

Faculty: FACULTY OF ELECTRICAL ENGINEERING		
Course : 3rd Year Electrical Laboratory	Review	: 3
Course Code : SKEE 3732	Release Date	: 2019
	Last Amendment	: 2025



SKEE 3732
FACULTY OF ELECTRICAL ENGINEERING,
UNIVERSITI TEKNOLOGI MALAYSIA, JOHOR BAHRU

BASIC COMMUNICATION LABORATORY
FREQUENCY MODULATION (FM)

Prepared by : HEAD OF BASIC COMMUNICATION LABORATORY Name : DR. NURUL ASHIKIN DAUD : TS. DR. NIK NOORDINI NIK ABD MALIK Assisted by : PN. NORHIDAYU BASIR : CIK NORAZAH ADZHAR : PN. SYUKHIRIZA ALI : Signature & Stamp :  : DR. NURUL ASHIKIN BINTI DAUD Senior Lecturer Faculty of Electrical Engineering Universiti Teknologi Malaysia 81310 Skudai, Johor, Malaysia Tel: +607-5557114 Email: nurulashikindaud@utm.my.	Approved by : HEAD OF COMMUNICATION ENGINEERING DEPARTMENT Name : ASSOC. PROF. IR. TS. DR. NURUL MU'AZZAH BINTI LATIFF Signature & Stamp :
Date :	Date :

1.0 OBJECTIVES

- To simulate basic communication system of frequency modulation (FM) signals using gnu-radio companion (GRC).
- To understand the concept of FM signals in terms of time and frequency domain representations.
- To examine the main parameters of FM signals.
- To develop FM signals on Universal Serial Radio Peripheral (USRP) Software Defined Radio (SDR) platform

2.0 FREQUENCY MODULATION(FM)

Frequency modulation is the instantaneous change of the carrier frequency, f_c by the information modulating signal, $v_m(t)$ while the carrier amplitude remains constant. As the amplitude of $v_m(t)$ increases, f_c increases and vice versa. Assume a periodic sinewave modulating signal, $v_m(t) = E_m \cos(\omega_m t)$. The amplitude of the information signal, E_m which changes with time, t will change the carrier frequency while the carrier amplitude remains fixed. The carrier frequency varies linearly with the amplitude of modulating signal. The higher the amplitude of modulating signal, the bigger is the produced frequency deviation as shown in Figure 2.1

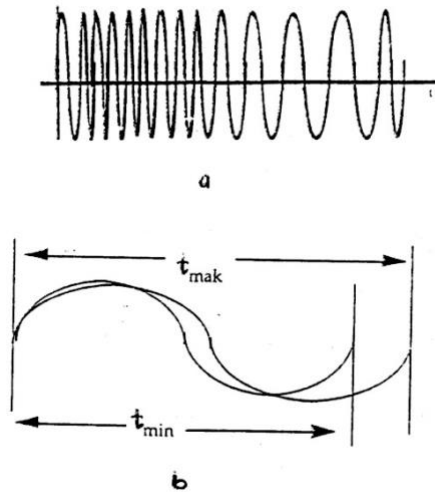


Figure 2.1: (a) FM waveform in time domain. (b) FM signal as seen on the oscilloscope.

FM signal, $v_{FM}(t)$ is:

$$v_{FM}(t) = E_c \cos \left(\omega_c t + k_f \int_0^t v_m(t) dt \right) \quad (1)$$

$$= E_c \cos \left(\omega_c t + \frac{k_f}{\omega_m} E_m \sin \omega_m t \right) \quad (2)$$

If modulation index, $\beta = \frac{k_f E_m}{\omega_m} = \frac{\Delta\omega_m}{\omega_m} = \frac{\Delta f_m}{f_m}$

$$v_{FM}(t) = E_c \cos [\omega_c t + \beta \sin (\omega_m t)] \quad (3)$$

$$v_{FM}(t) = E_c \cos(\omega_c t) \cos [\beta \sin (\omega_m t)] - E_c \sin(\omega_c t) \sin [\beta \sin (\omega_m t)] \quad (4)$$

However, for FM signal with small index modulation, i.e. $\beta < 1$, it is called as the Narrow Band FM (NBFM) signal. Let $\theta(t) = \beta \sin(\omega_m t) \ll 1$. Hence NBFM equation yields:

$$v_{FM}(t) \approx E_c \cos(\omega_c t) - E_c \theta(t) \sin(\omega_c t) \quad (5)$$

$$= E_c \cos(\omega_c t) - E_c \beta \sin(\omega_m t) \sin(\omega_c t) \quad (6)$$

$$= E_c \cos(\omega_c t) - \frac{\beta E_c}{2} \cos [(\omega_c - \omega_m)t] + \frac{\beta E_c}{2} \cos [(\omega_c + \omega_m)t] \quad (7)$$

It is shown that NBFM consists of one carrier component and two-sidebands components similar to AM-DSBFC signal.

