Experiment 5
Frequency Modulation

1. Objectives:

   - To demonstrate the general properties of frequency-modulated (FM) signals.
   - To investigate the use of a PLL as an FM detector.

2. Prelab Assignment:

   An unmodulated sinusoidal-carrier has an amplitude: $A_c = \sqrt{2}$V , and frequency: $f_c = 25$ kHz. The carrier wave is frequency-modulated by a sinusoidal signal with a frequency: $f_m = 2$ kHz, and amplitude: A_m V. The frequency sensitivity of the FM-modulator is 20 kHz/V.

   (a) Determine the values of A_m required to provide a modulation index: $\beta = 0.2$, 1 and 5

   (b) Use table (1) to find the rms-value and location of each frequency component of the FM signal, with $\beta = 0.2$, 1 and 5; use these rms-values to calculate the rms-values of the FM signals. How the calculated values of the FM signals compare with that of the unmodulated carrier?

   (c) For each value of β mentioned above, determine the approximate value of the transmission bandwidth of the FM signal, by using:

      (i) the Carson's rule

      (ii) the 99% bandwidth curve in Figure (1)

Table (1)
Selective values of $J_n(\beta)$

n	$J_n(0.1)$	$J_n(0.2)$	$J_n(0.5)$	$J_n(1.0)$	$J_n(2.0)$	$J_n(5.0)$	$J_n(10)$	n
0	1.00	0.99	0.94	0.77	0.22	-0.18	-0.25	0
1	0.05	0.10	0.24	0.44	0.58	-0.33	0.04	1
2			0.03	0.11	0.35	0.05	0.25	2
3				0.02	0.13	0.36	0.06	3
4					0.03	0.39	-0.22	4
5						0.26	-0.23	5
6						0.13	-0.01	6
7						0.05	0.22	7
8						0.02	0.32	8
9							0.29	9
10							0.21	10
11							0.12	11
12							0.06	12
13							0.03	13
14							0.01	14

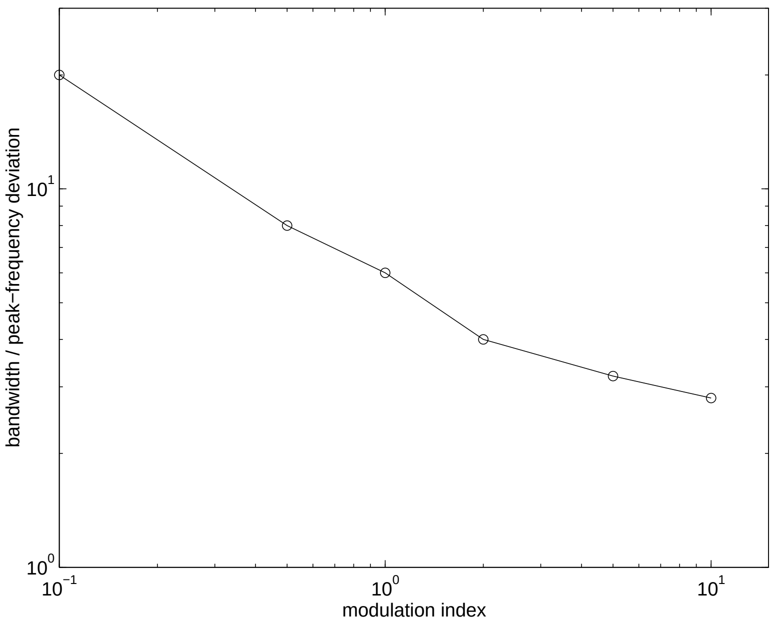


Figure (1)

3. Equipment:

- Function generators Tektronix CFG 253
- Model SR760 FFT Spectrum Analyzer
- Oscilloscope Tektronix TDS 340A
- Dual dc-power supply
- LPF module
- EVM dB scale

4. Procedure:

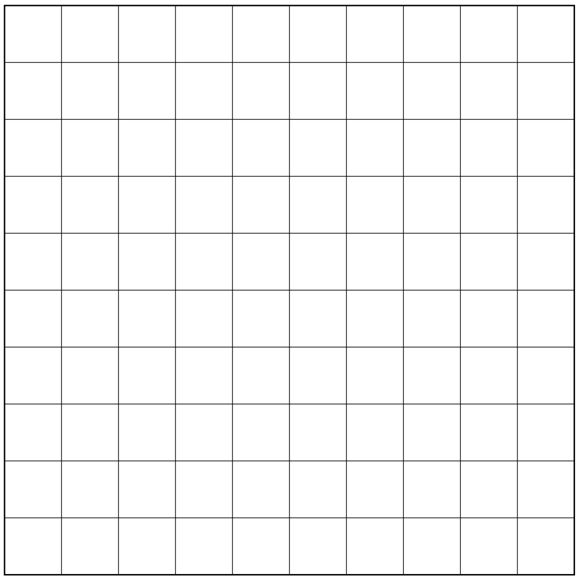
A The Voltage-Frequency Transfer Characteristic of a Voltage-Controlled Oscillator

