



## Experiment No. 6

### Frequency Modulation (FM), Generation and Detection, FM Optical Link

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#### Purpose

To look at the spectrum of FM signals. To generate FM signals using the LM 566 and drive an LED transmitter with FM signals. To build an FM optical link using a simple filter (slope detector) as the FM discriminator.

- Read this experiment and answer the pre-lab questions.

#### 1.0 FM Spectrum Measurements:

The Agilent 54645A scope does not have an excellent frequency resolution and therefore we will work at 122 KHz with modulation frequencies between 1 and 10 KHz. The maximum deviation will be fixed at 10 KHz from the center frequency.

Connect the sync. output of the Agilent33120A signal generator to the External Trigger input of the scope.

1. Set the center frequency (as usual) to 122 KHz with  $V_{ppk} = 2V$ .

a. Press to enter the FM mode

b. (To exist the FM mode, press at any time)

c. Press to set the maximum deviation (10 KHz)

d. Press to set the modulation frequency (10 KHz)

(This is the case of  $m_f = 1$  since  $f_M = \delta$ ).

2. a. It is hard to see FM on the scope in time domain since the signal is always changing. Still, look at it and see how it is changing with time.

b. Go into the FFT mode and choose a center frequency of 122 KHz and an automatic frequency span of 244 KHz. The FM signal should be there with all its sidebands. For more resolution, manually change the frequency span to 122 KHz using the softkey under the FFT menu.

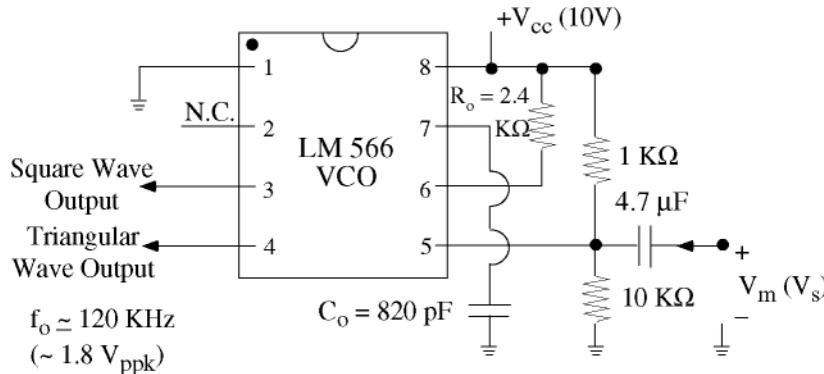
Look at the spectrum for  $m_f=1$  and note the 3 sidebands to the left and right of the carrier ( $J_0=0.77\equiv$ carrier in volts (not dB),  $J_1=0.44$ ,  $J_2=0.11$  and  $J_3=0.02\equiv$ very small).

- c. Change the modulation frequency to 5 KHz (this is the case of  $m_f = 2$ ).

- Look at the spectrum for  $m_f = 2$  and note the 4 sidebands to the left and right of the carrier. (Note also that  $J_0=0.22$ =carrier and  $J_1=0.58$ =first sideband,  $J_2=0.35$ =second sideband which are both higher than the carrier.)
- d. Change the modulation frequency to 4.2 KHz and notice what happens to the center frequency level. In this case,  $m_f=2.4$  and  $J_0=0$ , and no power is in the carrier frequency.
- e. Now set the modulation frequency to 1 KHz. This is the case of  $m_f = 10$ , but the scope cannot show all 14 sidebands on the left/right of the center frequency. All that you see is the "envelope" of the FM spectrum.

## 2.0 The LM 566C Voltage-Controlled Oscillator:

1. Connect the LM 566C as shown below. The center frequency is set by  $R_o$ ,  $C_o$ ,  $V_5/V^+$ . Set  $V^+$  ( $V_{cc}$ ) to 10 V.



