

1. Introduction

The DF9 series (Frequency Modulated Continuous Wave) microwave motion sensor modules are K-Band Bi-static FMCW transceiver front-end modules. These modules are designed for distance measurement, speed detection together with direction of motion recognition. It is suitable for intrusion detection and various traffic applications.

The module consists of Voltage controlled Oscillator (VCO), balanced mixers; patch antenna, built-in LNA for high sensitivity and a pre-amplifier (see Figure 1).

This Application Note highlights some important points for application with DF9 series.

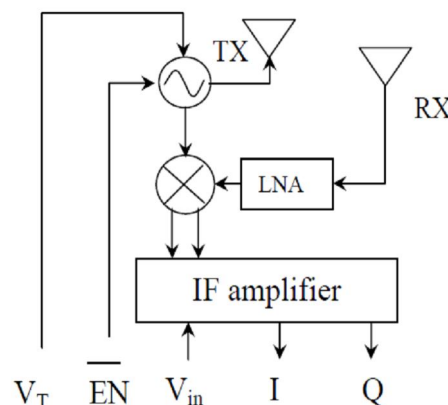


Figure 1: Block Diagram

2. User interface and mounting

6-way 2.54 mm pin header is used for user interface and the four mounting holes of M2.5 screw size are as shown in Figure 2

Pin definition

- 1: EN (Oscillator Enable)
- 2: V_{in} (Input Voltage)
- 3: GROUND (Ground)
- 4: I (IF Output)
- 5: Q (IF Output)
- 6: V_T (Tuning Voltage)

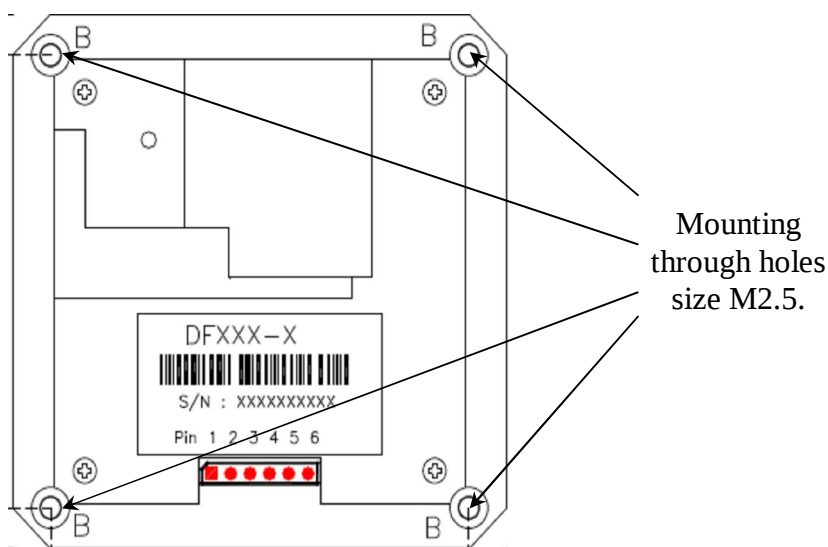


Figure 2: Pin definition and mounting holes

3. Power Supply

For supply voltage, there is a built-in voltage regulation in the DF series transceivers. As such, the performance of the DF9 series is not affected by variation of supply voltage as long as it is within the specification. For example, performance of DF9 series will not be affected for any supply voltage from 3.6V to 9V. In this case, DF9 series is capable of being powered by standard voltage of 5V.

4. Transmitting frequency and EIRP

The transmitting EIRP (Effective Isotropic Radiated Power) of various modules are factory-set and are not user-adjustable, while transmitting frequency is tunable and set by customer within given range. Table 1 shows the EIRP and transmitting frequency ranges of some of the DF9 series modules.

Model	EIRP	Frequency Range (FCC Part 15.245)	Tuning voltage, V_T
DF990	20 dBm	24.075 to 24.175 GHz	6V to 8V
DF995	17 dBm	24.075 to 24.175 GHz	6V to 8V

Table 1: Transmitting frequency for DF series

For most applications, the allowed operation frequency is between 24.075 to 24.175GHz for compliance to FCC standard part 15.245. The user must ensure that the frequency used must be within regulations of local communication authority by setting to the tuning voltage, V_T specified in table 1. Please refer to Annex 1 for more information on transmitting signal.

Local radio communication authority regulates the use of transmitting devices. Though user license may be exempted, type approval of equipment or other regulation compliance may be required.

For DF9 series motion sensor, typical tuning slope is 30MHz per volt. Figure 3 shows the frequency versus tuning voltage relationship of 4 units of randomly selected DF990.

