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Correcting Front-end RF Impedance Mismatch for 2.4GHz Wireless Long-Distance Data Transmission

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ABSTRACT

In order to increase the higher competition in low-power wireless network communication market, a high-performance and low-cost product is necessary to distinguish the difference with others. Through integrating the system performance with suitable L-shape impedance-match circuit assisting with some network analyzer, this target with a 2.4 GHz radio-frequency (RF) product in long-distance data transportation seems to be promisingly implemented.

In short-distance data transportation, the ideal output-link transportation rate (~ max. 54 Mb/sec) is slightly influenced by impedance mismatch between power amplifier (PA) and antenna port. However, it is tremendously reduced at long-distance condition and the transportation rate is decreased to ~ 24 Mb/sec.

Using the attenuator to attenuate the real input signal to -70dB to simulate the real signal transportation, the packet error rate (PER) is less than 10% at a physical sublayer service data unit (PSDU) length of 1000 bytes under the communication 802.11g spec. as the real transmission rate is 20 Mb/sec. If the impedance of the transmission line is shifted, the long-distance transportation rate will be reduced to, almost, 20 x 24 / 54 = 8.8 Mb/sec. The transportation performance is greatly deducted.

With the delicate design and the feasible component arrangement, the impedance mismatch influencing the long-distance (~ 100 m) data transportation is overcome and reduced to the acceptable range. In this investigation using 3.3 V power supply, we observe that the selection of electronic components with miniaturization is also an art to reduce the radiation side-effect.

1. Introduction

An excellent design in RF route can attribute the success to the good performance of transmission line and matching impedance circuit [1], as shown in Fig. 1. Most of them are composed by resistor (R), capacitor (C) and inductor (L). In route circuit, if the component length is close to one-tenth of radiated wavelength, then the radiation phenomenon is usually generated. To avoid this radiation effect, the RF components on printed circuit board (PCB) are miniaturized.

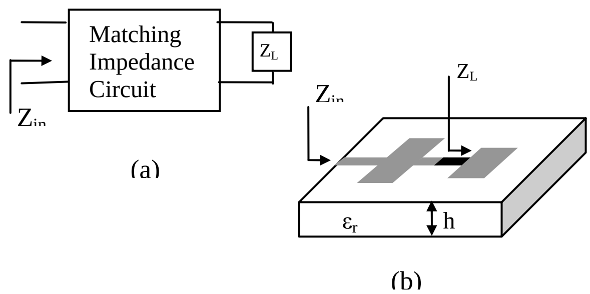


Fig. 1 Schematic of (a) match impedance circuit, and (b) mrcrostrip transmission line.

In the meantime, the matching impedance of transmission line must be, as possible as, approximated to the loaded transmission line 50 ohm (Z_L = 50 Ω) for applying to the 2.4 GHz ~ 2.5 GHz transmitted band [2]. Therefore, the transmission-line path and the line pitch also must be precisely calculated. In addition, there are some reserved component pads, closed to the transmitted end on PCB, to adjust the shift of final matching impedance during the PCB fabrication. In this study, the matching impedance circuit can be generally designed by L-type matching network [3-5], collocating with the short and open circuit transmission line and quarter-wave transmission line. The L-type matching network with the passive discrete components of resistor, inductor and capacitor is typically employed. One of advantages of L-type matching network is that the L-type passive components are discrete such as the pair of R and L, or L and C, etc.

2. L-type Matching Network

The useful microstrip technology allows the transmission line to fabricate directly on the printed circuit board. On PCB layout technology with computer, the impedance value is obtained, in advance, by simulation, as shown in Fig. 2. The widths, W1 and W2, the interval D1, the trace (tiny electrical line) thickness T1 and the layer stack of transmission line were presented in this Fig. 2.

