

ELG3175: Introduction to Communication Systems

Laboratory III: Frequency Modulation (FM)

Introduction:

In this experiment, we shall investigate some fundamental aspects of frequency modulation and demodulation.

References:

The chapter on frequency (angle) modulation in the course textbook.

Preparation:

1. Find the power spectrum of an FM signal modulated with a sinusoidal message signal.
2. Sketch the frequency spectrum of an FM signal modulated with a square wave of zero DC. Assume the carrier frequency (f_c), the amplitude (A_c) and the peak frequency deviation (Δf) are given and $\Delta f \gg 1/T_m$, where T_m is the square wave period.
3. Find the bandwidth of an FM modulated signal if the message has a frequency band between 20 Hz and 20 kHz and the peak frequency deviation is 75 kHz.
4. Bring at least 2 USB sticks to the Lab to record all your measurements (as screenshots in .png or .jpg files), 2nd stick is required in case 1st one does not work/fails. The format of the USB should be FAT32. All screenshots must be recorded on the USB (pictures taken by cell phones are **not acceptable**) and must be included in the reports in the original form, **no editing at all** (e.g. cropping etc.).

All preparation questions have to be answered in writing before coming to the lab and will be inspected by the TA.

All measurements have to be done and analyzed in the Lab. It is very important to do a preliminary analysis and interpretation of the measured data in the Lab so that if any inconsistencies or gaps are discovered, they can be corrected with extra measurements while still in the Lab.

Apparatus:

1. Waveform Generator (Agilent 33500B Series)
2. Dual Channel Oscilloscope (Rohde & Schwarz HMO722)
3. Spectrum Analyzer (Rohde & Schwarz HMS3010)
4. Lab-Volt (91018-20)

CAUTION	CAUTION	CAUTION
Spectrum analyzers are very expensive, delicate and sensitive pieces of equipment which can be very easily abused. Make sure that at all times the signals you apply to the input does not exceed the maximum allowable input level noted on the front of the unit. If you are unsure of a signal level, measure it on your oscilloscope or with a voltmeter before you apply the signal to the spectrum analyzer.		

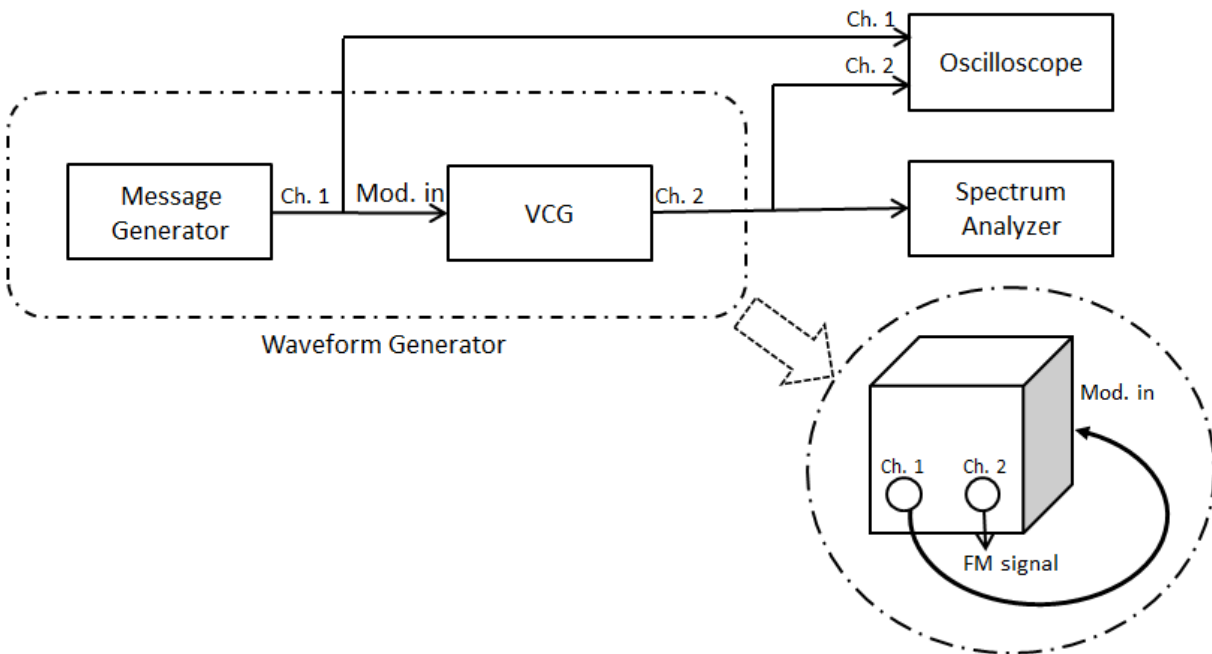
Procedure:**Part I: Determination of k_f (Method A)**