2.  Measure the output voltage  $V_o$  (pin #4). It should be a triangular wave with a frequency of 100-110 KHz and  $V_{ppk}$  around 1.8 V.
3. Connect the Agilent 33120A signal generator to the modulation input ( $V_s$ ) and set it to a sine wave with  $f = 5$  KHz and  $V_{ppk}= 200$  mV. Basically, the voltage at pin #5 is now varying by  $\pm 0.1$  V.

The output frequency of the LM 566 will vary by  $\pm 10$  KHz (this is the maximum deviation). This is the case of  $m_f = 2$  (since  $f_m=5$  KHz). Notice how the amplitude of the FM signal remains constant. Look at the output in frequency domain and check that this is correct (do not make any sideband measurements). Choose a center frequency of 244 KHz. You will see other sidebands due to the third harmonic of the triangular wave.

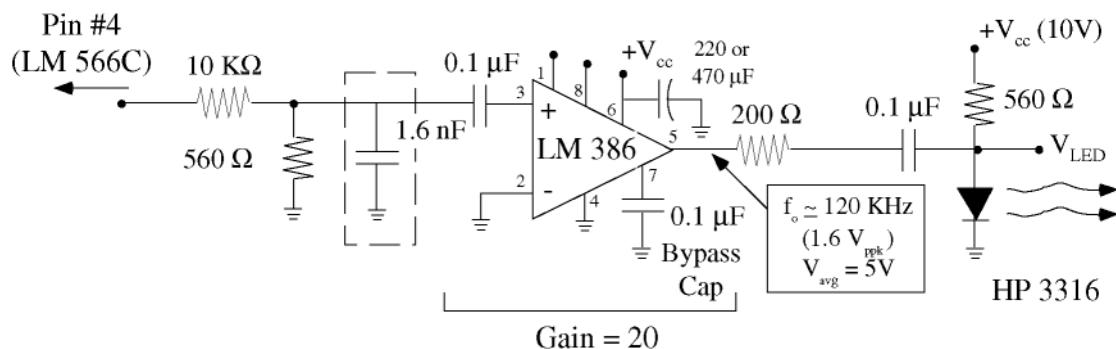
4. Change from a sinewave to a square wave with  $V_{ppk} = 400$  mV. You will have now only two frequencies, one around 80 KHz and one around 120 KHz. This is an FSK signal which is generated by the VCO.
  - Go into the time domain. The scope will lock to the FSK signal using the external trigger. Measure exactly these frequencies by expanding the timebase, stopping the scope, and using the Horizontal/delay knob. Ask your TA to show you how.
5. Disconnect the connection to pin #5.

### 3.0 The LM 386 Amplifier/Driver:

The LM 566C cannot drive the low ac impedance of the LED (around  $18 \Omega$ ). Therefore, we will use an LM 386 as an isolator/driver between the LM 566C and the LED. The LM 386 is a high frequency audio amplifier with a variable gain of 20-200 and a gain-bandwidth product of 10 MHz. The problem is that the LM 386 has a minimum gain of 20 and therefore, we must attenuate the input signal by a factor of at least 20, otherwise, we will saturate the LM 386.

(Actually, we could have used the LM 741 since it can source/sink 25 mA and can reasonably drive an LED. However, it needs  $\pm 12$  V for proper operation and I want to work with a single positive supply voltage).

1. Connect the circuit shown below to the LM 566. Notice the  $10 \text{ k}\Omega/560 \Omega$  voltage divider at the output of the LM 566, and the  $0.1 \mu\text{F}$  capacitor DC block between the LM 566 and the LM 386.



(Make sure to use the  $0.1 \mu\text{F}$  bypass capacitor and also the  $220$  or  $470 \mu\text{F}$  bias stabilization capacitor or the LM 386 may oscillate.)

