OPEN ACCESS
J. OF ICT, VOL. 1, NO. 1, PP.001-010, JUNE 2019

ISSN : 2622-8106 (ONLINE)
DOI: XXXXXX

Journal of Informatics and Communication Technology (JICT)

A Prototype of Phase Lock Loop System on Communication Device for Motorcycle Riders

Lukman Medriavin Silalahi[#1] Freddy Artadima Silaban[#2], Hary Nugroho [#3]

 # First-Second Electro Engineering, First-Second Mercu Buana University
 # Third Telecommunication Engineering, Third Telecommunication Engineering Sandhy Putra Jakarta Academy
[2]Jl. Raya Meruya Selatan, Kembangan, Jakarta 11650

[1] lukman.medriavin@mercubuana.ac.id
[2] freddy.artadima@mercubuana.ac.id
[3] harynug@gmail.com

Received on dd-mm-yyyy, revised on dd-mm-yyyy, accepted on dd-mm-yyyy

Abstract

In recent years, technology has developed rapidly, particularly technology in The telecommunication sector. As the electronic sector has been developing, as well as the increasing number of motorcycle riders and its communities, the authors are interested in designing an assistive device for motorcycle drivers. This device is designed as an additional communication tool for the coordination between the drivers. For communication, it is necessary to create a communication system without interfering with other riders. Therefore, the authors are motivated to design " a prototype of a phase lock loop system on a communication device for motorcycle riders". Using radio frequency as a media, this device aid motorcycle riders to communicate with each other. In this research, the authors design and implement the prototype regarding its ability to receive communication through helmet having a lock loop phase system. The main aim of the research is creating a device that can be used as an alternative communication device for motorcycle riders which is economical and provide convenient communication and coordination between riders without causing any disturbances and hazards.

Keywords: *Radio Frequency, Transmitter Block, Receiver Block, Communication, PLL System.*

I. INTRODUCTION

In recent years, technology has developed rapidly, particularly in the sector of telecommunication. Given that people's needs for communication and coordination between each other, it is essential that mobility system is created, such as the utilization of communication device, such as pager, handphone, etc, which support the mobility. For this reason, those communication tools, which previously considered as secondary needs, now is considered as primary needs. Likewise, the authors infer that telecommunication functions as a system in all human's aspects life, from the system of country's security to the mobility system of its society, thus causing it inseparable from society. (Astuti et al., 2012)

Likewise, electronic technology has developed, such as assistive device, which the authors design. This device is designed as an additional tool for motorcycle riders. Because the number of motorcycles riders and their community is increasing, it is essential to create a device for coordination between the riders. (Lukman et al., 2019)

During riding, communication is frequently done by the riders. However, communicating during riding often distract their concentration, thus possibly endanger riders' safety. In addition, it also disturbs other road users around, both in case of safety and health (hearing) because of its sound produced during communication. (Astuti et al., 2012)

To provide comforts for the rider during communication on the way without causing disturbances, the authors are motivated to design a prototype of phase lock loop on a communication device for motorcycle riders. Using radio frequency as a transmitter with phase lock loop system, this device is functioned as a communication device to help motorcycle riders communicate.

This device consists of a transmitter with phase lock loop system, in which the audio signal is sent by a transmitter using the mic as media input, then it will be received by the headphone as media output. Voice exchange between speaker and listener works automatically using a voice-operated switch "VOX". For this reason, it is not necessary for riders to manually switch on the device by hand, thus providing more safety and comfort. (Astuti et al., 2012)

II. LITERATURE REVIEW

A. PLL (Phase Lock Loop)

A frequency synthesizer is a frequency converter using PLL (phase locked loop) and digital counter in phase-error feedback system to retain the output stability to the reference signal. The output frequency stability is determined by a reference oscillator stability, which is usually controlled by a crystal oscillator. (Arunkarthik et al., 2018)