1. Use one of the signal generators (referred to here as generator 1) to generate a sinusoidal waveform of 10 kHz. Apply a NEGATIVE dc-voltage (referred to here as E) to the "VCF-INPUT" terminals of generator 1; E is set at any value between -0.1 and -2.5 volts. Use the oscilloscope to adjust the output level of the generator to 2.83 V (p-p); display this signal on the spectrum analyzer. The analyzer now displays the spectrum of an unmodulated carrier, whose frequency will be referred to as f_c; the rms-value is 1V. [You may have to fine adjust the output level to achieve a 1V rms].

2. For each setting value of E, as in table (2), measure f_c. Use Graph (1) to plot the voltage-frequency transfer characteristic of the generator; determine the frequency sensitivity, K_o in kHz/V.

Table (2)

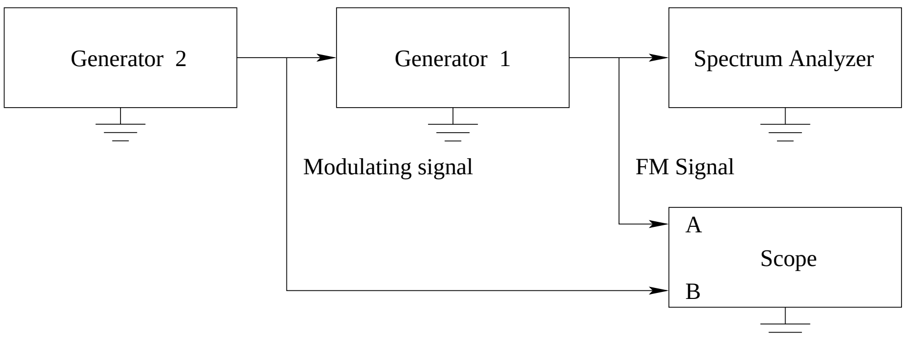
E (volts)	-0.1	-0.5	-1	-1.5	-2	-2.5
f_c (kHz)						



Graph (1)

B <u>General Properties of FM Signals</u>

3. Use the other signal generator (referred to here as generator 2) to generate a sinusoidal waveform with frequency (f_m) of 2 kHz. This waveform will be used as a modulating signal. For now, set the amplitude level (A_m) of the waveform to zero. Apply the waveform to the "VCF-input" terminal of generator 1. leave the oscilloscope and the frequency analyzer as before. Set the frequency of the output of generator 1 to 25 kHz. The FM-measuring system is now set as shown in Figure (2).



Graph (2)

4. Use the value of K_o (found in step 2) to set the output level (A_m) of generator 2 to provide an FM-modulated signal with:

- carrier frequency, f_c @ 25kHz
- amplitude, A_c of 1.41 V (peak)
- modulation index (B) of 0.2 @ $f_m = 2$kHz

Use Table (3) to list the rms-value and location of each frequency component in the spectrum of the FM-modulated signal; ignore the components with rms-values < 0.01 V.

5. Repeat step 4, for: i) B = 1, and ii) B = 5.

Table (3)

B	Frequency components (kHz)	rms-value (V)
0.2		
1		
5		

6. Calculate the total rms-value of the FM-modulated signal for each value of B, and record in table (4).

Table (4)

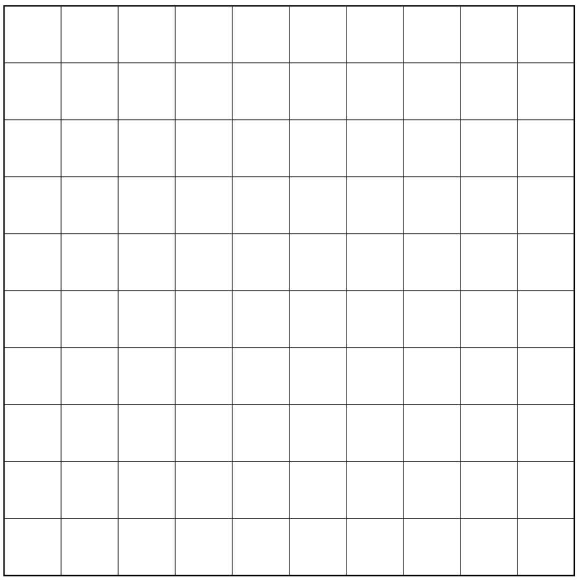
B	0.2	1	5
Total rms-value (V)			

7. With A_m set to provide B = 5 and f_m = 2kHz, change the modulating frequency f_m to 200 Hz. What is the value of the modulation index now?

