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Improving UAV Radio Control System with 433 MHz Radio Wave Using Lo-Ra based on QCZEK Model Communication System

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***Abstract*— UAV must have a reliable control system considering the UAV is an unmanned vehicle that relies on human control on the ground. Most of control system used in UAVs uses a 2.4 GHz as it frequency. This frequency has disadvantaged for UAV because it is mainly used for Wi-Fi communication system so when users of UAV's fly in urban areas where full of Wi-Fi system, there will be interference within UAV control system and Wi-Fi, so failsafe will often occur. From the theory, different frequencies produce different criteria for radiofrequency communication system to synchronize and manage and secure communication between transmitter and receiver. In this study, we will discuss the application of 433 MHz frequency for the control system for UAV. The goal of this research is to establish a reliable control system of UAV when used for the long-range mission. To make this control system, we use the Lo-Ra module with STM32 based Microcontroller designed for QCZEK TX/RX model communication. After several testing on the ground and the air, the purpose system serve 14 % longer distance than TBS system or market build system and 6 times longer distances than 2.4Ghz frequencies.**

***Index Terms*— UAV, Control System, QCZEK, Lo-Ra, Long Range System**

I. I. INTRODUCTION

UAV as an autonomous vehicle that can fly without a crew in it has become a special need in today's industry. This is considering the advantages of the UAV, which has many functions. Among them are monitoring, mapping, military, and so on that require monitoring in locations that are difficult to reach. Apart from its various functions, UAVs sold in the market give users many choices to buy a UAV that fits their budget. The UAV sold in the market has an average control frequency of 2.4 GHz. This frequency is quite commonly used for electronic devices at home, such as Wi-Fi which has a transmission distance of around 100 - 500 m.

As a UAV that is used as a playing tool, maybe the transmission distance is not too problematic. However, for the use of aircraft-type UAVs and used for industry, the UAV requires a system that can control the motion of the UAV further.

To carry out exploration and reconnaissance, a UAV is indeed required to fly with a fairly long range and can survive flying for quite a long time as well. By using the 2.4 GHz frequency for the UAV controller frequency, it will not be possible to transmit data further than 1000 meters without a large module.

Based on the existing theory, Radio Frequency (RF) that exists today is divided into several categories. The most commonly used in public are Very High Frequency (VHF), Ultra High Frequency (UHF), and Super High Frequency (SHF). The difference between each RF band is the wavelength of the frequency which will result in different transmission distances from the transmitter and receiver.

From the explanation of the theory, this study tries to take advantage of these problems to extend the range of the control system of the UAV using a lower RF than the RF control systems on the market.

II. II. RESEARCH METHOD

A. *Radio Frequency*

In theory, it is explained that the radio spectrum (or what is commonly called Radio Frequency) is a part of the electromagnetic wave spectrum with a frequency of Terahertz (THz) and below which we usually call Radio Band or Radio Waves . This RF band is spread between the wavelengths of 30 kHz to 300 GHz [1]. All existing transmissions operate in these radio wavelengths. These include analog radio, ship navigation systems, aircraft, amateur radio, television broadcasts, mobile phone networks, and even satellite systems [2]. The distribution and use of the RF Band can be seen in Table 1 [1].

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Table 1 Radio Frequency Band

Band Name	Frequency	Wave Length	Example Uses
Extremely low frequency (ELF)	3–30 Hz	100,000 –10,000 km	Submarines communication
Super low frequency (SLF)	30–300 Hz	10,000–1,000 km	Submarines communication
Ultra-low frequency (ULF)	300–3,000 Hz	1,000–100 km	Submarines or Mines communication
Very low frequency (VLF)	3–30 kHz	100–10 km	Navigation, time signals, submarine, wireless heart rate monitors, geophysics
Low frequency (LF)	30–300 kHz	10–1 km	AM longwave broadcasting (Europe and parts of Asia), RFID
Medium frequency (MF)	300–3,000 kHz	1,000–100 m	AM (medium-wave), amateur radio, avalanche beacons
High frequency (HF)	3–30 MHz	100–10 m	Shortwave broadcasts, citizens band radio, aviation communications, RFID, radar,
Very high frequency (VHF)	30–300 MHz	10–1 m	FM, television broadcasts, aircraft communication, maritime,
Ultra-high frequency (UHF)	300–3,000 MHz	1–0.1 m	Television broadcasts, microwave oven, radio astronomy, mobile phones, wireless LAN, Bluetooth, Remote control Systems, etc.
Super high frequency (SHF)	3–30 GHz	100–10 mm	Radio astronomy, microwave devices, wireless LAN, most modern radars, communications satellites, video transmitter
Extremely high frequency (EHF)	30–300 GHz	10–1 mm	high-frequency microwave radio relay, directed-energy weapon, millimeter-wave scanner, wireless LAN (802.11ad)
Terahertz or Tremendously high frequency (THz/THF)	300–3,000 GHz	1–0.1 mm	Experimental medical imaging to replace X-rays, ultrafast molecular dynamics, condensed-matter physics, terahertz time-domain spectroscopy, terahertz computing/communications, remote sensing

