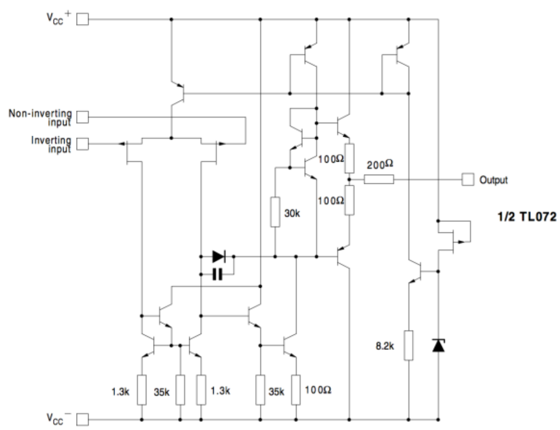
Simon Fraser University

School of Engineering Science

Functional Analysis of TL07x Series Operational Amplifier

ENSC – 220: Electric Circuits I



June 17 2014

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Abstract

With the release of Fairchild Semiconductor's LM101operational amplifier in 1967, the modern op-amp has found wide application across industry. In this paper, we attempt to verify the operational properties of two specific functions of the TL072 dual JFET operational amplifier, namely a comparator and analog amplifier. Under application as a comparator, a reference AC waveform was passed to the IC while a discrete stepwise output voltage was produced in comparison to the reference voltage. Recorded manufacturer slew rates and sensitivity were verified. While under application as an inverting and non-inverting amplifier, gain was compared against theoretical, while also investigating inherent limitations of the design. The rapid, high speed switching nature of the JFET makes this particular series suitable for application in high frequency devices such as audio pre amplifiers

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1.0 Introduction

Functional analysis of the model TL07X series operational amplifier shall be performed via a sequence of four distinct operational tests; specifically performed on model TL072CN manufactured by STMicroelectronics [1]. The op-amps function as both a comparator and amplifier shall be verified against theoretical values for both inverted and non-inverted modes of operation.

An experimental test bench was assembled consisting of a GPS-4303 [2] power supply providing +-10.00V DC @ 0.050A to the TL072CN. A GFG-3015 [3] function generator was configured to provide a 1.000 kHz @ 1.000V peak amplitude triangle or sine wave, respectively. Collection of the pre circuit / post circuit waveform was performed by a TDS-1012 Tektronix Oscilloscope [4] configured to allow for image capture on a desktop PC. Circuit characteristics were verified by a Fluke digital multi-meter [5].

1.1 Theory

The function of an operational amplifier can be found in detail from a variety of sources. For the scope of this report the necessary equations [6] are listed as follows;

Voltage division for open loop comparator

$$Vref = \frac{Rb}{Ra + Rb} Vcc$$

Closed loop inverting amplifier

$$Vout = -\frac{R2}{R1} Vin$$

Closed loop non inverting amplifier

$$Vout = (1 + \frac{R2}{R1}) Vin$$

Open loop operation shall be evaluated by confirming saturation for Vin > Vref and Vin < Vref. Closed loop amplification shall be evaluated by confirming a gain of 5x for the inverting amplifier and a gain of 9x for the non inverting amplifier.

2.0 Analysis

2.1 Open Loop Inverted Comparator

The open loop inverted comparator was assembled as shown in figure 1, with particular characteristics presented in table 1.

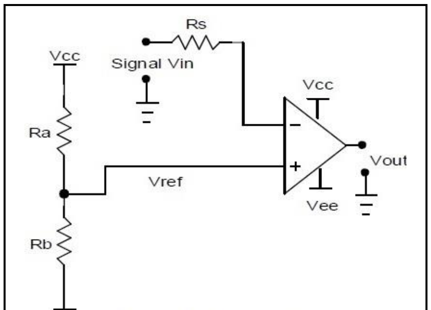

Figure 1 - Comparator

Element	Value
Ra	1.0012k Ω
Rb	0.9981k Ω
Rs	0.9812k Ω
Vcc	10.0026V DC
Vee	-10.0004V DC
Vin	1.0000V Triangle Peak
Vref – Calc.	5.0000V
Vref - Actual	5.0015V DC

Table 1 – Recorded values of comparator circuit elements

Signal collection via the oscilloscope is presented in figure 2; with the generated triangle wave displayed via channel 1 and the computed Vout square wave displayed via channel 2.

