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

**BASIC COMMUNICATION LABORATORY**  
**FREQUENCY MODULATION (FM)**

Prepared by : <b>HEAD OF BASIC COMMUNICATION LABORATORY</b>	Approved by: <b>DIRECTOR OF COMMUNICATION ENGINEERING DIVISION</b>
Name : <b>DR. NIK NOORDINI BT NIK ABD. MALIK</b> Assisted by <b>PN. SYUKHIRIZA BT ALI</b>	Name : <b>PM. DR. NORHUDAH BT SEMAN</b>
Signature & : Stamp :	Signature & : Stamp :
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## 1.0 OBJECTIVES

- a) To simulate basic communication system of frequency modulation (FM) signals using gnu-radio companion (GRC).
- b) To understand the concept of FM signals in terms of time and frequency domain representations.
- c) To examine the main parameters of FM signals.
- d) 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

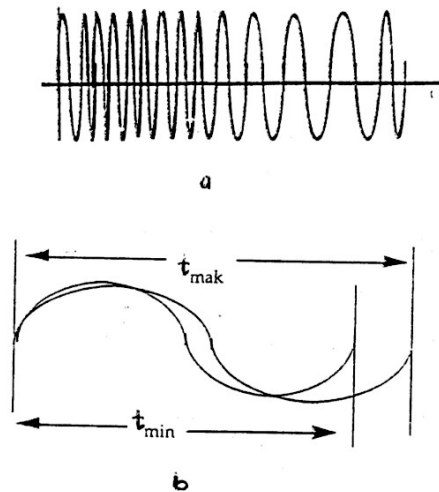


Figure 2.1: (a) FM waveform in time domain. (b) FM signal as seen on the oscilloscope.

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:

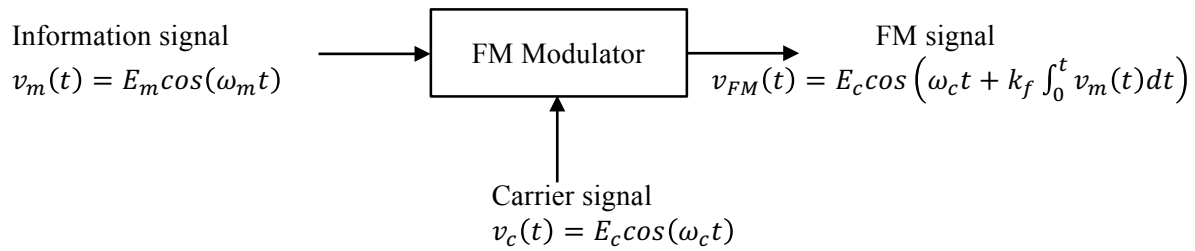


Figure 2.2: FM Modulator

## 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.

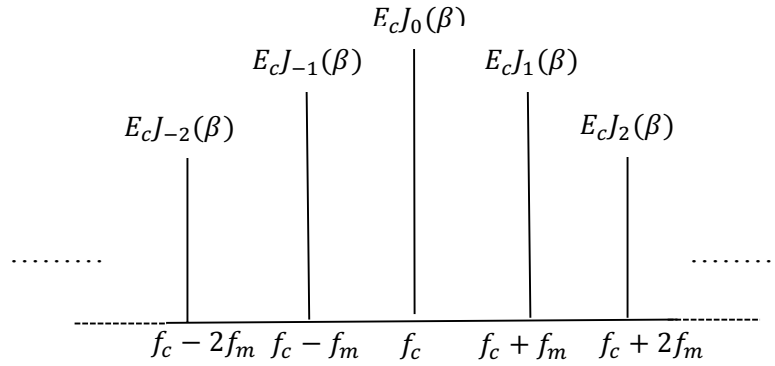


Figure 2.3: Frequency spectrum of FM signal

The number of sideband components are decided by modulation index value,  $\beta$ . 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  $180^\circ$ .

