Bidirectional Video Visible Light Communication

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Abstract

Video communication is needed for many applications used in both air and underwater environment, which require a bidirectional system during its transmission. Consequently, bidirectional video communication using visible light is essential. Recently, several communication technologies have been presented using various transmission mediums, i.e., radio frequency communications, acoustic communications, and visible light communications (VLC). VLC offers high data rates, a free spectrum, and it can be integrated with existing infrastructures, so VLC becomes promising technology for video communication both on the air and an underwater environment. Up to this stage, past studies on video communication are mostly done using a unidirectional method. In this study, a visible light-based bidirectional video communication is proposed. The system employs a bidirectional method where each of the Red, Green, and Blue (RGB) filters is utilized to represent respective wavelengths in each link. In link 1, a transmitter circuit transmits the video signal using a commercial white light-emitting diode (LED) through a colour filter to build unidirectional systems, which then received by photodiode (PD) arrays in the receiver circuit. The same system is used in link 2, where the video signal is transmitted from the transmitter circuit toward the receiver circuit through a colour filter, so the bidirectional systems is built. This proposed system was applied in bright and dark conditions. The measurement for the system was undertaken based on the distances of transmitter and receiver, as well as crosstalk measurement represented by the Near-End Crosstalk (NEXT) parameter. The results show that the video signal can be sent from the transmitter to the receiver at various distances using proposed systems. In bidirectional measurement, the video signal can be transmitted in two directions, where the best measurement results are obtained when the conditions of the two transmitters use different colour filters. It is a blue filter in link 1 and green filter in link 2, and then the red filter in link 1 and green filter in link 2. The other result shows the average voltage received during the experiment in the bright is higher than in the dark condition. The crosstalk measurement results show the NEXT parameter is only obtained when the systems utilize the same colour filter on both receivers. Therefore, for future use, the same wavelength in the bidirectional video communication system should be avoided. Based on those results, it is concluded that the system proposed in this study is a reliable bidirectional video communication system. We show that successful simultaneous high-quality video signal transmissions are possible without the need for optimized optics.

Keywords: Visible light communication (VLC), video, bidirectional, light emitting diode (LED), photodiode (PD)

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1. Introduction

Recently, multimedia-based communication technology, i.e., audio, video, and data, is developed. These technologies are utilized for many applications, such as education, healthcare, business, engineering, research, transportation, etc.

Video communication is needed in the air and in an underwater environment. Some underwater marine devices and vehicles are utilizing this communication for many applications, such as pipeline survey, disaster surveying, oceanographic, military, and offshore industry [1].

Furthermore, there are about 1000 Remotely Operated Vehicles (ROVs) and up to 700 Autonomous Underwater Vehicles (AUV's) in the world that need to build the high quality of video communication [2]. Therefore, a two way or bidirectional communication system between devices is essential.

Several communication technologies are presented using various transmission mediums, i.e., radio frequency communications, acoustic communications, and visible light communications (VLC).

Acoustic communications are used in underwater communication because it has low attenuation with a distance of up to 1 km [3], [4]. The main disadvantage of high-frequency communication is its high cost, as the use of frequency is not free. VLC offers data rates up to 1 Gbps and a distance of up to 100 m [3]. Furthermore, this technology used a free spectrum, and the lamp infrastructure has been existing. Due to the video bandwidth is 6 MHz, VLC becomes promising technology for video communication both on the air and an underwater environment. The research in VLC has been addressed for many applications [5] - [11].

The VLC research is started by Dominic O'Brien [12] from the University of Oxford in 2008, who uses white LED lights to provide information simultaneously. The research is followed by Jianyang Shi [4] from Fudan

University in 2014, performing real-time bidirectional communication using white LED phosphor bases with speeds of 100 Mbps and 200 Mbps using RGB LED, which used the audio signal as information.

In 2014, the study was conducted by Nurul Wulandari [13], implemented video signal in one-way communication (unidirectional). The results showed that video image, which appears on the monitor, is not perfect, as the factor of selecting LEDs and photodiodes are not yet suitable for sending data completely. The gain on the transceiver system has an average of 7.78dB. With the average delay factor, the frequency reading is 17.49 µs. In 2015, a study conducted by Ruediger Kays of TU Dortmund University, discussed VLC using video cameras in real-time [14].

