to Digital Converted (ADC) and the power detector unit along with the antenna and microcontroller as already

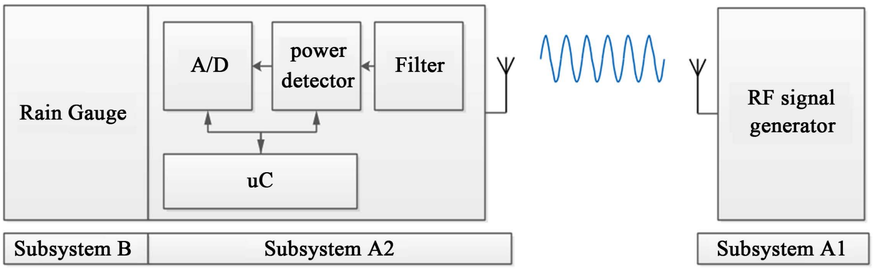

Figure 1. Experimental set-up.

mentioned. Specifically, the power detector exhibits a dynamic range of 75 dB while the sensitivity levels reach as low as −65 dBm. Its operating principle lies on the fact that the received analog voltage of the detector is converted to a digital signal with the use of the ADC. The latter is a precision Delta-Sigma converter which can output the digitized data with a maximum rate equal to 2 K samples/sec and with 24-bits of resolution.

Then the data are lead to the 8-bit microcontroller unit in order to take place the logging procedure whereas the storing operation is conducted in an SD card while the synchronization is accomplished by the Real Time Clock module (RTC). An already made logging shield is included on the board, while the other included RF detector unit was designed and constructed in our laboratory. In particular, the logging shield includes an SD socket of specific memory card type and the RTC for inserting the time stamps in the acquired samples. As for the acquisition of the latest, the samples originated from the output of the ADC are stored every 12 seconds and this procedure is controlled by the microcontroller.

Specifically, the microcontroller unit computes the mean of 32 sequential values at the output of the voltage detector (after the ADC) in order to compensate the included noise. In turn, the mean values along with the corresponding time-stamp (UTC) are stored in simple text files (comma separated) in the memory card. The key experimental parameters are summarized in Table 1.

The meteorological rain gauge is programmed to store rainfall amount (RA) in mm every five minutes. In order to evaluate our measurement system, we used the following methodology in case of rain events mainly after dry periods. For a rainfall event the signal attenuation is defined as:

$$P(t) = P_{ref} - P_{rx}(t) \tag{1}$$

where $P_{rx}(t)$ is the received power recorded every five times per minute during the rain event and P_{ref} is the average value of the received power over 30 minutes before the start of the rain event. In order to convert signal attenuation due to rainfall to the rainfall amount that conventional rain-gauge measures, Equation (1) turns to:

$$P_{rain} = \frac{\int_{t-\tau}^{t} P(t)\,\mathrm{d}t}{\tau} \tag{2}$$

Table 1. Key experimental parameters.

Resonant frequency	2 GHz
Distance	21.5 m
Dynamic range	75 dB
Sensitivity	−65 dBm
Resolution	24-bit
Storage rate	5 samples/min

where τ is the time that the conventional rain gauge measures the amount of rainfall that has fallen from $t-\tau$ to t. In our case $\tau = 5$ min. For every rain event, defined by 5 minutes logging intervals, we finally have the following set $\{R_A, P_{RA}\}$.

3. Results

The system came into operation in March 2015 and the data presented below were recorded between April 2015 and April 2016. Figure 2 shows a photograph of the implemented subsystem A2. Figure 3 shows time series $P(t)$ of Equation (1) for a 40 minutes period. The left-hand y-axis corresponds to the $P(t)$ while the right-hand y-axis corresponds to the rainfall amount. The rainfall amount was 0.2 mm (the minimum that can be recorded by a conventional rain gauge) and occurred on 16 November 2015 between 07:25 and 07:30, after a long dry period of about 10 days. Figure 4 shows time series for two consecutive rainfall

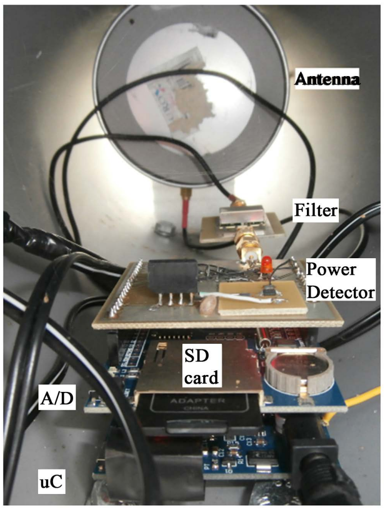

Figure 2. Experimental set-up.