Phase locked loop is the main part of the frequency synthesizer, shown in figure 1. In this figure, a stabile oscillator produces a reference frequency giving input frequency (*Fref*) into a phase detector. Reference frequency could be any score that is easily used with a crystal oscillator. A voltage control oscillator (VCO) produces final output with frequency fo and designed in such a way that could produce frequency within the designated minimum and maximum scale. The output of VCO is used to trigger programmable binary counter producing a function of simple-divide-by N counter. The output from the counter is a square waveform of the reference frequency which produces second input to a phase detector/phase comparator. (Nahak et al., 2018)

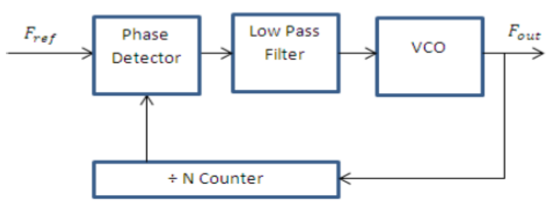

Figure 1. Block Diagram Of A PLL. (Nahak et al., 2018)

Phase comparator is a circuit generating DC (direct current) voltage that is proportional to the phase difference between the reference signal (Fr) and counter output Fo/N. The DC voltage is filtered to refine noise and slow down the circuit response so that it prevents overshoot or oscillation and adjusted as a control input to VCO. If the difference between Fr and f0/N is zero, DC output from phase comparator is what exactly needed to tune the VCO to be Nfr. However, if there is a difference between two signals, the phase comparator will produce varying voltage, either by increasing or decreasing frequency f0 to equalize the frequency difference to be zero. When VCO output reaches Nfr value, VCO will lock the frequency and the loop feedback will prevent VCO from drifting. (Pilipenko et al., 2017)

The output frequency f0 is adjusted to a new value by converting a numeric value dividing the counter. This process is performed by a thumbwheel switch or a register where a new numeric value (N) is input to reset the set point cycle of the counter. The numeric value (N), written as binary code, is a number of pulse calculated by counter before rerunning the cycle. (Herzel et al., 2017)

PLL is a feedback system based on phase difference. As shown in figure 1, PLL consists of these following components:

1. $V_1(t)$ = input signal, produced by a signal generator with frequency ω1.
2. $V_2(t)$ = feedback signal from VCO with ω2.
3. $V_3(t)$ = output signal from dividing frequency with frequency divided by an N, resulting in frequency of ω 3.
4. $V_d(t)$ = output signal of PD, generated from signal difference between signal V1 (t) and signal V3 (t).
5. $V_f(t)$ = output signal LPF, a component of DC voltage in which its value is equal to a signal difference between signal V1 (t) and signal V3 (t). (Rodwell et al., 2018)

B. Math Pattern

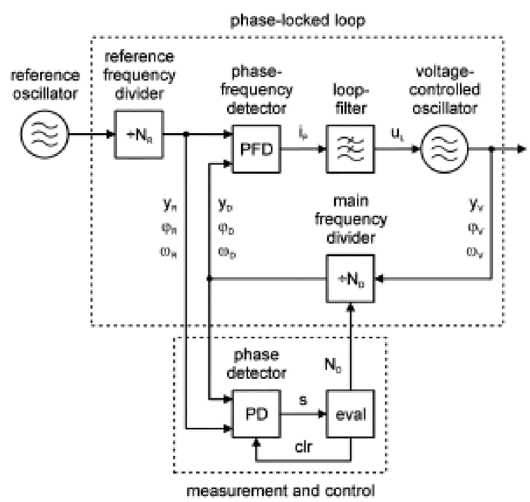

Figure 2. Block Diagram Of A PLL. (Pichler et al., 2007)

Reference frequency : Reference frequency is generated by oscillator to get an accurate and stable constant frequency oscillator. Its signal is divided in frequency by a reference divider that outputs a rising edge every NR oscillator cycles, so that the input to the Phase Frequency Detector (PFD) is a pulsed signal with constant angular frequency ω_R and constant period T_R. (Pichler et al., 2007)

$$\omega_R = \frac{2\pi}{T_R}$$

Phase Detector : The phase detector compares the phase of the reference signal and the phase of the output signal. It produces an error signal which is proportional to the phase difference of its two input signal. (Nahak et al., 2018)