The wavelength effect for each band can be how far the communication distance between transmitter and receiver. In addition, the wavelength affects the system's ability to transfer data quickly.

As seen in Fig. 1 and according to Table 1 data, the higher the frequency of a band, the shorter the wavelength. This results in increasingly dense radio waves sent by the transmitter in one unit of time so that the data sent will be more stable. And vice versa, when we use an RF band with a low frequency, then in one unit of time, the number of waves sent is getting smaller, so the data transfer rate will be reduced[3].

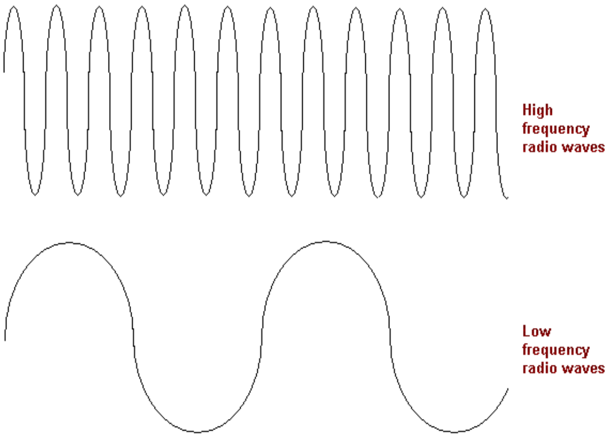

Fig. 1 Difference between High Frequency and Low-Frequency radio wave

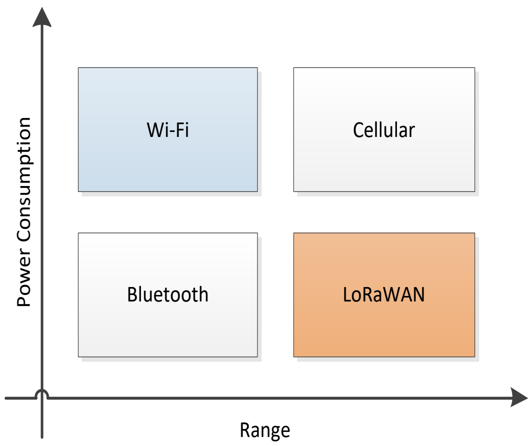

Fig. 2 Radio Frequency Device Comparison in Power Consumption and Range

Based on previous research, there are several wireless devices that can be used for 2-way communication. Among them are Bluetooth, Wi-Fi, Cellular, and the last are LoRa WAN. LoRa was one of several type of *Low Power Wide Area Network (LPWAN)*. LPWAN is wireless communication network for long range communication system based on Low Power device and small packet data transmission [4]. Judging from the power usage and communication distance between each device can be seen in Fig. 2.

According to the Fig. 2, Radio Frequency on Wi-Fi devices requires more power consumption and the resulting range is shorter. Therefore, because the device used in the average UAV control system on the market uses Wi-Fi, it makes the UAV unable to move far so this study uses a LoRa WAN network which is able to provide a longer communication distance than Wi-Fi [5].