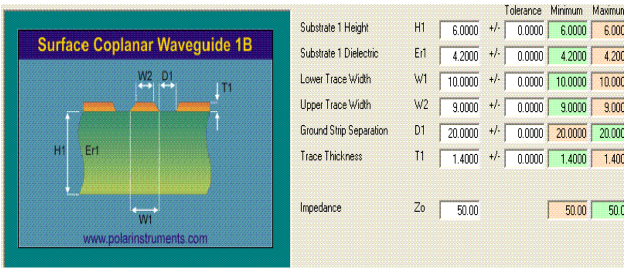
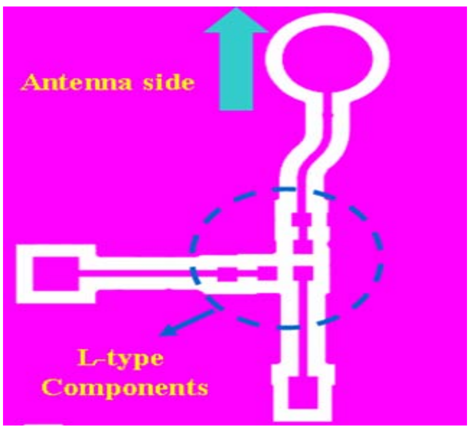
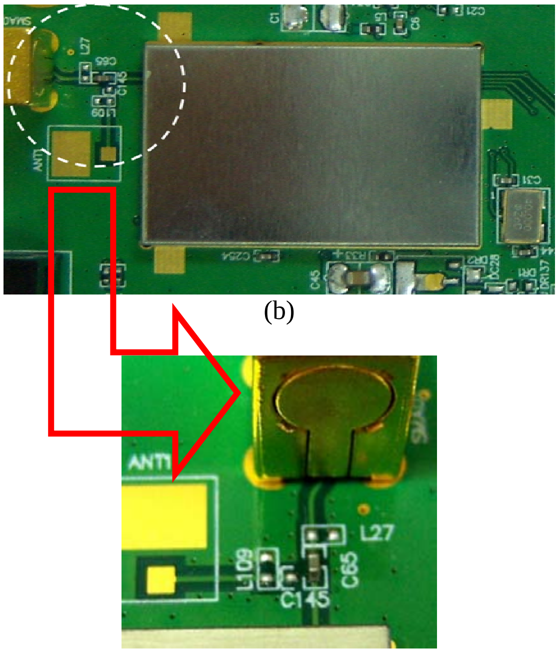


Fig. 2 Schematic cross-section profile of transmission line in simulation.

Additionally, before shipping RF products, the impedance of transmission line must be tested to make sure the fabrication error from PCB fabrication less than 5% under the requirement of 50 ohm impedance. In order to compensate the small uncertainty impedance shift, the L-type matching network on layout reserves some pin pads to insert some passive components, as shown in Fig. 3.



(a)



(b)

(c)

Fig. 3 L-type component location on PCB (a) top-view layout (b) top view of real fabrication pattern (c) magnification of part (b).

Next, the L-type matching network is presented in Fig. 4, where E_1 and E_2 are referred as resistor (R), capacitor (C) or inductor (L). However, the series or parallel connection is not fixed, but determined by the Smith chart [1]. In the combined ZY-Smith chart [6], as presented in Fig. 5, a dotted line and real line belongs to impedance-plane (Z-plane) and admittance (Y-plane), respectively. The Z-plane referring to a component is parallel with Z_S, and the Y-plane is series with Z_S.

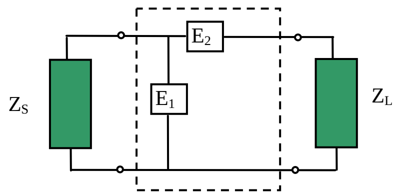


Fig. 4 Schematic circuit of L-type matching network.

When the measured impedance locates at point A and, the impedance change with a matching network, reaching the impedance at point B, can be observed and calculated. Of course, there are several analysis paths from point A to point B such as A-C-B, A-H-B, A-E-H-B or A-D-F-B, etc., which are suitable to the matching network. For instance, the impedance change is the A-C-G path. Considering a suitable capacitor or an adequate inductor, a typical way is to justify the trend of fall curves or rise curves when the specified point moves along on real line and dotted line. For a fall curve, it always adds a capacitor.

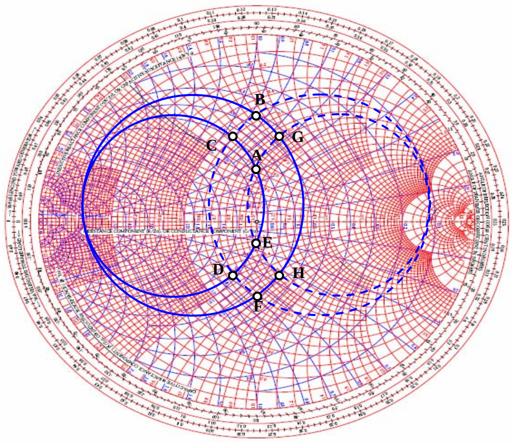


Fig. 5 Usage of the Smith chart to determine the passive components of L-type matching network.