## 2.2 BANDWIDTH

Bandwidth provides information on the frequency spectrum required for transmission. FM bandwidth depends on the modulation index,  $\beta$ . The higher the modulation index,  $\beta$ , 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

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

$\beta$	$J_0(\beta)$	$J_1(\beta)$	$J_2(\beta)$	$J_3(\beta)$	$J_4(\beta)$	$J_5(\beta)$	$J_6(\beta)$	$J_7(\beta)$	$J_8(\beta)$	$J_9(\beta)$
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

Table 2.1: Bessel Table

### 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.

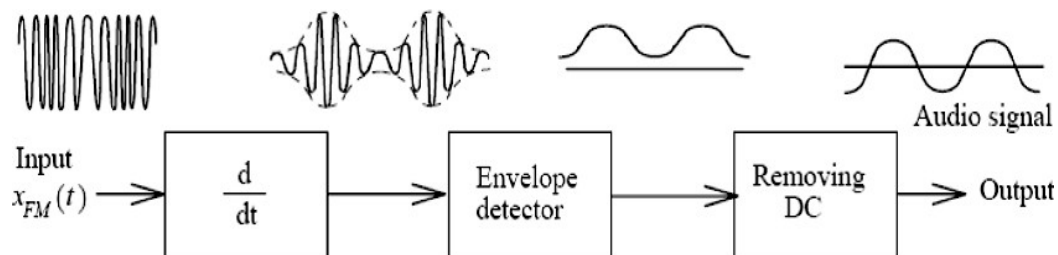


Figure 2.4: Block Diagram of an FM-AM conversion discriminator

#### 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.

## INSTRUMENT 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.*

## EXPERIMENT PROCEDURES

### EXPERIMENT 1 : FREQUENCY MODULATION (FM)

#### Experiment 1.1: FM Modulator/Transmitter

- 1.1.1 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.
- 1.1.2 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”.
- 1.1.3 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.
- 1.1.4 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.
- 1.1.5 After that, connect the output of the first carrier **Signal Source** block and the first **Transcendental** block to a **Multiply** block.
- 1.1.6 Then connect the output of the second carrier **Signal Source** block and the second **Transcendental** block to another **Multiply** block.
- 1.1.7 Add both outputs from **Multiply** blocks by using **Add** block.
- 1.1.8 Connect the output of **Add** block to **Throttle** block.
- 1.1.9 Finally, connect the output of the **Throttle** block to the input of **WX GUI Scope Sink** and **WX GUI FFT 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**.
- 1.1.10 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.
- 1.1.11 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 lab report.

- 1.1.12 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.
- 1.1.13 Change the name of file to **FMmusicwave.dat** in **File Sink** block.
- 1.1.14 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 1.1.11.

**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.

**Experiment 1.2: FM Demodulator/Receiver**

- 1.2.1 For FM demodulation experiment, add **File Source** block. Choose the folder in which you have saved the filename **FMsinuswave.dat** from Experiment 1.1.
- 1.2.2 Add two **Signal Source** blocks. Set the first **Signal Source** block with Waveform to Cosine, Frequency to 25kHz and amplitude to 1. Set the second **Signal Source** block with Waveform to Sine, Frequency to 25kHz and amplitude to -1.
- 1.2.3 Then, add two **Multiply** blocks and connect both **File Source** block and **Signal Source** block as inputs.
- 1.2.4 Add two **Low Pass Filter** blocks. Connect each of the **Multiply** blocks output to the **Low Pass Filter** block. Set cutoff frequency to 25kHz and the transition width to 100Hz.
- 1.2.5 After that connect both **Low Pass Filter** block outputs to **Float to Complex** block.
- 1.2.6 Add **Throttle** block. Connect it to **Delay** block. Set delay to 1.
- 1.2.7 Add **Multiply Conjugate** block. Connect the **Delay** block output and **Throttle** block output to the inputs of **Multiply Conjugate** block.
- 1.2.8 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.
- 1.2.9 Save the flow graph and execute. Observe the demodulated signals in both time and frequency domains. Take the snapshot, analyze and compare with Experiment 1.1.
- 1.2.10 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 lab report.
- 1.2.11 Repeat for file **FMmusicwave.dat** from Experiment 1.1. (Hint: Add an **Audio Sink** block to hear the music. Set Sample Rate to 8kHz). Observe the different from previous Step 1.2.9. Discuss in your lab report.

## Discussion and Analysis

- (a) What are the advantages of FM over AM?
- (b) What are the disadvantages of FM over AM?
- (c) How does the frequency-modulated signal differ at smaller and greater signal amplitudes of the input signal?
- (d) Which block in this flow graph is a modulation index? What happened after changing the value of modulation index?
- (e) How can the modulation factor be determined from the frequency spectrum?
- (f) In your opinion, when different modulating frequencies are used at the same signal amplitude, how do the modulation index and the frequency-modulated signal change?
- (g) The standard FM broadcast band has a frequency range of 88 - 108 MHz. Stations are spaced every 200 kHz beginning at 88.1 MHz and up to 107.9 MHz. The maximum permitted deviation is 75 kHz, with modulating frequencies up to 15 kHz. Compute the bandwidth of an FM station using two methods and then discuss how the bandwidth compares with the channel spacing.