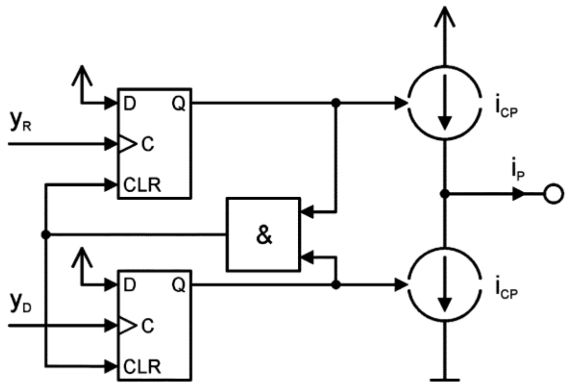

Figure 3. Example Circuit of Phase Detector With Current-Output (Pichler et al., 2007)

One way to implement such a Phase Detector is the circuit depicted in Fig 3.

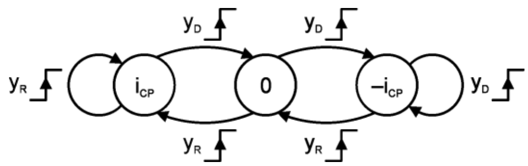

Figure 4. State Chart For Phase Detector Output. Transition Between States Occurs On The Risng Edge Of The Respective Signals (Pichler et al., 2007)

The current-output of this system follows the state-chart shown in Fig 4. And may change its constant value only on the rising edges of its input signals. The result is a pulsed output current as shown in Fig 5, whose temporal average is linearly dependent on the input phase difference. If the absolute value of this phase difference does not exceed 2π, i.e., there is a rising edge of the divider signal (y_D) immediately preceding or following every rising edge of the reference signal (y_R), then the PLL is said to be in lock.

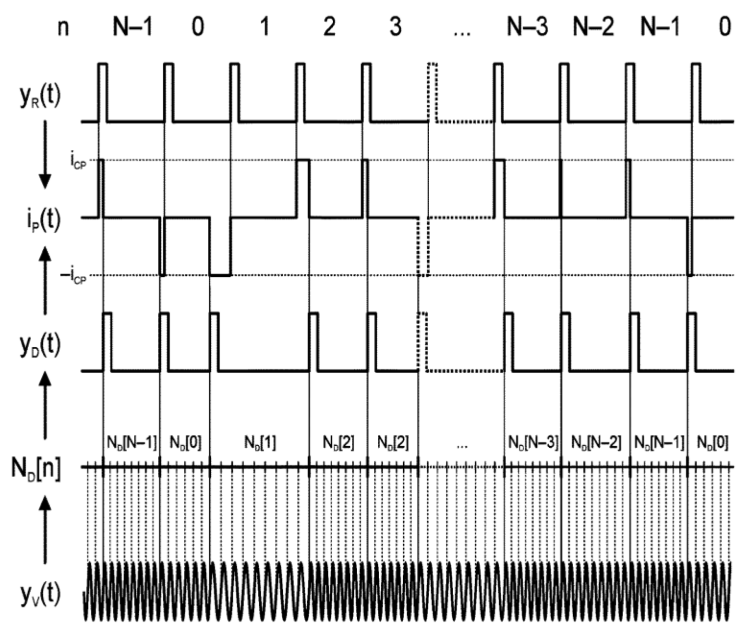

Figure 5. Signals In A PLL with An N-Periodic Divider Value Sequence. (Pichler et al., 2007)

Low Pass Filter : The output of phase detector is filtered to suppress the high frequency components and then is applied to the oscillator as a controlling signal (voltage or current). The most important characteristics of a PLL, such as loop bandwidth, settling time, and phase noise are highly dependent on loop filter design. The loop filter can be realized either with pure passive elements or with an operational amplifier to form an active loop filter. (Nahak et al., 2018)