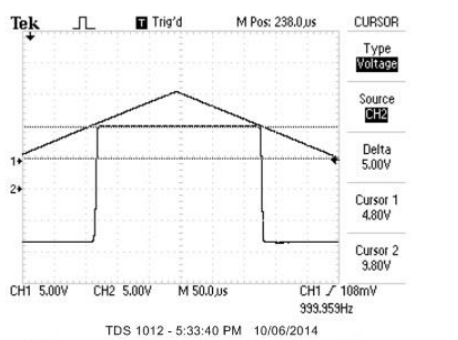

Figure 2 - Comparator Waveform

2.2 Open Loop Comparator

The open loop inverted comparator was assembled as shown in figure 3 with particular characteristics presented in table 2.

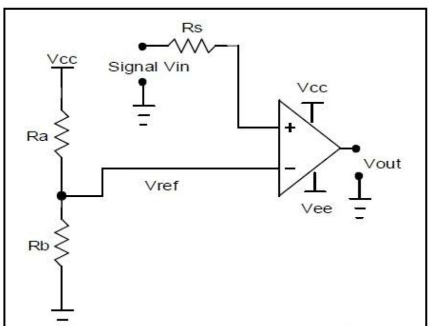

Figure 3 - Comparator

Element	Value
Ra	1.0012k Ω
Rb	0.9981k Ω
Rs	0.9812k Ω
Vcc	10.0026V DC
Vee	-10.0004V DC
Vin	1.0000V Triangle Peak
Vref - Calc.	5.0000V
Vref - Actual	5.0015V DC

Table 2 – Recorded values of comparator circuit elements

Signal collection via the oscilloscope is presented in figure 4; with the generated triangle wave displayed via channel 1 and the computed Vout square wave displayed via channel 2.

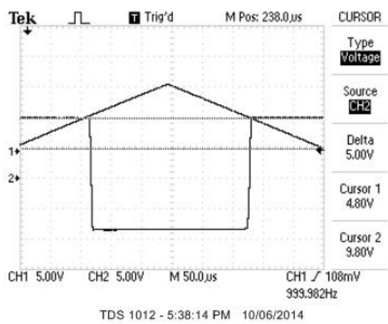

Figure 4 - Comparator Waveform

2.3 Closed Loop Inverting Amplifier

The close loop inverted comparator was assembled as shown in figure 5, with particular characteristics presented in table 3.

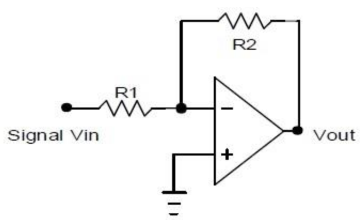

Figure 5 - Inverting Amplifier

Element	**Value**
R1	1.9993k Ω
R2	10.0118k Ω
Vcc	10.0026V DC
Vee	-10.0004V DC
Vin	1.0000V Sine Peak Amplitude
Gain – Calc.	5.01
Gain - Actual	5.10

Table 3 – Recorded values of amplifier circuit elements

Signal collection via the oscilloscope is presented in figure 6; with the generated sine wave displayed via channel 1 and the inverted, amplified Vout sine wave displayed via channel 2.

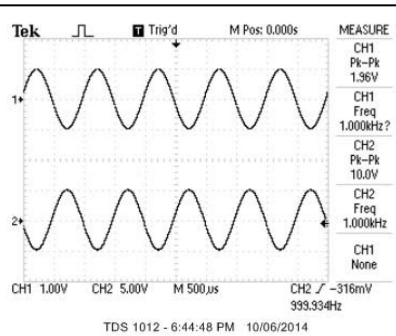

Figure 6 - Inverting Amplifier Waveform

2.4 Closed Loop Non Inverting Amplifier

The closed loop inverted comparator was assembled as shown in figure 7, with particular characteristics presented in table 4.