## EXPERIMENT 2: NARROW BAND FREQUENCY MODULATION (NBFM)

### Experiment 2.1: NBFM Modulator/Transmitter and NBFM Demodulator/Receiver

- 2.1.1 Design a Narrow Band Frequency Modulation (NBFM) modulator by referring to Equation (6)
- 2.1.2 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).
- 2.1.3 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**.
- 2.1.4 Observe both time and frequency representations of message signal before and after modulation. Record and analysis.
- 2.1.5 For NBFM demodulation experiment, open the flow graph from Experiment 1.2 (FM demodulator). In **File Source** block, choose the folder in which you have saved the filename **NBFMsinuswave.dat** from Step 2.4.
- 2.1.6 Verify the most suitable cut off frequency and gain of the low pass filter so that the initial message signal can be retrieved back.
- 2.1.7 Observe both time and frequency representations of message signal before and after modulation. Record and analysis.
- 2.1.8 Observe also time and frequency representations of modulated signal before and after demodulation process. Record and justify.
- 2.1.9 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.



- 2.1.10 Change the name of file to **NBFMmusicwave.dat** in **File Sink** block.
- 2.1.11 Observe the difference of modulated and demodulated music signal. Analyze and discuss in your lab report.

### **Discussion and Analysis**

- (a) What is the suitable value of modulation index in designing NBFM modulator system?
- (b) What are the advantages and disadvantages of this NBFM compared to the WBFM?
- (c) What is the application of NBFM?

## **EXPERIMENT 3 : WIDE BAND FREQUENCY MODULATION (USRP-based WBFM)**

### **Experiment 3.1 : USRP-based WBFM Transmitter**

- 3.1.1 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.
- 3.1.2 Create a signal source block by selecting **Wav File Source** block. Choose the folder in which you have saved the Music.wav file.
- 3.1.3 Add **WBFM Transmit** block. Set Audio Rate to audio\_rate and Quadrature Rate to samp\_rate. Then, connect it to the **Throttle** block.
- 3.1.4 Next, add **Rational Resampler** block. Add **Multiply** block.
- 3.1.5 Add **Signal Source** block. Set Amplitude to 142.857m and Frequency to 0. Connect to **Multiply** block.
- 3.1.6 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**.
- 3.1.7 Finally, add **WX GUI Scope Sink** and **WX GUI FFT Sink** to observe the demodulated signal
- 3.1.8 To send the modulated signal to the USRP board, add **UHD: USRP Sink** block. Change the properties of the **UHD: USRP Sink** block. Set Sample Rate to samp\_rate. Set Center Freq to 87.5MHz (Advisable to use different frequency from another group). Set the Gain to 20 dB and set Antenna to TX/RX.

### **Experiment 3.2 : USRP-based WBFM Receiver**

- 3.2.1 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.
- 3.2.2 Open **Variable** block. Set value to 500 kHz for samp\_rate.
- 3.2.3 For WBFM demodulation experiment, add **File Source** block. Choose the folder in which you have saved the filename **WBFMmusicwave.dat** from Experiment 3.1.

- 3.2.4 Add Throttle block. Then, add **WBFM Receive** block. Set Quadrature Rate to 500kHz and Audio Decimation to 10.
- 3.2.5 Next, add **Rational Resampler** block. Set Interpolation to 48 and Decimation to 50.
- 3.2.6 Add **Multiply Const** block. Set Constant to 2. Finally, add **WX GUI Scope Sink** and **WX GUI FFT Sink**. Add also **WX GUI FFT Sink** before **WBFM Receive** block to view the baseband signals.
- 3.2.7 Add an **Audio Sink** block to hear the music. Set Sample Rate to 8kHz. Observe the demodulated signals. Observe also the baseband signals before **WBFM Receive** block.
- 3.2.8 To receive music signal using USRP, add **UHD: USRP Source** block. Change the properties of the **UHD: USRP Source** block. Set Sample Rate to samp rate. Set Center Freq to 87.5MHz (Advisable to use different frequency from another group). Set the Gain to 20dB and set Antenna to TX/RX.
- 3.2.9 Connect the output of the **UHD: USRP Source** block to the input of **Frequency Xlating FIR Filter** block. Set Taps to 1MHz.
- 3.2.10 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.