Voltage Controlled Oscillator (VCO) : VCO is a circuit which generates periodic signal whose frequencty is the function of input voltage to the VCO. Its output frequency ω_0 is linearly proportional to the control voltage V_C which is generated by the phase detector. (Waks et al., 2018)

Divider : The functionality of this block is to divide the oscillator frequency by a factor *n*. In this configuration the VCO output frequency will be equal to *n* time the reference frequency. (Nahak et al., 2018)

III. RESEARCH METHOD

In this device, the PLL system is only used in the transmitter. The receiver and VOX (voice-operated switch) circuit use relay, in which the shifting from receiver to transmitter is activated by the user's voice.

The device scheme is an essential part of the device design. To simplify circuit design for antenna measuring application, a block diagram is made, as shown in the following figure 6.

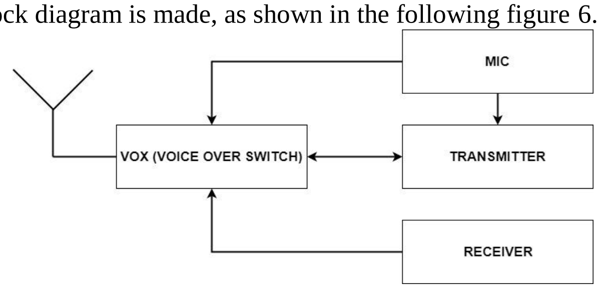

Figure 6. Block Diagram Of The Prototype Of Phase Lock Loop On Communication Device For Motorcycle Riders.

A. VOX (Voice Over Switch)

VOX or voice operated switch is a circuit activated by voice. When it detects user's voice on a certain threshold, it activates a relay to switch on the receiver and transmitter.

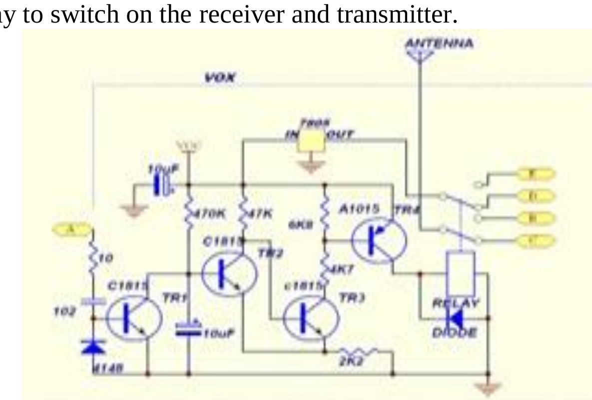

Figure 7. Schematic Diagram of VOX.

In figure 7, it is illustrated that when no voice is detected, C10µF on collector TR1 produces a voltage that turns on TR2, causing a TR3 short on C-E. As a result, TR4 is off, and relay on transmitter and transmitter does not work. On the other hand, when voice is detected, TR1 will be on and the voltage on C10µF is eliminated so that TR2 remains off. If there is voice input, TR3 is on and C-E is short, turning on the TR4, thus activating the relay. As a result, the transmitter works.

B. PLL

PLL system is created using IC MC145151. It includes reference frequency, programmable divider, and phase comparator that makes the circuit simpler. Because the IC MC145151-P2 does not include band VHF, it is necessary to supply pre-scaller circuit. The pre-scaller circuit divides frequency so that the output fits the input from IC MC145151-P2. The pre-scaller uses IC MC10131 and the variable control oscillator uses transistor as the frequency generator.