In some existing studies, there are some disadvantages where research is only done by conducting one-way (unidirectional) communication research, while many applications need to build video communication in a two-way (bidirectional) method. It shows the research from Son [15] implemented a video transceiver using VLC with the unidirectional method. Another research about bidirectional VLC is conducted by Darlis [16] that transmit an audio signal from the transmitter toward the receiver, and vice versa, in an underwater environment.

Other researches were done by Fuada [17], Deepa [18], and Qasin [19] that analyse VLC Technology that will be used for those systems. Visible Light Communication (VLC) has been applied in wide fields such as applied indoors [20]-[27], underwater [7], [16], [28]-[30], and Vehicle-to-vehicle (V2V) Communication [31].

In this paper, a bidirectional video visible light communication is proposed. The systems are implemented by the two transceivers (transmitter-receiver) that utilize the one of the Red Green Blue (RGB) filter that represents a wavelength to build the bidirectional systems. The bidirectional occurs while each link using a wavelength, which is represented by a colour filter.

In the first link, a transmitter circuit transmits the video signal using commercial white light-emitting diodes (LEDs) through a colour filter, and photodiode (PD) arrays receive this signal in the receiver circuit. In the second link, the information signal is transmitted from the VLC transmitter toward the VLC receiver using a different colour filter. In the measurement, the value of crosstalk measurement, which named NEXT, is used. Therefore, this research is prospective to give the contribution to finding the best of the colour pair for the bidirectional VLC system. The proposed systems can support the bidirectional communication between vehicles, divers, and devices on the air and in the underwater environment.

2. Materials and Methods

In this system, there were four components, i.e., two transmitters and two receivers. Each link was represented using a single transmitter and receiver, where a video signal is sent from the transmitter to the receiver.

In the system on link 1, the source of the video signal was a DVD player. The output from the DVD player was transmitted by the transmitter circuit, which acts as a video signal amplifier and regulator. The circuit also acted as a DC voltage converter, which converts DC voltage 9 volts to 5 volts. This component was needed to activate IC LM7171, so the video signal could be sent from the LED using visible light-medium. The visible light was received by the photodiodes and processed by the receiver circuit. Then, the signal was displayed on the television connected with the RCA-to-display video cable.

The same process occurred in link 2, where the source of the video signal came from a DVD player. The transmitter circuit transmitted the output from the DVD player so the video signal could be sent from the LED using visible light-medium. The receiver circuit received the visible light. Then, the signal was displayed on the television.

In the systems, the transmitter circuit consisted of several electronic components, i.e., video jack, an amplifier circuit, the voltage regulator, power supply, and LED which consisting of passive and active components, i.e., resistor 4,7 kΩ and 15 kΩ, capacitor 10 µF and 330 pF, ICLM7171, ICL7660s, RCA female, and white LED super bright. The amplifier circuit used the LM7171 component like a video amplifier. This transmitter circuit could work when it was supplied by the voltage of +9 volts and -5 volts. The voltage value of +9 volts was obtained from the power supply that connected to the V_{CC} port, while the voltage value of -5 volts was obtained from the regulator output. The LED had several parameters, i.e., a field of view (FOV) 50°, lens refractive index 1.5, LED half-power angle 60°, and the gain of an optical filter 1.

In the receiver circuit, the primary components were photodiodes because the photodiodes function as the light sensor, which converts light energy to electrical energy. This circuit used nine photodiodes arranged in an array, variable Resistor 100 Ω, Resistor 1k Ω, and RCA female. The output of the photodiode was connected to a resistor, which was then directly connected to the RCA video jack.

The optical path loss model of the proposed systems consist of air optical path L_M. Over the air optical channel, L_M is determined by a line-of-sight (LOS) VLC link with a Lambertian source. Hence, the path loss L_M can be approximated as [32]-[34]:

$$\mathrm{L}_M = \mathrm{a}_m \, \frac{A_r(m_1+1)}{2\pi d_m^2} cos^{m_1}(\phi) T_s(\psi) g(\psi) cos(\psi) \qquad (1)$$

where: m_1 is a Lambert mode number expressing a source beam directivity; a_m is attenuation. The detector is modeled as an aperture area Ar in the field of view ψ. The gain of an optical filter at the receiver is $T_s(\psi)$.