Based on research conducted by[6], LoRa can overcome communication with a distance of more than 30 km in the Free Space area. Of course the position of the antenna and the type of antenna used must be adjusted appropriately so that the distance obtained is optimal. In other studies [7], researching about LoRa Technology evaluation for implementation in rural areas. From their research, they conclude that on the field test in the rural sector, Colombia, LoRa technology can established the machine to machine (M2M) communication within radius no greater than 500 m. based on that research, makes LoRa technology to be an optimal candidate for implementation in areas with difficult access and without the possibility of connecting to traditional network.

B. LoRa Chirp Signal

LoRa communication system work based on Compressed High-Intensity Radar Pulse (CHIRP) [8]. Chirp is a signal for military radar system to locate unidentified object using microwave and signal processing. Chirp is frequency modulation that is a signal with increasing frequency (up-chirp) or decreasing frequency (down-chirp) by the time[9]. The advantages of the chirp signal are that it is strong and resistant to interference, strong against multipath fading, has a long range, and the power required is not too large. Chirp signal that used on radar is Linear Frequency Modulation (LFM) which is representing in equation 1.

$$s(t) = e^{fxWt^2/T} \quad (1)$$

Modulation was a technique to carrier message inside signal using two separate signal (information signal and carrier signal) and combining them into one[10]. There are 3 type of modulation on signal. Amplitude Shift Keying (ASK), Phase Shift Keying (PSK), and Frequency Shift Keying (FSK). ASK Modulation is a signal modulation based on the changes of amplitude high or low values over the time(t). The three type of modulation diagram can be analysed as shown as Fig. 2

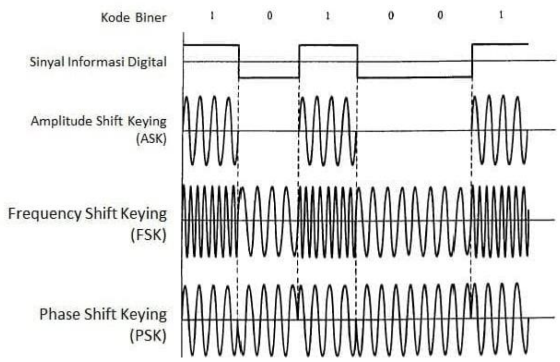

Fig. 3 Types of signal modulation

In ASK modulation, the binary signal changes create effect to the value of carrier signal frequency. While in FSK, the binary signal change output frequency of the carrier signal that makes the signal frequency to be denser or looser. In digital modulation, the change in the input rate to the modulator called "bit per second (bps)" while the change of rate on the output modulator is called "baud rate". FSK modulation can be formulated with equation 2.

$$s(t) = A\,cos(\omega t + \theta_c) \qquad 0 < t \le T \qquad (2)$$

A Is maximum amplitude of signal when in the FSK case, the amplitude is 1. ω Is angular speed of the signal frequency[11]. When equation 2 is simulated on matlab plot graph, it produces a graphic with $t = 1{:}10$ that resembles Fig. 4 and t = 1:40 resembles Fig 5.

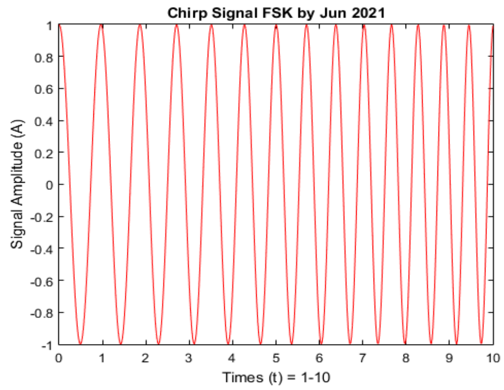

Fig. 4 Chirp FSK Signal with t=10

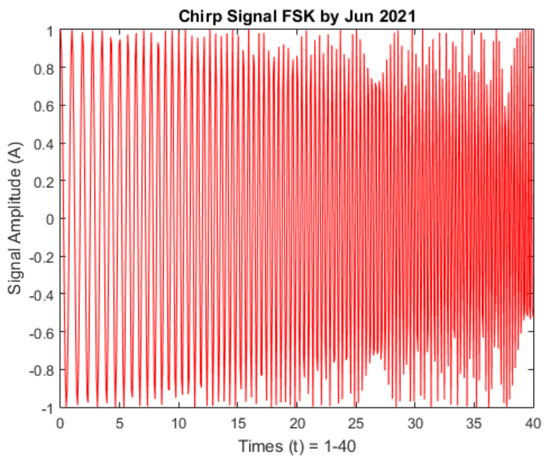

Fig. 5 Chirp FSK Signal with t=40

The last was PSK. In PSK the binary signal create signal shifting of a constant frequency. The modulation created varying the sine and cosine input at a precise time.
LoRa technology is used the FSK for its signal modulation and called Chirp Spread Spectrum (CSS). On CSS, chirp signal divided into two specific types: Frequency Increase (Up-Chirp) and Frequency Decrease (Down-Chirp) with time. It is as sown as Fig. 5.