Fig. 1: FM modulation block diagram.

1. Set up the system as in Fig. 1. Select FM in Channel 2 of the Waveform Generator (WG) before setting up any other modulation parameters. Press “Modulate” and then select “FM” using the “Type” softkey. Turn the modulation on using “Modulate” softkey. Set the source to “External” using the “Source” softkey. Use Channel 1 as an external source of the message signal. Connect the output of Channel 1 to the “Modulation In” on the rear panel of the Waveform Generator. Adjust the frequency and amplitude of the VCO to 1 MHz and 1 V_{pp}, respectively (Channel 2). Set the “Freq Dev” to 100 kHz in Channel 2. (It should always be kept 100 kHz during parts I to III of this lab). Note that the actual frequency deviation can be different from “Freq Dev”, depending on the message amplitude. We can measure the actual frequency deviation by the Spectrum Analyzer (SA) or the Oscilloscope. Apply a low-frequency (0.1 Hz) square-wave as a message signal (generated by Channel 1) to the modulator so as to produce two distinct frequencies at the output (corresponding to the two levels of the square wave), each occurring for a sufficiently long time to be measured by the Oscilloscope or the SA. Note the frequency deviation and message signal level. You can set the Ref. level on the SA to 500 mV, and the center and span frequencies to 1 MHz and 1 MHz to clearly see the spectrum lines. Vary the square-wave message amplitude and measure the respective frequency deviation of the modulated signal for a sufficient number of levels. Determine k_f (defined as the ratio of frequency deviation to message amplitude) and find the limit of the linear relationship between the message amplitude and frequency deviation.

Part II: Spectrum of a Sinusoidally-Modulated FM Signal

1. Apply a 10 kHz sinusoidal signal as the message signal to the VCG with sufficient amplitude to produce a 10 kHz frequency deviation corresponding to the modulation index $\beta = 1$. Use the k_f determined in previous Part to find the required message amplitude. You can set the start and span frequencies on the SA to 1 MHz and 200 kHz, respectively. Observe the spectrum of the signal on the SA and compare it with the theoretical prediction of the Preparation Part. Comment on similarities and differences and attempt to explain them.
2. Double the message amplitude to produce $\beta = 2$ and observe carefully the spectrum. Note that the spectral lines do not simply scale compared to those of Part I and hence the superposition principle does not apply to the FM, unlike the sidebands of the AM (conventional, SC and SSB).
3. Reduce the input amplitude to produce a small value of β (narrowband FM). Use the smallest value you can achieve reasonably well. Note that the spectrum of this FM signal consists mainly of the carrier and two side lobes. Increase the message amplitude or decrease its frequency to double the value of β just used. Observe carefully this new FM spectrum and compare it with the previous one. Comment on the differences and whether the superposition principle applies here to the sidebands.
4. Change the message (modulating) signal to a 10 kHz triangular wave (named as ramp with 50% symmetry on the SG) with enough amplitude to produce a frequency deviation of 100 kHz. Set the Ref. level to 300 mV and the span frequency to 500 kHz on the SA. Observe carefully the FM signal power spectrum and compare it to the flat spectrum predicted by Woodward's theorem. Comment on the similarities and differences.
5. Change the message signal to sinusoidal and then square-wave and repeat step 4.

