TELKOMNIKA, Vol.12, No.3, September 2014, pp. 733~740
ISSN: 1693-6930, accredited A by DIKTI, Decree No: 58/DIKTI/Kep/2013
DOI: 10.12928/TELKOMNIKA.v12i3.103

Diversity Combining Using Maxima Ratio Combining for All Modulation Mode

Yusuf Kurniawan*[1], Andyes Fourman D.A. Sudirja[2]
Department of Electrical Engineering, School of Electrical Engineering and Informatics
Institut Tekhnologi Bandung, Bandung, Indonesia
*Corresponding author, e-mail: yusufk@stei.itb.ac.id[1], andyes.sudirja@yahoo.com[2]

Abstract

The destruction caused by channel can be seen by the existence of Amplitude and Phase Shift. By using the 6 Ways Diversity Combining method (6 Antennas/Receivers), it is expected that the disruption caused by Amplitude and Phase Shift can be suppressed as small as possible. In addition, by using diversity combining module, we will get a large SNR output which has a value sum of SNR of each diversity path. The design of Diversity combining module begins with MATLAB functional design as a big picture of the whole system. Subsequently, it will be made the hardware based on the MATLAB functional. This architectural design that will be the cornerstone in the MATLAB bit precision manufacturing. Then MATLAB bit precision will be designed as the foundation of the VHDL design. Diversity combining the output module meets the standards specified by the DVB consortium. In the hardware (FPGA) test results of diversity combining, the maximum working frequency is 44.56 MHz which has shown that is qualified with the standard sampling clock (9.142 MHz). This design also needs 4% of total FPGA Cyclone II 484I8 combinational units which is 2499 units and it needs also 3% of total register of FPGA Cyclone II 484I8 which is 1720 register units.

***Keywords**: MRC, selective combining, diversity combining, OFDM*

1. Introduction

Rapid growth demand of society to the electronic device gives high luxury caused improvement in device technology. One of its impacts is Digital Television (DTV).There are so many types of DTV such as DVB-H, DVB-S and so forth, yet one of the most successful DTV is DVB-T (Digital Video Broadcasting Terrestrial). DVB-T is a standard of terrestrial digital television which is static and its receiver and transmitter are steady or not moving.

DVB-T uses OFDM (Orthogonal Frequency Division Multiplexing) technique. This modulation technique uses multi sub-carrier which is orthogonal between each other. This OFDM method allows each subcarrier to be overlapped to each other without any interference both Inter Symbol Interference (ISI) and ICI (Inter Carrier Interference)[1].

DVB-T utilizes an equalization module that is located between the input of Channel Decoder and the output of FFT. The Equalization module is used to compensate the channel noise from both noise caused by amplitude and phase noise. The module that commonly used to compensate these noises is Diversity Combining module. In the common use there is only 2 ways diversity but in fact, it is not enough to reduce the noise both AWGN and Rayleigh Noise and 6 ways Diversity (Received Antenna) is the highest number of Antenna so the received data are still correlated between one and another.

2. Diversity Combining

This chapter discusses about general algorithm of Diversity Combining. This module is used to combine (or selecting) the SNR of receivers in order to get the better SNR output.

2.1 Maxima Ratio Combining

In Maxima Ratio Combining methods, the data output of each FFT will be co-phased due to the influence of phase shift Θ because of channels that is multiplied by the weighting $\propto_i=a_i.e^{-j\theta}$ with amplitude a_i. Without co-phasing, each branch is not summed coherently that still contains damaged data due to fading. As explained in [2].