Again, for a rise curve, it frequently inserts an inductor. Hence, the A-C path is along with dotted line and, therefore, Z_s is parallel with an inductor. Then, the C-B path moves along on real line on complex-variable coordinate, and E1 is parallel with an inductor. Similarly, the C-B path moves along on dotted line, and E2 is series with an inductor, too. In this case, the bandwidth (BW) of this L-matching network is 2.4GHz if the loaded quality factor Q_{LD} (= central carrier frequency / BW_{3dB}) is set at 1.

3. Experimental Measurement

First, the load impedance is set at 0 ohm as a short-type transmission line to test the designed RF trace with Agilent 8719ES network analyzer. Regardless of anticipated target, the whole RF circuit response or characteristic trace was depicted in Fig. 6. Because the input reflection coefficient S11 shows the negative phase, this measurement mode with zero ohm at 2.4 ~ 2.5 GHz operation is a capacitor-like behavior. Furthermore, the signal magnitude with LOG format is presented in Fig. 7.

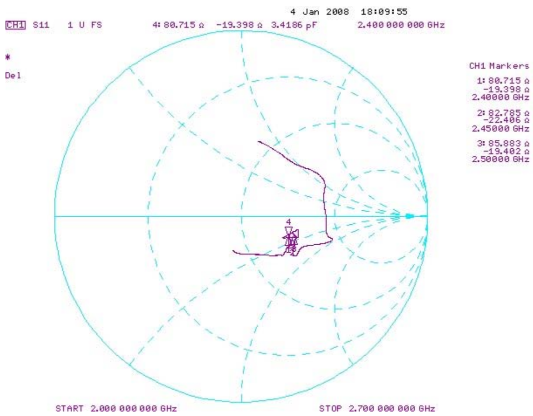


Fig. 6 S11 distribution of short-type transmission line under 2.4-2.5GHz operation on Smith chart.

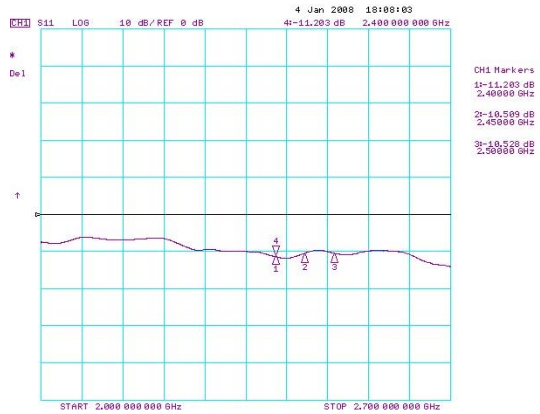


Fig. 7 LOG MAG value is about -10dB with short-type transmission line under 2.4~2.5GHz operation.

Then, using a vector signal analyzer, the error vector magnitudes (EVM) of the transmitted signals [7-8] on orthogonal frequency-division multiplexing (OFDM) constellation [9], as shown in Fig. 8, can be sensed. The energy in each read point, circled by a yellow-dash circle, is dispersed. This means that the transmitted signal overlap is serious. It is a warning sign.

Again, using an attenuator to simulate the attenuated degree of short-type transmitted signal under a certain distance is a feasible method. In this case, a 70dBm attenuation is treated as a long-distance transmission. The transmitting data rate through some elapsed time was decreased, as depicted in Fig. 9. The red-dash rectangle in Fig. 9 indicated the throughput of transmitted data after 20 sec was gradually degraded. Using the same method, ten-time repeatable measurement was shown at the Table I. The test results show a large standard deviation about 3.680 Mbps.

