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Evaluation of the predistortion technique by neural network algorithm in MIMO-OFDM system using USRP

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Abstract — Multiple Input Multiple Output - Orthogonal Frequency Division Multiplexing (MIMO-OFDM) is the key technology of 4G network system. The MIMO-OFDM system enhances the spectrum efficiency and increases the capacity of the system. The implementation of Universal Software Radio Peripheral (USRP) hardware to MIMO OFDM system has attracted some researchers to conduct the experiments. As far as we know, no experiments of MIMO-OFDM system by using the predistortion technique in USRP were reported. Since high power amplifier at each MIMO antenna produces the signal distortions and predistortion techniques have been proved can remove those distortions, so our interest to conduct the experiments in a MIMO OFDM system that applies the predistortion technique in USRP hardware. In this experiment, we evaluate performances of the predistortion technique by using the artificial neural network. USRP 2920 hardware which is supported by the LabVIEW and Phyton softwares are used in this experiment. The OFDM system uses 128 subcarriers to produce an OFDM symbol, and MIMO system uses 2 antennas on the transmitter and receiver side. The performances of the predistortion technique using the artificial neural network algorithm are shown in symbol constellation points or Error Vector Magnitude (EVM) at the receiver. To evaluate the performance of the predistortion, we use texts or characters as the input and output of the system. From the experiment results it can be seen that the predistortion technique produces the EVM improvement or reduce the deviation of the constellation points of symbol signals.

Keywords – EVM, MIMO, neural network, OFDM, predistortion, USRP

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I. INTRODUCTION

Recently, Orthogonal Frequency Division Multiplexing (OFDM) has been widely applied in several wireless communication systems such as Wireless Local Area Networks (WLAN), Digital Video Broadcasting Terrestrial (DVB-T), Long-term Evolution (LTE), and LTE-Advanced [1], [2]. OFDM produces a high transmission rate, increases bandwidth efficiency also robust against multipath fading effects. While Multiple Input Multiple Output (MIMO) system can increase the throughput, transmission reliability, and network capacity [3]. With those advantages then the MIMO-OFDM system is developed continuously to implement in modern wireless communication systems. In each Radio Frequency (RF) transmitter such as the MIMO-OFDM transmitters, the Power Amplifiers (PAs) are put before antennas to gain the power of the transmitted signal.

Unfortunately, PAs are nonlinear devices, and the nonlinear behavior of PAs produces signal distortions and generates spectral regrowth which causes interference with signals which are transmitted in neighboring channels. In order to remove those signal distortions the PAs must be backed-off to operate within the linear region or be linearized by using the predistortion technique to increase its linear region. The characteristics of the predistorter are inversions of the PA characteristics, so the nonlinearity of PA will be compensated by the predistorter.

Some researchers of OFDM and MIMO-OFDM systems with the predistortion technique have been studied in [4]–[9]. And research MIMO-OFDM systems using USRP hardware or Software-defined Radio (SDR) based have been reported in [10]–[12]. In [10], Zhao *et al.* applied the Vertical Bell Laboratories Layered Space-time (VBLAST) transmission model for MIMO 2×2 system and using the Zero Forcing-ordered Successive Interference Cancellation (ZF-OSIC) detection algorithm at the receiver. Zhao *et al.* [10] studies until the MIMO Alamouti system with one and two receiver antennas and the system's performances are represented in Bit Error Rate (BER) values.

Ridlo *et al.* [11] studies until the MIMO Alamouti system with two transmitter and receiver antennas. The Selection Combining (SC) and Maximal Ratio Combining (MRC) receiver diversities plus MMSE algorithm detection are applied to produce the system's performances. The results are represented in BER values and symbol constellations. But those papers did not apply the predistortion techniques.

The studies of the Predistortion (PD) techniques using USRP hardware are reported in [13]–[15]. In [13], Marsalek and Pospisil use the Look-up-table (LUT) approach as the predistorter and the results are represented in Amplitude Modulation (AM)-AM transfer characteristic curve PA and PA plus PD also reducement of the power spectra after using PD. While in [14], Islam uses the SIMULINK to communicate with the USRP and uses the LUT Digital Predistorter (DPD) and using the external PA.