Principles of PLL are :

1. Reference frequency : Reference frequency is generated by crystal 6.4 MHz and capacitor 100 pF. A trimmer capacitor 30pF of pin 26 and pin 27 IC MC145151-P2 is used to adjust capacitance accurately, hence the generator vibrates precisely at a frequency of 6.4 MHz.The frequency of 6.4 MHz is subsequently divided with 512 KHz, generating stable frequency of 12.5 KHz. This frequency is a reference frequency on phase comparator.
2. Pre-scaller : Pre-scaler circuit uses IC MC10131, having a divider value of 4. For example, the output frequency of VCO is 85 MHz, which is divided with 4, generating 21.25 MHz, where the input is on pin 15 and the output is on pin 6. Because the frequency capacity of IC PLL MC145151 is under 40 MHz, it is necessary to use pre-scaler for the generator over 40 MHz.
3. Programmable divider: Frequency dividing by programmable divider is performed on pin 11 to pin 20 and pin 22 to pin 25 or N0 to N11. The output frequency of 22 MHz from pre-scaler is divided with 1700, operated on pin 11 to pin 20. As a result, the output frequency from programmable divider is 12.5 Khz.
4. Low pass filter : The output of phase comparator from pin 4 IC MC145151-P2 enters to LPF circuit, specifically two resistors of 100K, a resistor of 68 KΩ, and a ceramic capacitor of 10 nF and 100 nF, then enter to IC Op-Amp LM741 on pin 3 and out via pin 6, which is a DC voltage. The output is used in VCO circuit as a frequency converter by supplying the voltage to varactor diode BB105.
5. Variable control oscillator : is an oscillator controlled by a voltage. The applied voltage determines a capacitor variable or a varicap's (varactor diode) capacitance. A harmonization of varicap and inductor generates resonant frequency, controlled by voltage. This effect is utilized by PLL system, in which the generated voltage by phase detector and low pass filter converts the intended frequency via varicap. The output from VCO can be managed by varactor diode BB105, LI and Q1, as well as C 22pF and 33 pF as resonance circuit. Also, the output from the collector enters to pre-scaler circuit, while the output from emitter enters to RF amplifier circuit.

Meanwhile, to transmit voice, the IC Op-Amp amplifier LM741 is used. The voice recorded by a microphone enters via pin 2, amplified by LM74, then the output enters to varactor BB 105 of the VCO circuit, generating a frequency modulation (FM). The amplification is controlled by trimpot (trimmer potentiator). Also, the output from pin 6 enters to VOX circuit.

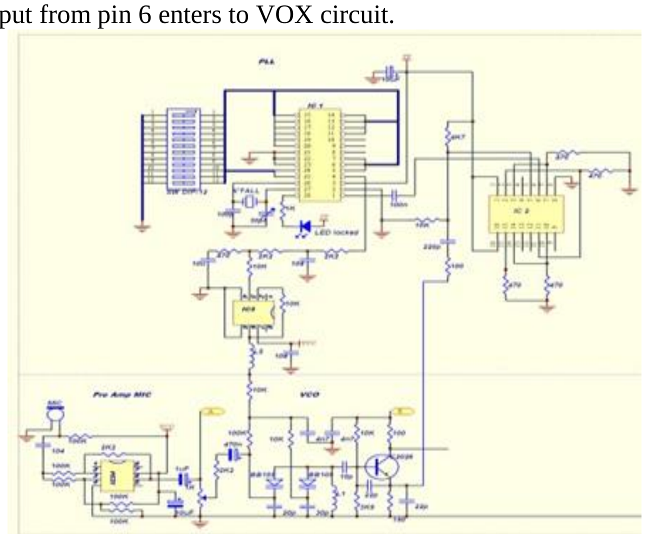

Figure 8. PLL Circuit.

In figure 8, it is shown that the output from TR1 is so low that an amplifier is required to reach out the further distance. An amplifier is made up of transistor C390. Trimmer 30 pF is used for the input, which can be adjusted so that the amplifier circuit works at an exact frequency of 85MHz. Then, the output reenters to transistor C930 via trimmer 30 pF, and its output from trimmer 30 pF enters to transistor C1970.

Subsequently, it enters to L circuit. The C variable as a matching circuit is emitted by the antenna to the air as electromagnetic waves.

