LED Anti-Log Drive

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- Semiconductor Quality Assurance support in Japan for foreign semiconductor company
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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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Do you have felt non-linearity when you try LED brightness control?

"PWM works normally except non-linearity" for example. Non-linearity come from your eyes. Human eye has logarithmic characteristic.

From this, "If eye has log (logarithm), we can linearize it with anti-log" is the basic idea of Anti-Log Drive. More accurate expression is, convert from linear input voltage to anti-logarithmic current and drive LED with it.

Figure 1 is the basic circuit. I think very easy.

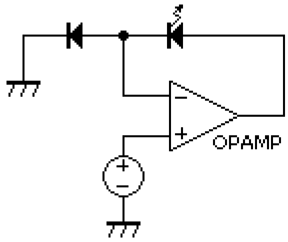

Figure 1. Basic Circuit

Basic Theory of the Circuit

Figure 1 circuit generates anti-log current for LED drive with the following mechanism:
Diode forward current and forward voltage has the following relation:

$$I = Is \times (\exp\frac{V}{Vt} - 1) \quad (1)$$

$$V = Vt \times \ln(\frac{I}{Is} + 1) \quad (2)$$

I: Forward Current [A]
Is: Saturation Current (Reverse bias current) [A]
Vt: Threshold Voltage（25.875[mV]）[V]
V: Forward Voltage [V]
exp: An Abbreviation of Natural Exponential Function or $\exp(x) = e^x$

An equation (2) is deformation of equation (1). From Equation (2), we can express "Forward voltage V is Logarithmic function of the forward current I (exp V/Vt >> 1 as usual)" From another side, we can also express "Forward current I is exponential function of the forward voltage V (I/Is >> 1 as usual)" An exponential function is the inverse function of logarithm, so we can call "Anti-Log"

Figure 1 correspond to equation (1). In general, operational amplifier operation is "Output voltage settle when inverting and non-inverting input voltage are the same" So inverting input voltage pursues non-inverting input voltage.

We apply this operation to Figure 1, non-inverting voltage is the same as the diode voltage and diode current is equation (1). This current supplies from operational amplifier output through LED. So LED current is Anti-Log. We can drive LED with anti-logarithmic current with Figure 1 circuit.

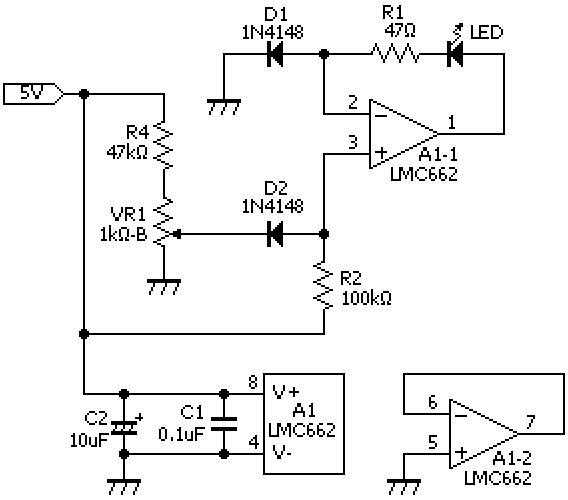

Figure 2 Easy Practical Circuit

Figure 2 is practical circuit of LED brightness controller. LMC662 is useful operational amplifier of this application, because it has single power supply, wide output swing voltage and allows low impedance drive. R1 (47[ohm]) use for an improvement of stability of negative feedback (prevention of the oscillation). D2 is compensation of D1 forward voltage. VR1 is a linear taper potentiometer.

When use small power LED, D1 forward voltage range (voltage difference between minimum and maximum) is ~100[mV]. The power supply voltage in Figure 2 is 5[V], however that circuit works 5[V] to 15[V] with change the setting of R4 and VR1.

If you can build Figure 2 circuit on the bread board, you can confirm linear characteristic. This circuit doesn't have switching devices, so you can use this circuit in low noise application.