The gain of an optical lens is $g(\psi)$ that is determined by ψ and lens refractive index. Meanwhile, ϕ is half the power angle. In the VLC system, LED is commonly used as a light source [35], where its basic geometry is shown in Figure 1.

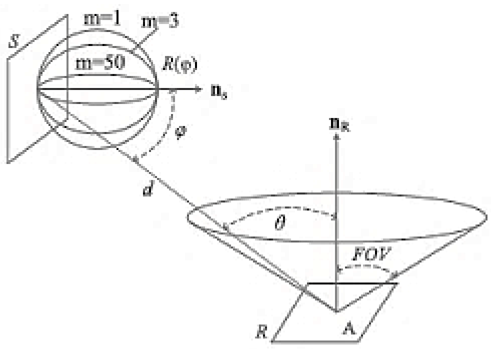

Figure 1. Basic geometry of visible light communication source, reflector, and receiver [35]

The reflection shows the field of view denoted as (FOV) on a line-of-sight (LOS) environment. That basic geometry of VLC leads to a transmission limitation in terms of reflection and Non-LOS cases due to building constructions.

Before testing the system, there is a preliminary test to determine the condition of the video signal to be sent. This measurement aims to assess the magnitude of the value of reinforcement in the transmitter circuit by comparing the value of the output voltage to the input voltage obtained from the results of using an oscilloscope.

The measurement of the reinforcement value is done connecting the CH 1 from the oscilloscope at the RCA input from the DVD player in the circuit. And them the CH 2 oscilloscope connected to the output circuit in the form of an LED. In these measurements, the transmitters which have been implemented are used.

Figure 2 shows the output signal measurement, which is a video signal on the transmitter.

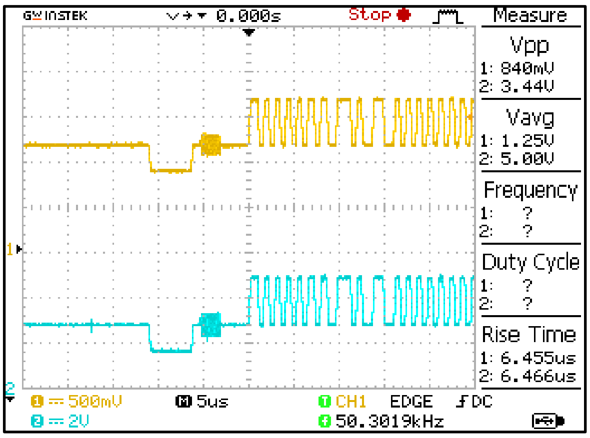

Figure 2. Video Measurement results on the transmitter

The first signal (above) is a video signal from DVD Player, and the second signal (below) is video signal transmitter output.

The input on the transmitter circuit is connected to the DVD player, and the transmitter circuit is given an input voltage of 9 volts from the power supply. It can be seen in the form of the signal displayed on the oscilloscope that the signal measured at the DVD player's output point and the video signal measured at the transmitter circuit's output point has a similar shape, which is the form of the video signal in the time domain [21]. This proves that the form of the video signal has not weakened, but it has even experienced a gain of at least 4 x before it is influenced by the visible light channel in proposed systems.

The system employs a bidirectional method where each of the Red, Green, and Blue (RGB) filters is utilized to represent respective wavelengths in each link. In link 1, a transmitter circuit transmits the video signal using a commercial white light-emitting diode (LED) through a colour filter to build unidirectional systems, which then received by photodiode (PD) arrays in the receiver circuit. The same system is used in link 2, where the video signal is transmitted from the transmitter circuit toward the receiver circuit through a colour filter, so the bidirectional systems are built.

3. Results and Discussion

After the design and implement the systems, the next step is to test and retrieve data from the system. Testing and data retrieval is carried out, aiming to obtain data that can be compared to determine the performance of the tools that have been made. The results of the testing of data can be used as a reference for the overall analysis. The stages of data testing are the measurement of 1-way (directional) systems, measurement of 2-way (bidirectional) systems, and measurement of the Crosstalk System.

3.1 Measurement of 1-way (unidirectional) systems

This measurement was carried out to find out the best output value produced from several colour filters used. This measurement will be a reference to the next measurements, where used colour filter will determine quality from the systems.

