

# Design and Development of a Low-Cost 2.4 GHz GFSK Modulation based Walkie-Talkie

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## ABSTRACT

A walkie-talkie device can be quite useful in the location where there is no cellphone coverage. Even in the cellphone coverage area it provides communication at very low cost. Currently the law enforcement and military personnel uses frequency modulation (FM) based walkie-talkie systems. The main goal of this research is to design and develop a low-cost walkie-talkie device that can be used by anyone other than the military and law enforcement personals. To construct the walkie-talkie system, the 2.4 GHz industrial, scientific, and medical (ISM) band and GFSK modulation technology have been chosen. In addition, the device includes transceiver module, dc power source, microphone amplifier, audio amplifier, dc-dc booster, and speaker. The coverage range of the implemented walkie-talkie system has been determined and found up to 200 meters. The gadget incorporates a li-ion battery charging system. The voltage, current and power levels at various locations of the device have been measured. It has been found that the maximum operating power consumption is 4.81W and standby power is 1mW. Moreover, the waveforms of different signals at different points of the systems have been observed on the oscilloscope. All of the development process of the system and the performance data are presented in this paper.

**Keywords:** Walkie-Talkie; Modulation; Transceiver; Li-ion battery; Arduino Nano

## 1. Introduction

Communication has always been an important issue because progress is inextricably linked to it. Walkie-talkie is an achievement of communication technology, which is a two-way, small battery operated, compact radio transceiver. Law enforcement and military professionals are the principal users of this equipment. Governments all over the world are increasing their spending on this gadget due to public safety reasons. Hence the market for walkie-talkies is increasing. The market for walkie-talkies was estimated to be worth 3.3 billion dollars in 2020 and is projected to reach 5.9 billion dollars by 2027, as shown in Fig. 1 [1].

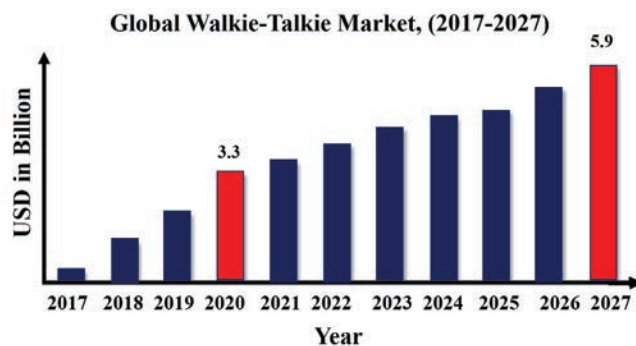


Fig. 1. Global Walkie-Talkie Market, (2017-2028)

The history of the walkie-talkie is supposed to have begun around 1937 [2]. But the importance of the device came to attention during World War II and the technology has advanced significantly over the years [3-7]. The walkie-talkie is a proven and robust technology that needs little

maintenance. Thus, along with other countries, Bangladesh is a prominent user of this device. However, in Bangladesh, walkie-talkie is mainly used by law enforcement and military personals. Nevertheless it can be used for wide range of applications including intra-building communication, emergency communication during natural disasters, medical emergencies, a team's management system, communication amongst motorcyclists, etc.

Therefore, the primary objective of this research is to design and develop a low-cost walkie-talkie device that can be used for purposes other than law enforcement and military applications.

Market survey shows many companies such as Motorola, Baofeng, Kenwood, etc. manufacture and sell walkie-talkie devices. Walkie-talkies developed by these companies operate in the ultra-high frequency (UHF) band between 400 MHz and 512 MHz using the frequency modulation (FM) technique [8]. FM modulation is an analog modulation technique. But in the context of noise cancellation, digital modulation is better than analog modulation. There are quite a number of digital modulation techniques; gaussian frequency shift keying (GFSK) is one of them. Research indicates that many studies have been conducted using the 2.4 GHz GFSK modulation technique [9-12]. The 2.4 GHz is an industrial, scientific, and medical (ISM) band frequency [13]. Furthermore, it is easily possible to generate 2.4 GHz ISM band using readily available inexpensive ICs [14]. As a result, the 2.4 GHz ISM band and GFSK modulation technique have been chosen to construct a walkie-talkie system.

Literature study reveals that ZHU Huiyan *et al.*, Noel B. Linsangan *et al.*, Mobasshir Mahbub, Qiu Jigang *et al.* and many others used nRF24L01+ PA/LNA module as transceiver [9-13]. Hence, in this work nRF24L01+ PA/LNA module has been used to generate 2.4 GHz ISM band and GFSK modulation technique.