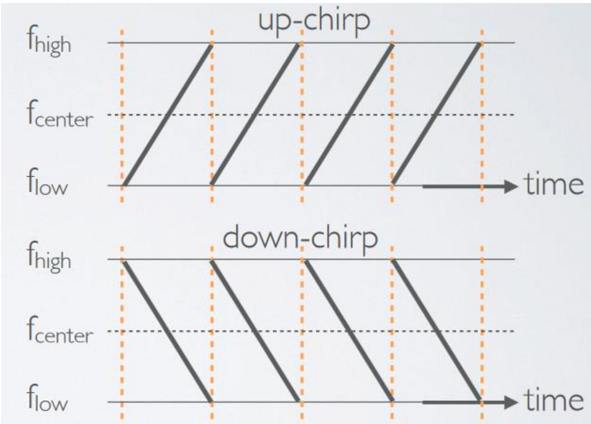

Fig. 6 LoRa Chirp Up--Chirp and Down Chirp Signal

C. *LoRa 433 MHz E32*

Lora develops several communication device modules. There are SX1278 433T20C, SX1278 433T30D, SX1276 915T30D, SX1276 915T20D and several other. SX1278 is for 433 MHz frequency and SX1276 is for 915 or 866 MHz. E32 is Microcontroller based on stm32 microchip combined with LoRa module. The module is available with 2 output power options 1W or 100 mW. The greater the output power of the module, the longer transmission distance. But every government has regulations to control wireless system in their country.

In this study, the control system we build based on SX1278 E32 433T20C as receiver and SX1278 E32 433T30D as transmitter. E32 433T20C has maximum output power 100mW smaller than transmitter which use E32 433T30D that can give output power up into 1W (1000mW). That because when high power module operates on its full power, it can make inference to the other electronic system like Video Transmitter or GPS System. Broadly speaking, LoRa SX1278 433XXX has specification as shown in the Table 2.

Table 2 Lora Spesicification

Main Parameter	Performance			Remark
	Min	Typ	Max	
Operating Voltage (V)	3.3	5.0	5.2	≥ 5.0 V ensures output power
Communication level (V)	-	3.3	-	For 5V TTL, it may be at risk of burning down
Operating Temp. (^{0}C)	-40	0	85	Industrial Design
Max Tx power (dBm)	29.5	30	30.5	-
Receiving sensitivity (dBm)	-145	-147	-148	Air data rate is 2.4 kbps
Air data rate (bps)	0.3k	2.4k	19.2k	Controlled via user's programming

Main Parameter	Description	Remark
Tx Length	58 Byte	Maximum capacity of single package
Buffer	512 Byte	-
Modulation	LoRa™	-
Communication interface	TTL	@3.3V
Package	DIP	-
Connector	2.54mm	-
Size	24 * 43mm	-
Antenna	SMA-K	50 ohm impedance

Dimension of the module is 24x43mm. It is relative small for high power transceiver. It is perfect form if the module used for light weight project like for small sensor monitoring or for the robot wireless control system. The module has 7 pin for TTL connection and for programming[12].