2.  Measure the output of the LM 386. It should be a nice triangular wave with  $V_{ppk}$  around  $1.6$  V. (If you cannot find an output or it is oscillating, talk to your TA).
3. Connect a  $1.6 \text{ nF}$  capacitor in parallel with the  $560 \Omega$  resistor. This capacitor results in a corner frequency of around  $180$  KHz and therefore passes the  $100$  KHz component and attenuates the third and fifth harmonic components of the triangular wave. Look at the output waveform of the LM 386 and notice that it now resembles a sinewave.
  - Measure the frequency components of the LM 386 output for the quasi-sine waveform ( $V_{ppk}$ , fundamental and second/third harmonic levels only).
  - Connect  $V_s$  to pin #5 of the LM 566 through the  $4.7 \mu\text{F}$  DC-block capacitor, and set  $V_s$  to  $200 \text{ mV}_{ppk}$ ,  $f = 5$  KHz sinewave. Measure the output voltage of the LM 386. Look at the resulting spectrum and notice that the harmonic modulation components are lower now.

(Actually, if you look now at the output of the LM 566 (pin #4), you will find that it is has a small oscillating component at  $25$  MHz which is superimposed over the  $100$  KHz triangular wave. The LM 566 just does not like the  $1.6 \text{ nF}$  capacitor at its output! These oscillations do not make it past the LM 386 amplifier since it has a gain.bandwidth product of  $10$  MHz).

4. Connect the LM 386 to the Agilent 3316 LED via the  $0.1 \mu\text{F}$  capacitor (DC block) and the  $200 \Omega$  resistor (again, a voltage divider). This is needed to drop the voltage from  $1.8 \text{ V}_{ppk}$  to around  $150 \text{ mV}_{ppk}$ .

- Measure the ac voltage across the LED and make sure that it is less than 150 mVppk. If it is larger, increase the  $200\ \Omega$  series resistance to  $470\ \Omega$ . If it is smaller, decrease the  $200\ \Omega$  series resistance to  $100\ \Omega$ .

Remember from lab #5 that only a small portion of this 150 mV<sub>ppk</sub> is across the LED junction diode ( $r_d \approx 3\Omega$ ). Most of the voltage is dropped across the series resistance of the LED ( $R_s \approx 15 \Omega$ ).

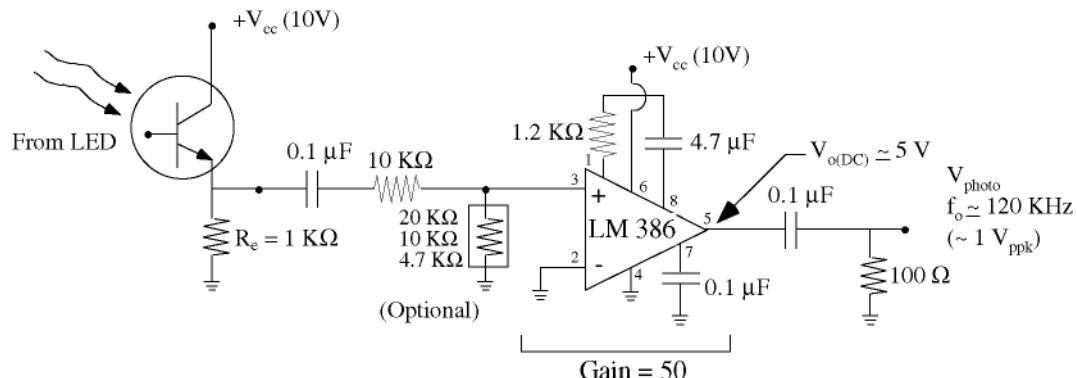
You have now completed the transmit section of the FM optical link.

## 4.0 Optical Link FM Receiver:

In the interest of time, the receiver is build for you. This will let you concentrate on measuring the performance of the receiver and on listening to FM music.