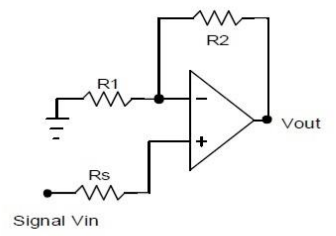

Figure 7 - Non Inverting Amplifier

Element	Value
R1	1.2433k Ω
R2	10.0118k Ω
Vcc	10.0026V DC
Vee	-10.0004V DC
Vin	1.0000V Sine Peak Amplitude
Gain - Calc.	9.05
Gain - Actual	8.82

Table 4 – Recorded values of amplifier circuit elements

Signal collection via the oscilloscope is presented in figure 8; with the generated sine wave displayed via channel 1 and the amplified Vout sine wave displayed via channel 2.

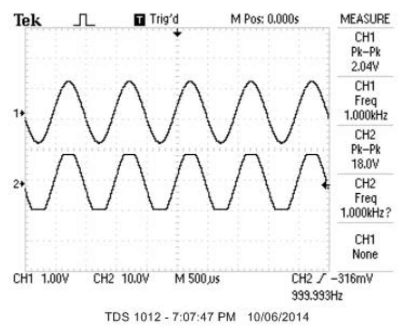

Figure 8 - Non Inverting Amplifier Waveform

3.0 Interpretation

The operational amplifiers comparator performance is summarized in table 5 below:

	Expected Saturation Voltage	Actual Saturation Voltage	Percent Error
Rising Comparator	5.0015 DC	5.00 DC	0.0299%
Falling Comparator	5.0015 DC	5.00 DC	0.0299%

Table 5 – Comparator Results

The operational amplifiers amplification performance is summarized in table 6 below:

	Expected Gain	Actual Gain	Percent Error
Inverting Amplifier	5.01	5.10	1.78%
Non Inverting Amplifier	9.05	8.82	2.57%

Table 6 – Amplifier Results

4.0 Conclusion

Under all four experimental conditions, the operational amplifier performed as expected. Comparator analysis was well within an acceptable margin of error, with a deviation of 0.0299% from the calculated saturation voltage. Experimental slew rate of the amplifier was within the typical 16V/μs shown in figure 2, 4. Under inverting amplification, the measured gain was 1.78% greater than the calculated gain. Manufacturers testing showed a constant voltage output for the target frequency, figure 2, 3 [7]; with linear response based on input voltage, figure 7 [7]. A possible explanation for the difference recorded may be thermal saturation of both the circuit's resistors as well as the amplifier itself. ST Microelectronics confirms peak output voltage occurring at an ambient 25 degrees Celsius, figure 5 [7], slightly more than typical room temperature. Ambient temperature was not recorded for these trials.

The non-inverting amplifier had the largest error, of 2.57%, from calculated. There was noticeable wave form clipping of Vout, figure 8. The clipping was expected as the supply voltage Vcc, Vee was +-10V volts, with the expected Vout being 9.05V. Such a limitation is confirmed by the manufacturer with a maximum peak-to-peak output voltage of ~18V for a 10V input, figure 7 [7].

Further analysis of the TL072 amplifier may consist of testing around the 4 kHz input signal range as both input noise and THD appear minimized. Also maintaining a controlled atmosphere around the amplifier should increase efficiency, as the peak output is reached at STP conditions [7], atmospheric pressure notwithstanding.

5.0 References

[1] STMicroelectronics, model TL072CN. www.st.com

[2] Power Supply GPS-4303. www.gwinstek.com

[3] Function Generator GFG-3015. www.gwinstek.com

[4] Oscilloscope TDS 1012. www.tek.com

[5] Fluke 45 Dual Display Digital Multimeter. www.fluke.com

[6] Nilsson, Riedel, *Electric Circuits – 9th Edition,* Prentice Hall, 2011. Section 3.3, 5.1 – 5.5

[7] http://www.st.com/st-web-ui/static/active/en/resource/technical/document/datasheet/CD00000490.pdf