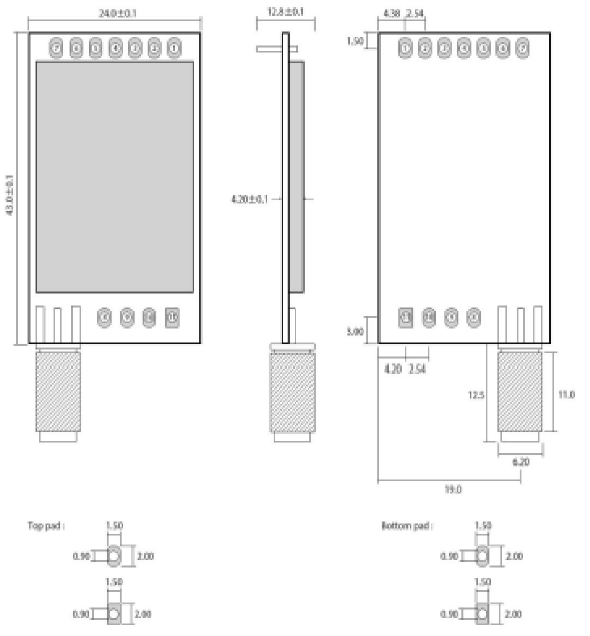

Fig. 7 Lora SX1278 E32 Module Dimension

For flashing firmware, E32 use external ST-LINK V2 and use SWIM flashing mode. There are 4 pins behind the module. It is SWIM, RESET, GND, and VCC.

Detail dimension of E32 module is represent on Fig. 7 and Table 3.

Table 3. Sx1278 E32 Pin Function

No	Name	Direction	Function
1	M0	Input (weak pull-up)	Work with M1 to decide 4 working modes of module
2	M1	Input (weak pull-up)	Work with M0 to decide 4 working modes of module
3	RXD	Input	TTL UART inputs, connect to external TXD (MCU/PC) output pin. Can be configured as open-drain or pull-up input
4	TXD	Output	TTL UART outputs, connect to external RXD (MCU/PC) input pin. Can be configured as open-drain or push-up output
5	AUX	Output	To indicate modules working status & wakes up the external MCU. During the procedure of self-check initialization, the pin outputs low level. Can be configured as push-pull output.
6	VCC	Input	Power supply (3.3 ~ 5.2V DC)
7	GND	Input	Ground

LoRa SX1278 E32 module can be set to 4 mode of transmission. The first is Normal Mode when M1 = 0 and M0 = 0. Second is Wake Up Mode, it active when M1 = 0 and M0 = 1. Third is Power-Saving Mode when M1 = 1 and M0 = 0. The last is Sleep Mode, active if M1=1 and M0 = 1.

.

There are several research about LoRa technology. On [13] research, they testing LoRa performance to break the limitation of the it is ability about small transfer data rate. In their research LoRa technology was used to transmit image data. The other research by [14], evaluating LoRa technology on Quality of Services (QoS). Their research is testing RSSI, SNR, Payload size, and Spreading Factor of the module. In research [15], their research comparing LoRa with Sigfox in terms of the probability LoRa and Sigfox modul create some Bit Error in their transmission. And there is [16] who research the limitation of LoRa technology to transmitting multiple end device with multiple Payload data.

D. *Wireless Range Calculations*

Power and dBm Value

Power of Wireless module commonly expressed using decibel (dBm) with a milliwatt (mW) as reference[17]. Decibel used for measurement of frequency wave. A decibel is equivalent with ten bell. Decibel is a logarithmic unit to describe some ratio too. It can be power, sound pressure, current or voltage, intensity, and the other. To measure power, decibel or further we call it as dBm based on logarithmic scale. If output power increase twice, it will increase 3 dBm value, and when output power increase tenfold, it represents with the increase of 10 dBm value. The conversion formula between dBm and Power (mW) can be seen on equation 3 and 4.

$$P_{dBm} = 10\ Log_{10}(P_{mW}) \quad (3)$$

$$P_{mW} = 10^{\frac{P_{dBm}}{10}} \quad (4)$$

For example, when power of a device is 100mW it same as 20 on dBm value. And vice versa, a device with 15 dBm value it same as 31mW.

Path Loss

When the device separate over a distance, there will be reduction in power density that called Path Loss. The primary factor is because when separate over a distance, the signal strength of the radio wave will decrease.

As a part of force energy, the power density of radio wave follows an inverse square law. It is say that intensity of power equals with the inverse square of the distance from the source. Assuming radio wave uses spherical shape for spreading, it can represent as Fig. 8.