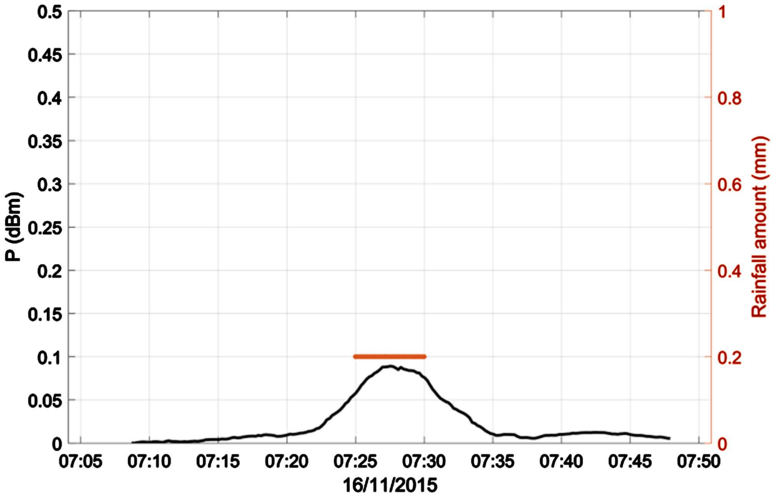

Figure 3. Time series $P(t)$ and rainfall amount for the rain event of 16 November 2015.

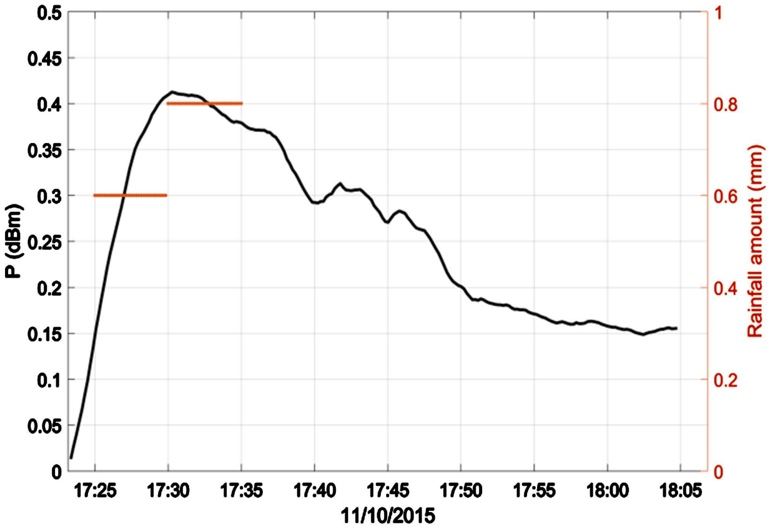

Figure 4. Time series $P(t)$ and rainfall amount for two rain events of 11 October 2015.

events of 0.6 mm and 0.8 mm that took place on 11 October 2015 from 17:25 to 17:35. Between 17:40 and 17:45 there is a smaller rainfall event of 0.2 mm. Such events in the present work have been excluded as it has already been said and focused mainly on events after dry periods. Such kinds of events demand redefining the P_{ref} commonly known as the "Baseline". We also notice that in Figure 4 after the end of the third rainfall event the P_{rx} does not tend to P_{ref} but it remains smaller than the P_{ref} due to high humidity in the atmosphere.

For forty rainfall events similar to those described above, we measured signal attenuation based on Equation (1) and Equation (2). Each series of measurements appears in the columns of Table 2. Median P_{RA} values for rainfall amounts 0.2, 0.4, 0.6 and 0.8 mm are shown in Table 2. Values range from 0.09 to 0.43 dBm.

With regard to the box plots as illustrated in Figure 5 for the four rainfall amounts it is clear that there is a separation of the boundaries of the boxes. It can be seen that there is no overlap for the width of the boxes, defined as the separation between the 25th and 75th percentiles for every rainfall amount.