Part III: Determination of k_f (Method B)

It is often not possible to apply a low frequency square wave input to a modulator due to DC blocking capacitors that may be part of the modulator input or other frequency response limitations of the modulator. An alternative method exists based on the oscillating nature of the Bessel function. Fig. 2 illustrates Bessel functions of the first kind and different orders. See also the notes of Lecture 8 for more details.

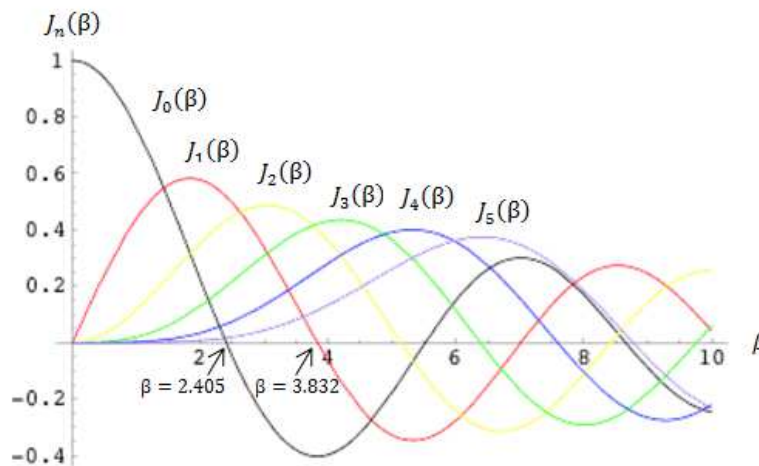


Fig. 2: Bessel functions of the first kind, $J_n(\beta)$.

As we know, the amplitude of the spectral component of a sinusoidally modulated FM signal at frequency $f_c + nF_m$ is proportional to $J_n(\beta)$, where f_c and F_m are the carrier and message frequencies respectively. Measuring the amplitudes of the message signal corresponding to the nulls of Bessel functions in Fig. 2 (for which spectral lines on the SA vanish) allows Δf and hence k_f to be determined.

1. Set the frequency of the VCG to 1 MHz. Apply a 10 kHz sinusoid to the VCG. Set the Ref. level to 500 mV and the span frequency to 200 kHz on the SA. Increase the amplitude of the message signal from zero until you observe the first null of the signal component at precisely the carrier frequency on the SA. This should correspond to $\beta = 2.405$ in Fig. 2. Note the amplitude of the message signal. Increase this amplitude to determine the next null in this spectral component corresponding to $\beta = 5.520$. Repeat the above to find the amplitudes corresponding to the first nulls of $J_1(\beta)$ ($\beta = 3.832$) and $J_2(\beta)$ ($\beta = 5.136$). Determine k_f from each of these four measurements and compare them. Explain the difference, if any.

Part IV: Demodulation of FM

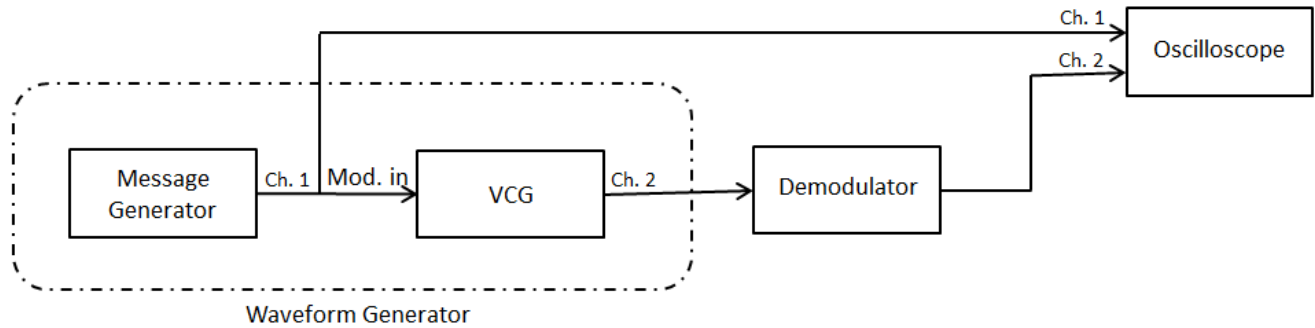


Fig. 3: A block diagram of the FM demodulation setup.