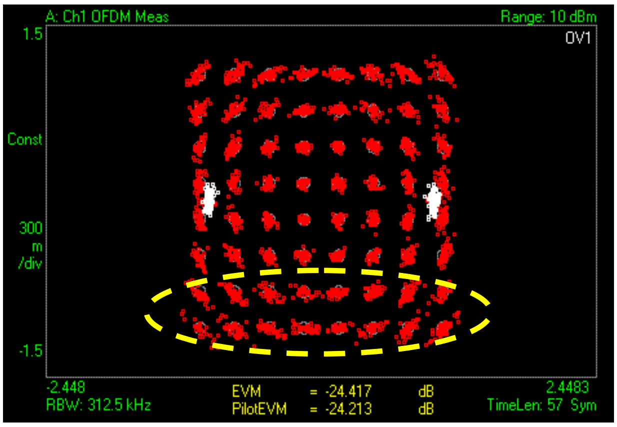


Fig. 8 Relative constellation error on OFDM constellation is about -24.4 dB.

Based on these test results, the degradation or the vibration of data throughput seriously affected the transmitted quality of transmitting data and caused some data loss. In ideal calculation, the transmission speed should be greater than 20 Mbps. After analyzing these results at Table I, this weak performance was chiefly generated by impedance mismatch. Using the Smith chart as an auxiliary, the capacitor-like phenomenon in this short-type transmission line can be adjusted as an inductor-like behavior, as shown in Fig. 10 and Fig. 11.

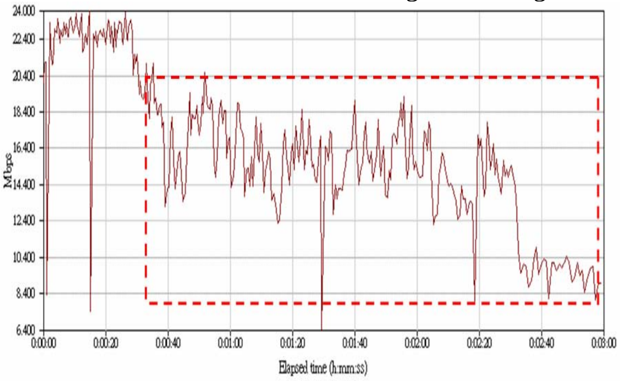


Fig. 9 Degradation of transmitted signal throughput (Mbps) after some elapsed time (h:mm:ss). [10].

Table I. The short-type transmitted throughput for 10-time repeated test before adjusting.

Times	Throughput (Mbps)
1	16.51
2	7.22
3	7.58
4	12.85
5	8.11
6	13.43
7	15.9
8	15.24
9	14.9
10	15.52
AVG.	12.726
Std. Dev.	3.680

To compensate the front-end RF impedance mismatch, a pico-level capacitance was shunted in this circuit to correct the amplitude in Fig. 10. The shifting path from point A to point B is path 1. To obtain a predicted shifting path from point B to point C, called path 2, a nano-level inductance was series to adjust the phase of transmission line toward the inductor-like behaviour on Smith chart, as shown in Fig. 11. The LOG MAG after adjustment also demonstrates in Fig. 12. The S11 value indeed reduced to -11~ -20 dB. The acceptable spec. for S11 in front-end of wireless transmission products is basically less than -10 dB.

While the same test method, comparing it with the previous case, with a vector signal analyzer to measure the error vector magnitude on OFDM constellation, the relative constellation error also decrease to -26.0 dB, as shown in Fig. 13. Each data in Fig. 13 depicts the inseparable shape. It indicates the transmitted signal energy is not dispersed. The signal overlap issue is not critical.

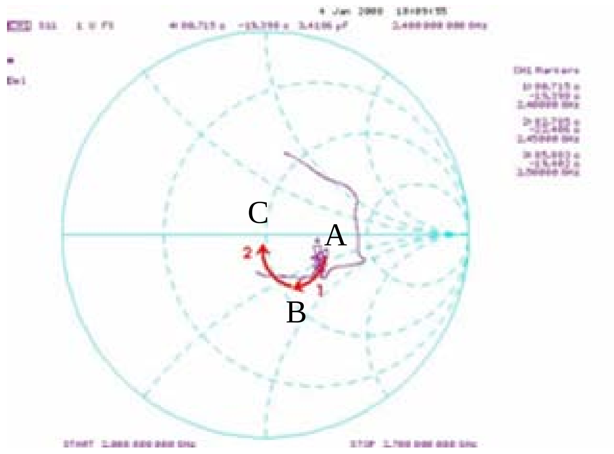


Fig. 10 Predicting impedance change from capacitor-like behaviour to inductor-like characteristic with S11.