The measurements were carried out in 2 conditions, i.e., the first measurements were made on bright room conditions using three colour filters, including red, green, blue. The second was the measurement in the condition of the darkroom, which also used the same colour filter as during bright room conditions. The voltage that was owned by the video signal from the DVD Player had a value ranging from 800 mV to 1.5 V. It is because of the inconsistency of the video signal, which had a fluctuating voltage due to images that were always moving. In this measurement, the measurement range used was from 10 cm to 40 cm. This range is the limit reached so that the video signal received still had good image quality. In this measurement, there are four methods, i.e., measurement of the system without using a colour filter, measurement using a red filter, a green filter, and finally a blue filter.

Table 1 showed the measurement results of 1-way (unidirectional) systems both without and using the colour filters in the bright and darkroom.

Table 1. Measurement results of 1-way (directional) systems

Distance (cm)	Room Condition			
	Bright		Dark	
	Vin[1]	Vo[2]	Vin[1]	Vo[2]
Without Colour Filter				
10	1.48	74	1.03	86
15	1.48	66	0.98	116
20	1.17	72	0.48	90
25	1.48	55	0.98	116
30	1.44	102	0.84	104
35	1.44	94	1.00	99
40	1.48	66	0.98	124
Average	1,41	74.85	0.89	104.57
Using the red filter				
10	1.01	23	1.00	25.6
15	1.00	42	0.98	20.7
20	1.00	13.3	1.00	64
25	1.01	30	0.96	21
30	0.96	32	0.96	20.7
35	0.98	30	1.08	21
40	1.22	18	0.98	18.3
Average	1.03	26.7	0.99	27.4
Using the green filter				
10	1.17	94	1.03	80
15	1.2	180	1.17	96
20	1.13	160	1.13	52
25	1.00	54	1.20	46
30	0.98	38	0.96	38
35	1.17	36	1.00	48
40	0.82	38	1.00	40
Average	1.06	85.7	1.07	57.1
Using the blue filter				
10	0.98	16.0	1.00	30
15	0.96	50	1.19	30
20	1.03	30	1.00	34
25	0.98	16	1.00	30
30	1.01	20	1.17	26
35	0.96	19	1.05	19.2
40	1.00	16.7	1.15	17.6
Average	0.99	28.42	1.08	26.5

Note: [1]in V, [2]in mV

The parameter used in this measurement is the output voltage of the receiver circuit, which is measured using an oscilloscope. The use of this colour filter is essential in building two-way communication using visible light channels, so that information signal interference occurs between channels.

The measurement results in a unidirectional system without using filters showed that received voltage in a dark condition has better performance, around 100 mV, than a bright condition. This result shows that interference from lighting and sunlight from the window is affecting the system performance.

The effect of lights and sunlight can be seen from the change in the voltage of the video signal as input and output signals, wherein light conditions the input signal voltage will increase by about 500 mV compared to dark conditions. The addition of voltage occurs when the electrical signal output of the transmitter circuit that has been converted using LEDs into visible light is mixed with light from the external so that they strengthen each other. The visible light will be received by the PD in the receiver circuit, so there will be an increase in the voltage processed in the circuit. The light that interferes with visible light that contains information signals will be measured as noise, so this needs to be avoided. Thus, it can be concluded that increasing the voltage at the input in bright conditions will make the quality of the video signal transmitted will decrease.

In addition, as discussed earlier, it is seen that the stress condition, which is the main parameter in the measurement system with this 1-way method, has a better voltage with an average of 100 mV in dark conditions than in light conditions. This is due to the signal processing process at the receiver in dark conditions having less noise than in bright conditions.

Table 1 also shows the results of measurement systems that use red, green, and blue colour filters. The measurement results show that the influence of interference from outside light, both the room lights and sunlight from the window, does not affect the system in bright and dark conditions. This is because the tool has been able to filter the incoming light so that it will improve the quality of the video signal that is sent. This can be seen from the condition of the received video signal for the better.

The measurement results using the red filter shows the fluctuating results and low received voltage. The results show the received voltage has a higher value in the small distance, which results in measurements that are not too different in bright or dark rooms, with an average received voltage of around 27 mV.

This received voltage value is much smaller than the results shown in the measurement system without using a filter. This proves that the effect of the filter on both the wavelength type and the structure of the material will affect the measurement results.