C. Receiver

The receiver uses IC TDA7000 so that it can be made as small as possible for the receiver

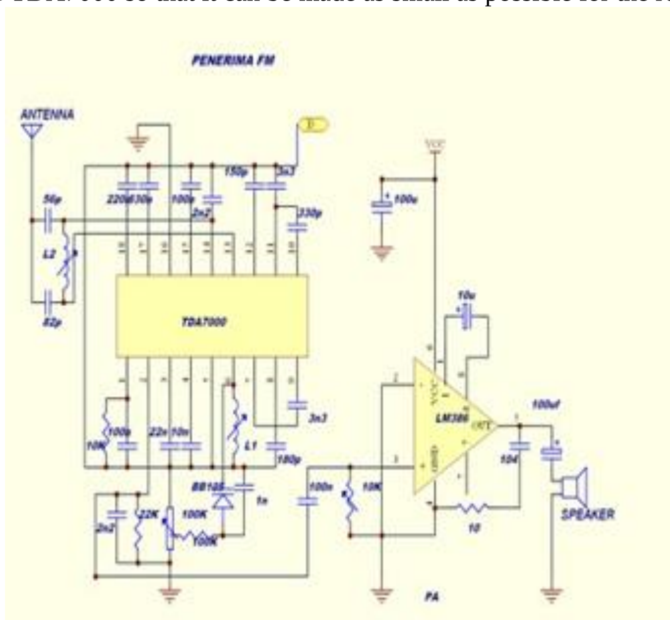

Figure 9. Receiver circuit

IC TDA 7000 is used for the receiver. It consists of a receiver circuit, oscillator, demodulator FM, etc. The signal information received via the receiver's antenna is audio and transmitter frequency, which is previously filtered by L1 and surrounding circuit, thus the receiver circuit is only able to receive on determined frequency. L1 is functioned as oscillator circuit fixed to a predetermined frequency, such as 86 MHz. The oscillator circuit is specified by L1, diode varactor, and surrounding component. The output from pin 2 is subsequently filtered by resistor 10K and capacitor 10K, resulting in audio. Then, the audio is amplified by IC LM386 to trigger the speaker so that the voice can be heard.

IV. RESULTS AND DISCUSSION

The discussion explained is the analysis of the result, as follows.

A. Measurement of VOX Relay Voltage

The measurement of voice-operated switch (VOX) is performed by measuring voltage in relay both when no voice and voice is input to the microphone.

Figure 10. Measurement of VOX with voice (left) and without voice (right)

Analysis of VOX relay voltage measurement:

Based on the VOX measurement in Fig 10, it is shown that the voltage value of VOX when it is input with voice and without the voice is 9 V and 0 V, respectively. Therefore, when there is voice input, relay works, while without voice input, it stops working.

B. Measurement of Frequency Stability

The measurement aims to know whether the generated frequency is stable. It is performed at a frequency of 85 MHz for 12 hours by measuring and observing the output frequency using a frequency counter for a designated time. It is performed on the circuit output of a frequency synthesizer generator (RF PLL OUT).

Table 1. Result of Frequency Stability Measurement

Time (hour)	Frequency Output (Mhz)
0	85.000
1	85.000
2	85.000
3	85.000
4	85.000
5	85.000
6	85.000
7	85.000
8	85.000
9	85.000
10	85.000
11	85.000
12	85.000

Analysis of frequency stability measurement:

As shown in Table 1, measurement of frequency for 12 hours, the output of PLL synthesizer does not change, proving that frequency generator using frequency synthesizer method is good. Therefore, the analysis of frequency stability is appropriate.

C. Measurement of Frequency Generator Bandwidth

The measurement aims to determine the bandwidth, known as the minimum and maximum frequency that can be generated. It is conducted using a frequency counter by converting dip switch value from the lowest to the highest. During converting, the LED indicator on a lock detector is observed to know whether the system remains locked. A locked system is indicated by an illuminating LED.

Figure 11. Result of Frequency Generator Measurement

The Result is as follows in Table 2.