Received March 9, 2014; Revised July 25, 2014; Accepted August 10, 2014

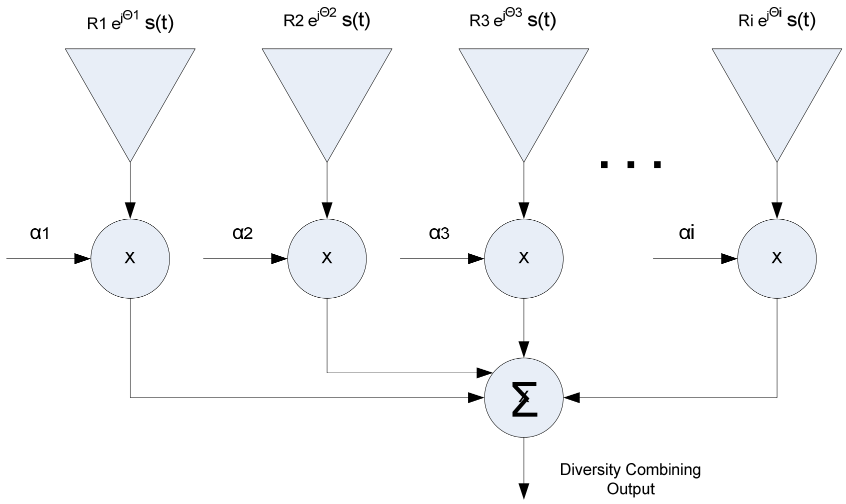

Figure 1. Linier Combiner Diversity Combining

In Figure 1 The transmitted signal s(t) which has interferences from Channel $R_i e^{j\Theta i}$ will be multiplied with complex amplitude $\propto_i = a_i e^{-j\theta}$ So will be get the combined SNR With $r = e^{-j\theta}$. This equation can be simplified using Cauchy Schwartz Method.
We get that γΣ will be

$$\gamma\Sigma = \frac{\left[\sum_{i=1}^{M} E_s\right]^2}{N0\left[\sum_{i=1}^{M} E_s\right]} = \frac{ME_s}{N_0} = M\bar{\gamma} \quad (1)$$

With $\bar{\gamma}$ is the mean SNR from each receiver. From above equation, we can get the SNR gain of combined SNR compared with mean SNR from each receiver is M value. As has been explained in [2] to get BER from common MRC will be used an equation

$$P_b(E) = \int_0^\infty Q\left(\sqrt{2g\gamma_t}\right)P_{\gamma_t}(\gamma_t)d\gamma_t \quad (2)$$

In this case we will assume that used channel will be i.i.d Rayleigh Fading Paths. SNR per bit per path γ_i has an exponential PDS with mean SNR per bit $\bar{\gamma}$.

$$P_{\gamma_l}(\gamma_l) = \frac{1}{\bar{\gamma}}e^{-\gamma l/\bar{\gamma}} \quad (3)$$

And for SNR per bit for combined SNR γ_t has PDF.

$$P_{\gamma_t}(\gamma_t) = \frac{1}{(L-1)!\bar{\gamma}^L}\gamma_t^{L-1}e^{-\gamma_t/\bar{\gamma}} \quad (4)$$

In the end, we can get the error probability for BPSK mode will be

$$P_b(E) = \left(\frac{1-\mu}{2}\right)^L \sum_{l=0}^{L-1}\binom{L-1+l}{l}\left(\frac{1+\mu}{2}\right)^l \quad (5)$$

Equ. 1 Error Probability (Pb) Equation in BPSK mode. With

$$\mu = \sqrt{\frac{\bar{\gamma}}{1+\bar{\gamma}}} \quad (6)$$

In the below graph, BER graph which is created from created DVB system to test the MRC module is represented with colored graph and the BER graph comes from theory (Pb) is represented with "Black" graph.

In Figure 2, it can be observed that the MRC BER graph from created DVB system has a very similar BER graph with BER from theory. So that the created DVB System is valid to test the MRC modeled and it can be used to test other methods too (Selective Combining, Equal Gain Combining, etc).

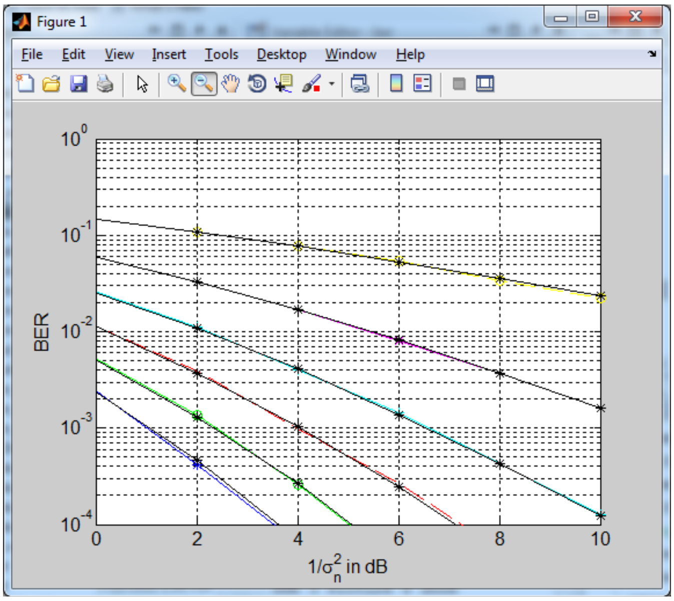

Figure 2. MRC BER, from designed system (color one) VS theory (Pb) with L is number of diversity path