The measurement results using the green filter shows the fluctuating received voltage. This is clearly seen at low distances, whereas at higher distances it is relatively more stable. The effect of light and darkroom conditions is seen in measurements using this filter, where at low distances, interference from other incoming light still affects the system by using this green filter. The value of the received voltage measured at the system output is greater than the value generated by the use of a red filter, with an average receiving voltage of around 85.7 mV in bright conditions and 57.1 mV in dark conditions. From these results, it can be seen that the voltage generated under bright conditions cannot be used as a reference because there is the influence of noise from outside light. With the results obtained from measurements with a green filter in a dark room, it can be concluded that it is still better than using a red filter.

The measurement results using the blue filter shows the same condition with the measure results suing the red filter where it has the fluctuating results and low received voltage. It can be seen from this result that the effect of noise from external light does not affect system performance, as evidenced by the stability of the receiving voltage. This is in line with the increase in the distance to the received voltage value. The use of this blue filter causes the received voltage to be too low so that the displayed video signal has poor quality, as evidenced by an average receive voltage of around

27mV as well as the results of measurements using a red filter.

The measurement results obtained in Table 1 with unfiltered measurement conditions and the use of red, green, and blue colour filters show the best results are obtained in darkroom conditions. This result can be seen from the result of voltage measurements is darker conditions are higher than when the room conditions are bright. However, the measurement results are not stable because of the influence of distance and voltage values that are always changing at any time.

It can be seen from these results that the communication system using visible light using the green filter is better than using red and blue filters, both in bright and dark conditions. The blue filter shows the second of good performance. However, it can be seen that at a distance of 15 cm and 20 cm, the voltage is reduced to 20 mV due to the influence of the dynamic lights. It was also found that the effect of lighting on dark and light conditions did not have too much influence on the performance of a one-way communication system.

3.2. Measurement of 2-way (bidirectional) systems

The proposed of the bidirectional method in this study is used in communication systems using visible light with an information signal in the form of a video signal. In this study, the bidirectional method was constructed using wavelengths in the uplink (link 1) and downlink (link 2) using a layered filter mounted on the transmitter. In addition, in measurement, this system also discusses the use of the same filter on link 1 and link 2.

In this test, the system used two transceiver systems consisting of two transmitters and two receivers. Link 1 was made by sending a video signal from transmitter 1 that is issued from an electrical signal into visible light using Light Emitting Diode (LED) 1, to the receiver 1 after passing through a colour filter. Furthermore, Photodiode (PD) 1 array received visible light and processed by a receivers 1 so that a video signal is generated as sent by the sender. Just like completing the process that occurs at link 1, the process of sending video signals on link 2 is done by transmitting a video signal using transmission 2 using LED 2. The signal will pass through a coloured filter and process it on the visible light channel, and ultimately it is received by PD 2 to processed by receiver 2 to become the desired video signal. In this study, the transmitter circuit 1, LED 1, PD 2, and receiver circuit 2 are made in an integrated system. Start with integration transmitter 2, LED 2, PD 1, and receiver in the system.

In this measurement, the distance used is the same as the 1-way measurement, which is from 10 cm to 40 cm. This is intended to maintain the consistency of measurements with previous measurements. This measurement analysed the best pair of filters for use in a bidirectional system in a video visible light communication system.

Based on the measurement of 1 way systems, in the measurement of bidirectional systems, there are 4 methods, i.e., measurement the system without using a colour filter, measurement using the red filter in link 1 and green filter in link 2, measurement using the blue filter in link 1 and green filter in link 2, and measurement using the blue filter in link 1 and a red filter in link 2. Like the previous measurements, this measurement is carried out in bright and darkroom conditions.

Table 2 showed the measurement results of 2-way (bidirectional) systems both without and using the colour filters in the bright and darkroom.