In addition to the transceiver module, the system also includes, a dc power source, microphone amplifier, audio amplifier, dc-dc booster, li-ion battery charge controller, and a 4 W mini speaker.

### 2. The Walkie-Talkie System

The block diagram of a conventional walkie-talkie system is shown in Fig. 2.

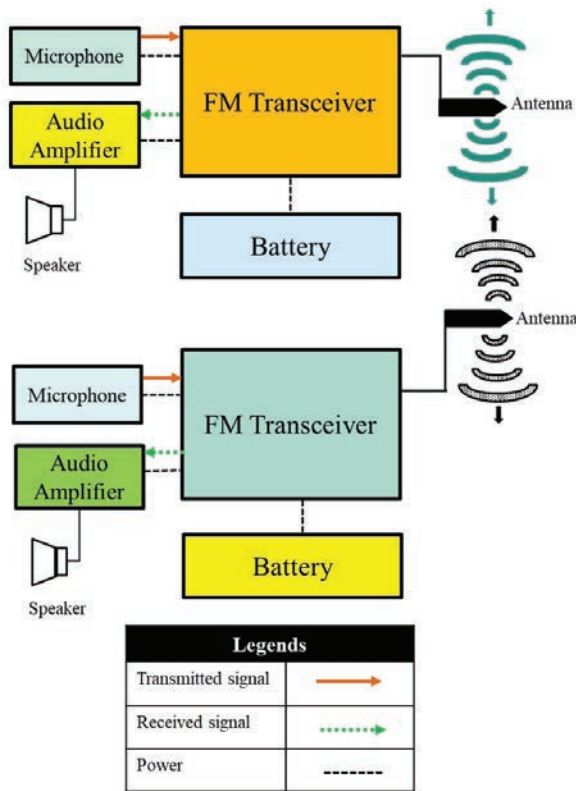


Fig. 2. Block Diagram of a Conventional Walkie-Talkie System

The microphone of this walkie-talkie system converts the audio (voice) signal to an electrical signal, which is subsequently FM modulated. After that, the FM transceiver transmits and receives the modulated signal. The received signal is then demodulated and amplified before applying to the speaker.

The operation of the developed walkie-talkie system initiates with the built-in microphone (MAX9814) module. The “audio signal” generated by the microphone is amplified and applied to the microcontroller (arduino). The analog to digital (ADC) converter of the microcontroller converts the analog signal into a digital signal. The digital signal is sent to the nRF24L01+ PA/LNA transceiver. The transceiver then converts the digital signal to a 2.4 GHz GFSK modulated

signal, when requested by the microcontroller. Then embedded power amplifier (PA) chip amplifies the modulated GFSK signal and transmits by the antenna. The other walkie-talkies transceiver receives the GFSK modulated signal and amplifies it the in-built low noise amplifier (LNA). After that, the microcontroller demodulates the amplified signal. The digital to analog (DAC) converter of the microcontroller then converts the recovered digital signal to a demodulated digital signal. The audio amplifier subsequently amplifies the signal and sends to the speaker. The speaker converts the demodulated digital signal into sound. In Fig. 3, a block diagram depicts the entire procedure.

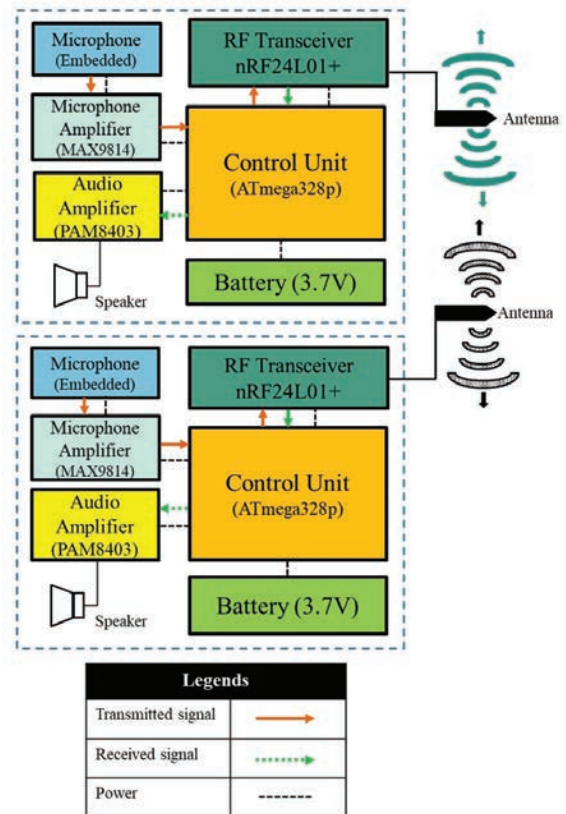


Fig. 3. Block Diagram of the Proposed Walkie-Talkie System

### 3. Implementation of the System

The detailed connections of the circuit have been shown in Fig. 4.