Pillai *et al.* [15] uses the orthogonal memory polynomial model as DPD. The power spectra reducements are reported in this paper. But they did not apply the predistortion techniques in multi-antennas or MIMO systems. In [16], DPD Wiener model as predistorter is used to compensate the Hammerstein PA at the transmitter side. The experimental results are reported in the AM-AM transfer characteristic curve of PA and PA plus PD, power spectra reducements after using PD, and symbol constellations of the transmitted signal. At the RF transmitter with multi antennas such as the MIMO-OFDM system the signal distortions generated by High-Performance Antenna (HPA) at each antenna should be removed. And one solution is the implementation of the predistortion techniques at each antenna before HPA.

Since no experiments of the MIMO-OFDM system by using the predistortion technique in USRP were reported, therefore, we propose an experiment to evaluate the performance of the predistortion technique in 2×2 MIMO-OFDM system using National Instrument (NI)-USRP N2920 hardware. Meanwhile, Neural Network (NN) algorithm is used as the predistorter to compensate the PA nonlinearity Rapp model [17]. Our contribution is the application of the NN algorithm for predistortion technique in hardware USRP has been conducted and can be implemented to MIMO transmitter. In addition, the impacts of the predistortion can be shown on the receiver compared to the impacts of PA.

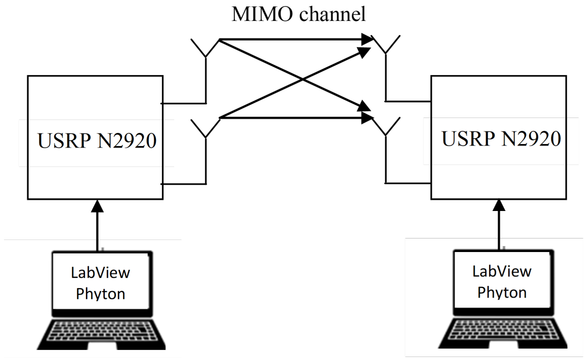

Fig. 1. Transmitter and receiver architecture SDR-based.

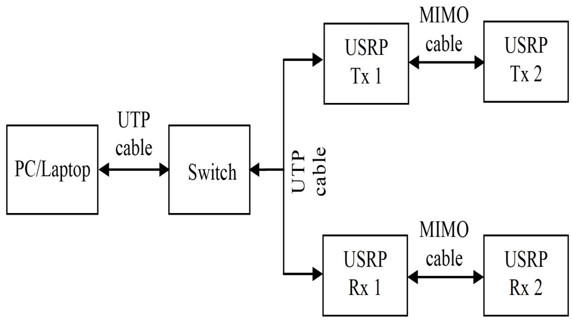

Fig. 2. Cable connections of two USRP hardwares.

II. System Model

A. Basic Architecture Measurement

Transmitter and receiver architecture for experiment measurement I showed in Fig. 1, contain of two NI-USRP-2920 hardwares as transmitter system and two NI-USRP-2920 hardwares as receiver system. Range frequency is 50 MHz to 2.2 GHz. LabVIEW version 2018 and Python 3.6 software are used to support NN algorithm program to USRP. And cable connections between USRP hardware and computer is shown in Fig. 2, MIMO cables are used to synchronize the clock and frequency between two USRP hardware at transmitter and receiver respectively.

B. MIMO-OFDM Tx-Rx Model

Diagram block of MIMO-OFDM transmitter and receiver systems with 2 transmit antennas and receive antennas which are used in this experiment are shown in Fig. 3 and Fig. 4.

