Low Cost & Simple Quiz Table

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Business Field:

- Semiconductor Quality Assurance support in Japan for foreign semiconductor company
- Analog related Circuit Design

Book:

TITLE: Operational Amplifier Specifications and Applications (Japanese)

This book refer operational amplifier specification, measurement method and application of the specification. This book covers DC/AC/Noise specifications. "Application of the specification" mean calculation method of errors on the application circuit. This book also has some suggestions of calculation method and measurement method for cases that difficult to calculate from ideal models, "know-how" in other words. 452 pages.

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This is an expandable Quiz Table. This Quiz Table uses operational amplifier (comparator operation) and it uses one operational amplifier for one player. Figure 1 is the circuit and it's for four players. LED indicates who is the first. External LED reset circuit included.

Basically, this circuit works 5 to 30[V] of wide power supply voltage range, however you should care LED current limit resistor. This document includes this calculation.

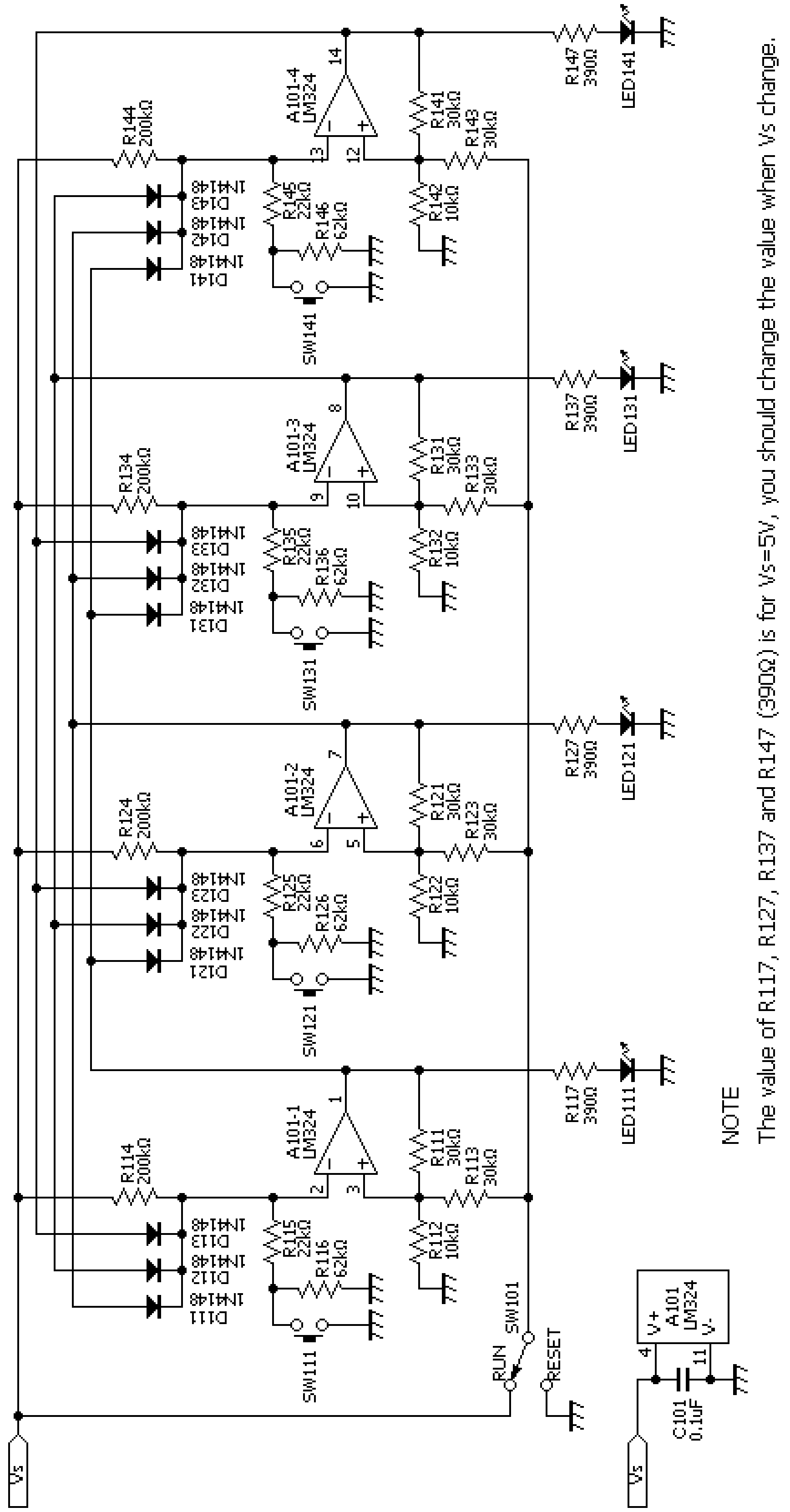

Figure 1. Circuit Diagram

Basic Theory of the Circuit

Figure 1 consists of four basic circuits. The explanation is for A101-1 and peripheral devices. The other basic circuits are the same idea.