The phototransistor has a  $1\text{ K}\Omega$  load and therefore a cutoff frequency of around 10 KHz. The phototransistor therefore acts as a low pass filter at 100 KHz and turns the FM signal into an AM signal. The output of the phototransistor is first passed by a DC block ( $0.1\text{ }\mu\text{F}$  cap.) and then amplified by the LM 386. Notice the  $1.2\text{ K}\Omega/4.7\text{ }\mu\text{F}$  between pin #1 and pin #8, which set the LM 386 gain to 50.

A most interesting component is the  $0.1\mu\text{F}/100\ \Omega$  load at the output of the LM 386. This capacitor, other than providing a DC block, results in a high-pass corner frequency of around 16 KHz. It does not affect the 100 KHz component, but it attenuates greatly the 120 Hz pickup noise from the fluorescent lighting system/phototransistor and also the low-frequency noise resulting from the dark current of the phototransistor.



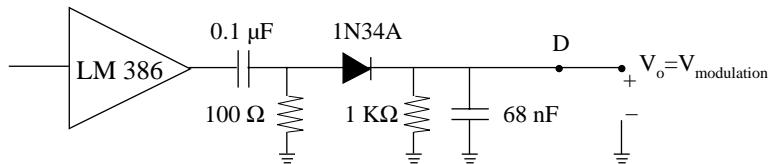
The output of the LM 386 should be at a DC voltage of 5 V (before the  $0.1\mu\text{F}$  capacitor) and has a 100 KHz component between  $0.8 \text{ V}_{\text{ppk}}$  and  $1.2 \text{ V}_{\text{ppk}}$ . If it is larger than  $1.5 \text{ V}_{\text{ppk}}$ , use a resistor divider at the input of the LM 386 to reduce the voltage. If it is lower than  $0.8 \text{ V}_{\text{ppk}}$ , align the LED and the phototransistor (or get them closer) to get a larger voltage.

1. Measure the voltage at the output of the LM 386 and make sure that it is between 0.8 V<sub>ppk</sub> and 1.2 V<sub>ppk</sub>.
2. Connect  $V_S$  to the modulation input of the LM 566 (pin #5) and set it at  $V_{ppk} = 400$  mV and  $f = 2$  KHz sinewave. The maximum frequency deviation of the LM 566 is therefore  $\pm 20$  KHz.
  - a. Measure the output of the LM 386. Use the SYNC signal and External Trigger to lock on the waveform. Measure the peak voltage  $A(1+m)$  and the minimum voltage  $A(1-m)$  of the sinusoidal envelope and determine the AM modulation level,  $m$ .

Notice the frequency of the signal under the envelope. At the peak envelope voltage, the frequency is 80 KHz. At the minimum envelope voltage, the frequency is 120 KHz. This is the FM demodulation process due to the slope detector (low-pass filter) of the phototransistor.

## 5.0 The AM Detector/Audio Amplifier:

1. Connect the 1N34A diode envelope detector to the output of the LM 386. The capacitor is 68 nF to provide a good short to the frequencies between 80 KHz and 120 KHz. The load is 1 K $\Omega$  so as to provide a reasonable demodulation bandwidth (around 6 KHz).

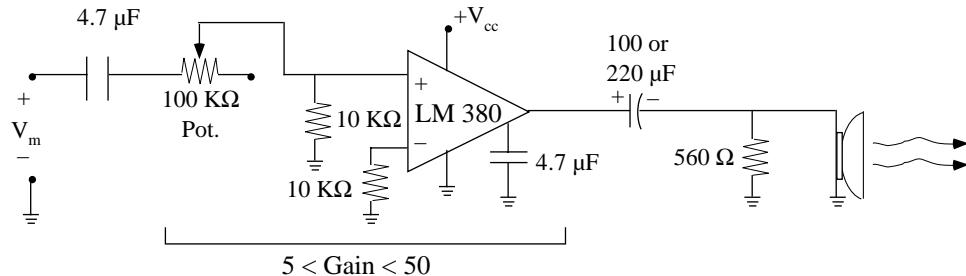


a. Measure the voltage ( $V_{DC}$  and  $V_{ppk}$ ) at the output of the AM detector (node D) for  $V_s = 200 \text{ mV}_{ppk}$  and  $f = 2 \text{ KHz}$  (at pin 5 of LM 566C). Look also at the frequency components and determine the levels at  $f$  (2 KHz) and its harmonics (second/third). This is the modulation signal!