Specifically 50% of values lies between 0.0834 to 0.1069 dBm for RA = 0.2 mm, 0.1903 to 0.2521 dBm for RA = 0.4 mm, 0.3014 to 0.3572 dBm for RA = 0.6 mm and 0.3691 to 0.4390 dBm for RA = 0.8 mm. From Figure 5, it can be argued that the ranges of P_{RA} values for rainfall amounts equal or greater than 0.4 mm do not overlap.

4. Conclusions and Future Work

In this work we present a new experimental system for rainfall measurement via the radio frequency (RF) signal attenuation at 2 GHz caused by rainfall. We measured small rainfall amounts from 0.2 to 0.8 mm and for one year period. The measured results indicate the very good accuracy of our system. Such kind of measurements could infill spatial gaps in used rainfall monitoring techniques.

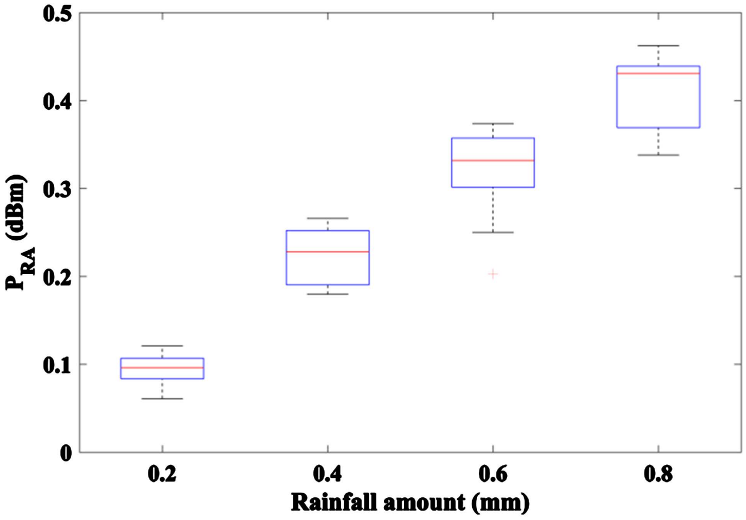

Figure 5. The box plots of P_{RA} values obtained during 40 rain events for rainfall amount 0.2, 0.4, 0.6 and 0.8 mm.

Table 2. P_{RA}, RA = 0.2, 0.4, 0.6, 0.8 mm for 40 rain events.

Event	$P_{0.2}$ (dBm)	$P_{0.4}$ (dBm)	$P_{0.6}$ (dBm)	$P_{0.8}$ (dBm)
1 RA	0.0608	0.1886	0.3091	0.4557
2 RA	0.0627	0.2575	0.3738	0.4321
3 RA	0.0882	0.2659	0.2028	0.3591
4 RA	0.0943	0.1796	0.2500	0.4379
5 RA	0.0980	0.2032	0.3339	0.4212
6 RA	0.0834	0.1903	0.3297	0.4390
7 RA	0.1069	0.2358	0.3014	0.4292
8 RA	0.1150	0.2297	0.3439	0.3379
9 RA	0.1044	0.2262	0.3572	0.4624
10 RA	0.1208	0.2521	0.3582	0.3691
Median P_{RA} (dBm)	**0.0962**	**0.2280**	**0.3318**	**0.4306**

Future scopes of the presented research are 1) the improvement of the spatial rainfall measurement accuracy due to measuring signals' attenuation in frequency bands that are overwhelmed by standards of IEEE, WiMAX, ISM bands, cellular communications, etc. and 2) the estimation of the rainfall due to signal attenuation in cm-area and the creation of an empirical rainfall model as a function of the specific attenuation rate for Europe and especially for the Greek area.

Furthermore, the proposed system works for a given frequency band by transmitting and receiving only one carrier each time, and for finding the attenuation due to rain effects. In turn, the system could be upgraded with OFDM scheme [16] [17] in order to work with multiple S-Band frequencies for real-time processing of the received signals and in this way to estimate multiple frequency attenuation at the same time. Moreover MIMO techniques could be employed for acquiring a more "precise image" of the attenuated channels [18] [19] due to rain, while the add on of an Ultra Wideband (UWB) scheme [20] [21] [22] could provide detailed attenuation measurements of an enormous frequency band. All the aforementioned could not be possible without the use of high precision tunable antennas [23] [24] [25] and without the use of software radio techniques [26].