Firstly, a text as the source is converted to a bit sequence and then mapped to a sequence of the QAM symbols constellation. This experiment allocates 128 subcarriers, 96 subcarrriers is used to carry QAM symbols, 23 subcarriers is used to carry null symbols and 9 subcarriers is used to carry pilot symbols. A set of serial symbols with length n ($n = 2N$, $N = 96$), is separated into two serial symbol sequences, with length $n/2$ respectively. The first symbol sequence contains of first symbol to $n/2nd$ symbol, and the second sequence contains of $(n/2 + 1)th$ symbol to the nth. So each serial symbol sequence has 96 symbols. Each serial symbol sequence is converted to a parallel symbol using a serial to parallel converter. Then 23 null symbols and

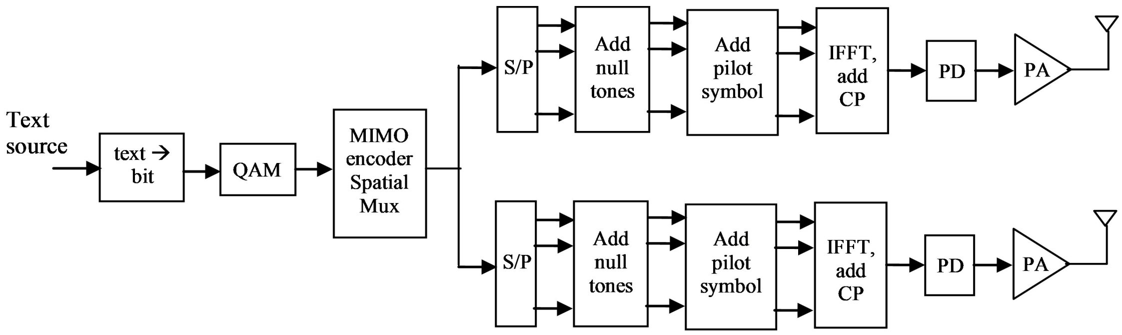

Fig. 3. MIMO-OFDM transmitter system with predistorter (PD).

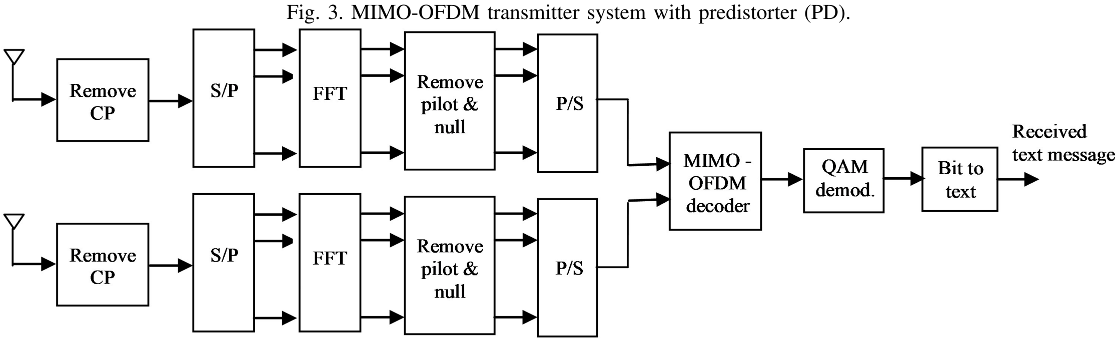

Fig. 4. Diagram block MIMO-OFDM receiver system.

9 pilot symbols are inserted into each parallel symbol, thus a parallel symbol with length 128 is resulted. The IFFT process is used to produce an OFDM symbol in time domain from each parallel symbols, then the cyclic prefix is added in order to mitigate inter-symbol interference due to multipath signals. 32 samples of cyclic prefix are inserted in front of OFDM symbol, makes the total samples become 160 in one OFDM symbol. Each OFDM symbol is sent to predistorter and internal PA in each USRP and antennas.

At each receiver the cyclic prefix is removed and the remaining samples by using FFT process are converted to frequency domain symbols. And the sequence processes such as channel estimation, channel equalization and remove the pilot and null symbols apply to the frequency domain symbols. Then by using parallel to serial converter this symbol is converted to time domain symbols. The two time domain symbols from each antenna receiver are combined by MIMO-OFDM decoder to produce one QAM symbol sequence. And by the QAM demapper a QAM symbol sequence is demapper of bit sequence. Finally, this bit sequences are converted to text form.

C. Neural Network as Predistorter

An NN algorithm is used as the pre-disorter to compensate for the non-linearity characteristic of PA have bedd studed in [18], [19]. We used the Artificial Neural Network Autoencoder architecture, since it has the ability to de-noise data. The NN architecture design for this experiment shown in Fig. 5 and LabVIEW diagram block of the transmitter and receiver are shown in Fig. 6 and Fig. 7.