B =

Use Graph (2) to sketch the spectrum of the FM modulated signal. What is the approximate value of the FM-signal bandwidth?

BW =



Graph (2)

8. Set f_m @ 1kHz and A_m @ zero. Gradually increase A_m until a spectral null occurs at the carrier frequency $f_c = 25$kHz; measure the value of A_m and determine the corresponding modulation index B.

B =

9. Increase further the value of A_m until a second spectral null occurs at f_c; measure A_m and determine the value of B.

B =

C The PLL as an FM Detector

10. Connect the PLL-unit circuit as shown in Figure (2) of Exp. 5; adjust R1 to achieve a free-running frequency of 25 kHz.

11. Connect the block diagram in Figure (3); set f_c @ 25 kHz, A_c @ 0.5V (peak), f_m @ 100 Hz, and B @ 1 (by adjusting A_m).

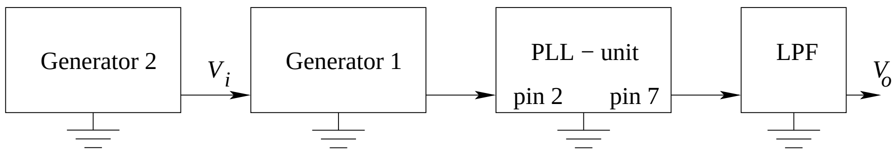
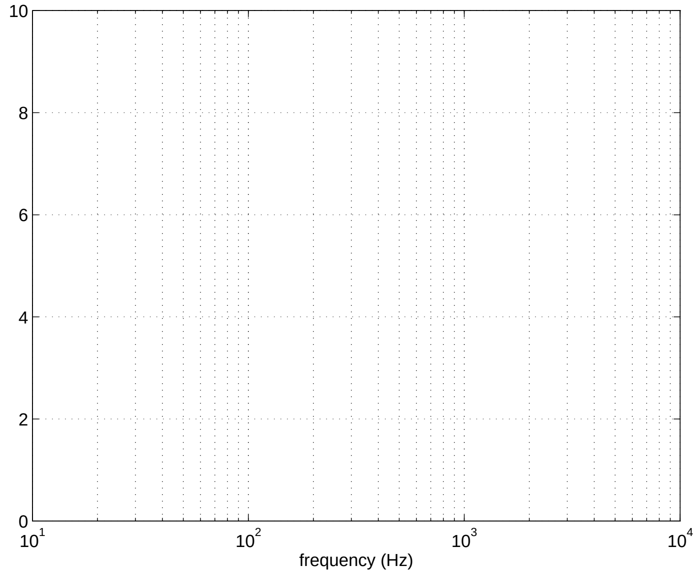


Figure (3)

The LPF module (which is a second-order Butterworth biquad) is used to provide extra low-pass filtering for the FM-demodulated output signal, V_o. Display the modulating signal $V_i(t)$ and the demodulated output $V_o(t)$ on the oscilloscope [use AC coupling].

12. Test the LPF module separately, and set its cut-off (-3dB) frequency @ 1 kHz. Run a frequency response test for (V_o/V_i) in dB vs the frequency, f_m in Hz, for the block diagram in Figure (3); use at least seven strategically-located frequency values in the range: 100 Hz $\geq f_m \geq$ 4 kHz. Use Graph (3) to plot (V_o/V_i) in dB vs f_m in Hz.

13. Once more test the LPF module separately, and set its cut-off frequency @ 4 kHz; repeat as in step 12.



Graph (3)

5. Comments and Conclusions:

1. Compare your results in table (3) with those calculated in the prelab assignment. Comment on any deviations.

2. A spectral null did occur at the carrier frequency of the FM-modulated signal for specific values of B. Explain briefly the effect of this phenomenon on:

   (a) the total rms-value of the FM signal

   (b) the rms-value and location of each component in the spectrum

3. The frequency-response plot found from step 13 is very much different from that found in step 12; why?

4. Use the frequency response from step 13 to estimate the natural frequency and the damping ratio of the second-order locked loop.