The circuit observe the button, when detect button pressed at first, circuit have to memorize button pressed and send disable signal to the other circuit block. This circuit realize this operation with a comparator that has hysteresis. Let's start explanation of the operation with step by step.

At first, SW101 switch to RESET side and return to RUN side. This is the reset operation in the circuit. The reset state of A101-1 to A101-4 outputs are L (~0[V]). When we use 0.1[V] for A101-1 output voltage (This is an actual data in the bench test) and Vs=5[V] also, Pin3 voltage (V3) calculate with nodal analysis steps. Figure 2 is an equivalent circuit around Pin3.

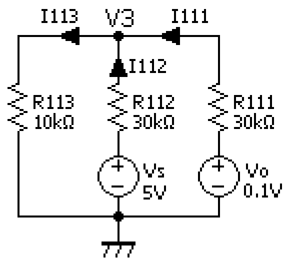

Figure 2. Equivalent Circuit around Pin3

Top of the node in Figure 2 is Pin3 connected node. From nodal analysis steps, we can get the following three equations:

$$I111=\frac{Vo-V3}{R111} \quad (1)$$

$$I112=\frac{Vs-V3}{R112} \quad (2)$$

$$I113=\frac{V3}{R113} \quad (3)$$

We can get V3 from these equations and $I113=I111+I112$. From this, equation (1) to (3) is,

$$\frac{V3}{R113}=\frac{Vo-V3}{R111}+\frac{Vs-V3}{R112}$$

$$V3\times(\frac{1}{R111}+\frac{1}{R112}+\frac{1}{R113})=\frac{Vo}{R111}+\frac{Vs}{R112}$$

$$V3=(\frac{Vo}{R111}+\frac{Vs}{R112})\times(\frac{1}{\frac{1}{R111}+\frac{1}{R112}+\frac{1}{R113}}) \quad (4)$$

$$V3=(\frac{0.1}{30E3}+\frac{5}{30E3})\times(\frac{1}{\frac{1}{30E3}+\frac{1}{30E3}+\frac{1}{10E3}})=(\frac{0.1}{30E3}+\frac{5}{30E3})\times 6E3\approx 1[V]$$

Before calculation of Pin2 voltage, we should understand about we can neglect D111, D112 and D113. These diodes connect to other operational amplifier output and we already assumed L (~0[V]) for these outputs. 0[V] is lowest voltage in this circuit, so D111-D113 doesn't have forward bias. This mean we can neglect them at here.
We can calculate Pin2 voltage (V2) with the following equation (SW111=open):

$$V2 = Vs \times \frac{R115 + R116}{R114 + R115 + R116} = 5 \times \frac{22E3 + 62E3}{200E3 + 22E3 + 62E3} \approx 1.5[V] \quad (5)$$

From these calculations, we got V2>V3, this state match to assuming of L for the operational amplifier output.

V2=1.5[V] and V3=1[V] is the condition of the reset state.

When press the button (SW111), V2 will change and V2 calculate with equation (5) as the following.

$$V2 = \frac{22E3 + 0}{200E3 + 22E3 + 0} \approx 0.5[V]$$

From this number, the relation between V2 and V3 change from V2>V3 to V2<V3 and A101-1 output turn to H (~3.5[V], this is typical output voltage of LM324 when comparator operation with Vs=5[V]). So we have to calculate V3 again with equation (4):

$$V3 = \left(\frac{3.5}{30E3} + \frac{5}{30E3}\right) \times 6E3 = 1.7[V]$$

The relation between V2 and V3 is still V2<V3, so A101-1 output is H (~3.5[V]) and stable.

After A101-1 output turn to H, A101-1 output voltage make effect to other operational amplifiers through diodes. At A101-2 inverting input pin (Pin6) connects to A101-1 output through D121. A101-2 inverting input voltage is 1.5[V] before A101-1 turn to H. So A101-1 apply forward bias to D121. When we assume 0.6[V] for voltage drop at the diode, A101-2 inverting input pin voltage become 2.9[V] (=3.6-0.6) and SW121 disabled. "Disable" mean inverting input voltage doesn't change when SW121 pressed. A101-3 and A101-4 has the same situation. So A101-1 output turn to H with exclusive.