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Toreti, A., Giannakaki, P. and Martius, O. (2015) Precipitation Extremes in the Mediterranean Region and Associated Upper-Level Synoptic-Scale Flow Structures. *Climate Dynamics*, **47**, 1925-1941. https://doi.org/10.1007/s00382-015-2942-1

[2] Barcikowska, M., Kapnick, S. and Feser, F. (2017) Impact of Large-Scale Circulation Changes in the North Atlantic Sector on the Current and Future Mediterranean Winter Hydroclimate. *Climate Dynamics*, **50**, 2039-2059. https://doi.org/10.1007/s00382-017-3735-5

[3] Vieux, B. and Vieux, J. (2005) Rainfall Accuracy Considerations Using Radar and Rain Gauge Networks for Rainfall-Runoff Monitoring. *Journal of Water Management Modeling*, 333-352. https://doi.org/10.14796/JWMM.R223-17

[4] Fotiadi, A., Metaxas, D. and Bartzokas, A. (1999) A Statistical Study of Precipitation in Northwest Greece. *International Journal of Climatology*, **19**, 1221-1232. https://doi.org/10.1002/(SICI)1097-0088(199909)19:11<1221::AID-JOC436>3.0.CO;2-H

[5] Karagianni, E., Vazouras, C., Papageorgiou, E., Sarantopoulos, A. and Nistazakis, H. (2016) Maximum Rain-Rate Evaluations in Aegean Archipelagos Hellas for Rain Attenuation Modeling at Microwave Frequencies. *The International Journal on Marine Navigation and Safety of Sea Transportation*, **10**, 117-123. https://doi.org/10.12716/1001.10.01.13

[6] Fang, S. and Yang, Y. (2016) The Impact of Weather Condition on Radio-Based Distance Estimation: A Case Study in GSM Networks with Mobile Measurements. *IEEE Transactions on Vehicular Technology*, **65**, 6444-6453. https://doi.org/10.1109/TVT.2015.2479591

[7] Labuguen, R., Caballa, J., Abrajano, G., Guico, M., Pineda, C., Libatique, N. and Tangonan, G. (2015) Nationwide 5GHz-Fixed Wireless Network for Prototype Rain Alarm System. 2015 *IEEE Tenth International Conference on Intelligent Sensors, Sensor Networks and Information Processing* (*ISSNIP*), 7-9 April 2015. https://doi.org/10.1109/ISSNIP.2015.7106962

[8] Ulaganathen, K., Tharek, A., Islam, R. and Abdullah, K. (2017) Rain Attenuation for 5G Network in Tropical Region (Malaysia) for Terrestrial Link. 2017 *IEEE* 13*th Malaysia International Conference on Communications* (*MICC*), Johor Bahru, 28-30 November 2017. https://doi.org/10.1109/MICC.2017.8311727

[9] Overeem, A., Leijnse, H. and Uijlenhoet, R. (2016) Two and a Half Years of Country-Wide Rainfall Maps Using Radio Links from Commercial Cellular Telecommunication Networks. *Water Resources Research*, **52**, 8039-8065.

https://doi.org/10.1002/2016WR019412

[10] Uijlenhoet, R., Overeem, A. and Leijnse, H. (2018) Opportunistic Remote Sensing of Rainfall Using Microwave Links from Cellular Communication Networks. *Wiley Interdisciplinary Reviews*: *Water*, **5**, e1289.

[11] Overeem, A., Leijnse, H. and Uijlenhoet, R. (2011) Measuring Urban Rainfall Using Microwave Links from Commercial Cellular Communication Networks. *Water Resources Research*, **47**, 1-16. https://doi.org/10.1029/2010WR010350

[12] Messer, H. (2006) Environmental Monitoring by Wireless Communication Networks. *Science*, **312**, 713. https://doi.org/10.1126/science.1120034

[13] Goldshtein, O., Messer, H. and Zinevich, A. (2009) Rain Rate Estimation Using Measurements from Commercial Telecommunications Links. *IEEE Transactions on Signal Processing*, **57**, 1616-1625. https://doi.org/10.1109/TSP.2009.2012554

[14] Brauer, C., Overeem, A., Leijnse, H. and Uijlenhoet, R. (2016) The Effect of Differences between Rainfall Measurement Techniques on Groundwater and Discharge Simulations in a Lowland Catchment. *Hydrological Processes*, **30**, 3885-3900. https://doi.org/10.1002/hyp.10898