Table 2.Result of Bandwidth Frequency Measurement

No	Experiment frequency	Measured frequency	Indicating LED (ON/OFF)
1	*79.900*	*86.571*	***OFF***
	80.000	***80.000***	***ON***
2	**87.500**	**87.500**	***ON***
3	**88.00**	**88.00**	***ON***
4	**93.000**	**93.000**	***ON***
5	**95.000**	**95.000**	***ON***
6	**99.000**	**99.000**	***ON***
7	**100.000**	**100.000**	***ON***
8	**102.000**	**102.000**	***ON***
9	**105.000**	**105.000**	***ON***
10	**108.000**	**108.000**	***ON***
11	**109.100**	**109.100**	***ON***
12	*109.600*	*109.766*	***OFF***

Analysis of bandwidth frequency measurement.

As shown in table 2, the measured bandwidth on the condition of the locked system, indicated by illuminating LED, is 80 to 109.1 MHz. In this research, the system uses 85 MHz, which is between the measured bandwidth.

D. Measurement of voltage, current, and power

This measurement aims to determine voltage, current, and power generated by the amplifier. It is performed by a power meter, measuring last amplifier voltage and current, as well as output power directly, which are the output from trimmer condensator 30 pF and antenna.

Voltage measurement is conducted by installing voltmeter on the last amplifier, which is on collector transistor C1970 and negative power supply.

Figure 12. Result of voltage measurement

Current measurement is conducted by installing amperemeter on the last amplifier which is on Vcc and collector transistor C1970.

Figure 13. Result of current measurement

Power measurement is conducted by using wattmeter. The output power of emitter is determined by each bandwidth frequency.

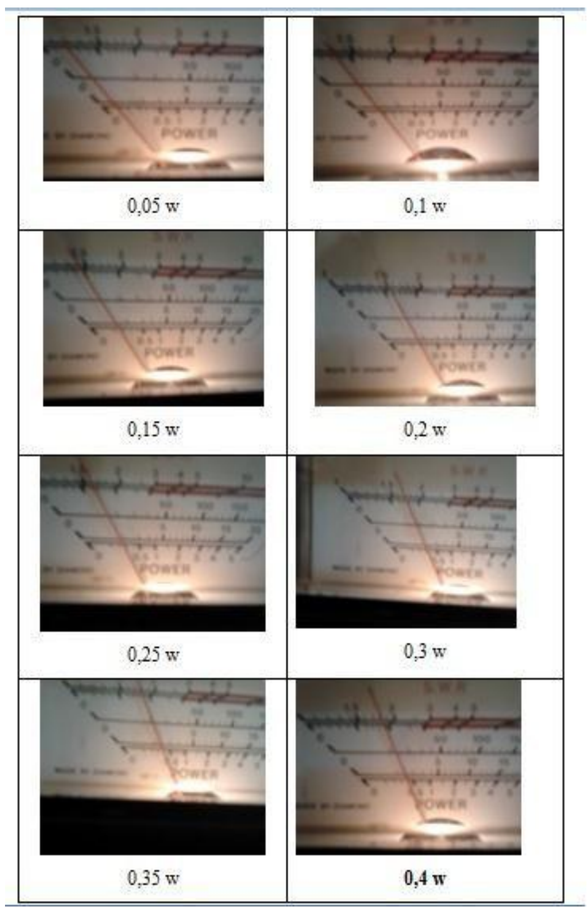

Figure 14. Result of power measurement relative to the frequency

Table 3. Result of Power Measurement

No	Frequency Experiment (MHz)	Measurable Frequency (MHz)	Indicator LED	Power Measurement Result (Watt)
1	79.90	86.571	**OFF**	0.05
2	80.00	80.00	ON	0.2
3	85.00	85.00	ON	0.4
4	87.50	87.50	ON	0.35
5	88.00	88.00	ON	0.35
6	93.00	93.00	ON	0.3
7	95.00	95.00	ON	0.3
8	99.00	99.00	ON	0.25
9	100.00	100.00	ON	0.2
10	102.00	102.00	ON	0.2
11	105.00	105.00	ON	0.2
12	108.00	108.00	ON	0.15
13	109.10	109.10	ON	0.1
14	109.60	109.766	**OFF**	0.05

Analysis of power measurement toward band frequency:

Based on power measurement toward bandwidth frequency, shown in table 3, it is shown that the greatest power generated when the frequency used is 85 MHz, which is 0.4 W. It is proven that the reference frequency of 85 MHz generates considerable power.