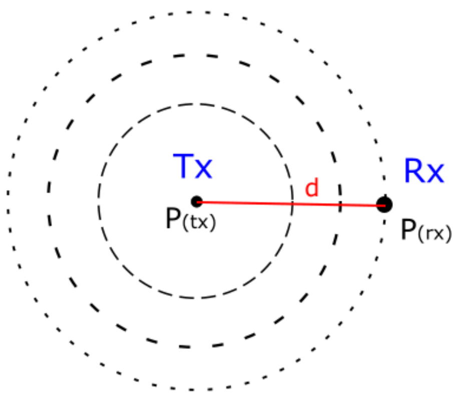

Fig. 8 Spread of Radio Wave

P_{tx} And P_{rx} are transmitter and receiver power (on dBm value), d is distance between transmitter and receiver. We can calculate power intensity using the proportion between transmitter power and the power when it reaches receiver. It can be represents with equation 5.

$$I \propto \frac{4\pi P^2}{4\pi P^2 d^2} \quad (5)$$

Where I the density of the radio is wave power, and d is distance from the radio source. From equation number 5, it can be simplified to be equation number 6.

$$I \propto \frac{1}{d^2} \quad (6)$$

Although transmitter power be a primary factor to affecting range of transmission, but there is another factor that affecting too. It is receiver sensitivity. Receiver sensitivity usually expressed in (-dBm) and because transmitter power and receiver sensitivity are on the same stated (stated in dBm), it can used simple addition and subtraction to calculate maximum path loss (equation 7).

$$\max_{pL} = P_{tx} - S_{rx} + g - l \quad (7)$$

Based on equation 6, we can get maximum path loss ($\max_{pL}$), by subtraction between transmitter power (P_{tx}) and receiver sensitivity (S_{rx}), and with addition of antenna gain (g) subtraction with the losses (l). g are total gains of transmitter and receiver antenna. Antenna gain usually expressed in dBi value, it is referenced to an isotropic antenna. And losses (l) is degradation because of any filter or cable resistance, or another known environment condition. Assuming the simulation is on vacuum space, we can ignore l value. After we have maximum path loss equation, we can estimate transmission distance using equation 8.

$$\max_{pL} = 20\log(d) + 20\log(\lambda) + c \quad (8)$$

$$20\log(d) = \max_{pL} - c - 20\log(\lambda) \quad (9)$$

$$\log(d) = \frac{\max_{pL} - c - 20\log(\lambda)}{20} \quad (10)$$

$$d = 10^{\max_{pL} - c - 20\log(f)\,/20} \quad (11)$$

c is a constant value depending on the distance and frequency units used. c is 32.44 when we calculate distance in kilometers and frequency in MHz. c is -27.55 when we calculate distance in meters and frequency in MHz. c is -87.55 when we calculate distance in meters and frequency in KHz. The graph between path loss and the transmission distance can be shown as Fig. 9.

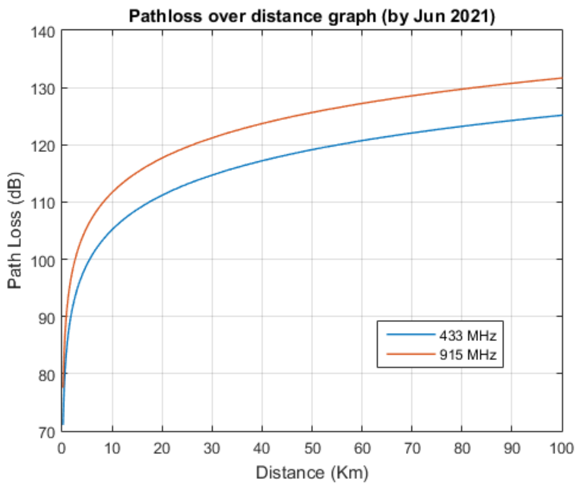

Fig. 9 Graph between path loss over distance in Lora E32 915 MHz and 433 Mhz

From the graph on Fig. 9, we can say that Lora E32 915 MHz has path loss value bigger than 433 MHz. it is mean, the further transmission, 433 MHz have more advantages in transmitting data because it has smaller value on path loss.

