



EL 351 - Linear Integrated Circuits Laboratory

GAIN-BANDWIDTH PRODUCT & SLEW RATE

By: Walter Banzhaf
University of Hartford
Ward College of Technology
USA

Equipment:

- Agilent 54622A Deep-Memory Oscilloscope
- Agilent E3631A Triple-Output DC power supply
- Agilent 33120A Function Generator
- Agilent 34401A Digital Multimeter

Introduction:

Two key parameters that determine how an op-amp will perform with high frequency signals, and also with quickly-changing signals are the **gain-bandwidth product** (also known as unity-gain bandwidth) and the **slew rate**. In this experiment you will explore in detail those parameters for that old workhorse, the 741, and also measure them for five different op-amps.

I. Slew Rate of 741C, Observation of Effects with Sine & Square Input Voltages

1. Construct a non-inverting amplifier with a gain of 2 V/V. Use a 741 op-amp.
2. With a 10 Vpp sinusoidal input voltage, raise the source frequency from 10 Hz to 30 KHz, adjusting the oscilloscope time base as you do so. Make sure you can see the shape of the output voltage. Describe what happens to the output voltage waveform as the frequency increases. *Hint: 1 picture = 1 keyword.*
3. Apply an appropriate (remember the slew rate affects large signals more than small signals) squarewave input voltage. Measure the slew rate, by adjusting vertical and horizontal controls until you get a linear diagonal on the screen. $SR = \phi V / \phi t$. Do this for positive and negative slopes.
4. Now change the gain to +5 V/V. Measure the slew rates (+ and -) again.
5. Compare results in I.3 and I.4 with typical value of 741C slew rate.

II. Gain-Bandwidth Product Determination, 741C

1. Construct an amplifier with a gain of +20 V/V. Make $R_1 = 1K \Omega$, and $R_L = 5K \Omega$ (output-to-ground).
2. With V_{in} kept small enough to avoid slew-rate distortion, measure the bandwidth of the amplifier. Be sure to record this V_{in} and BW, and subsequent data, in a table. **See p.2 of this lab experiment for information on experimentally determining bandwidth.**
3. Repeat step 2, with gains of +1, +2, +5, +10, +50, +100, +200, +500 V/V.

N.B. For each gain above, be sure, after making the bandwidth measurement, that your op-amp was not slew-rate limiting at the frequency you determined to be the bandwidth. If it was, reduce the magnitude of V_{in} and repeat the measurement.

4. Construct a neat, full-page graph of bandwidth vs. voltage gain magnitude **on linear paper**. What shape does this curve have?
5. Construct a neat, full-page graph of voltage gain (in dB) vs. bandwidth. **Use semi-log paper**, with bandwidth on the logarithmic axis. What shape does this curve have?