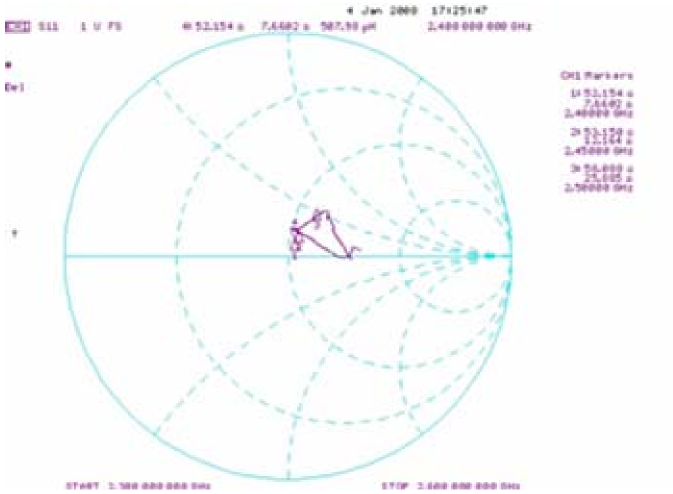


Fig. 11 S11 parameter of short-type transmission line at 2.4 ~ 2.5 GHz operation after adjusting.

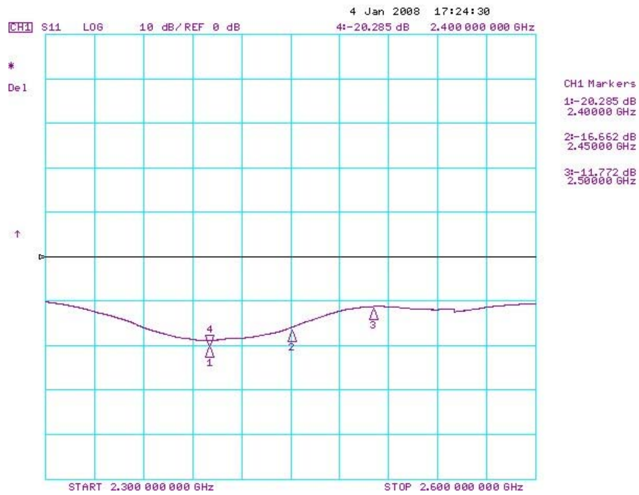


Fig. 12 S11 value showing with LOG MAG format at 2.4 ~ 2.5 GHz operation.

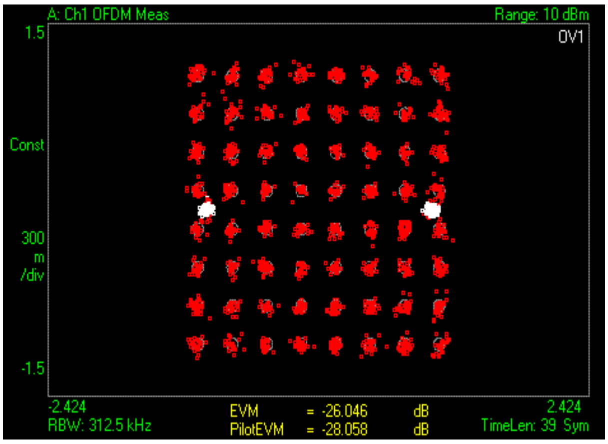


Fig. 13 Relative constellation error on OFDM constellation is about -26.0 dB.

Continuously, repeating the transmission test for short-type transmission line at 70 dBm attenuation, the low transmission-speed phenomenon after 3 minutes was not observed, as shown in Fig. 14. The transmission throughput was generally maintained over 20 Mbps.

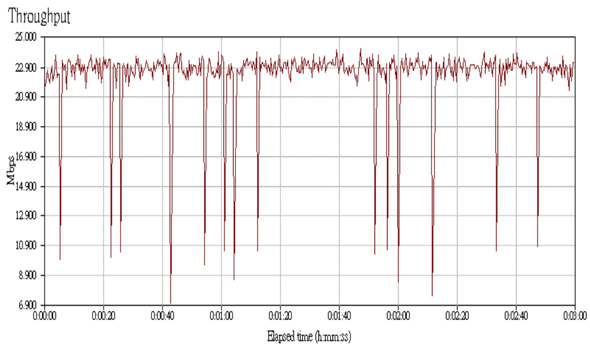


Fig. 14 Data transmission test under 70 dBm attenuation for transmission line after L-value and C-value compensation.