III. 3. DESIGN SYSTEM

A. *QCZEK LRS System*

Qczek LRS system is a *Do It Yourself (DIY)* radio transmission system based on LoRa SX1278 433Mhz or 915MHz with integrated 1W / 30 dBm transmission power. It is working with Micro Air Vehicle Communication Protocol (MAVLINK) Telemetry that supports transmission data for UAV to the ground station. Mavlink is a telemetry based on modern technology to communication between transmitter and receiver using hybrids publish-subscribe and point to point design pattern. Mavlink was first release by Lorenz Meier early 2009. The main feature of QCZEK LRS following:

- Can transmit 16 CPPM channel every 66ms (15Hz) but only first 8 channel are updated at 13Hz frequency due to limited band.
- Can transmit 4 bytes of serial data every frame from ground to UAV
- After reviving every single frame, the telemetry data transmitted to ground station
- Support MAVLINK telemetry (HEATBEAT, ATTITUDE, POSITION_INT, SYS_STATUS, RC_CHANNELS_RAW)
- Adjustable RF Power 200mW(23dBm) – 1000mW(30dBm)
- Ful Failsafe Support
- RSSI Injection to the selected RC channel
- 16 bit pairing code

The diagram how to build QCZEK LRS, can be seen on Fig. 10.

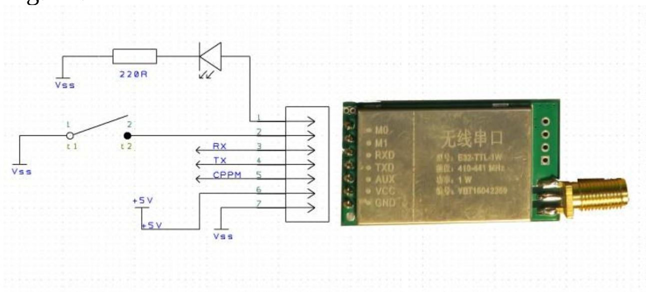

Fig. 10 QCZEK LRS Wiring Diagram

Switch that connects to the M1 pin is for entering settings mode, and for saving failsafe values. And additionally, we must solder small SWIM, RESET, 5v and GND pin for connection to the ST-LINK Programmer. The pin out diagram can be seen on Fig. 11

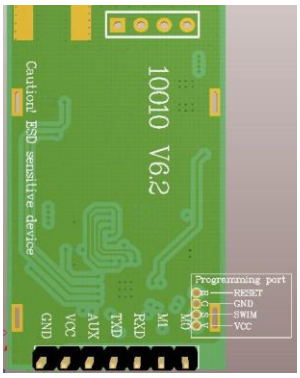

Fig. 11 ST-Link Programmer Wiring Diagram

B. Transmitter & Receiver System

For this research, LoRa E32 will be our main component to transmitting data. We use two of LoRa E32, one for Transmitter (1 Watt power) and as receiver, we use 100mW Lora E32. Wiring diagram could be seen on Fig. 12

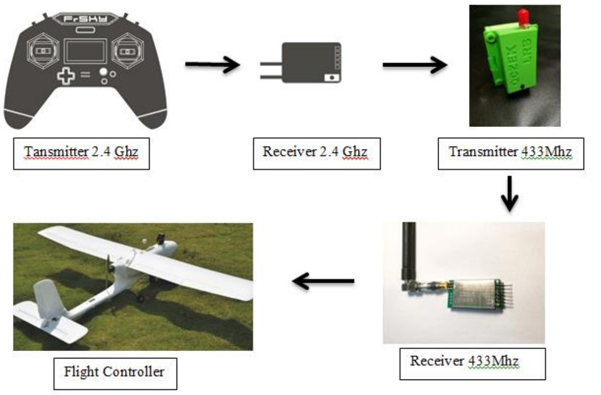

Fig. 12 Data Flow System

According to the figure, we use dual system communication data. The fist one is when PPm data come out from Remote, 2.4 GHz communication system will work. Data will transmitting to 2.4 GHz receiver than forwarded to LoRa 433MHz (Fig. 13a)as PPm again then LoRa will transmitting again to the LoRa receiver on the plane (Fig. 13b). On the aircraft, received data will forwarded to Flight Controller (FC) as PPm data and FC produce telemetry feedback that will send back to LoRa Transmitter. After LoRa transmitter receive the feedback, rather than send it back to the remote, it will send to the Ground Control Station application on the phone or PC via bluetooth.