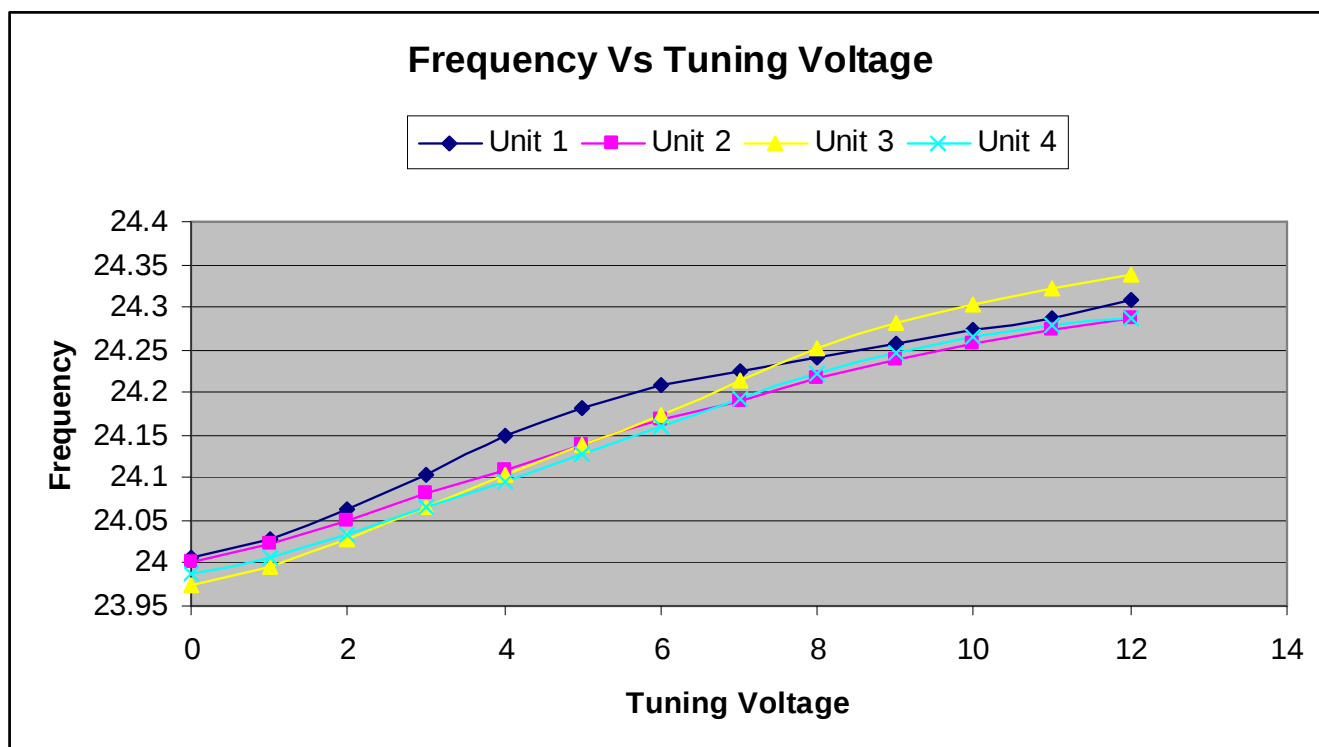


Figure 3: FMCW Tuning Slope

Calibration is highly recommended for every unit.

5. FMCW Application and Theory

Introduction

Unlike normal continuous wave sensor which transmits signal at a fixed frequency, the FMCW sensor transmits frequency that are swept at a pre-determined pattern. Due to the time of flight associated with the distance, there will be a frequency difference between transmitted signal and received reflected signal. The resulting signal therefore provides information on:

- Distance measurement
- Velocity measurement
- Direction of motion recognition

The following section explains the basic operation of FMCW sensor.

Stationary Object

For stationary object, simple sawtooth shape frequency sweeping is suggested as there is no requirements for measuring velocity. By varying tuning voltage, user will be able to obtain plot of frequency versus time.

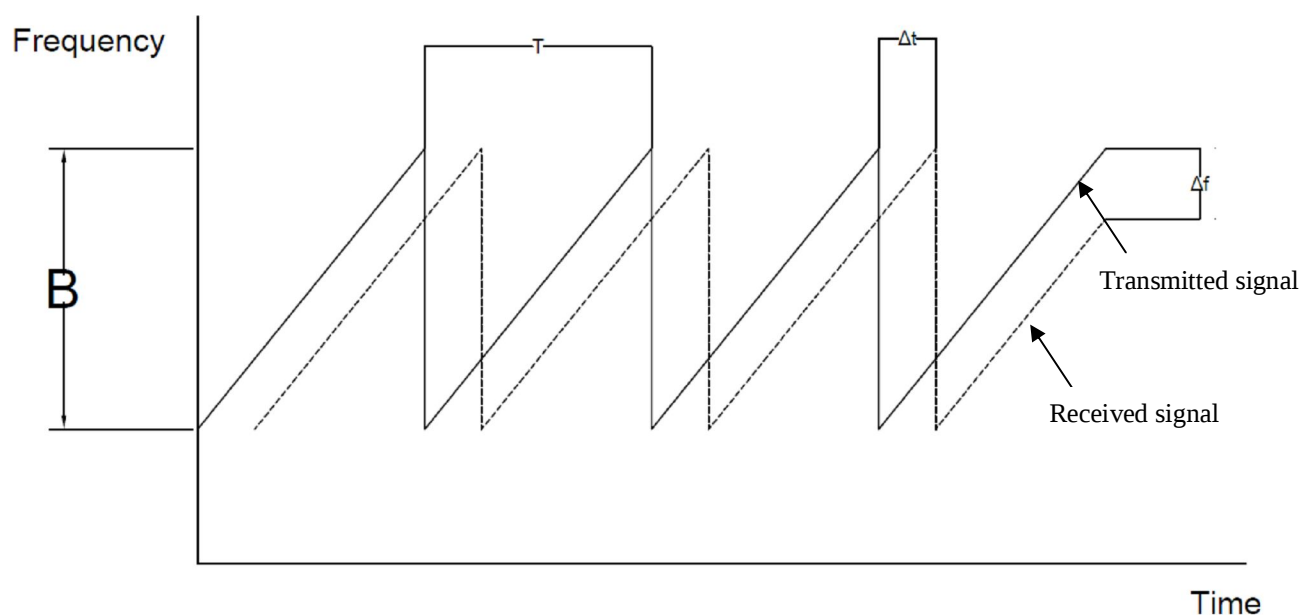


Figure 4: Detection of Stationary Object

The solid line indicates transmitting signal while the dashed line indicates received signal from object. As can be seen, there is a frequency difference Δf between transmitted and received signal due to time delay introduced by signal propagation in air.