2.2 Normalized MRC

In the paper [3], it adopts a method of MRC in general but with addition of compensation of amplitude noise channel. It explains a method which described that conventional MRC found that good for processing in QAM modulation both QAM 16 and QAM64 mode. In equation conventional MRC output of MRC is

$$Z(k) = W_k^H Y(k) \quad (7)$$

With W is the weighting from the estimated channel with the below equation

$$W = \left[\hat{H}_1(k), \widehat{H}_1(k), \Lambda, \hat{H}_M(k)\right]^T \quad (8)$$

And Y is the Fast Fourier Transform (FFT) output with

$$k = 0, \Lambda, N-1 \quad (9)$$

While at MRC algorithm, it has a different weighting with Weighting in the conventional MRC with

$$W_{k,norm} = \frac{W_k}{W_k^H W_k} \quad (10)$$

It can be observed that in conventional MRC, there is uncompensated amplitude $|H|^2$ that shown in below equation

$$Z(k) = W_k^H Y(k) \quad (11)$$
$$Y = H X$$

With **X** is transmitted data

$$Z(k) = H^H H X \quad (12)$$
$$Z(k) = |H|^2 X$$

It can be observed that the output of the conventional MRC still leaves $|H|^2$. Using MRC method that proposed by this paper [3], the value of $|H|^2$ is eliminated or reduced by normalization using $W_k^H W_k$ which is equal with $|H|^2$. With the same equation as the MRC, it can be derived that the total value of SNR γ_Σ on this paper has a similar combined SNR with the conventional MRC.

2.3 Selective Combining (SC)

In SC-type systems [2], it processes only one of the diversity branches. Specifically, in its conventional form, the SC combiner chooses the branch with the highest SNR. In addition, since the output of the SC combiner is equal to the signal on only one of the highest SNR branch, the sum of the individual branch signals is not required like in MRC and EGC.

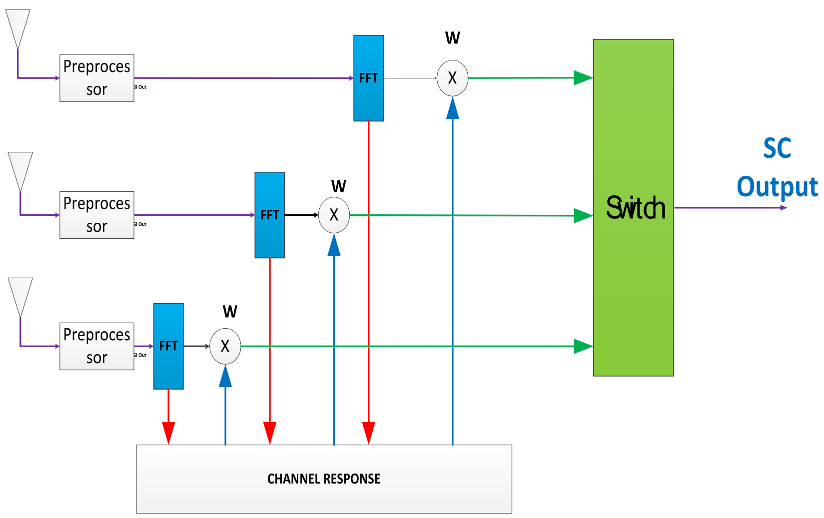

Figure 3. Selective Combining Diagram

For M branch diversity, the CDF of combining SNR $\gamma\Sigma$ is given by

$$P_{\gamma\Sigma} = p(\gamma\Sigma < \gamma) = p(\max[\gamma 1, \gamma 2, \ldots, \gamma M] < \gamma) \quad (13)$$

We obtain the pdf of $\gamma\Sigma$ by differentiating $P\ \gamma\Sigma(\gamma)$ relative to γ and the outage probability by evaluating $P\ \gamma\Sigma(\gamma)$ at $\gamma = \gamma 0$. Assume that we have M branches with uncorrelated Rayleigh fading amplitudes $\mathbf{r_i}$. The instantaneous SNR on the $\mathbf{i^{th}}$ branch is therefore given by $\gamma_i = \frac{r_i^2}{N}$. Defining the average SNR on the $\mathbf{i^{th}}$ branch as $\overline{\gamma_i} = E[\gamma i]$ the SNR distribution will be exponential:

$$p(\gamma_i) = \frac{1}{\overline{\gamma_i}} e^{-\gamma i/\overline{\gamma_i}} \quad (14)$$