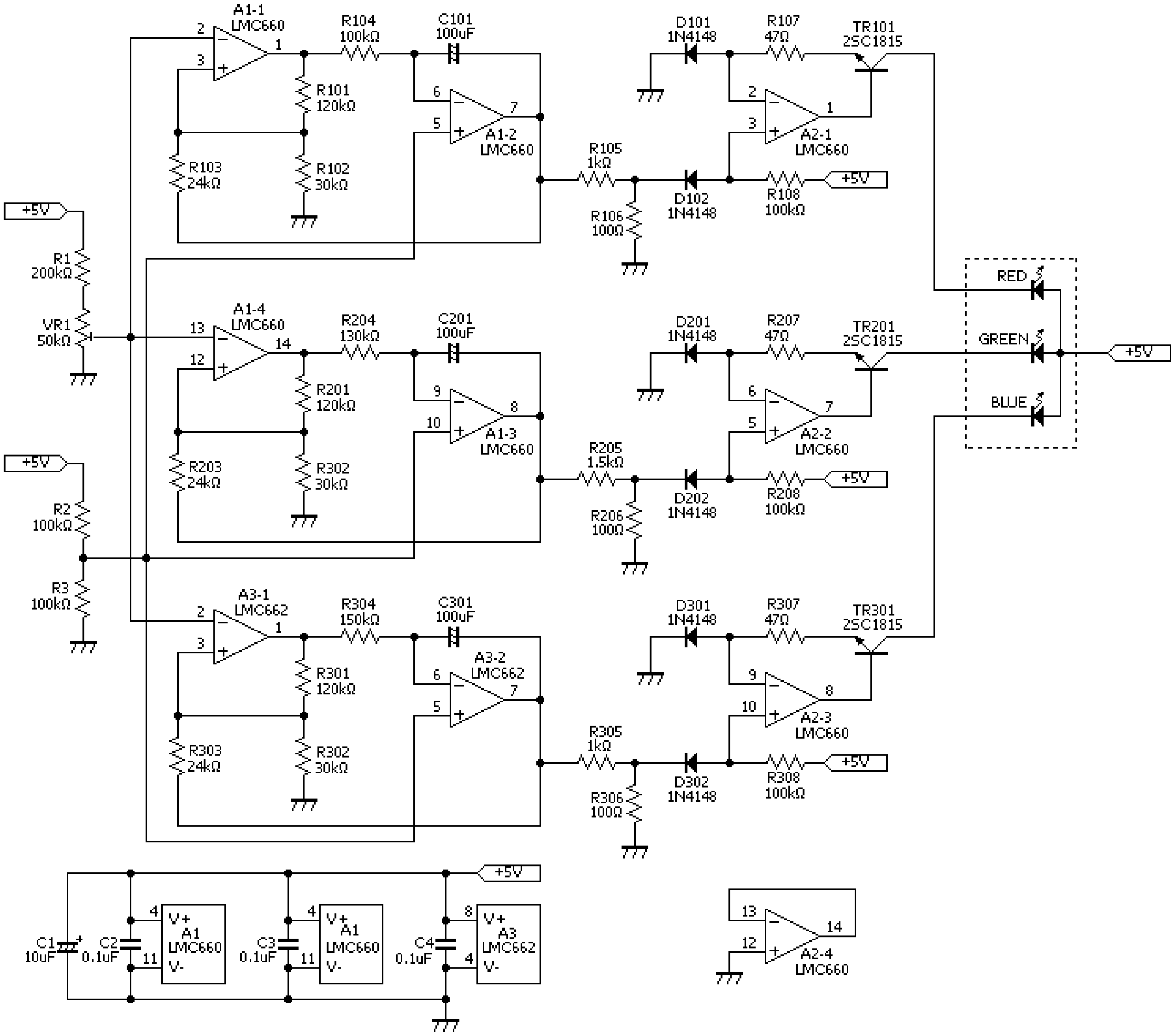

Figure 3. RGB-LED Triangle wave drive

Figure 3 is an application of RGB-LED driver. RGB-LED in Figure 3 has four leads and one lead assigned for anode-common. The operation of this circuit is RGB-LED drive by triangle wave and each LED has independent triangle wave generator.

A2-1 to A2-3 are Anti-Log Drive circuit. A1-1 to A1-4 and A3-1 and A3-2 are triangle wave generator. There is voltage divider between them.

Explanation start from the triangle wave generator regarding A1-1and A1-2 circuit block. Other circuit blocks are the same idea.

Integrator (A1-2) output voltage change straightly with A1-1 (comparator with hysteresis) square wave output voltage. LMC660 (LMC662 or A3 is dual amplifier version of LMC660) output voltage swing GND to Vs (power supply voltage). So when apply a half voltage of Vs-GND to non-inverting input (Inverting input voltage becomes the same voltage), the current flows R4 and it is the same value of alternate current. As the result, triangle wave appears at A1-2 output.

About the setting of R101, R102 and R103. The design of triangle wave amplitude is GND to Vs/5 (Vs: power supply voltage). When A1-2 output voltage reach to Vs/5, A1-1 output turn to H (~Vs). A1-2 output voltage reach to GND, A1-1 output turn to L (~GND). From this operation and integrator operation, circuit will oscillate.

VR1 should set to ~Vs/10 of voltage. When VR1 set <Vs/10, oscillation will stop. When VR1 set >Vs/10, it effect to amplitude of triangle wave.