The process carried out by an FM modulator is as illustrated as in Figure 2.2:

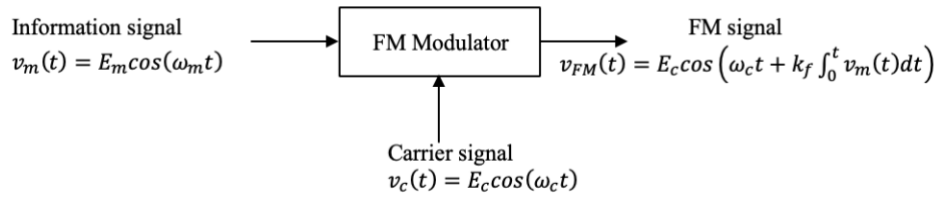


Figure 2.2: FM Modulator

2.1 FREQUENCY SPECTRUM

In theory, the FM wave contains an infinite number of sidebands thus suggesting an infinite bandwidth requirement for transmission or reception. The sidebands are at $(f_c \pm f_m)$, $(f_c \pm 2f_m)$, $(f_c \pm 3f_m)$ $(f_c \pm nf_m)$, where n is the integer representing the furthest sideband. Figure 2.3 shows a frequency spectrum which refers to the FM signal in frequency domain, as seen on the spectrum analyzer.

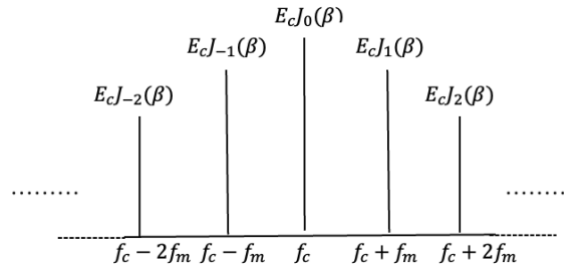


Figure 2.3: Frequency spectrum of FM signal

The number of sideband components are decided by modulation index value, β . The amplitude of sidebands depends on the value of coefficient $J_n(\beta)$ as given in the Bessel table as in Table 2.1. The sidebands are symmetrically around f_c . Two sidebands at a similar distance to the f will have the same amplitude. J with negative value shows a phase difference of 180° .

2.2 BANDWIDTH

Bandwidth provides information on the frequency spectrum required for transmission. FM bandwidth depends on the modulation index, β . The higher the modulation index, β , the greater required system bandwidth. FM bandwidth is given by the formula: $f_{max} - f_{min}$. FM signal bandwidth also can be calculated using equations below:

- (i) Low-index modulation, $\beta < 1$ (Narrow Band FM)

$$BW = 2f_m \quad (8)$$

- (ii) High-index modulation, $\beta > 10$ (Wide Band FM)

$$BW = 2\Delta f \quad (9)$$

- (iii) Actual/Bessel BW

$$BW = 2nf_m \quad (10)$$

where n is the number of significant sidebands

- (iv) Carlson's rule

$$BW = 2(\beta + 1)f_m = 2(\Delta f + f_m) \quad (11)$$

Table 2.1: Bessel Table

β	$J_0(\beta)$	$J_1(\beta)$	$J_2(\beta)$	$J_3(\beta)$	$J_4(\beta)$	$J_5(\beta)$	$J_6(\beta)$	$J_7(\beta)$	$J_8(\beta)$	$J_9(\beta)$
0.01	1.0	0.005								
0.2	0.99	0.1								
0.5	0.94	0.24	0.03							
1	0.77	0.44	0.11	0.02						
2	0.22	0.58	0.35	0.13	0.03					
3	-0.26	0.34	0.49	0.31	0.13	0.04	0.01			
4	-0.4	-0.7	0.36	0.43	0.28	0.13	0.05	0.02		
5	-0.18	-0.33	0.05	0.37	0.39	0.26	0.13	0.05	0.02	
6	0.15	-0.28	-0.23	0.12	0.36	0.36	0.25	0.13	0.06	0.02

2.3 FM DEMODULATION

Frequency demodulator, also called frequency discriminator, is a circuit, which converts instantaneous frequency variations to linear voltage changes. There are many types of circuit used in communication system such as FM to AM conversion, balanced, phase-shift discriminators and phase-locked loop (PLL) frequency demodulators. Figure 2.4 illustrates the process involved.