The outage probability for a target $\gamma 0$ on the $\mathbf{i^{th}}$ branch in Rayleigh fading is

$$\text{Pout}(\gamma_0) = 1 - e^{-\gamma i/\bar{\gamma}_i} \quad (15)$$

The outage probability of the selection combiner for target γ0 is then

$$\text{Pout}(\gamma_0) = \prod_{i=1}^{M} p(\gamma i < \gamma 0) = \prod_{i=1}^{M} 1 - e^{-\gamma i/\bar{\gamma}_i} \quad (16)$$

Relative to γ0 yields the pdf for γΣ:

$$P_{\gamma\Sigma} = \frac{M}{\bar{\gamma}_i}[1 - e^{-\gamma i/\bar{\gamma}_i}]^{M-1} e^{-\gamma/\bar{\gamma}} \quad (17)$$

We see that the average SNR of the combiner in i.i.d Rayleigh fading is

$$\begin{aligned}\overline{\gamma_\Sigma} &= \int_0^\infty \gamma p_{\gamma\Sigma}(\gamma) d\gamma \\ &= \int_0^\infty \frac{\gamma M}{\gamma}\left[1 - e^{-\frac{\gamma i}{\bar{\gamma}_i}}\right]^{M-1} e^{-\gamma/\bar{\gamma}} d\gamma \\ &= \bar{\gamma}\sum_{i=1}^{M}\frac{1}{i} \quad (18)\end{aligned}$$

Thus, the average SNR gain increases with M but not linearly. The higher amount of diversity the higher SNR output we get [5].

2.4 Equal Gain Combining

A simpler technique like MRC is equal-gain combining which co-phases the signals on each branch and then combines them with equal weighting $\alpha_i = e^{-\theta i}$. The SNR of the combined output, assuming equal noise PSD N0 in each branch is given by [6]

$$\gamma_\Sigma = \frac{1}{N_0 M}\left(\sum_{i=1}^{M} ri\right)^2 \quad (19)$$

3. Proposed Diversity Combining Method

To obtain the best BER output, we cannot just use one method of Diversity Combining. In QPSK and BPSK modulation method, using MRC method is the best method compared with other methods. It is due to the MRC can provide the greatest value of the combined SNR compared to others. While for QAM 16 and QAM 64 modulation, using the MRC method is no longer effective because it offers SNR gain with out any improvement in amplitude shift compensation. For the QAM method, bothQAM16 and QAM64, the best method is to use Selective Combining method. This is because this method has the largest instantaneous SNR and it can repair phase shift (such as MRC) and amplitude shift that are not on the MRC method.

By observing these improvements, this paper provides a method of weighting that combines two or more methods of Diversity Combining. In this case, it will take 3 weighting methods by combining the MRC method that has the best BER for BPSK/QPSK modulation and Selective Combining for QAM modulation. The third method is Normalize MRC which has a good BER value at any modulation mode even it is not the best in every modulation method [7].

The weighting is based on the value of SNR for specific BER to each method [8].For example in QPSK modulation mode in BER $2\text{x}10^{-4}$, It has been simulated for BER graph in Figure 5.

Using MRC method, we get SNR 7dB for BER $2\text{x}10^{-4}$. For Selective Combining Method [9], It can be seen that required SNR is 11 dB and for NMRC, it needs 26 dB SNR.

γMRC_{linear} 7dB = 2.2387

Whereas for SC method (11dB) it is similar with 3.548 linear SNR and required linear SNR for Normalized MRC (26dB) as much as 19.953. By doing weighting, from the BER graph, it is obtained that the probability of using the MRC output is closer to the transmitted data compared with SC it is because MRC BER <SC BER <Normalized MRC BER

$$W_{MRC} = 1 - \frac{\gamma MRC}{\gamma MRC + \gamma SC + \gamma NormMRC} \quad (20)$$
$$W_{MRC} = 1 - \frac{2.2387}{2.2387 + 3.548 + 19.953}$$
$$W_{MRC} = 0.913$$

And weighting for Normalize MRC

$$W_{NMRC} = 1 - \frac{\gamma Normalized\ MRC}{\gamma MRC + \gamma SC + \gamma NormMRC} \quad (22)$$
$$W_{NMRC} = 1 - \frac{19.953}{2.2387 + 3.548 + 19.953}$$
$$W_{NMRC} = 0.2248$$

With the results of this weighting, the value of the demodulator of each method is used to get a better approximation instead of only using one specific diversity combining method. If the demodulator output of used two methods has a same value then the output of demodulator in Figure 4 is equal to this value. By using this method, it is expected to get the higher probability of getting the same output as the transmitted data.

