UNIVERSITY OF NORTH CAROLINA AT CHARLOTTE
Department of Electrical and Computer Engineering

EXPERIMENT 5 – GAIN-BANDWIDTH PRODUCT AND SLEW RATE

OBJECTIVES

In this experiment the student will explore two parameters that affect the performance of the op-amp at high frequencies. These parameters are the gain-bandwidth product (GBP) and the slew rate.

INTRODUCTION

Gain-Bandwidth Product: For an Op-Amp the gain, G is defined as the gain when a signal is fed differentially into the op-amp and no feedback loop is present. This gain is ideally infinite, but in reality is finite, and depends on the frequency. At low frequency this gain is maximum, decreases linearly with increasing frequency, and has a value of one at the frequency commonly referred to as the cut-off frequency (in equation form, $G_{fc} = 1$). For the 741 op-amp, f_c is given as 1 MHz, and the open-loop gain at this frequency is simply one. G_f is defined as the gain-bandwidth product, and for all frequencies this product must be a constant equal to f_c. Figure 5-1 below graphically illustrates this relationship for the 741 op-amp. When feedback is provided, as in an inverting amplifier, the gain is given by $G = - R_f / R_1$; however, it must be recognized that the magnitude of this gain can never exceed the gain as given by the gain-bandwidth product.
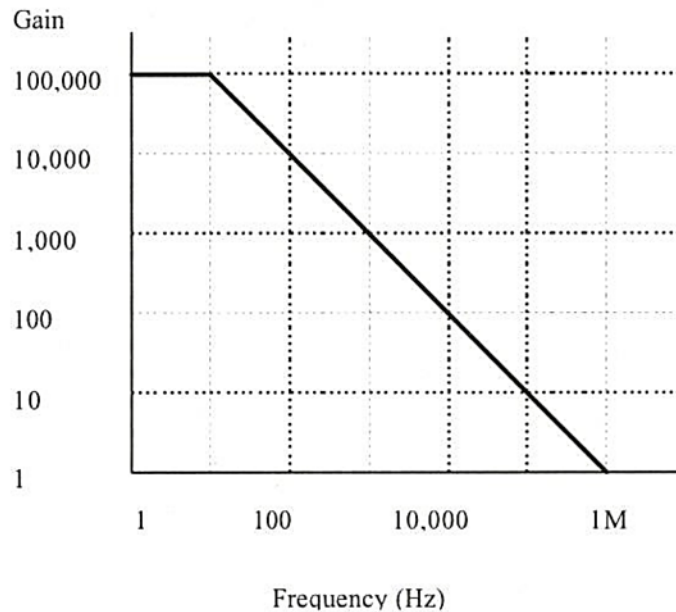

Figure 5-1 Open-loop Gain for 741

Slew Rate: The ideal op-amp has an infinite frequency response. This means that no matter how fast the input changes, the output will be able to keep up. In real op-amps, this is not the case, and when the input changes too fast the output is not able to keep up. The specification known as slew rate defines the maximum rate at which the output voltage can change with time. It is generally given in V/μs, and for the 741 op-amp is something close to 1v/μs.

When an ideal square wave (i.e., one with an infinitely sharp edge) is applied, as shown in the figure below, the slope of the output pulse provides a measurement of the slew rate. The frequency of the input square wave is increased until the slope of the output triangular waveform can be measured. It should be clear that measuring the slew rate of an op-amp with this method requires that the rate of change of voltage for the input square wave must be greater than the slew rate of the op-amp for which slew rate is being measured. While the frequency of operation is related to slew rate it must be recognized that both slew rate and output voltage range are required to determine the maximum frequency without distortion.