Based on this architecture, we have the equation as:

$$\hat{y} = f_1(w^{[5]}.BN(f_2(w^{[4]}.BN(f_2(w^{[3]}.BN(f_2(w^{[2]}.BN(f_2(w^{[1]}.X + b^{[1]})) + b^{[2]})) + b^{[3]}))+ b^{[4]})) + b^{[5]})) \quad (1)$$

where $\hat{y}$ is the encoder output, f_1 is the activation function linear, f_2 is the activation function ReLu, BN is the batch normalization, w is the weight, b is the bias, and X is the data input.

In this architecture the 3rd hidden layer is the bottleneck layer. This architecture also is trained in 2 dimensions because the input data are in complex format. And we used for batch normalization to scale the output from the activation function. And batch normalization can reduce the internal covariate shift and improve the performance [20].

The output $\hat{y}$ at this architecture is evaluated using the MSE loss function. Loss function for this architecture can be written as:

$$\mathfrak{L}(\hat{y}, y) = \frac{1}{n}\mathbf{\Sigma}(y - \hat{y})^2 \quad (2)$$

which is the squared differences between true value y and the predicted value, $\hat{y}$. The evaluation results of ŷ then are used to optimize the NN, and we used for the adaptive moment estimation (Adam) to optimize.

III. Experiment Layouts and Measurement Results

Two examples of experiment layout MIMO OFDM system for distance of 60 cm and 420 cm are shown in Fig. 8 and Fig. 9.

The performance of predistortion technique is shown in Fig. 10 as the AM/AM transfer characteristic. In this experiment the Rapp model is used as an internal

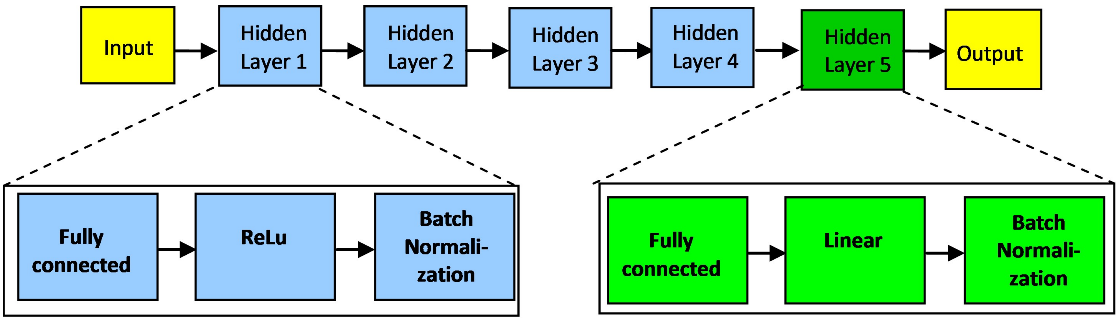

Fig. 5. Neural networks architecture for predistortion.