In the other hand, because in QPSK modulation it doesn't have amplitude noise then it not needs an amplitude compensator as in QAM16 and QAM64.In QAM modulation, without amplitude compensator, each point in the constellation will be overlapping. Therefore opposite than Figure 5, instead of having the best SNR, MRC has the worst SNR.

Figure 5 shows that processed data using only 1 method is not enough to handle all modulation modes. For the further simulation, Comparison of constellation between the proposed method and another paper shown that constellation using proposed method is better than using paper in [3].

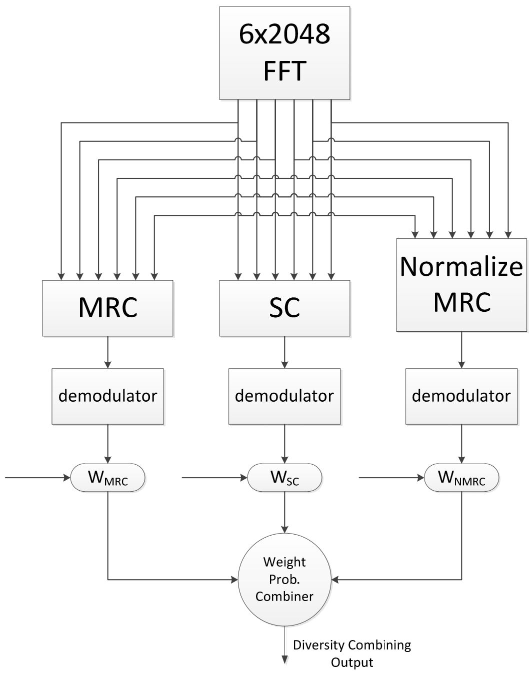

Figure 4. The 6 way Diversity Combining with Weighting Probability Combining

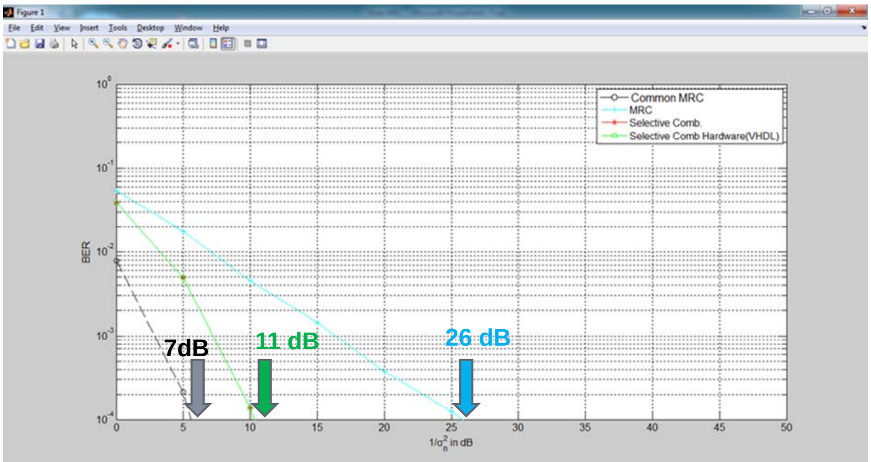

Figure 5. BER Graph of MRC, SC and NMR for QPSK modulation

4. FPGA Simulation

Because this new method uses 3 methods at once, then it needs to be smart to remove the doubled module which the module that can be shared for 2 modules or more. Figure 8 gives the illustration for the shared modules. Each method (MRC, NMRC and SC) [10] use phase compensator. Therefore, the resulted value of phase compensator can be distributed to each method to be processed furthermore in each part separately.