How to Determine the Bandwidth of an Amplifier Experimentally

1. Assume that we wish to determine the useful frequency range for a particular amplifier that has a gain, determined by the input and feedback resistors, R_1 and R_f (this could be a standard inverting amplifier).We apply a sinusoidal input voltage from a function generator, being sure to keep the frequency low at first, below the expected upper breakpoint frequency, and the amplitude small enough to avoid slew-rate limiting of the output voltage.
2. Observe the output voltage, and adjust the generator amplitude so that the display is eight divisions on the screen of the oscilloscope when the vertical sensitivity is 100 mV/div. In the figure below, this is the sinusoid voltage with a single cycle displayed and an amplitude of eight divisions peak-to- peak or simply 800 mVp-p.
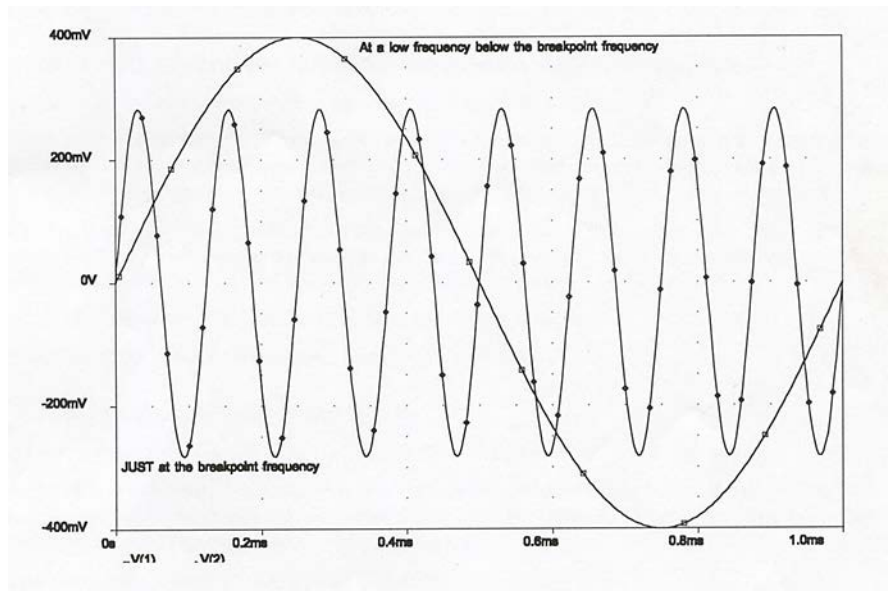
3. At the breakpoint frequency, the amplitude of the output voltage will drop by 3 db to 0.707 of its pass band value. Using 8 divisions as the peak-to-peak pass band value, the output at the breakpoint frequency will be 0.707x 8 or 5.66 divisions (566 mVp-p).
4. Slowly increase the frequency until the amplitude drops to 5.66 divisions (566 mVp-p). The frequency has changed so that eight cycles of the sinusoid are now displayed (i.e., the frequency has been increased by a factor of eight). At this time we can measure the period and determine the breakpoint frequency (f = 1/ T).
5. Before concluding that this is the experimentally determined bandwidth, you must determine that the output voltage did not decrease in amplitude due to slew-rate limiting. This can be done by a combination of slew-rate calculations and repeated measurements at lower amplitudes. If you are experiencing slew-rate limiting in step 4, simply decreasing the amplitude of the generator will produce a different result.

PRELAB

1. Obtain and record the gain bandwidth product, slew rate, and pin connections for the LM741 Op-amp from the manufacturer's datasheet.
2. Using the LM741 Op-amp, design a non-inverting amplifier with a gain of +2v/v
3. Using the LM741 Op-amp, design inverting amplifiers with a gains of
   a.   -1v/v
   b.   -10v/v
   c.   -100v/v

   Hint: Make R_1=1kΩ (the negative input resistor) and choose appropriate values for R_f

PROCEDURE

1. Construct the non-inverting amplifier with a gain of +2v/v designed during the Pre-Lab.
2. With a 10 V_{p-p} sinusoidal input voltage, slowly raise the frequency from 10 Hz to 30 kHz.
   a. To be sure you can observe the shape of the output voltage as it changes with frequency, you will need to continually adjust the oscilloscope time base.
   b. Describe what happens to the output voltage waveform as the frequency increases.
3. To measure the slew rate
   a. Apply an appropriate square wave input voltage (remember that slew rate affects large signals more than small signals).
   b. Measure the slew rate, by adjusting vertical and horizontal controls until you get a linear diagonal on the screen.
   c. Do this for positive and negative slopes. Record the images.
   d. Compare the results with the published value of slew rate for the 741op-amp.
4. Construct the inverting amplifier with a gain of -1v/v designed during the Pre-Lab.
5. With V_{in} small enough to avoid slew-rate distortion, measure and record the bandwidth of the amplifier (See the description in the introduction section).
   a. Record this V_{in} and BW, and subsequent data, in a table.
6. Repeat for gains of -10 and -100 v/v. For each gain be sure that V_{in} is small enough to avoid slew-rate distortion at the frequency you determined to be the bandwidth. This can be corrected by reducing the magnitude of V_{in} and repeating the measurement.

POST-LAB
Post-Lab questions must be answered in each experiment's laboratory report.

1. Construct a graph of voltage gain magnitude vs. bandwidth (log axes) for the inverting amplifiers with gains -1v/v, -10v/v and -100v/v. What shape does the curve have? What differences exist between this graph and the theoretical graph?
2. The gain bandwidth product is given by $G(BW) = f_c$, where f_c is the unity gain bandwidth or cutoff-frequency. Using the values from the inverting amplifiers with gains -1v/v, -10v/v and -100v/v, calculate the average value of f_c and compare with the LM741 data sheet value.
3. How did the measured values of gain-bandwidth product and slew rate compare with the data-sheet values for the LM741? Do you believe the slew rate values found for the LM741 during the experiment are correct? Why or why not?