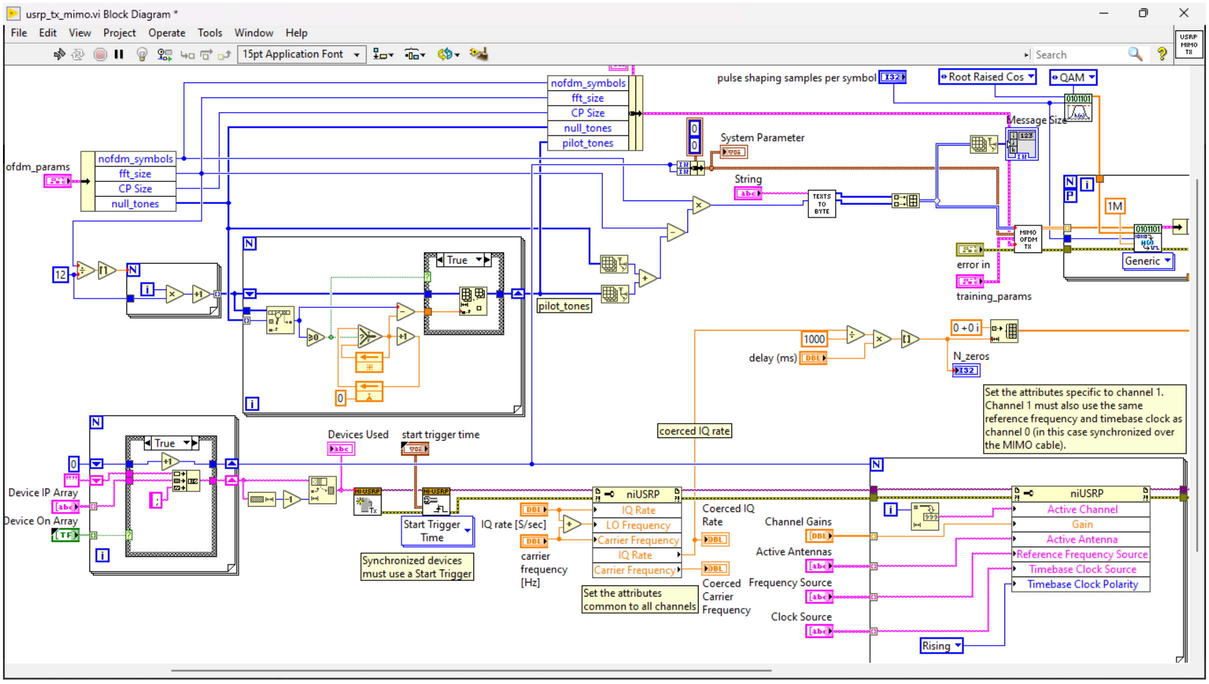

Fig. 6. LabVIEW diagram block of transmitter system.

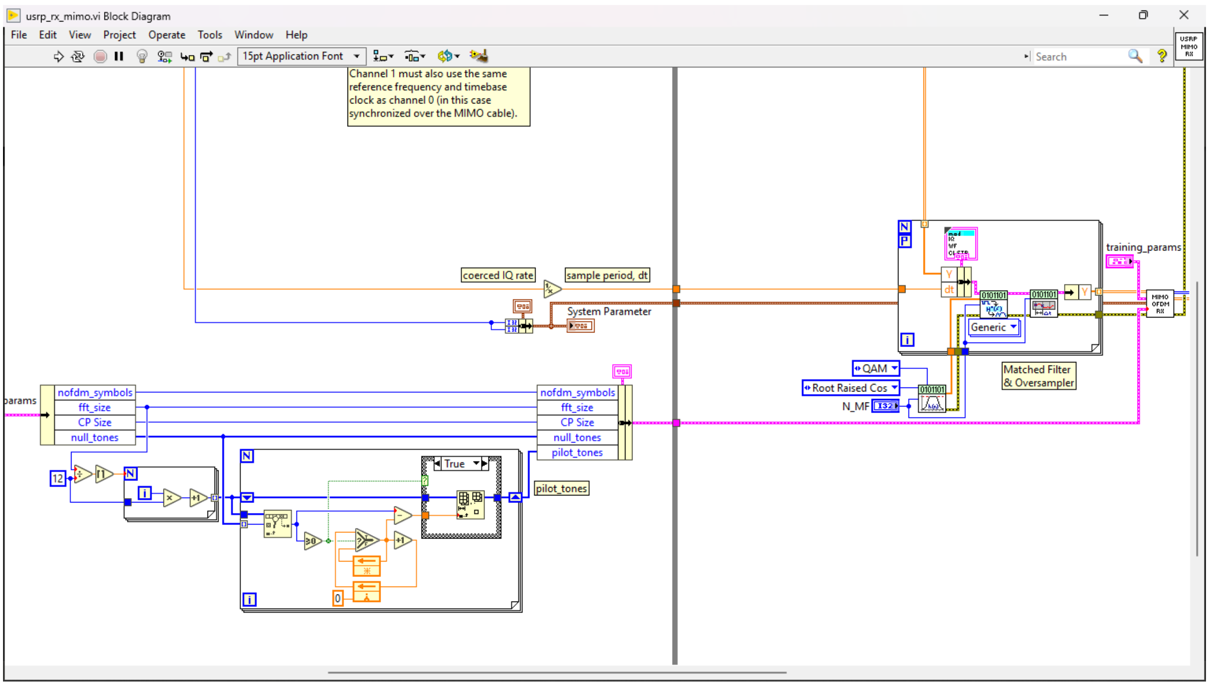

Fig. 7. LabVIEW diagram block of receiver system.