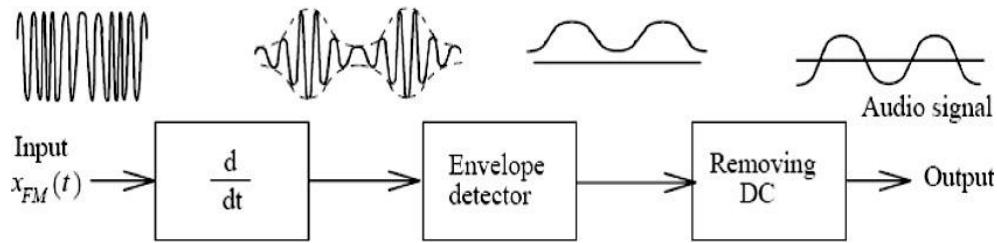


Figure 2.4: Block Diagram of an FM-AM conversion discriminator

References:

1. Rozeha A. Rashid & et al., Prinsip Kejuruteraan Telekomunikasi, Penerbit UTM 2007
2. Abu Sahmah & et al., Principles of Communication, Pearson 2011
3. Devidas Kushnure, Murtaza Jiniyawala, Sushama Molawade, Snehal Patil, “Implementation of FM Transceiver using Software Defined Radio (SDR)”, International Journal of Engineering Development and Research, 2017.

3.0 INSTRUMENTATION REQUIRED

1. Universal Software Radio Peripheral (USRP) Software Defined Radio (SDR) B200.
2. LP0965 Log Periodic PCB Antenna (850 MHz to 6.5 GHz).
3. FM antenna
4. SMA-SMA Cable.
5. GNU-Radio Companion (GRC).

Read all procedures before you do this experiment. If you have any problems, get the lab instructor/supervisor to help you.

4.0 PRE-LAB EXPERIMENT PROCEDURE

- Install the windows-based GNU radio by referring to the link provided (use **version 3.7**)
Link:
<https://drive.google.com/drive/u/1/folders/1N0SzktKDeLhIFOKOJ9C608CLeK9litxl>
- Each group **must complete the Pre-Lab experiment and discussion before attending the laboratory session**. The completed answers (including flow graph, output signals, and short discussions) must be **printed**, brought **to the lab** and **shown to the supervisor for verification** at the beginning of the session.
- Students must **save** all flow graph files on a **portable storage device** (e.g., pendrive, external hard disk, or other suitable media) or **cloud storage** (google drive, one drive, etc.) to ensure they can be readily accessed and executed the flow graph during the lab session.

4.1 PRE-LAB EXPERIMENT: FREQUENCY MODULATION (FM)

4.1.1 FM MODULATOR/TRANSMITTER

- (1) Start a new file in GNU Radio Companion (GRC). There will be two blocks in the workspace, i.e. **Options** block and **Variable** block. Open **Variable** block. Set the Sampling Rate in the Variable block to 200 kHz and variable name to samp_rate. In **Options** block, select WX GUI.
- (2) Create a signal source block by selecting **Signal Source** block as the message modulating signal. Change the frequency to 2kHz. Change the output type from “Complex” to “Float”.
- (3) Connect the **Signal Source** block to a **Multiply Const** block. Set value constant to 5. Then connect this block to two **Transcendental** blocks. Set Function Name to cos and sin for the first **Transcendental** block and second **Transcendental** block, respectively.
- (4) Add another two **Signal Source** blocks which acts as a carrier signals. Change the frequency to 25 kHz. This will be the carrier frequencies. Set Waveform to Cosine with amplitude 1 for the first carrier **Signal Source** block, while Waveform to Sine with amplitude -1 for the second carrier **Signal Source** block.
- (5) After that, connect the output of the first carrier **Signal Source** block and the first **Transcendental** block to a **Multiply** block.
- (6) Then connect the output of the second carrier **Signal Source** block and the second **Transcendental** block to another **Multiply** block.
- (7) Add both outputs from **Multiply** blocks by using **Add** block.
- (8) Connect the output of **Add** block to **Throttle** block.
- (9) Finally, connect the output of the **Throttle** block to the input of **WX GUI Scope Sink**, **WX GUI FFT Sink** and **File Sink**. Save the generated modulated signal using **File Sink** block. Choose the folder in which you want to save the file and name it as **FMsinuswave.dat**.
- (10) Save and execute the flow graph. Now, observe and print screen the output signals both in time and frequency domain representations. Compare these output signals with input signals. Analyze and answer all the questions in discussion.
- (11) Change the value of Multiply Const, modulating signal frequency, f_m and carrier signal frequency, f_c . Discuss what happen to the signals. Analyze and discuss in your pre-lab report.
- (12) Now, replace the sinusoid message signal with music wave signal. Add **Wav File Source** block. Choose the folder in which you have saved the Music.wav file.
- (13) Change the name of file to **FMmusicwave.dat** in **File Sink** block.
- (14) Execute. Now, observe and print screen the output signals both in time and frequency domain representations. Discuss what happened to the signals. Compare with signals from Step (9).