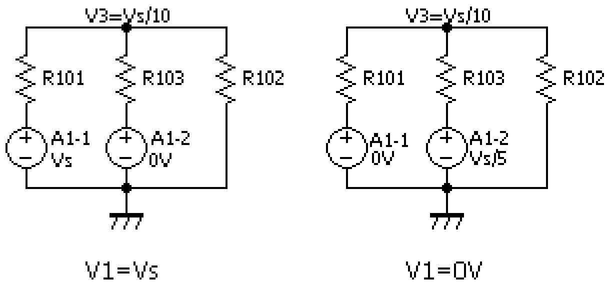

Figure 4. Equivalent Circuit around R101, R102 and R103

About the R101, R102 and R103 calculation method. Figure 4 is two states of the circuit models and this circuit oscillate when V3=Vs/10 (V3: A1-1 Pin3 voltage). We have to find combination of R101, R102 and R103.

At the left side circuit, A1-2 is 0[V], so voltage source is A1-1 (Vs) only. This circuit mean "The voltage divider that consist of R101 and R102||R103 generate Vs/10", so resistance ratio is

$$R101=\frac{9}{\frac{1}{R102}+\frac{1}{R103}} \quad (3)$$

At the right side circuit, A1-1 is 0[V], so voltage source is A1-2 (Vs/5) only. This circuit mean "The voltage divider that consist of R103 and R101||R102 generate a half of voltage of Vs/5 (=Vs/10)", so resistance ratio is

$$R103=\frac{1}{\frac{1}{R101}+\frac{1}{R102}} \quad (4)$$

We have three unknown resistors, so we need three equations. One of way is we decide 1 for resistor value with temporally and solve the equations, we will get resistance ratio. At this point we decide R102=1 and start the solving equation.

At first, substitute equation (4) for equation (3)

$$R101=\frac{9}{1+\frac{1}{R101}+\frac{1}{R102}}=\frac{9}{\frac{1}{R101}+2}$$

$$\frac{R101}{R101}+2\times R101=9$$

$$R101=\frac{9-1}{2}=4 \quad (5)$$

Substitute result of equation (5) for equation

$$R103=\frac{1}{\frac{1}{4}+1}=0.8$$

We got R101 : R102 : R103 = 4 : 1 : 0.8 of resistance ratio. From E24 series numbers, the combination of 120[kohm] : 30[kohm] : 24[kohm] are fit numbers for the ratio.

VR1 determine V3 (A1-1 Pin3 voltage) from explanation so far. When V3 set <Vs/10, the circuit doesn't work, because A1-2 cannot supply negative voltage. When V3 set >Vs/10, triangle wave lowest voltage go up and LED does not dim enough.

So VR1 best setting position is close to Vs/10 and oscillate stably. VR1 use for three triangle wave generators, so you should check the state for all of generators.

The triangle wave amplitude has power supply voltage dependency. Lowest voltage is 0[V] (=GND) and highest voltage is Vs/5. Figure 3 is for 5[V] power supply. However the circuit works less than 15[V] of power supply from LMC660 and LMC662 operation voltage range. When you use different power supply voltage, you should change voltage divider resistors (R105, R106, R205, R206, R305 and R306) to ~100[mV] at divider output. In Figure 3 use 1.5[kohm] for R205 (for GREEN LED). GREEN LED lighted too strong when use the same value (1[kohm]), I changed. This mean you can change tone of the color.

A2-1, A2-2 and A2-3 in Figure 3 are the same circuit. The difference from Figure 1 or 2 is existence of TR101, TR201 and TR301. Anode of RGB-LED connected together at inside of the LED package, so we cannot use Figure 1 or 2 type of circuit. These transistors are the solution of this. However Figure 3 is also the solution for high power LED drive that exceeded operational amplifier drive performance.

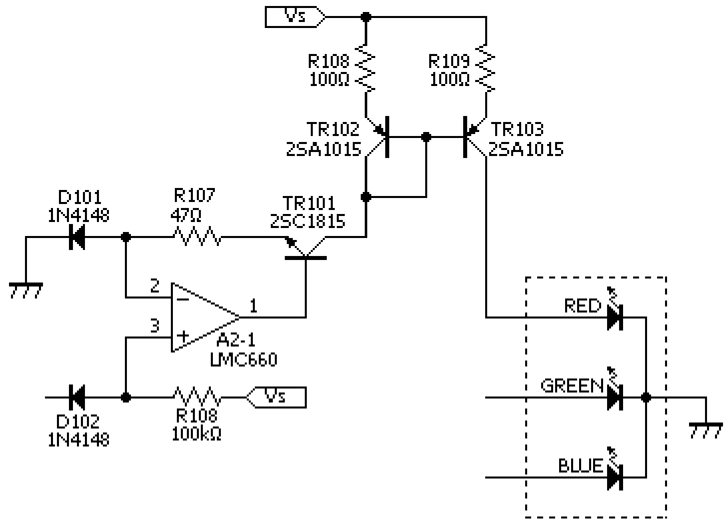

Figure 5. Cathode Common LED Drive

There is cathode common RGB-LED and Figure 5 is a solution for that. This circuit use a current mirror that consist of TR102 and TR103. The same value of current flows TR2 and TR3, so this circuit need double value of the current. So I recommend to use anode common LED.