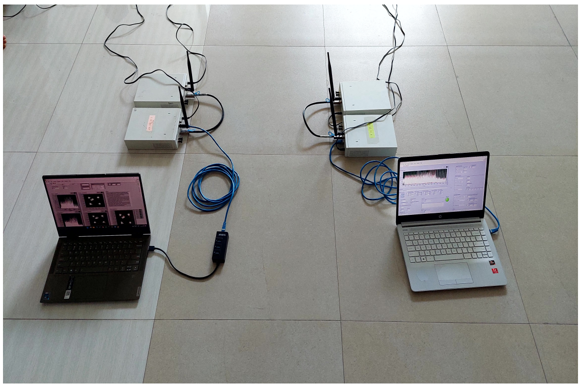

Fig. 8. Layout of experiment for distance of 60 cm.

Fig. 9. Layout of experiment for distance of 420 cm.

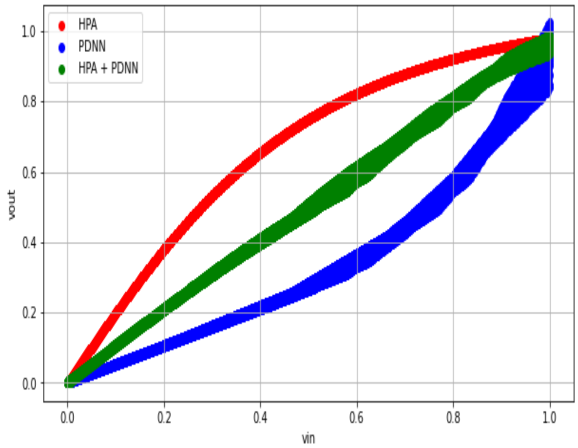

Fig. 10. AM/AM transfer characteristics of PA, PD and PD plus PA.

PA model, and from Fig. 10 can be seen that the predistorter compensates the nonlinearity PA and results the linearization of PA. The measurement results in QAM symbol constellation points and text for distance of 60 cm without PD and with using PD are shown in Fig. 11 and Fig. 12, while the measurement without PD and by using PD for distance of 420 cm are shown in Fig. 13 and Fig. 14.

IV. Conclusion

Based on the experimental results proved that the NN algorithm can be used as predistorter at USRP hardware successfully. And the performance of the predistorter can be shown in a 2×2 MIMO OFDM system. The experimental results have seen the predistortion technique affects improvement of

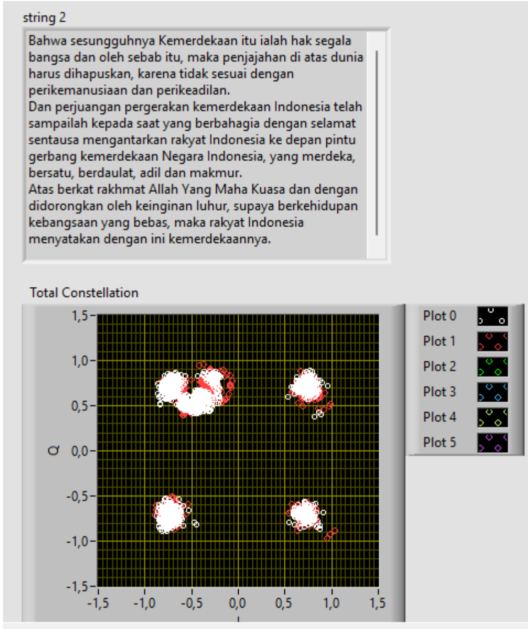

Fig. 11. Measurement results for distance of 60 cm without PD.

