Knight Rider Light Scanner

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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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Here is a Night Rider Light Scanner and Trailing Light of course!

Analog devices use for the circuit. Figure 1 is the all of circuit diagram. Around LED, the circuit is repeating the same circuit, so arrangement of the parts is key factor.

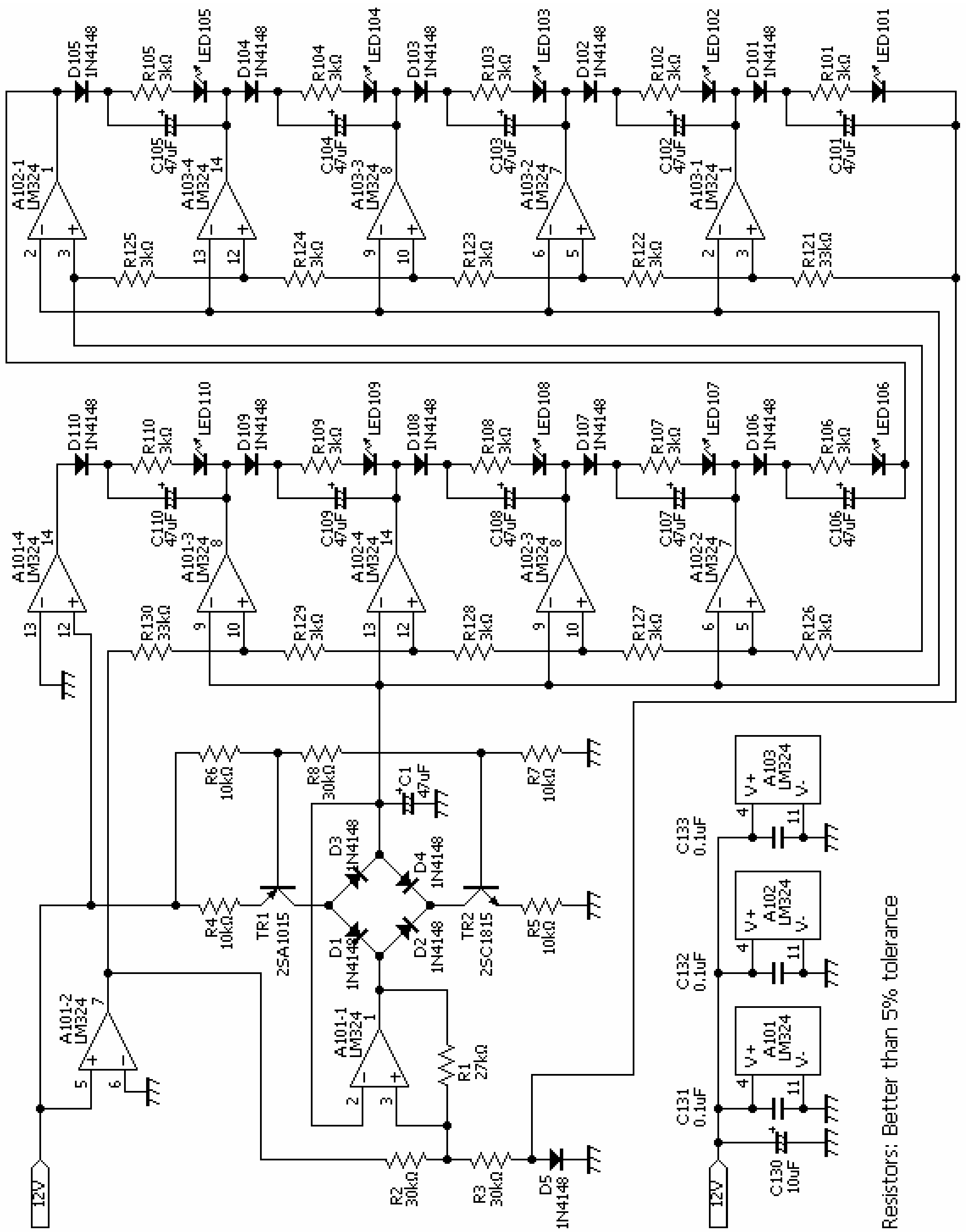

Figure 1. Circuit Diagram (ALL)

Basic Theory of the Circuit

A101-1 in Figure 1 is triangle wave generator. Triangle wave go into comparators. Comparator (using operational amplifier) output turn H/L depending on non-inverting input voltage. LED locates between adjacent comparator outputs and LED lights when adjacent comparator outputs has H/L difference, so one LED lights. Input signal is triangle wave, so LED light scan.