4.1.2 FM DEMODULATION/RECEIVER

- (1) Start new file and add **File Source** block. Choose the folder in which you have saved the filename **FMsinuswave.dat** from **Pre-Lab Experiment 4.1.1**.

- (2) Add two **Signal Source** blocks. Set the first **Signal Source** block with Waveform to Cosine, Frequency to 25 kHz and amplitude to 1. Set the second **Signal Source** block with Waveform to Sine, Frequency to 25 kHz and amplitude to -1.
- (3) Then, add two **Multiply** blocks and connect both **File Source** block and **Signal Source** block as inputs.
- (4) Add two **Low Pass Filter** blocks. Connect each of the **Multiply** blocks output to the **Low Pass Filter** block. Set cutoff frequency to 25 kHz and the transition width to 100 Hz.
- (5) After that connect both **Low Pass Filter** block outputs to **Float to Complex** block.
- (6) Add **Throttle** block. Connect the input of the block to Float to Complex block and the output to **Delay** block. Set delay to 1.
- (7) Add **Multiply Conjugate** block. Connect the **Delay** block output and **Throttle** block output to the inputs of **Multiply Conjugate** block. Ensure that the Throttle, Delay and Multiply Conjugate blocks type are in Complex.
- (8) Finally, connect the output of the **Multiply Conjugate** block to the **Complex to Arg** block and then to **WX GUI Scope Sink** and **WX GUI FFT Sink** to view the demodulated signals. Ensure that both of this block's type is in Float.
- (9) Save the flow graph and execute. Observe the demodulated signals in both time and frequency domains. Take the snapshot, analyze and compare with Experiment 4.1.1.
- (10) Change the value of frequency of carrier signals and cut off frequency of LPF. Discuss what happen to the signals. Analyze and discuss in your pre-lab report.
- (11) Repeat for file **FMmusicwave.dat** from Experiment 4.1.1. (Hint: Add an **Audio Sink** block to hear the music. Set Sample Rate to 32 kHz). Observe the different from previous Step (9). Discuss in your pre-lab report.

Additional Hint:

1. **WX GUI Notebook** block enables to show several plots in a single window using different tabs.
2. **WX GUI Slider** block enable to change the values of any variables that you want. Example: modulation frequency, modulation factor or USRP gain.

Discussion and Analysis

1. What are the advantages and disadvantages of FM over AM?
2. How does the amplitude of the modulating signal affect the FM signal?
3. What is the role of the modulation index in FM, what happens when its value changes, and which block in GNU radio represents this function?
4. How can the modulation factor (index) be determined from the frequency spectrum?
5. How does changing the modulating frequency (while keeping the amplitude constant) affect the FM signal and modulation index?

5.0 IN-LAB EXPERIMENT PROCEDURE

5.1 EXPERIMENT: NARROW BAND FREQUENCY MODULATION (NBFM)

5.1.1 NBFM Modulator/Transmitter and NBFM Demodulator/Receiver

- (1) Design a Narrow Band Frequency Modulation (NBFM) modulator by referring to Equation (6)
- (2) Choose your own modulating message signal with modulating frequency, f_m , suitable carrier frequency, f_c and value of constant in **Multiply Const** block (Hint: the value of constant must be in certain limit. Refer to NBFM theory).
- (3) Save the generated modulated signal using **File Sink** block. Choose the folder in which you want to save the file and name it as **NBFMsinuswave.dat**. Ensure that the File Sink block type is Float.
- (4) Observe both time and frequency representations of message signal before and after modulation. Record and analysis.
- (5) For NBFM demodulation experiment, open the flow graph from **pre-lab Experiment 4.1.2** (FM demodulator). In **File Source** block, choose the folder in which you have saved the filename **NBFMsinuswave.dat** from Step (3) (NBFM Modulator).
- (6) Verify the most suitable cut off frequency and gain of the low pass filter so that the initial message signal can be retrieved back.
- (7) Observe both time and frequency representations of message signal before and after modulation. Record and analysis.
- (8) Observe also time and frequency representations of modulated signal before and after demodulation process. Record and justify.
- (9) Now, replace the sinusoid message signal with music wave signal. Add **Wav File Source** block. Choose the folder in which you have saved the Music.wav file.
- (10) Change the name of file to **NBFMmusicwave.dat** in **File Sink** block.
- (11) Observe the difference of modulated and demodulated music signal. Analyze and discuss in your lab report. (Add **Audio Sink** block at the output of **Complex to Arg** block at the demodulator to hear the music file)

Discussion and Analysis

1. What is the suitable value of modulation index in designing NBFM modulator system?
2. What are the advantages and disadvantages of this NBFM compared to the WBFM?
3. What is the application of NBFM?