(The voltage is a bit noisy and I recommend that you use the Average softkey under the DISPLAY command).

- b. Repeat the spectrum measurements for  $V_S=800$  mVppk. Notice the increase in distortion for  $V_S = 800$  mVppk (this is a frequency deviation of +/- 40% and the slope detector is definitely not linear!).
- c. Sweep  $V_S$  (at 200 mVppk) from 200 Hz to 10 KHz and determine the 3-dB bandwidth of the demodulator (you will calculate this in the lab report).

2. Connect the output of the AM envelope detector via the 4.7  $\mu$ F capacitor to the LM 380 audio amplifier (it is already built for you). The output of the LM 380 is connected to the headphones.



- a. Listen to the demodulated 2 KHz tone for  $V_S = 100 \text{ mV}_{\text{ppk}}$ . Set the gain of the LM 380 to result in a comfortable sound level. Change the frequency of  $V_S$  from 200 Hz to 6 KHz and listen to the tone.
- b. Set  $V_S$  to a nice frequency (600 Hz for example) and increase its amplitude from 100 mV<sub>ppk</sub> to 800 mV<sub>ppk</sub>. You are now changing the deviation. Listen to the distortion at 400 mV and 800 mV voltages!

- c. Connect the tape-payer to the modulation input of the LM 566 and listen to the music. Change the sound level and the gain of the LM 380 to get a good music response. The best quality sound will be achieved with a small input at the LM 566 (small deviation) and a reasonable gain at the LM 380 amplifier. Also, turn the lights off to eliminate the 120 Hz noise. You can display the music by looking at the output of the AM detector or the output of the LM 380 amplifier. You can display the modulated FM signal by looking at the output of the transmit LM 386 amplifier in time and frequency domain.

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#### Pre-Lab Assignment

1. a. Calculate and plot the spectrum (in dB) of an FM signal centered at 122 KHz with a maximum deviation of 10 KHz and  $m_f = 1$  and  $m_f = 2$ .  
b. For each case, determine the modulation frequency and the Carson's bandwidth of the signal. Also, label the sideband number and levels (in dB) which occur outside the Carson's bandwidth.
2. Determine the decrease in the third, fifth and seventh harmonic level (in dB) of a 100 KHz triangular wave when passed by a low-pass filter with  $f_C = 180$  KHz.
3. a. Make sure that the LM 566C component values ( $R_0$ ,  $C_0$ ,  $V_5$ ) given in the experiment result in a center frequency around 100-110 KHz for  $V_+ = 10$  V.  
b. Calculate the frequency deviation of the LM 566 when an input ac modulation voltage of  $+- 0.1$  V is applied to pin #5 (this means that the voltage at pin #5 increases/decreases by 0.1 V)
4. a. Calculate the impedance of the  $0.1\mu F$  DC blocking capacitor at 100 KHz, the  $4.7\mu F$  capacitor (at 1 KHz) and the  $220\mu F$  at (1 KHz). Make sure that they are much smaller than the resistances around them (there are 4 DC block  $0.1\mu F$  capacitors, one  $4.7\mu F$  capacitor after the AM detector, one DC block capacitor after the LM 380 amplifier).  
b. Calculate the corner frequency set by the  $1.6\text{ nF}$  capacitor at the input of the LM 386 amplifier/driver.

#### Optional:

You are welcome to review the Agilent FM Fundamentals computer-based training package. Talk to your TA about it.