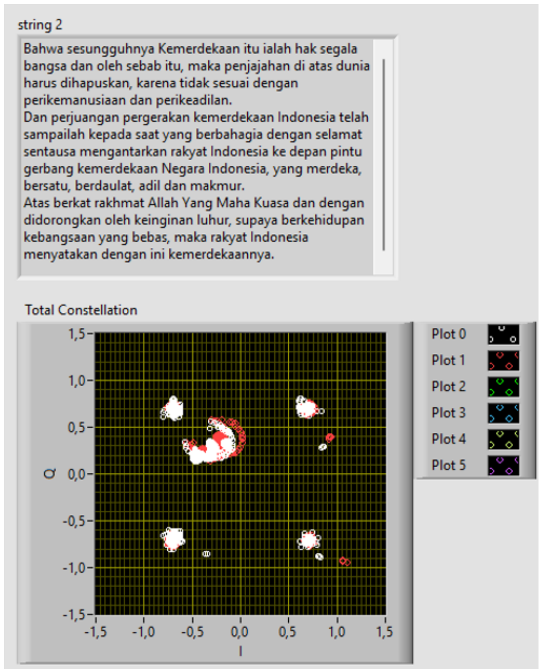

Fig. 12. Measurement results for distance of 60 cm by using PD.

the system's performance. The constellation points of the received signals are one improvement of the predistortion which are presented in this paper. Before using predistortion the constellation points are spread, it indicates the received signals are distorted since its amplitudes and phases are big different to ideal QAM signal or the EVM is high. After using predistortion the spreading of the constellation points becomes small or the deviation of the constellation points are reduced. Thus, the distortions of the received signal are reduced and the EVM value is improved.

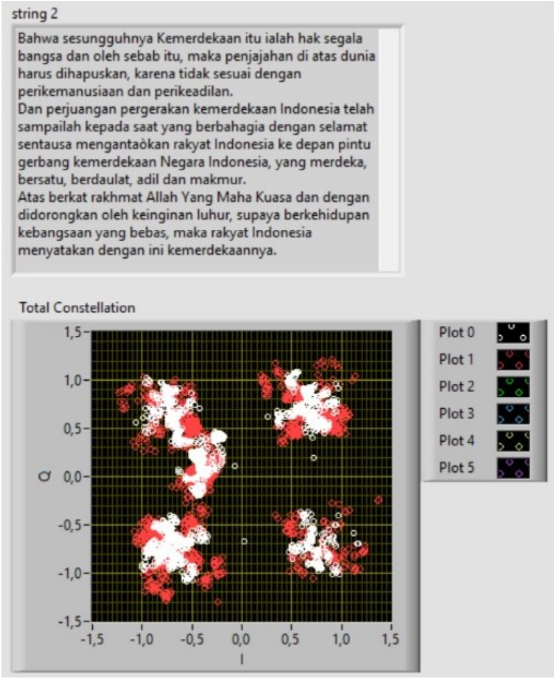

Fig. 13. Measurement results for distance of 420 cm without PD.

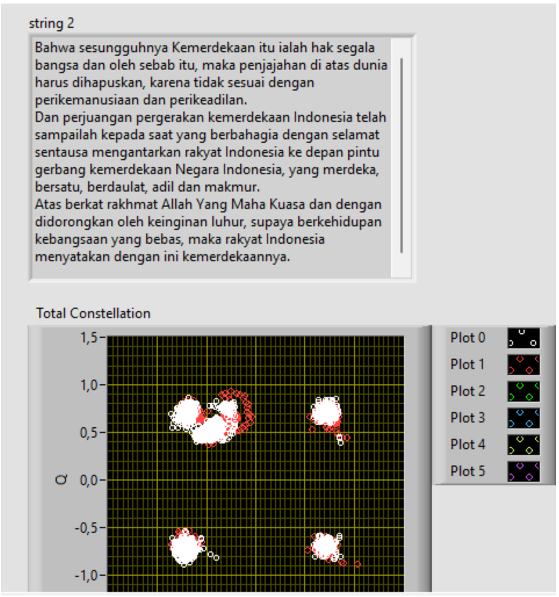

Fig. 14. Measurement results for distance of 420 cm distance by using PD.

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