Distance between sensor and detected object can be calculated based on formula:

$$R = \frac{c \times \Delta f}{2 \times k}$$

Where

- R: Distance between sensor and object.
- c: speed of light in free space, 3×10^8 m/s.
- Δf : frequency difference between sent and received signal.
- k: gradient of frequency change.

Please refer to Annex 2 for more detailed FMCW stationary object range calculation.

Moving Object

For detection of moving object, the triangle wave is suggested in order to obtain information on distance and velocity (Figure 5).

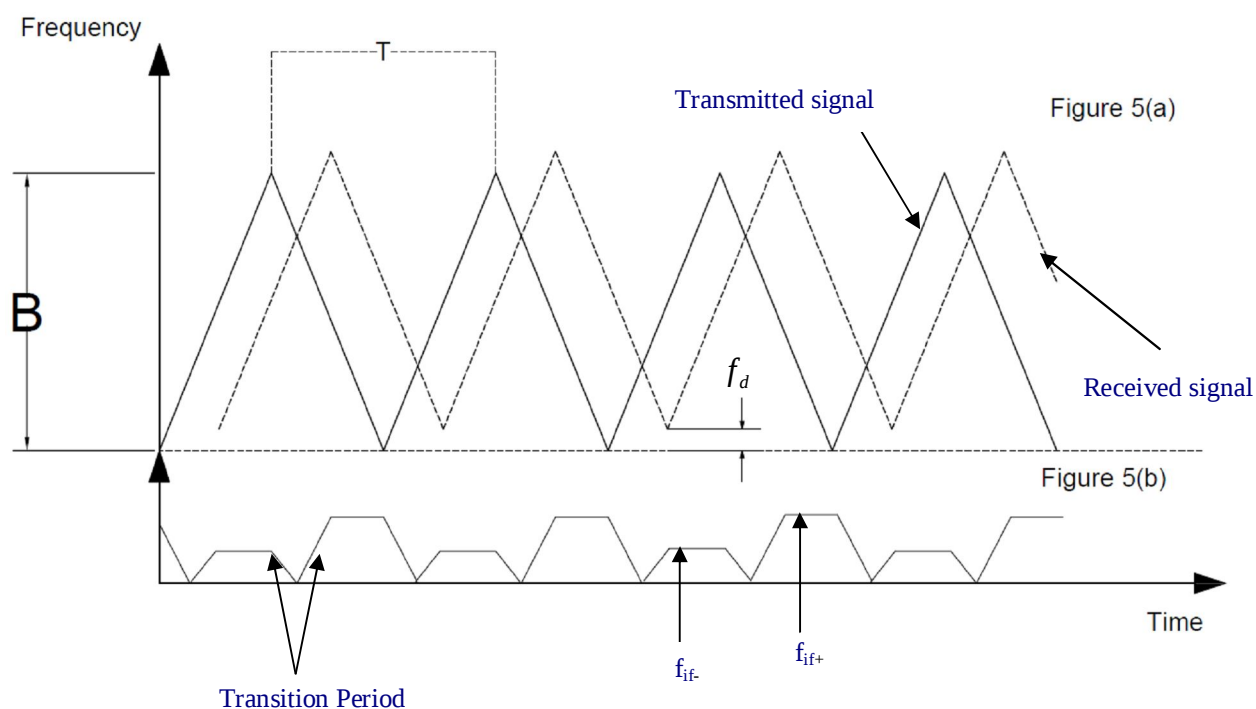


Figure 5: Detection of Moving Object

The solid line in figure 5(a) indicates transmitted signal while the dashed line indicates reflected signal. The solid line in figure 5(b) stands for absolute value of frequency difference between transmitted signal and received signal.

Note: Typically, computation of data takes place for period that generates stable f_{if+} and f_{if-} ; transition period is normally avoid.

By varying tuning voltage, user is suggested to increase frequency linearly from f_b (base frequency) to $f_b + B$ (bandwidth) in half T (period) time and then decrease frequency linearly back to f_b in another half T time. Compared to stationary object, moving object's received signal not only has time delay which introduces f_R , but also has upper or lower displacement due to the doppler frequency f_d .

So, object's distance R can be calculated based on this formula:

$$R = \frac{c \times f_R}{2 \times k}$$

Where

$$f_R = \frac{f_{if^+} + f_{if^-}}{2}$$

Object's velocity v is given by:

$$v = \frac{f_d \times c}{2 \times f_0}$$

Where f_0 is the frequency of transmitted signal and

$$f_d = \frac{f_{if^+} - f_{if^-}}{2}$$

Please refer to Annex 2 for more detailed FMCW moving object range and velocity calculation.