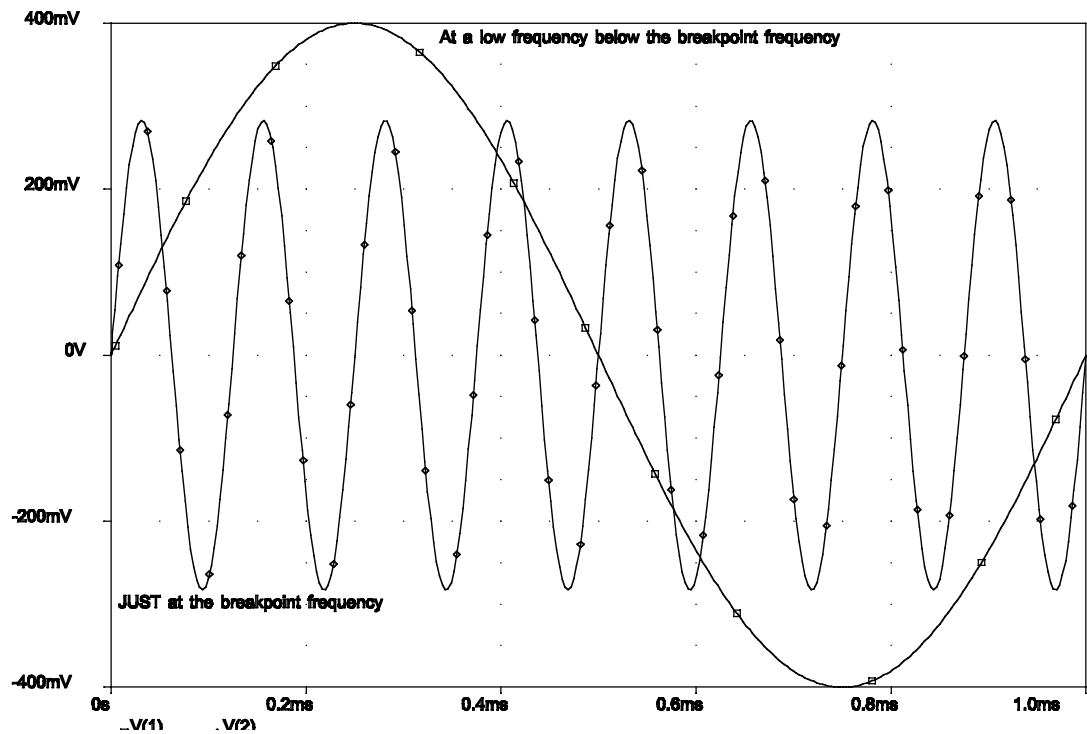
- From the graphs in steps 5 and 6, what conclusion can you draw about the relationship between gain and bandwidth for this 741C?

III. Slew-Rate and Gain-Bandwidth Product Determination, Other Op-Amps

- Measure the slew-rate and the gain-bandwidth product for several other op-amps: (e.g. LM 324, LF 351, CA 3140, CA 3130). You don't have to take data for graphs; simply determine the parameters for each op-amp, and record data in a table.

How to Determine the Bandwidth of an Amplifier Experimentally:

- Assuming you have an amplifier with a particular gain (determined by the feedback resistors R_1 and R_F), connect a generator producing a **sinusoidal** input voltage (and it **MUST** be sinusoidal, since any other waveform has harmonics, and to measure bandwidth you must put in a single frequency). Be sure to keep the **frequency low** at first (low means well below the expected upper breakpoint frequency), and the **amplitude small** enough to avoid slew-rate limiting of the output voltage.
- Observe the output voltage, and adjust the generator amplitude so that the display is one full screen (that's eight divisions peak-to-peak) on the oscilloscope. In the figure below, the sinusoid with a single cycle displayed has an amplitude of 8 divisions p-p (800 mVpp), which is also 4 divisions peak (400 mVp).



- At the breakpoint frequency, the amplitude of the output voltage will drop by 3 dB (i.e. it will drop to $(0.5)^{-3} = 0.707$ of its value in the passband. Using 4 divisions as the passband value, 4 divisions $(0.707) = 2.83$ divisions at the breakpoint frequency.



- 4) Slowly increase the frequency until the amplitude drops to 2.83 divisions peak (here, 283 mVp). In the figure above, the sinusoid with eight cycles displayed has an amplitude of 5.66 divisions p-p, which is also 2.83 divisions peak. Once we have determined, using this method, that we are at the breakpoint frequency, the period can be measured, and the breakpoint frequency can then be calculated using this period.
- 5) Before writing down that this is the experimentally determined **bandwidth**, make sure, by calculation, that the output amplitude **didn't decrease in amplitude due to slew-rate limiting**. If you were near the slew-rate limit in step 4, simply decrease the amplitude of the generator output and do the procedure again. Remember, slew-rate limiting is a large-signal phenomenon that can be ameliorated by using a smaller output voltage. Gain-bandwidth product is a small-signal phenomenon, which affects ALL signals.