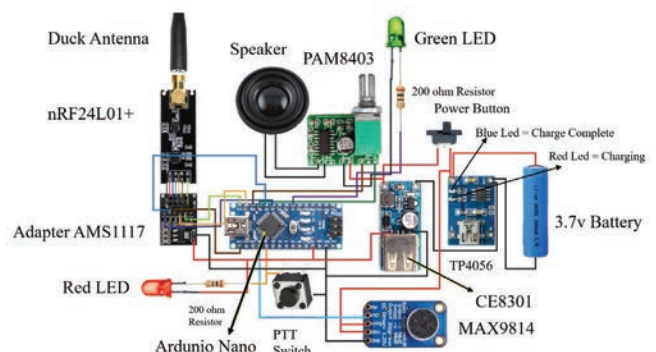
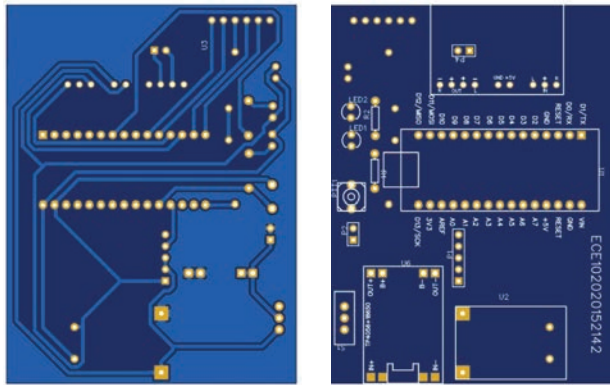


Fig. 4. Circuit Diagram of the System

Most of the walkie-talkies do not provide a battery charging unit. But the developed system incorporates a 3.7 V, 1300 mAh li-ion battery charging unit. The 3.7 V li-ion battery is connected to the TP4056 1A li-ion battery charge controller. The micro B USB port on the charge controller allows the li-ion battery to be charged quickly [14]. The red and blue LED indicates the charging and full battery state, respectively. A couple of the system components (like arduino nano, AMS1117 adapter) require a 5 V input voltage that cannot be supplied by the 3.7 V li-ion battery. Hence, the CE8301 5 V dc-to-dc booster has been used to produce a steady 5 V. The voice data from the microphone can only be transmitted if the push-to-talk (PTT) switch is pressed. Thus, a four-pin tactile switch has been used to do the function of the push-to-talk (PTT) switch. A 2.4 GHz duck antenna has been attached to the nRf42L01+PA/LNA module for transmission and reception. The 4 W speaker has been connected to the PAM8403 audio amplifier. Because, the audio amplifier amplifies the received signal and then converts it to sound by the 4 W speaker. To make the hardware operational, a controlling software has been written using an integrated development environment (IDE) open-source software. After converting the program into HEX code, it is uploaded into the microcontroller.

A printed circuit board (PCB) layout for the system has been created (as shown in Fig. 5) using an “EasyEDA” online PCB editor.



(a) Bottom Side

(b) Top Side

Fig. 5. PCB Layout Output View from EasyEDA

With the help of the PCB layout, the PCB has been fabricated which is shown in Fig. 6.

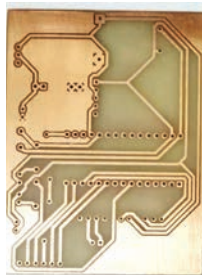


Fig. 6. Fabricated Printed Circuit Board

The bottom side PCB layout (Fig. 5(a)) is printed on a glossy paper with a LASER printer. The glossy paper is then placed on a copper board in such a way that the inked side touches the copper. Heat is provided to the paper using an iron. The heat transfers the printed design to the copper board. The copper board is then gently submerged in a ferric chloride solution. The solution dissolves the uninked part of the copper board. After that, terpinol is used to remove the ink from the copper plate. The PCB construction process has been finished by drilling holes using a PCB drilling machine. The complete hardware implementation of the system is shown in Fig. 7.