6. Radiation Pattern

The module to be mounted with the antenna patches facing to the desired detection zone. The user may vary the orientation of the module to get the best coverage. The radiation patterns of the antenna and their 3dB beam width are shown in below diagram.

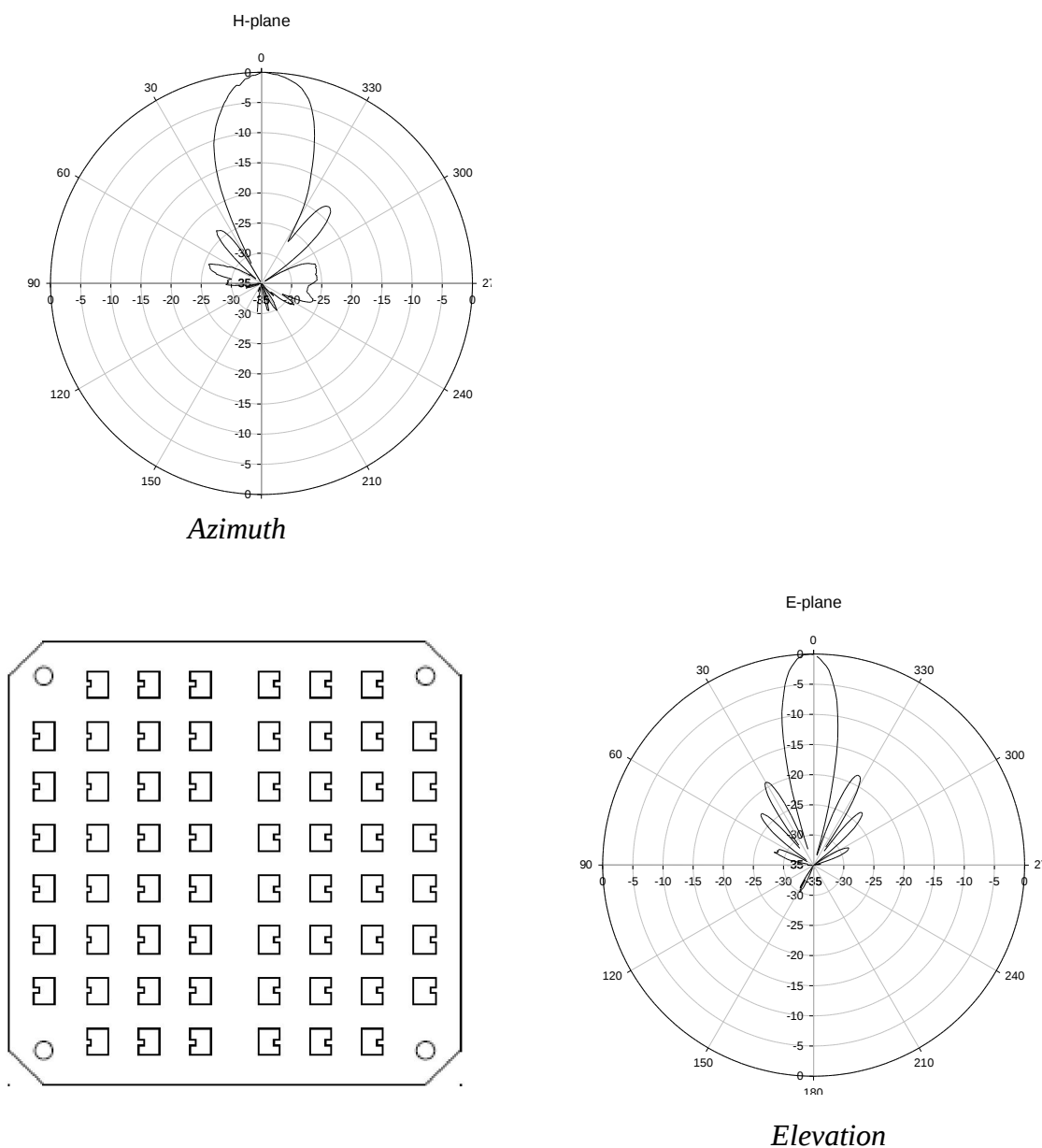


Figure 6: Beam pattern of DF990

7. IF amplifier gain and frequency response

The DF9 series transceiver module comes with a built-in two-stage IF amplifier. The amplifier is designed to provide low noise and hence, higher sensitivity. Besides, this amplifier acts as a buffer so that the performance of the DF module is not affected by the loading at the IF output. A loading of at least 1 k Ω is recommended at the IF output.