Knight Rider light scanner has trailing light. This circuit realize trailing light with C101 to C110 charge.

The circuit operation is the following:

Triangle wave generator that uses A101-1, this circuit generate triangle wave with charge/discharge with two current sources that uses TR1 and TR2. A101-1 is comparator operation that has hysteresis. D1 to D4 are diode switch. Diode switch determines charge/discharge by A101-1 output voltage. When charge/discharge capacitor with current source, voltage of the capacitor change with linear.

Oscillating operation of the triangle wave generator is the following. Before that, I call V2 (inverting output) for Pin2 voltage, V3 (non-inverting output) for Pin3 voltage, V1 (output) for Pin1 voltage. And V2 is the same as C1 voltage.

V1=H when V2<V3, at this state and the case of V1>V2, A101-1 output sources TR2 output current (collector current). Because TR2 collector voltage go up close to V1 (H-level) through D2 forward voltage and D4 will be reverse bias. The other hand, TR1 source current (collector current) charges C1 through D3 and D1 will be reverse bias.

V2 reach to V2=V3, V1 turn to L-level and the state of V2>V3 generates because of hysteresis of the comparator. At this state, C1 connect to TR2 output (collector) and discharges C1 and D4 will be reverse bias. TR1 output current go into A101-1output through D1 and D3 will be reverse bias.

V2 reach to V2=V3, V1 turn to H-level and repeat above cycle. This is the oscillation mechanism.

From above explanation, the amplitude of triangle wave determine by V3 (Pin3 voltage). A101-2 output voltage is constant H-level. In case of LM324, H-level output voltage is 1.5[V] of lower voltage from power supply voltage in typical. A101-2 supply this reference voltage. D5 is also reference voltage for L-level output voltage (~0.6[V]) of LM324.

As the result, H-L reference voltage apply to R2 and R3 and the center voltage of them is V3 and R1 also connect to V3 for positive feedback (generates hysteresis).

The operation of the circuit is, when V1 (A101-1 output) is L-level, this is equivalent of R1||R3. When V1 is H-level, this is equivalent of R1||R2. The value of R1 is 27[kohm], when replace this to 30[kohm], V3 takes 1/3 of H-L voltage difference when L-level output or 2/3 voltage of H-L voltage difference when H-level output. This is the amplitude of triangle wave.

R121 to R130 (reference voltage for comparators) also uses to A102-2 and D5. This mean comparator reference voltage uses the same reference voltage with the triangle wave generator. Resistance of R121 to R130, R121 and R130 is 33[kohm] and R122 to R129 is 3[kohm]. Total resistance of R122 to R129 is 24[kohm](=3[kohm]*8). The voltage at R122 and R129 are approximately 1/3 and 2/3 of H-L voltage difference. This is the same voltage as amplitude of triangle wave.

There is some effect from tolerance of resistors. These values are for 5[%] tolerance and both end of LED should lights. There is some margin for this purpose, however when take too much margin, it will lose smoothly light scanning. It needs trade-off.

About the trailing light. At the comparator output (ex. A103-1), LED (include current limit resistor) and capacitor connect to comparator output through reverse current protection diode (ex D101) . During comparator drives a LED, comparator also charges a capacitor. Right after stop the comparator driving, LED brightness still remain with capacitor discharge and LED brightness will be down. This is trailing light.

At this point, operational amplifier supply large current during charge a capacitor. LM324 and many operational amplifier has output current limiter and guarantee output short, so this we can use type of this circuit. You should not try this circuit to digital devices.

Basically this circuit possible to work with 5[V] of power supply. However you need large capacitor for trailing light. You can calculate the capacitance when power supply voltage change.

When keep the LED brightness with capacitor discharge, it need some electrical charge. When you use lower power supply voltage, you should keep the same value of electrical charge. So you have to use larger capacitor.

Calculation method of the capacitance is the following:

From Figure 1, the comparator H-L output voltage difference is 9.9[V] (H-level is 10.5[V] and L-level is 0.6[V]). The voltage of the capacitor that contribute LED brightness is, reverse current protection diode forward voltage (0.6[V]) and the LED forward voltage (1.6[V]) subtract from 9.9[V]. Capacitance is 47[uF]. From these numbers, we can get the value of the electrical charge.

$$Q = C1 \times V = 47\text{E-}6 \times (9.9 - (0.6 + 1.6)) = 361.9\text{E-}6 [coulomb] \quad (1)$$

We can get capacitance with 5[V] power supply (H-L output voltage difference is 2.9[V]) and keep the same electrical charge.

$$C = \frac{Q}{V} = \frac{361.9\text{E-}6}{2.9 - (0.6 + 1.6)} = 517 [uF] \quad (2)$$

It's ten times of 12[V] supply capacitor! It's not acceptable...