Table II. The result of transmitted speed for 10-time repeated test after adjusting.

Times	Throughput (Mbps)
1	21.12
2	22.01
3	21.86
4	21.55
5	21.38
6	22.1
7	21.67
8	20.92
9	22.07
10	22.08
AVG.	21.676
Std. Dev.	0.425

After impedance correction, repeating ten-time throughput test was also executed. The test results were demonstrated at Table II.

4. Test results and discussion

According to these two tests, the wireless transmission rate after component adjustment is really better than that without adjustment in short-type transmission line, as shown in Fig. 15. All of test values after adjustment are over 20 Mbps. The average value is about 21.68 Mbps at Table II. Again, the measurement variation after adjustment is also smaller. The standard deviation is only 0.425 Mbps. It means that this passive component compensation in impedance match is valuable and stabilizes the output transmission rate. In the meantime, the improvement of transmission rate is about 8.95 Mbps. In general, the S21 value (forward voltage gain) and the S12 value (reverse voltage gain) are also important in impedance design. However, the impedance mismatch is concerned in this study. The S11 value is sufficient to describe the matching quality.

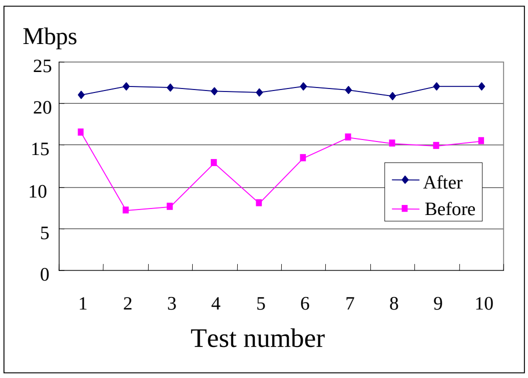


Fig. 15 Comparison of transmission rate before and after passive component adjustment during 10-time test.

5. Conclusion

Through this experiment, good impedance match between power amplifier and antenna port in front-end RF part indeed and strongly influences the data transmission quality. Not only the transmission quality, but also the transmission distance at the same RF output power. The adequate simulation and calculation adding some passive components improve the data transmission rate, increasing about 8.95 Mbps. Again, the transmission characteristic is more stable, too.

Deliberately designing high-efficiency wireless communication products is very important in marketing competition. This design is suitable to this requirement increasing the 2.4GHz long-distance data transmission under a low-power 3.3V operation. It also satisfies IEEE 802.11b/g spec. and can be applied to network cards with 2.4GHz central carrier frequency.

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References

[1] Reinhold Ludwing and Pavel Bretchko, 2000 : *RF Circuit Design--- Theory and Applications*, Prentice-Hall, New Jersey, pp. 42-132.

[2] P. Sjoblom, *et al*, 2005, "An adaptive impedance tuning CMOS circuit for ISM 2.4-GHz band," *IEEE Transactions on Circuits and Systems I*, vol. 52, issue 6, pp. 1115 – 1124.

[3] Y. S. Lin, *et al*, 2004, "Lumped-element impedance-transforming uniplanar transitions and their antenna applications," *IEEE Transactions on Microwave Theory and Techniques*, vol. 52, iss. 4, pp. 1157-1165.

[4] G. Smith, 1977, "Efficiency of electrically small antennas combined with matching networks," *IEEE Transactions on Antennas and Propagation*, vol. 25, iss. 3, pp. 369-373.

[5] H.M. Elkamchouchi, *et al*, 1996, "Smith chart based analytical design of lumped transistor amplifiers," *Radio Science Conference*, pp. 395-407.

[6] C. Thimaporn, *et al*, 2004, "Applications of the ZY T-chart for nonreciprocal stub tuners," *IEEE Region 10 Conference*, pp. 620-623.

[7] Pak Kay Tang, *et al*, 2004, "PER and EVM measurements of a radio-over-fiber network for cellular and WLAN system applications," *Journal of Lightwave Technology*, vol. 22, iss. 11, pp. 2370-2376.

[8] J. K. Stuart, *et al*, 2003.06, "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications," *IEEE-SA Standard Board Approved*, pp. 41-42, 12.

[9] Behzad Razavi, 1998 : *RF Microelectronics*, Prentice-Hall, New Jersey, pp. 313-314.

[10] AboCom Systems, Inc., the web-site "http://www.abocom.com.tw"