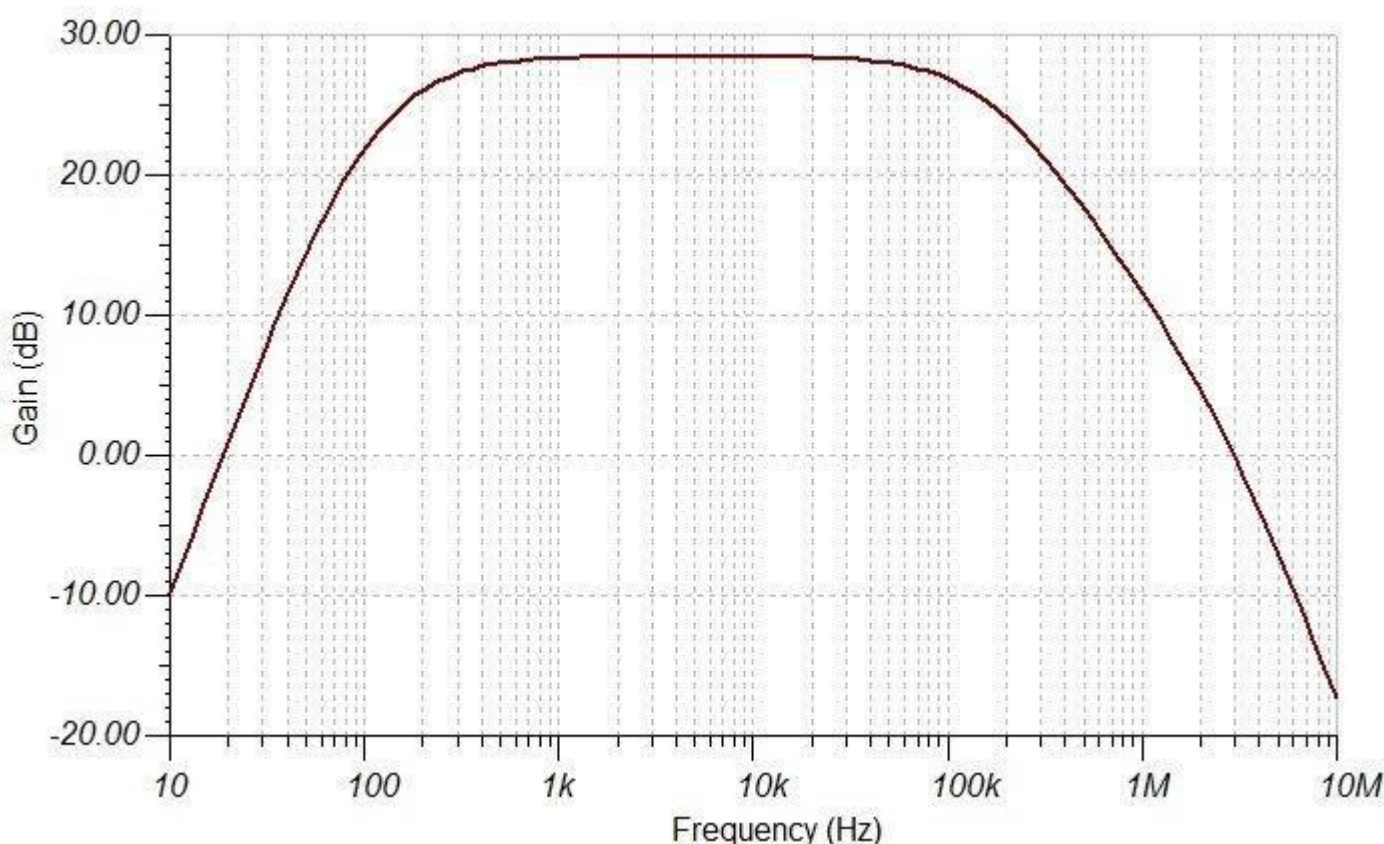


Figure 7: Frequency response of IF amplifier of DF990

8. IF output signals

This section shows a typical signal at output from DF990 when pointed to the wall at certain distance. This section means to serve as a guide.

Tuning Voltage Frequency: 10 KHz
Tuning Voltage Range: 1-6V
Sweeping Type: Triangle Function.

Figure 8 shows the signal at IF output when there is no target in the detection range of sensor. Channel 2 (the blue line) indicates tuning voltage while Channel 1 (the yellow line) is the signal from Q channel.

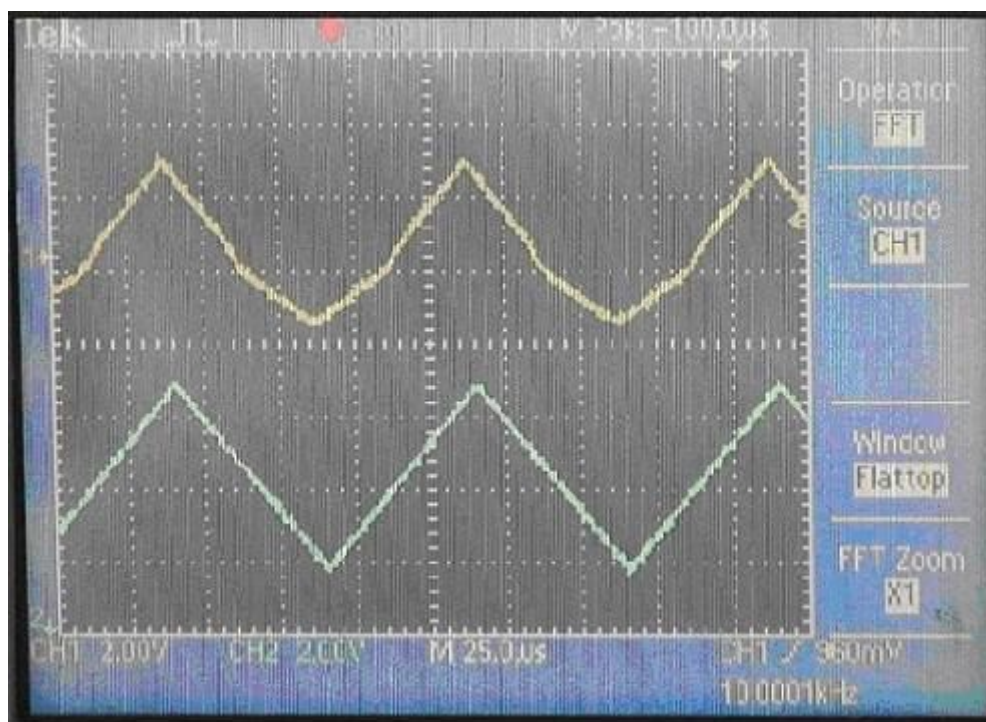


Figure 8: IF Output Signal and Input Tuning Voltage with no targets detected.