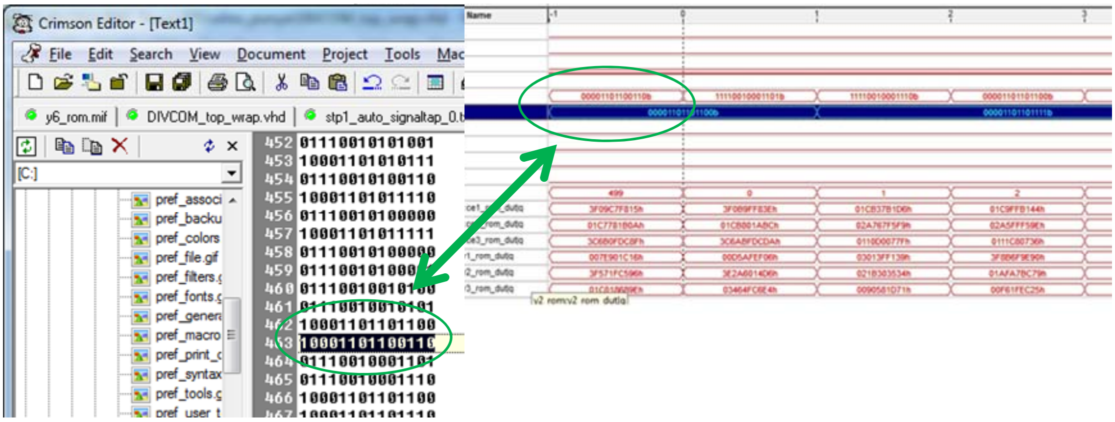

Figure 6. Signal Tap simulation

Figure 6 shows a simulation using CYCLONE II FPGA using Signal Tap software from QUATRUS have had the same output with the output of MATLAB. It can be shown that the similarities between the output of MATLAB, MODELSIM and Simulation in hardware (FPGA) so that it can be analyzed that the architecture which has been created is correct and have a good design. Besides the designed architecture fulfilled the expectation, it is because there is no jitter or delay combinational affecting in the data processing in 1 clock. While the simulation also shows that hardware able to calculate in the high speed mode which has 4 times faster (81 MHz) sampling rate than the standard speed in ETSI (9.142 MHz).

5. FPGA Test Scenario

To comprehend the true condition as in nature, it needs to design the testing scenario due to the robustness of our module in the real test field.

Figure 7. FPGA Test Scenario

To obtain the desired simulation results it is necessary that proper testing system is designed (Figure 7) so that the output of the FPGA can represent the output of a Diversity Combining [11] module in the real DVB system.

At first, VHDL code will be downloaded to the Cyclone II FPGA module from Personal Computer (PC). Besides VHDL Top of Diversity Combining module, It is downloaded also 2 ROM of data that contain data from the output of the FFT and output Channel Response.

After that the data of FFT output and Channel Response will be included in the input of Digital to Analog Converter (DAC) that amended the original digital signal into an analog signal. FPGA output will be fed back into the Signal Tap is one of the features of the software Quartus to get results back from FPGA output loop. The data from these Tap signal will be dumped and the outcome would be checked in accordance with the desired constellation or not.

6. Conclusion

This paper shows that we need not to use only one method of diversity combining for specific modulation mode. It gives an explanation that we need to consider the output of other methods even they don't have the best BER output (such as Selective Combining and Normalized MRC in BPSK/QPSK modulation).The proposed method gives a breakthrough in Diversity Combining Issue. It solved a problem of MRC that only gives good performance only in modulation BPSK and QPSK.

References

[1] Union EB. ETSI EN 300 744 V1.6.1. *European Standard.* 2009.
[2] Proakis JG. *Digital Communication over Fading Channels*. Willey.
[3] Ning M. A Simple and Effective Post-FFT Beam forming Technique. China. *IEEE.* 2007.
[4] El-Dean SG. Performance Of Switched Diversity With Post- Examining Selection In Cdma System. *Ubiquitous Computing and Communication Journal*. 2010.
[5] Lioumpas AS. Adaptive Generalized Selection Combining (A-GSC) Receivers. *IEEE.* 2008.
[6] Goldsmith A. *Wireless Communications*. Cambridge University Press. 2005.
[7] Kee Bong Song. A Low Complexity Space-Frequency BICM MIMO-OFDM System for next-Generation WLANs. *IEEE.* 2003.
[8] El-Dean S. Performance of Switched Diversity with Post Examining selection in CDMA system. *IEEE.* 2003.
[9] Martin V. Clark. Adaptive Frequency-Domain Equalization and Diversity Combining for Broadband Wireless Communications. *IEEE,* 2002; 20(2).
[10] Shifen Ou. Improved a Priori SNR Estimation for Speech Enhancement Incorporating Speech Distortion Component. *TELKOMNIKA Indonesian Journal of Electrical Engine.* 2013; 11(9): 5359-5364.
[11] Jianbin Xue. Transmission Performance Research of Digital Modulation Signals in AWGN Channel. *TELKOMNIKA Indonesian Journal of Electrical Engineering.* 2013; 11(2): 991-997.