This is the basic theory of the circuit.

Application

LED Current Limiter

Figure 1 is for Vs=5[V]. When you change Vs, you should change LED current limiter resistors (R117, R127, R137 and R147). When you use LM324, H-level output voltage is Vs-1.5[V]. And LM324 output current is 20[mA]. When we use 5[mA] for LED drive current with Vs=12[V], we can calculate these resistance:

$$R=\frac{Vs-1.5}{I}=\frac{12-1.5}{\text{5E-3}}=\text{2.1E3}[ohm]$$

2.0[kohm] or 2.2[kohm] are the appropriate resistance for this case.

Operational Amplifier selection

Operational Amplifier use for comparator in this circuit. The reason of operational amplifier is, we don't need pull-up resistor to the output and this circuit doesn't need high speed switching. However when you select operational amplifier, there are some selection points.

You should select single power supply operational amplifiers. Some dual power supply operational amplifiers has phase reversal when apply voltage that close to negative power supply voltage.

You should care Differential Input Voltage Range in Absolute Maximum Ratings in a data-sheet. LM324 is the same as power supply voltage range, but in case of OP27 is +/-0.7[V]. Type of this operational amplifiers has the diode voltage-current characteristics between inverting and non-inverting input terminals. Type of this operational amplifiers are not good for comparator operation.

LM324 uses in Figure 1. When you replace to LMC660, you will have better margin.

In case of LM324 with run state after reset operation, V2 (Pin 2 voltage) becomes 1.5[V] and V3 (Pin3 voltage) becomes 1.7[V]. There is 0.2[V] of margin.

In case of LMC660, V2 is the same as case of LM324 and V3 becomes 2.0[V]. We got 0.5[V] of margin.

The reason of this is H-state output voltage. LMC660 output close to Vs level.

However, the margin proportion to power supply voltage and LM324 has acceptable number (0.2[V]). LM324 has many suppliers and cheapness. LM324 works <30[V] of wide power supply range (LMC660 is <15[V]). These are the selection points of LM324.

Expanding Number of Players

This circuit doesn't have maximum limit of number of players.

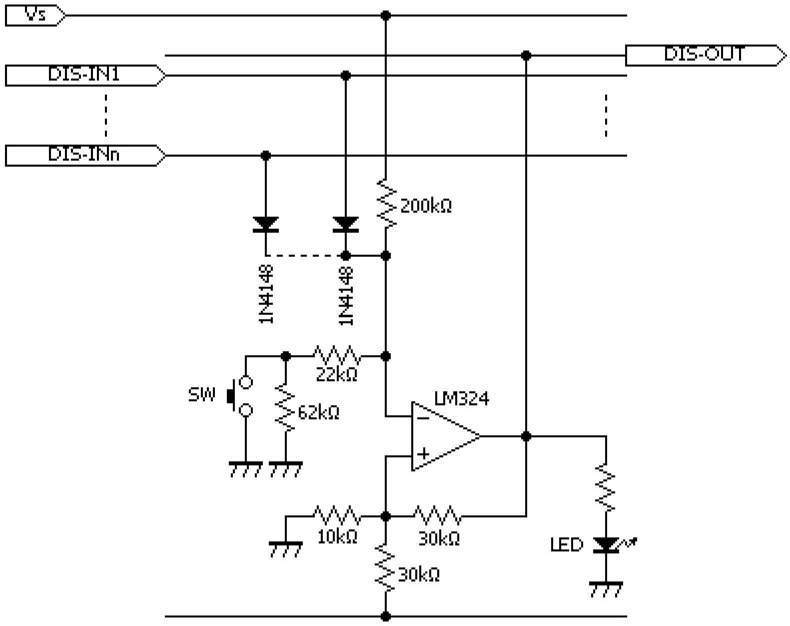

Figure 3 Circuit Block for One Player

The basic expanding method is the following.

Figure 3 is the circuit block for one player. When "n" use for number of players, provide n-1 of diode for each circuit block. Figure 1 is for four players, so each circuit block has three diodes. When expanded to eight players, you should provide seven diodes for each circuit block, so total number of diode is 56.

Cathode of each diode connect to inverting input node. Anode connect to each operational amplifier output except myself.

This is the expanding method.

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