Figure 9 shows the signal at IF output when there is target in the detection range of sensor. Channel 2 (the blue line) indicates tuning voltage while Channel 1 (the yellow line) shows the signal of Q channel.

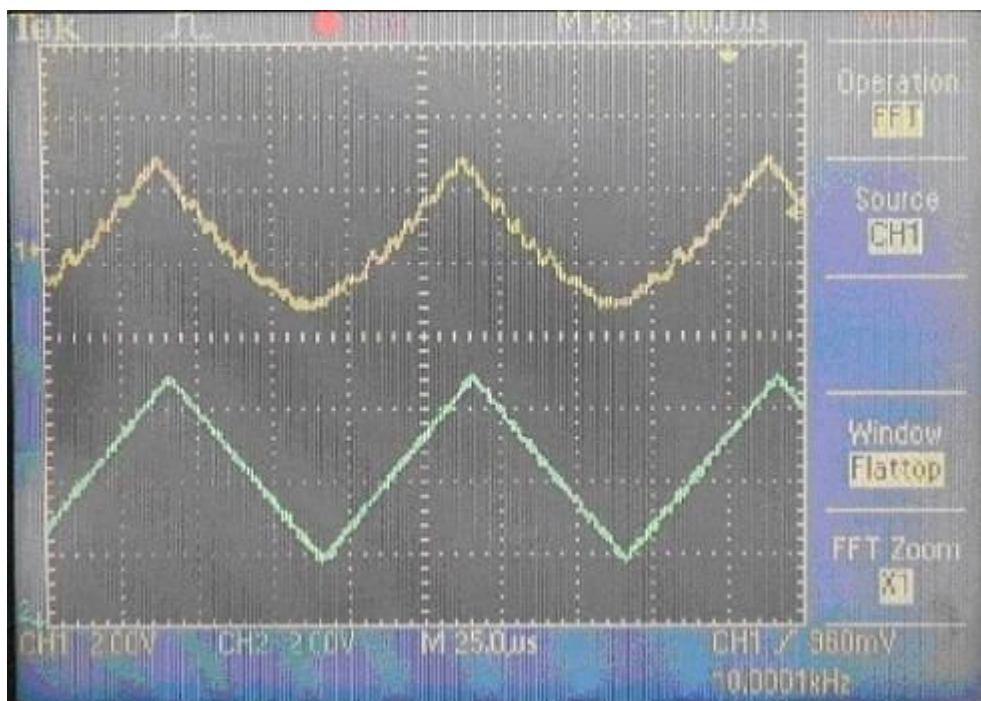


Figure 9: IF Output Signal and Input Tuning Voltage with target detected.

Figure 10 to 13 show the signals from IF output when targets at different distance are detected.