E. System Measurement

System measurement is conducted to know who the created device works. It is performed by activating transmitter and receiver alternately, until reaching 100 m.

VOX1 and VOX2 condition is LOS (line of sight) or unobstructed. The Transmitter is activated via a microphone and the speaker of the receiver is used to monitor transmission on collocutor.

Table 4. Result of System Measurement

No	VOX 1		VOX 2	
	Distance (m)	Indicator Speaker	Distance (m)	Indicator Speaker
1	1	Clear Voice	1	Clear Voice
2	5	Clear Voice	5	Clear Voice
3	10	Clear Voice	10	Clear Voice
4	15	Clear Voice	15	Clear Voice
5	20	Clear Voice	20	Clear Voice
6	25	Clear Voice	25	Clear Voice
7	30	Clear Voice	30	Clear Voice
8	35	Clear Voice	35	Clear Voice
9	40	Clear Voice	40	Clear Voice
10	45	Clear Voice	45	Clear Voice
11	50	Clear Voice	50	Clear Voice
12	55	Clear Voice	55	Clear Voice
13	60	Clear Voice	60	Clear Voice
14	65	Clear Voice	65	Clear Voice
15	70	Clear Voice	70	Clear Voice
16	75	Clear Voice	75	Clear Voice
17	80	Clear Voice	80	Clear Voice
18	85	Clear Voice	85	Clear Voice
19	90	Clear Voice	90	Clear Voice
20	95	Clear Voice	95	Clear Voice
21	100	Clear Voice	100	Clear Voice
22	105	Clear Voice	105	**Clear Voice + Noise**
23	115	**Clear Voice + Noise**	115	**Clear Voice + Noise**
24	120	**Clear Voice + Noise**	120	**Clear Voice + Noise**

Analysis of distance measurement :

Based on table 4, The range between VOX1 and VOX2 is over 100 meters. The measurement is performed unobstructed (LOS).

V. Conclusion

Based on device design and its voice transmission trial, it is concluded that:

1. Generator circuit using the synthesizer system work stably. Although it is used for a long time, frequency does not change.
2. This device works by using half-duplex system, in which both parties can communicate with each other. It is controlled by VOX (voice-operated switch), in which a voice input activates the device as the transmitter, while no voice input activates the device as the receiver.
3. The programming is conducted by converting dip switch on programmable divider.
4. The device works optimally at 100 meters and 85 MHz .It can work at the furthest distance of 120 meters, but generates noise.
5. The device works using PLL (phase lock system) and frequency modulation (FM) as its modulation system. The frequency is generated from the ration of reference frequency to PLL output frequency produced by programmable divider. Needless to say, PLL is a system, in which its frequency and phase are locked as its part, the phase detector, works as the reference frequency.

After designing and intercom device trial to mp3 player, there are several suggestions, as follows :

1. An Up-down counter and addition of a microcontroller with an LCD display can be used instead of dip swicth to perfect frequency transfer.
2. For further distance, output power should be amplified.
3. For greater transmission, it is necessary to add a bigger power amplifier.
4. On the receiver, use phase lock loop system synchronized with transmitter, so that the frequency setting is performed on only a phase lock loop.

ACKNOWLEDGMENT

I thank Mr. Yudhi Gunardi as my supervisor at Mercubuana University and Dr. Harry Nugroho as my supervisor at Akademi Telkom Jakarta for their support and motivation. Lastly, I thank all experts' supervision in the field during this research.

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