Table 2. Measurement results of 2-way (bidirectional) systems

Dist. (cm)	Room Condition							
	Link 1				Link 2			
	Bright		Dark		Bright		Dark	
	Vin[1]	Vo[2]	Vin[1]	Vo[2]	Vin[1]	Vo[2]	Vin[1]	Vo[2]
Without colour filters								
10	0.9	116	1.2	98	0.9	123	0.7	25
15	0.9	80	0.9	72	1.4	31	1	15
20	0.6	90	0.9	116	1	96	0.8	15
25	0.7	80	0.9	124	0.6	23	0.9	12
30	0.8	94	1.4	61	1.2	36	0.7	32
35	0.9	94	1.5	66	1.3	45	0.7	46
40	0.4	48	1.4	102	0.6	18	0.7	25
Avg.	0.7	86	1.2	91	1	53	0.8	24
Using the red filter in link 1 and green filter in link 2								
10	1.4	106	1.5	128	0.4	58	1	112
15	1.4	96	1	42	0.7	74	0.7	82
20	1.4	94	0.7	46	0.8	50	0.4	62
25	1.5	58	1.4	68	1	50	1	54
30	1.4	80	1.4	42	0.5	52	0.5	38
35	1	18	1	33	0.7	12	1	36
40	0.9	14	1	42	0.9	11	0.3	34
Avg.	1.3	66	1.1	57	0.8	43	0.7	60
Using the blue filter in link 1 and green filter in link 2								
10	1	92	1.4	66	1	116	1.2	98
15	1.4	92	1.4	102	1	88	0.8	72
20	1.4	94	0.9	47	0.7	90	1	116
25	1.5	74	1.6	66	0.8	88	0.9	124
30	1	23	1.5	66	0.8	94	1	124
35	1.5	55	1	29	1	94	1	116
40	1	48	1	26	1	94	1	116
Avg.	1.3	68	1.3	57	0.9	95	1	109
Using the blue filter in link 1 and a red filter in link 2								
10	1.3	308	1.3	104	0.5	98	1.4	106
15	1.5	306	0.9	90	1.0	96	1.4	96
20	1.4	232	1.5	260	0.9	98	1.4	94
25	1.4	350	1.4	312	1.0	144	1.4	58
30	1.4	312	1.5	66	1	114	1.4	80
35	1.5	264	0.9	47	1	82	1	18
40	1.1	192	2	116	1	90	1	14
Avg.	1.4	280	1.4	142	0.9	103	1.3	67

Note: [1]in V, [2]in mV

The measurement results in the bidirectional system without using filters showed that in bright conditions, the video signal used as an input signal experienced inconsistency in link 2. This phenomenon occurs due to lighting and sunlight interference. The signal voltage generated from link 1 is better than link 2, with an average voltage of around 86 mV. There was an interesting phenomenon in the output voltage measurement results on link 2, where there is an inconsistency of the voltage value obtained. This is due to the phenomenon of light interference, where the visible light produced at link 1 dominates the visible light emitted at link 2. This causes the PD at link 2 to detect inconsistent visible light.

Conversely, the same thing occurs in the communication process in darkroom conditions, where the input voltage of the video signal has an increase in link 1. As discussed earlier, this is due to external light interference from sunlight and lighting. In dark conditions, the output voltage has the same phenomenon as in bright conditions, where the output signal on one of the links, link 1, has an average value that is much greater than link 2, which is about 91 mV.

From this phenomenon, it can be concluded that the input signal and the video signal output in bright and dark conditions affect each other without using filters.

The measurement results using the red filter on link 1 and the green filter on link 2 show relatively stable where the output voltage of each link is hardly affected by each other. However, it can be seen from the results that the output voltage has a fairly small value. This is because, according to measurements in the unidirectional method, the red colour filter is to reduce the visible light received by PD. It appears that the farther the distance, the voltage received will be smaller too, both in light and dark conditions.

The measurement results on the use of the blue filter on link 1 and the green filter on link 2 show good results. Even measurements in darkroom conditions show results where the output voltage reaches 109 mV. This is almost close to the voltage of the video input signal with good image quality.

The last measurement used blue and red filters at two transmitters. This was chosen because in both filters, it has a different wavelength for red with a wavelength of 620-750 nm and blue colour 450-495 nm. The measurements using the blue filter on link 1 and the coloured filter on link 2 show a very large increase in voltage, reaching 280 mV in bright conditions and 142 mV in dark conditions. This shows that this colour pair shows the best results compared to other colour filter pairs.

It shows the best results are obtained when the conditions of the two transmitters use different colour filters, which using a blue filter in link 1 and green filter in link two on the bright condition and using the red filter in link 1 and green filter in link 2.