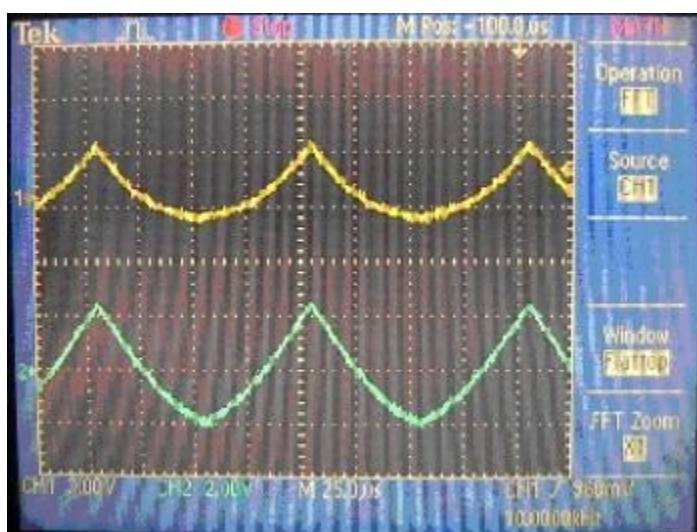


Figure 10: I and Q signal when no target detected

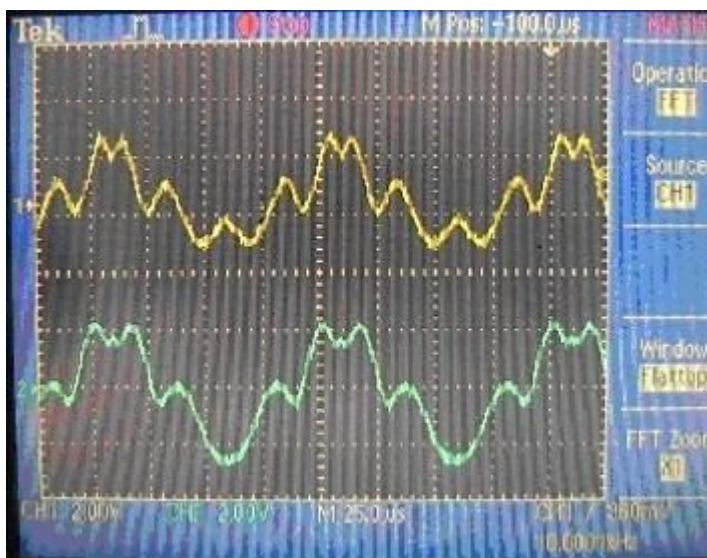


Figure 11: I and Q signal with target detected at 1m away

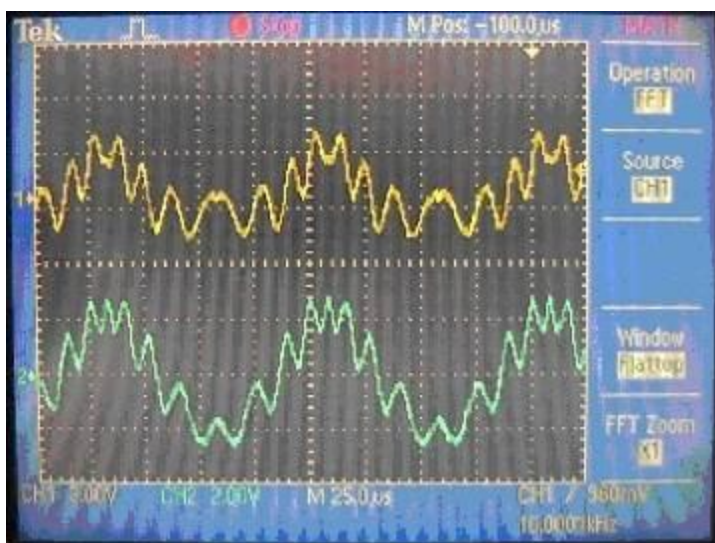


Figure 12: I and Q signal with target detected at 3m away

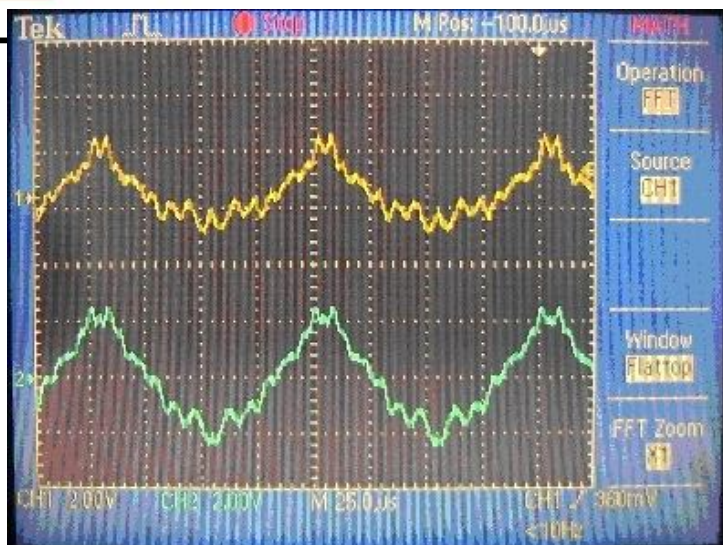


Figure 13: I and Q signal with target detected at 5m away

There are two output signals in DF9 series: I and Q signal. As the figures shown, amplitude of output signal becomes smaller when distance increases, while the frequency of output signal increases with distance. When the distance of detected object is small enough, frequency difference of transmitted and received signal will be equal or even less than sweeping frequency. In that case, user may not be able to isolate frequency difference from sweeping frequency.

The minimum detection range for DF9 series will be:

$$R = \frac{c}{2 \times B}$$

Where

c : speed of light in free space, 3×10^8 m/s

B : frequency sweeping bandwidth.

Reader may also notice the phase difference between I and Q signals. Ideally, there is a 90 degree phase difference between I and Q signals. By identifying phase lagging/leading, information of movement direction can be determined.

9. Placing the module in enclosure

As the applications of DF series are mostly in traffic (outdoor), it is inevitable that the module needs to be housed in an enclosure. As such, it is important to ensure that the performance of the module is not significantly degraded by the presence of enclosure.

The recommended material for the enclosure is plastic (such as ABS), as microwave can penetrate through the material without significant loss. For comparison purpose, a metal results in full reflection while water results in high absorption of the microwave. It is therefore important not to use any metallic material as the enclosure.

V1.01

It is recommended that the cover placed in front of the DF antenna is of flat panel, so that the beam width of the antenna is not significantly distorted. The thickness of the cover, h_1 and the spacing between the antenna and the cover, h_2 should be ideally half-wavelength of the microwave signal.

In this case, for DF series module whose transmission frequency is $\sim 24\text{GHz}$, the recommended h_1 and h_2 are 3-4mm and 6mm.

A half wavelength of a 24 GHz in the air is about 6mm. However, the half wavelength of the signal in other medium depends on the dielectric constant of the material. In the case of ABS which has a dielectric constant of between 2.5 to 3.5, the half wavelength of the signal is 3 – 4 mm.