About the current source that use TR1 and TR2. These current sources has dependency of the power supply voltage. The reason of the dependency is reducing power supply voltage variation effect to the scanning time. The mechanism of this is the following.

At TR1 side, R6, R7 and R8 of series circuit connect between power supply lines (rail). The voltage drop at each resistor determine by resistance ratio (approximately). The voltage drop at R6 is 2.4[V]=(12*1/5). This voltage apply to TR1 VBE (0.6[V]) and R4, so R4 voltage drop is 1.8[V] (=2.4-0.6) and 180[uA] (=1.8/10E3) of current flows at R4. This current value nearly equal collector current (TR1 output current). TR2 side works with the same mechanism.

Therefore TR1 output current (collector current) Io is

$$Io = \frac{Vs \times \frac{R6}{R6 + R7 + R8} - VBE}{R4} \quad (3)$$

The amplitude of triangle wave also has dependency of power supply current and it's 2.1[V] subtract from power supply voltage in case of LM324. Capacitor charge/discharge is the mechanism of triangle wave generation. From this, the time period (t) for charge (or discharge) is

$$t = \frac{C1 \times (Vs - 2.1)}{Io} \quad (4)$$

Substitute (3) for (4)

$$t = \frac{C1 \times (Vs - 2.1) \times R4}{Vs \times \frac{R6}{R6 + R7 + R8} - VBE} = \frac{Vs \times C1 \times R4 - 2.1 \times C1\,R4}{Vs \times \frac{R6}{R6 + R7 + R8} - VBE} \quad (5)$$

The character of equation (5) is, when Vs (power supply voltage) takes large number, Vs dependency of t is small because Vs cancel between denominator and numerator. The following table is calculated results at useful power supply voltage.

Vs [V]	5	6	9	12	15	24	30
t [sec]	3.41	3.06	2.7	2.59	2.53	2.45	2.43

Table 1. Scanning Time (t) Power Supply (Vs) dependency

This reducing effect to scanning time is the reason of power supply voltage depended current source.

Application

Change of Power Supply Voltage

Figure 1 is the setting for 12[V] of power supply. When you change the power supply voltage, you should change LED current limiters (R101 to R110) and maybe trailing capacitors (C101 to C110).

About the LED current limiter, the method is the following:

When you use LM324, H-level voltage is Vs-1.5[V] and L-level voltage is 0.6[V]. And D101 to D110 forward voltage is 0.6[V]. When we assume 5[mA] for diode driving current and 24[V] for the power supply voltage, you can calculate limiting resistor as the following,

$$R=\frac{Vs-(1.5+0.6+0.6)}{I}=\frac{24-2.7}{\text{5E-3}}=\text{4.26E3}[ohm]$$

4.3[kohm] is appropriate resistor for this case.

About trailing light capacitors, I already explained about that in Basic Theory of the Circuit. I will explain about in case of change to 24[V] of power supply.

You can calculate capacitance with equation (1) and (2). LM324 H-level voltage is Vs-1.5[V] and L-level is 0.6[V]. In the case of Vs=24[V], H-L voltage difference is 21.9[V] (=24-(1.5+0.6)). When we aim 361.9[coulomb] (refer to equation (1)) of electrical charge for trailing light, we can get capacitance from equation (2) as the following:

$$C=\frac{Q}{V}=\frac{\text{361.9E-6}}{24-4.3}=18.4[uF]$$

From the result, you can reduce capacitance when you use higher supply voltage. When you use small capacitors, you can reduce an area on the board for capacitors. Recently we can get smaller size capacitor, it's helpful for reducing the area.

Operational Amplifier Selection

This circuit uses Operational Amplifiers for Comparators. 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 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.

There is a small problem in this circuit. The problem is, adjacent LED lights slightly at fall side of the triangle wave. I think this slight lighting come from large charge current for trailing capacitor. LM324 output driving performance of Source/Sink current is not symmetric, the relation of Source/ Sink current is Source > Sink. So when short H-level and L-level, L-level voltage go up.

However, I determined to use LM324 from reducing parts count, cheapness and good availability.

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