[15] Tatsis, G., Christofilakis, V., Votis, V., Chronopoulos, S.K., Kostarakis, P., Lolis, C. J., Bartzokas, A. and Nistazakis, H.E. (2018) Rainfall Events' Correlation with S-Band Signal Attenuation. 2018 7*th International Conference on Modern Circuits and Systems Technologies* (*MOCAST*), Thessaloniki, 7-9 May 2018, 1-4. https://doi.org/10.1109/MOCAST.2018.8376582

[16] Chronopoulos, S.K., Christofilakis, V., Tatsis, G. and Kostarakis, P. (2016) Performance of Turbo Coded OFDM under the Presence of Various Noise Types. *Wireless Personal Communications*, **87**, 1319-1336. https://doi.org/10.1007/s11277-015-3055-1

[17] Chronopoulos, S.K., Christofilakis, V., Tatsis, G. and Kostarakis, P. (2016) Preliminary BER Study of a TC-OFDM System Operating under Noisy Conditions. *Journal of Engineering Science and Technology Review*, **9**, 13-16.

[18] Votis, C., Christofilakis, V., Raptis, V., Tatsis, G., Chronopoulos, S.K. and Kostarakis, P. (2010) Design and Analysis of a Multiple-Output Transmitter Based on DDS Architecture for Modern Wireless Communications. *AIP Conference Proceedings*, **1203**, 421-426. https://doi.org/10.1063/1.3322480

[19] Votis, C., Christofilakis, V., Raptis, V., Tatsis, G., Chronopoulos, S.K. and Kostarakis, P. (2010) Effects of Variations on Geometrical Parameters on a 2.4 GHz Printed Dipole Antenna Architecture. *AIP Conference Proceedings*, **1203**, 427-432. http://doi.org/10.1063/1.3322481

[20] Tatsis, G., Christofilakis, V., Votis, C., Kostarakis, P., Ivrissimtzis, L. and Chronopoulos, S.K. (2011) BER Performance of an Ultra-Wideband Impulse Radio Correlator Receiver. *WSEAS Transactions on Information Science and Applications*, **8**, 401-406. http://www.wseas.us/e-library/transactions/information/2011/54-113.pdf

[21] Tatsis, G., Votis, C., Raptis, V., Christofilakis, V., Chronopoulos, S.K. and Kostarakis, P. (2010) Performance of UWB-Impulse Radio Receiver Based on Matched Filter Implementation with Imperfect Channel Estimation. *AIP Conference Proceedings*, **1203**, 573-578. https://doi.org/10.1063/1.3322512

[22] Tatsis, G., Votis, C., Raptis, V., Christofilakis, V., Chronopoulos, S.K. and Kostarakis, P. (2010) Design and Implementation of Ultra-Wideband Impulse Radio Transmitter. *AIP Conference Proceedings*, **1203**, 579-584. https://doi.org/10.1063/1.3322513

[23] Raptis, V., Tatsis, G., Chronopoulos, S.K., Mallios, S. and Kostarakis, P. (2013) Development and Experimental Measurements of a Tunable Antenna. *Communications and Network*, **5**, 220-224. https://doi.org/10.4236/cn.2013.53026

[24] Raptis, V., Tatsis, G., Votis, C., Chronopoulos, S.K., Christofilakis, V. and Kostarakis, P. (2010) Tuning Techniques for Planar Antennas in Wireless Communication. *AIP Conference Proceedings*, **1203**, 1053-1057. http://doi.org/10.1063/1.3322309

[25] Raptis, V., Tatsis, G., Votis, C., Chronopoulos, S.K., Christofilakis, V. and Kostarakis, P. (2010) Active Tuning Antennas for Wireless Communication. *AIP Conference Proceedings*, **1203**, 1058-1062. https://doi.org/10.1063/1.3322310

[26] Christofilakis, V., Tatsis, G., Votis, C. and Kostarakis, P. (2018) From Software to UWB Radio Communications: A Brief Introduction. In: Stavros, A., Ed., *Advances in Communications and Media Research*, 12nd Edition, Nova Science Publishers, Hauppauge, 1-34.
https://www.novapublishers.com/catalog/product_info.php?products_id=61216