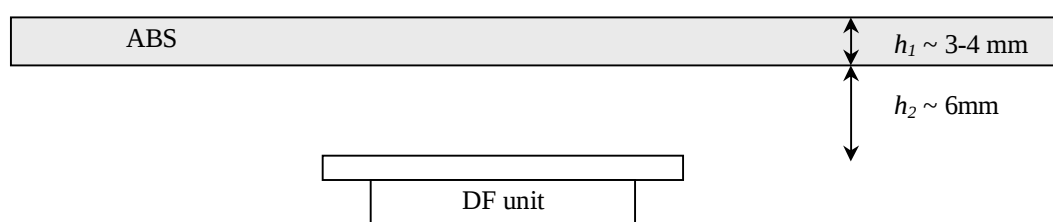


Figure 14: Recommended thickness and clearance for ABS placed in front of DF sensor

10. Using EN (pin 1)

EN (pin 1) can be used to control the oscillator. The internal voltage source is supplied to the oscillator via a PNP transistor switch. When EN is asserted LOW (GND), the switch is on and internal voltage is supplied to the oscillator, resulting in a transmission of 24GHz microwave signal. On the other hand, when it is driven HIGH (+3.3V or higher), the oscillator is de-activated. The current drawn from the EN pin is typically less than 1mA, and hence, it can be driven by TTL or CMOS as long as the voltage high is +3.3V or more.

This feature can be used to reduce power consumption by introducing pulse to this pin.

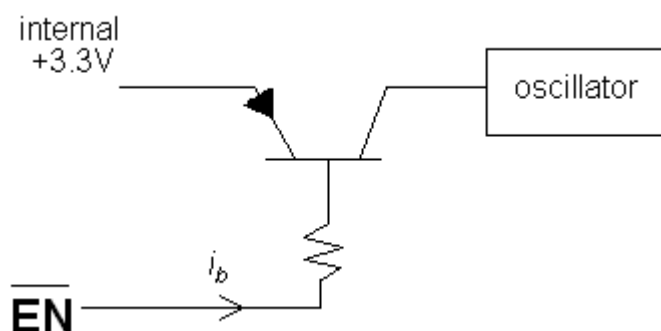


Figure 15: Internal circuit of EN function in DF sensor

12. Radiation Safety

Microwave radiation from the module is well below established safety standards for general public environment, like ANSI C95.1-1991 of USA and NRPB-G11 of United Kingdom.

13. Handling

The module has been fully tested to specifications. Opening, tightening or loosening the chassis may result in performance deterioration.

The module is an electrostatic sensitive device (ESD). Precautions shall be observed for handling and assembly.

14. Product Support

Please contact our product support engineers in the factory for technical assistance whenever necessary.

Product Support (Microwave Sensors)

Tel: (65) 6521 7888

Fax: (65) 6521 7801

E-mail: info@agilsense.com

This device complies with part 15 of FCC Rules.

Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Any changes or modifications to ST Electronics equipment not expressly approved by ST Electronics could void the user authority to operate the equipment.

The system integrated the radio should have label indicated the FCC ID of approved Radio.
Such as putting a label on system as below: CONTAIN FCC ID: VECDF990

Warning : The radio does not allow to be installed and operated with other radio simultaneously when integrated in host system.
Installed in such configuration may subject to additional FCC testing and equipment authorization.

Annex 1: Transmission of RF

1. Though same frequency is allocated in some countries, national regulations may specify different EIRP, spurious emission or other requirements.
2. The DF990 model is designed to meet the FCC standard part 15.245 and is aimed for use in the America.
3. The regulations are subjected to change from time to time, please contact appropriate authorities for full and up-to-dated information.
4. Useful websites:

Agency	Website
The Code of Federal Regulations, USA	http://www.access.gpo.gov/cgi-bin/cfrassemble.cgi?title=199847
Federal Communications Commission	http://www.fcc.gov/

Annex 2: FMCW Theory

Stationary Object

The relation between distance and frequency difference is:

$$\Delta f = \Delta t \times k = \frac{2 \times R}{c} \times k$$

Where

R: Distance between sensor and object.
c: speed of light in free space, 3×10^8 m/s
 Δt : measured time difference
k : gradient of frequency change.

Where

$$k = \frac{B}{T}$$

T: frequency sweeping period of sensor
B : frequency sweeping bandwidth.

So, distance is given by:

$$R = \frac{c \times \Delta f}{2 \times k}$$

Moving Object

Due to the existence of doppler frequency in the f_{if+} and f_{if-} , the frequency associated to range is given by:

$$f_R = \frac{f_{if+} + f_{if-}}{2}$$

Hence, object's distance is given by:

$$R = \frac{c \times f_R}{2 \times k}$$

Where

$$k = \frac{B}{T}$$

T: frequency sweeping period of sensor
B : frequency sweeping bandwidth.

From the graph, the doppler frequency f_d can be obtained by the following:

$$f_d = \frac{f_{if+} - f_{if-}}{2}$$

The relationship between doppler frequency and velocity is given by:

$$v = \frac{f_d \times c}{2 \times f_0}$$

Where

v: velocity of the moving object
 f_0 : frequency of transmitted signal
c: speed of light in free space, 3×10^8 m/s

Note: based on the phase of two channels' output, moving direction of object can be identified.