From the results of voltage measurements in the various distance, the measurement of bright room conditions, the average voltage value is higher than the average voltage value in dark conditions. The measurement value obtained changes due to differences in distance factors and changes in the value of the sending voltage that is not certain.

3.3. Measurement of the Crosstalk System

The occurrence of noise generally dominates the crosstalk signal between a pair of parallel transmission media, mostly occurs on the side of the transmitter (near the end), where the transmitted signal has maximum amplitude and frequency. The transmitted signal will then lose the amplitude and high-frequency components that propagate along the transmission line. Near-End Crosstalk (NEXT) is caused by a kind of magnetic coupling that occurs between the two ends of the transmission media that are adjacent to the transmitter end (Tx). NEXT can be described as an unwanted coupling signal from a pair of parallel transitional channels. This type of crosstalk is dominated by capacitive coupling, which transmits high frequencies directly to the near side of the receiver (Rx).

By finding out the intensity of the value between channels, crosstalk measurements were carried out by involving two transceivers simultaneously, but in this measurement state, one of the transmitters was not given an input signal during the measurement process. The input signal given to transmitter 1 is a signal from the DVD player. In this measurement, the first oscilloscope is connected to the CH 1 transmitter at the input and CH 2 at the output. The second oscilloscope two is only connected to the output in the receiver 2. This measurement aims to determine the crosstalk value that occurs in the system. This measurement uses a colour filter and does not use a colour filter to determine the effect of the crosstalk value on each colour filter used.

From the results of the measurement and retrieval of this data, the results of data measurement are obtained as follows.

Table 3. Crosstalk Measurement based on Received Voltage

Colour FIlter	Bright		Dark	
	VTx (V)	VRx (mV)	VTx (V)	VRx (mV)
No FIlter	4.07	8.00	4.07	6.80
Red – Red		6.80		7.59
Green - Green		7.36		6.40
Blue - Blue		6.96		7.19
Red - Green		-		-
Blue - Green		-		-
Red - Blue		-		-

The calculation of crosstalk from the filters are obtained as follows [15]:

$$\mathrm{NEXT(dB)} = -20\log\left(\frac{\mathrm{VRx}}{\mathrm{VTx}}\right) \quad (2)$$

Table 4. Crosstalk Measurement based on NEXT

Colour Filter	NEXT in Bright Condition (dB)	NEXT in Dark Condition (dB)
No FIlter	54,14	55,54
Red – Red	55,54	54,58
Green - Green	54,85	56,06
Blue - Blue	55,33	55,05
Red - Green	-	-
Blue - Green	-	-
Red - Blue	-	-

Tables 3 and 4 show results using the same colour filters have Voltage and NEXT value where interference occurs. It causes the signal from a VLC link to influence another link.

From the results of the crosstalk measurement using a colour filter and not using a colour filter, the crosstalk value is only obtained when the system works with the same colour filter on both transmitters, but when transmitter 1 is given a red filter, and the receiver 2 is blue the crosstalk value cannot be measured, this indicates that the sending of video signals can be sent well in two directions using a colour filter, so there is no crosstalk on the transmission line.

4. Conclusions

From the results of design, implementation, and measurement, several conclusions can be described:

- Results show that the video signal can be sent from the transmitter to the receiver at various distances.
- Reinforcement value from transmitter output 1 is four times from the calculation result with the input value of 840 mV and output of 3.44 V and at transmitter two input value of 1 V and output of 4.07 V.
- The value of the sending voltage of all tests ranges from 850 mV until 1.32 V.
- Measuring the VLC work system in two directions can be done up to 40 cm.
- In bidirectional measurements, the best measurement results are obtained when the conditions of the two transmitters use different colour filters, i.e., a blue filter in link 1 and green filter in link 2 on the bright condition, and using the red filter in link 1 and green filter in link 2.
- On crosstalk, NEXT measurements with a send voltage of 1 V on average using a colour filter, the crosstalk NEXT values range from 54.13 dB to 55.05 dB. However, when different colour filters are used, there is no crosstalk, this proves that the colour difference in the light used to send the video can be made simultaneously.
- The average voltage received during the experiment in the bright is higher than in the dark condition.
- The same wavelength in the bidirectional video communication system should be avoided.

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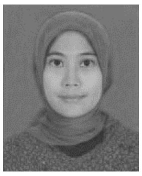

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