In RGB-LEDs, there is LED that has the leads independently. In this case, you can use Figure 2 circuit and the circuit volume can be minimize.

When you use RGB-LED, I recommend to use silicone rubber cap, because RGB light should spread at close to the source of the light.

Figure 6 is using for compare three different LED drivers that uploaded to YouTube. That video is comparison result of this circuit. Current Drive and PWM Drive had the same brightness change but it's not linear. Anti-Log Drive had linear brightness change. You can confirm it with Figure 6 circuit.

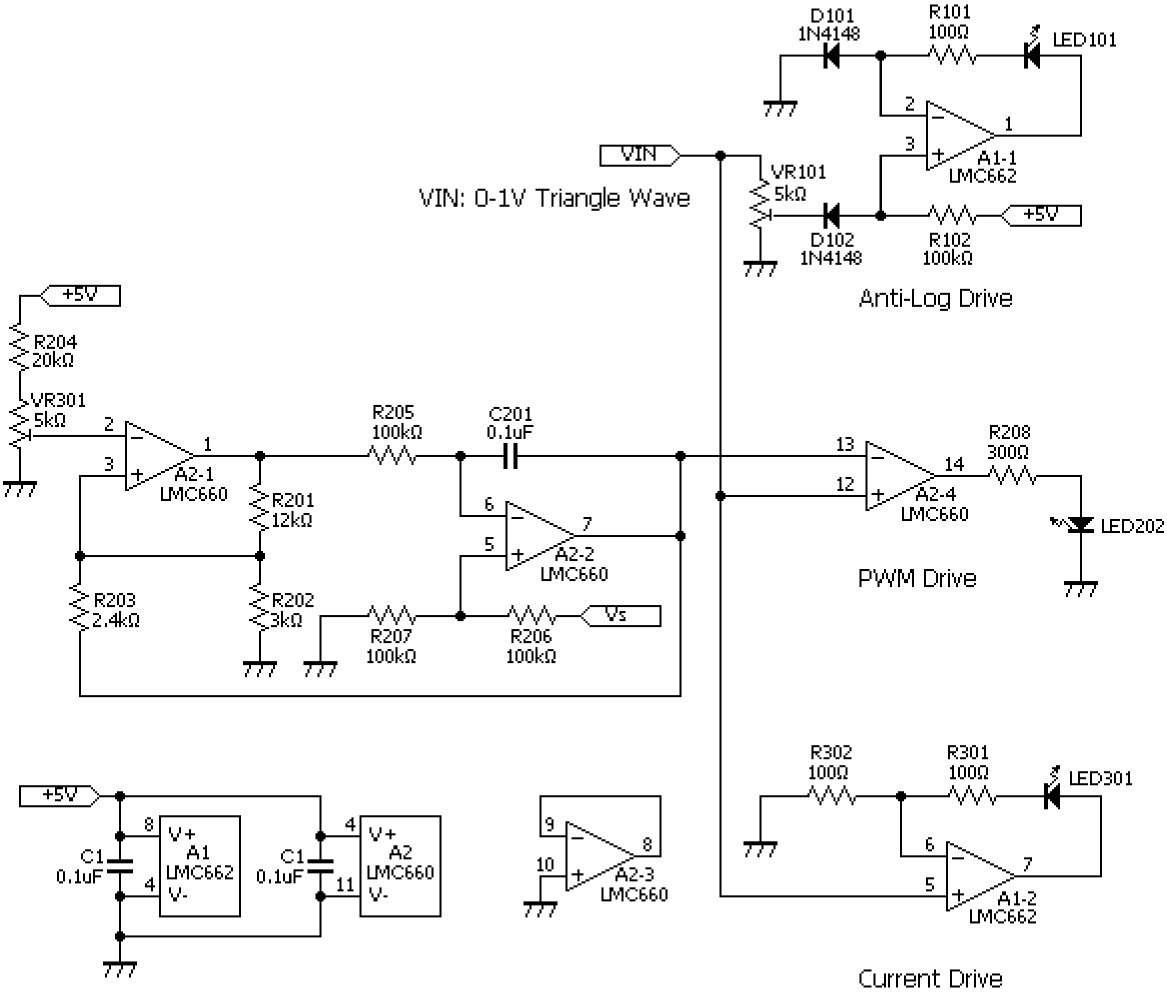

Figure 6 Brightness Test Circuit for Three different Drives

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