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### Frequency Modulation (FM), Generation and Detection, FM Optical link

#### Lab Report Assignment

1. On a single large page, draw neatly the entire FM transmitter system in detail and label the voltages ( $V_{DC}$  and  $V_{ppk}$ ) that you measured at several points along the circuit (for the case of the 1.6 nF capacitor included). Also label the measured harmonic levels at the output of the LM 386.
2. On a single large page, draw neatly the entire FM receiver system in detail and label the voltages ( $V_{DC}$  and  $V_{ppk}$ ) that you measured at several points along the circuit. Label the frequencies at different points along the circuit and the modulation index,  $m$ , for  $V_s = 400 \text{ mVppk}$  (Section 4.0).

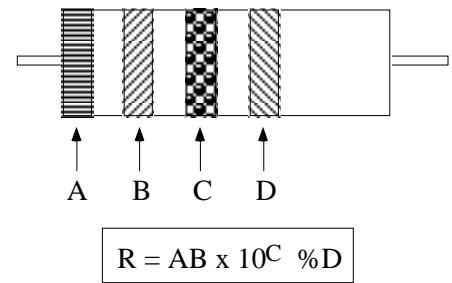
Label the measured harmonic levels at the output of the AM detector for a modulation voltage  $V_s=200 \text{ mVppk}$ , and  $V_s=800 \text{ mVppk}$  (harmonic levels). Label the measured bandwidth of the AM detector.

3. From the measured DC voltage across the  $1 \text{ K}\Omega$  load at the AM detector, calculate the current in the 1N34A diode and determine its total small signal ac resistance ( $n = 1.5$ ,  $R_s = 100 \Omega$ ). Using this information (and the  $1 \text{ K}\Omega$  and  $100 \Omega$  resistors in the AM detector), determine the AM modulator cut-off frequency set by the 68 nF capacitor. Compare with measurements.

## Appendix A

### Color Coding of Resistors/Capacitors

Color	Significant Figure	Decimal Multiplier ( $10^*$ )
Black	0	1
Brown	1	10
Red	2	100
Orange	3	1,000
Yellow	4	10,000
Green	5	100,000
Blue	6	1,000,000
Violet	7	10,000,000
Gray	8	100,000,000
White	9	1,000,000,000
Gold	—	0.1
Silver	—	0.01
No Color	—	—



Standard Resistance Values	
1.0, 1.2, 1.5, 1.8, 2.0, 2.2, 2.4, 2.7, 3, 3.3, 3.6, 3.9, 4.3, 4.7, 5.1., 5.6, 6.2, 6.8, 7.5, 8.2, 9.1	

Axial Leads	Color
A	Indicates first significant figure of resistance value in ohms.
B	Indicates second significant figure.
C	Indicates decimal multiplier.
D	If any, indicates tolerance in percent about nominal resistance value. If no color appears in this position, tolerance is 20%.

<u>Examples:</u>	$R = 2.2 \text{ k}\Omega$	Red, Red, Red	$(22 \times 10^2)$
	$R = 1.0 \text{ k}\Omega$	Brown, Black, Red	$(10 \times 10^2)$
	$R = 100 \text{ k}\Omega$	Brown, Black, Yellow	$(10 \times 10^4)$
	$R = 560 \Omega$	Green, Blue, Brown	$(56 \times 10^1)$
	$R = 47 \Omega$	Yellow, Violet, Black	$(47 \times 10^0)$

## Appendix B

### Data Sheet Table of Contents

1. LM 741 Op-Amp
2. LM 380 Audio Power Amp
3. LM 386 Low Voltage Audio Power Amp
4. LM 566C Voltage Controlled Oscillator
5. 1N 4148 Ultra-Fast Switching Diode
6. MUR 120 Ultra-Fast Rectifier Diode
7. HLMP 3316 High Intensity LED
8. Siemens BPX 81 Silicon NPN Phototransistor
9. LM 105 Voltage Regulator
10. AN-146 FM Remote Speaker System Application Note