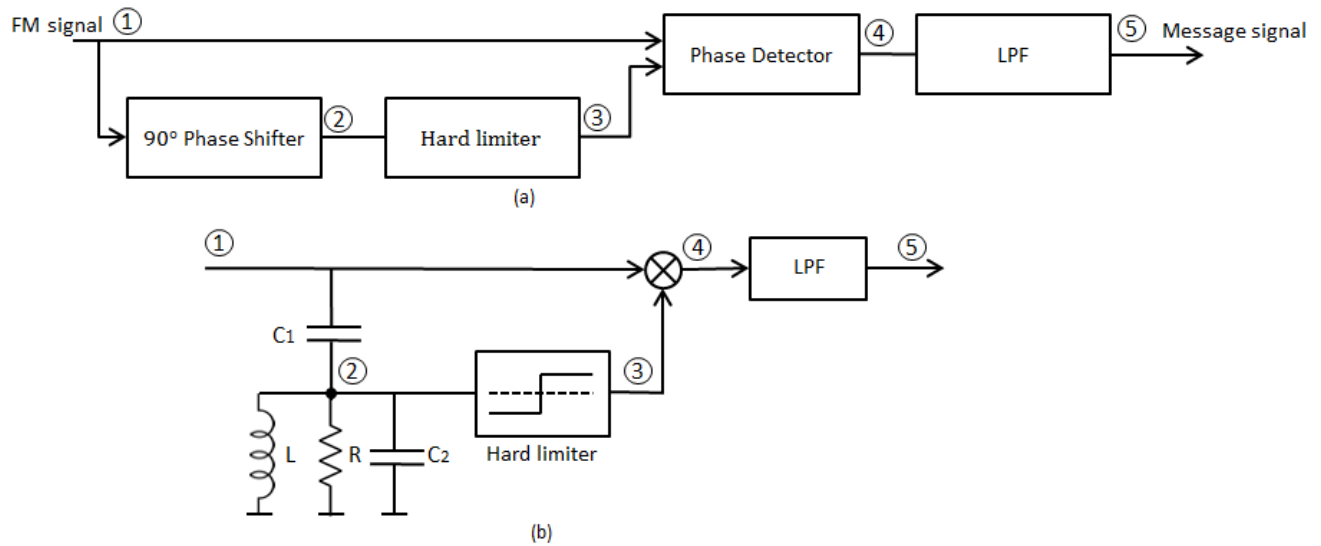


Fig. 4: FM detector (Quadrature detector on the Lab-Volt panel): (a) block diagram, (b) partial circuit design.

1. Assemble the demodulation block diagram as shown in Fig. 3. Adjust the frequency and the amplitude of the VCG to 452 kHz and 0.5 Vpp, respectively. Set “Freq Dev” of Channel 2 of the WG to 3 kHz. Apply a 1 kHz sinusoid with 5 Vpp amplitude (the message) to the VCG. Use the quadrature detector part of the Lab-Volt panel for FM demodulation as shown in Fig. 4a. Observe the demodulated signal on the Oscilloscope and compare it with the message.
2. Change the message to a square wave with the same frequency and amplitude and observe the output as in step 1. Is the message perfectly recovered? Why?
3. Change the amplitude of the VCG output (e.g., double or half it) and observe the output again. Comment on the impact of the VCG’s amplitude.

4. Decrease the carrier frequency slightly and then increase it and observe the output. What is the impact of these variations in the carrier frequency? Explain it.
5. Change the message frequency (e.g., double or halve it) and observe the output. Explain your observations.
6. From the above, what happens when (a) the FM signal amplitude is changed; (b) the carrier frequency is changed; and (c) the modulating frequency is changed. Provide explanations based on your knowledge of the theory.