(a) LoRa Transmitter

(b) Lora Receiver

Fig. 13 QCZEK LoRa Transmiter (a) and QCZEK Lora Receiver (b)

IV. 4. RESULT AND DISCUSSION

For the optimal longrange testing, we used RC fixed wing as shown as in the Fig. 14 for the carrier of LoRa receiver system. With wingspan of 1900mm, 1250kV + 7 inch prop, and used 4S Li-Ion 3000Mah. The wing got 30km travel distance.

Fig. 14 Fixed wing RC for experiments

Before we going to the sky, we establish a field experiment to test how powerfull the lower band are. From fiveteen times of experiment, we obtained several variated data from each band (see Fig. 15). Data came from manual trials of the transmissions carried out at residential area with medium house density level. According to the chart, we can see that 433mHz band from time to time topped the chart with overall distance over than 550 meters. Followed by 900 MHz band that still on the same range with 433 MHz but it slighty worse. However 2.4 GHz have the worst result. It only reach a peak around 125 meters for all the trial times. All of the trials was conduct with the same power of transmitter (around 25 mW power).

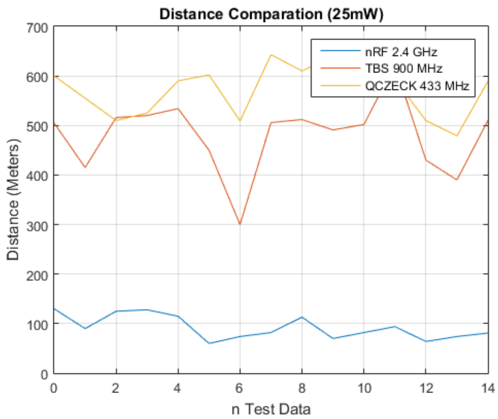

Fig. 15 Field test result graph for all band. All of band have 25 mW power of transmitting

For safety of the aircraft, there are several foremost feature on RC Control system. One of them are link quality and RSSI. With that feature, we can play it safe because we know when transmission system will lost the connection. We obtained link quality data log when we landed safely to the home point. Comparation result for three main RF band in this research, shown as Fig. 14. As stated by the graph, we can see that 2.4GHz transmission system, unable to go beyond 3 Km distance. After 1 Km, link quality drop dramastically bellow 70, and after over 1.5 Km it completely lost the connection. Meanwhile, the Low Band RF can go throught over 7Km easily.

The proposed device in this paper can reach 10Km without having connection lost. After reach 10 Km distances, link quality gradually drop to around 80. It still can reach 15 Km without lost connection. Slightly difference with the proposed device, TBS 900MHz module can reach 7km distance easily, and after around 10 Km, the link quality dramastic fall. It still have connection until around 15 Km, the signal was completely disconnect. We can see details of comparison data on Fig. 16.

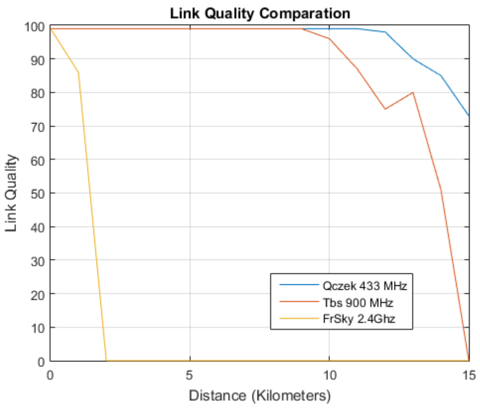

Fig. 16 Link quality comparison between 433MHz, 900MHz, and 2.4 GHz

V. CONCLUSION

There are several module for making wireless communication. However each module have their uniqueness. Depend on their RF Band, a module could serve longer distance communication network. After several dabbling on the ground and on air, we know that Low Band RF could establish better connection than Higher Band like 2.4 GHz. And when we used QCZEK Lrs system, we could obtained over 10 Km until 15 Km. Ccompare with TBS System, it is quite different between two of them. But, QCZEK Lrs present longer distance than TBS. So we could draw a conclusion that the lower RF Band, the farther communication range.

VI. ACKNOWLEDGE

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