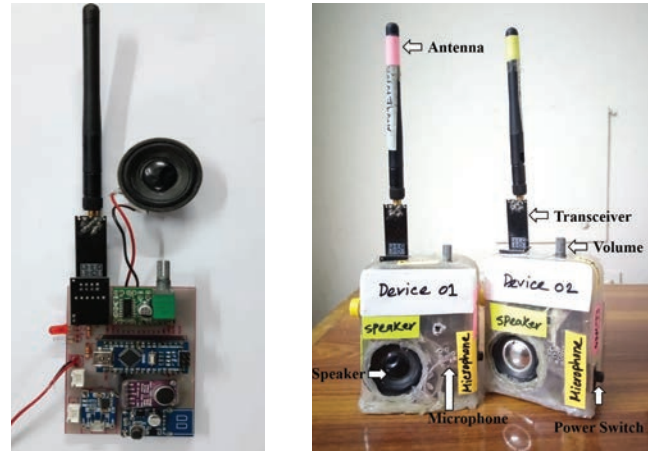


Fig. 7. Walkie-Talkie system (a) Without case (b) With case

### 3. Results and Discussion

The voice signal produced by the microphone, is observed by an oscilloscope (RIGOL DS1054, 4-channel, 50 MHz, digital oscilloscope) and is presented in Fig. 8.



Fig. 8. Voice Signal Produced by the Microphone

This signal is the unmodulated voice signal and oscilloscope shows its frequency is 139 Hz. At a first glance it seems to be noise, but the fundamental frequency of an adult male’s voice ranges from 85 Hz to 155 Hz, and an adult female’s ranges from 165 Hz to 255 Hz [15]. The 139 Hz signal has enough of the harmonic series to create the impression of hearing from the fundamental tone. The microphone being very cheap, it just barely works, but the performance of the walkie-talkie system can be improved by using a quality microphone.

The oscilloscope has been used to observe the speaker’s input prior to sound emanating from the speaker, and the results are shown in Fig. 9.



Fig. 9. The Speaker’s Input Signal

This image (Fig. 9) depicts the contraction and expansion of the frequency. This contraction and expansion of the frequency causes the back-and-forth motion of the voice coil of the speaker [16-17]. Thus, the conversion of electrical energy into mechanical energy (motion) takes place. In addition, the back and forth motion of the voice coil produces sound energy.

The Fig. 9 also shows the frequency of the signal is 33.3 KHz. The GFSK modulated 2.4 GHz signal should not be confused with this signal. The 33.3 KHz signal is the demodulated digital signal. Despite having a 33.3 KHz frequency, contraction and expansion contain the speech information and the speaker can convert the signal to analog output.

Table 1 presents the voice clarity as a function of distance during communication through the system.

Table 1: Voice Clarity Measurement with Different Distances

Obstacles	Propagation Type	Distance (Approx.)	Sound Status
None	LOS (Horizontal)	200.0 m	Clear
None	LOS (Vertical)	30.00 m	Clear
Yes	NLOS (Horizontal)	20.00 m	Clear
Yes	NLOS (Vertical)	10.00 m	Clear

Footnote: LOS means line of site and NLOS means non- line of site.

The coverage range of the developed walkie-talkie has been studied both in horizontal (distance on the street) and vertical directions (ground floor to upwards). The horizontal range of the walkie-talkie devices has been measured up to 200 meters

without any obstructions. The device functions smoothly within this range. When the walkie-talkies are used in two opposite side of a high-rise building the coverage range falls to 20 meters. The vertical NLOS commutation range, with same obstacles is found between the users, only 10 meters. Interestingly, for vertical LOS communication, clear sound has been heard up to the 9<sup>th</sup> floor of a building (30 meter). It has been observed during the range measurement process that, when there are too many obstructions the speech message becomes garbled and cannot be heard through the speaker.

The measured voltage and current rating of different part of the system are given in Table 2 and Table 3.

Table 2: Measured Voltage Levels of Different Components

Parameters / Components	Measured Voltage (V)
Input Voltage	3.6
DC Booster output voltage	5.04
PAM Audio Amplifier	3.4
MAX9814	3.3
nRF24L01+ Adapter	4.9
nRF24L01+ Module	3.3
Arduino Nano	5
LED Red	1.9
LED Green	2.9

The system uses very low voltage, current and power. It has been found that, the maximum operating power consumption of the system is 4.81W but stand by power is only 1 mW which ensures the very low power consumption of the system.

Table 3: Measured Current Data of Different Components

Parameters/ Components	Measured Current (mA)
DC Booster	2.3
nRF24L01+ Module	0.58
Arduino Nano	0.25
PAM Audio Amplifier	0.97
MAX9814	3.1

Instead of using traditional analog to analog approaches, a distinct form of technology has been utilized in this study. Table 4 provides a comparison of the proposed system with the BanFeng BF-888S and Kenwood TK-3207 walkie-talkie systems.