5.2 EXPERIMENT: WIDE BAND FREQUENCY MODULATION (USRP-based WBFM)

5.2.1 USRP-based WBFM Transmitter

- (1) Start a new file in GNU Radio Companion (GRC). In **Options** block, select WX GUI. Open **Variable** block. Set value to 192 kHz. Add another **Variable** block. Set ID to audio_rate and value to 48kHz.
- (2) Create a signal source block by selecting **Wav File Source** block. Choose the folder in which you have saved the Music.wav file.
- (3) Add **WBFM Transmit** block. Set Audio Rate to audio_rate and Quadrature Rate to samp_rate. Then, connect it to the **Throttle** block.
- (4) Next, add **Rational Resampler** block and connect it to **Multiply** block.
- (5) Add **Signal Source** block. Set Amplitude to 142.857 and Frequency to 0. Connect to **Multiply** block.
- (6) Save the generated modulated signal using **File Sink** block. Choose the folder in which you want to save the file and name it as **WBFMmusicwave.dat**.
- (7) Finally, add **WX GUI Scope Sink** and **WX GUI FFT Sink** to observe the demodulated signal
- (8) To send the modulated signal to the USRP board, add **UHD: USRP Sink** block. Change the properties by setting the Sample Rate to samp_rate and Center Freq at the RF Options tab to 85.7MHz (Advisable to use different frequency from another group). Set the Gain to 40 dB (not over 100 dB) and set Antenna to TX/RX.

5.2.2 USRP-based WBFM Receiver

- (1) Start a new file in GNU Radio Companion (GRC). There will be two blocks in the workspace, i.e. **Options** block and **Variable** block. In **Options** block, select WX GUI.
- (2) Open **Variable** block. Set value to 500 kHz for samp_rate.
- (3) For WBFM demodulation experiment, add **File Source** block. Choose the folder in which you have saved the filename **WBFMmusicwave.dat** from Experiment 5.2.1 in Step (6).
- (4) Connect the previous block to **Throttle** block. Then, connect the block to **WBFM Receive** block. Set Quadrature Rate to 500kHz and Audio Decimation to 10.
- (5) Next, connect to **Rational Resampler** block. Set Interpolation to 48, Decimation to 50 and type to Float ->Float (Real Taps).
- (6) Then, connect to **Multiply Const** block. Set Constant to 2. Finally, connect the block to **WX GUI Scope Sink** and **WX GUI FFT Sink**. Add also **WX GUI FFT Sink** before **WBFM Receive** block to view the baseband signals.
- (7) Add an **Audio Sink** block to hear the music. Set Sample Rate to 44kHz. Observe the demodulated signals. Observe also the baseband signals before **WBFM Receive** block.
- (8) To receive music signal using USRP, add **UHD: USRP Source** block. Disable the previous File Source and Throttle block. Change the properties of the **UHD: USRP Source** block by

setting the Sample Rate to samp rate, Center Freq to 85.7MHz (Advisable to use different frequency from another group). Set the Gain to 40dB and set Antenna to TX/RX.

- (9) Connect the output of the **UHD: USRP Source** block to the input of **Frequency Xlating FIR Filter** block. Set Taps to 1MHz. Connect the output of this block to the input of **WBFM Receive** block.
- (10) By using this USRP setup, you can hear the FM radio signals. Change the Center Freq in **UHD: USRP Source** to any FM radio frequency. Change the Sample Rate to 48kHz in **Audio Sink** block. (Hint: Increase the gain value of **USRP** block or increase the constant value of **Multiply Const** block to achieve a clearer FM radio signals).

FOR SHORT REPORT

1. Attach every flow graph for each experiment.
2. Attach all plots and explain the results. Analyze the results.
3. Answer all questions in this handout.

FOR LONG REPORT

1. Attach every flow graph for each experiment.
2. Answer all questions in this handout. Attach all plots and explain the results
3. Explain the advantages/disadvantages of FM in general.
4. Include FM commercial applications such as the FM broadcast technical standards.
5. Discuss the superheterodyne FM receiver with the aid of a block diagram.