The Pocket "Color Organ"[1]

© Steve Lee, Christmas 2014
EpiphanyBySteveLee.com

Introduction:

The Pocket Color Organ is a relatively simple and entertaining electronics project to build, making it a good choice for beginners and experts alike. It only requires a handful of common parts and yet it exposes the builder to some very useful fundamental circuit elements and concepts – not to mention putting on a fairly cool light show when completed.

The heart of the Color Organ is the LM324 Quad "Op Amp" (operational amplifier) IC. This chip is a very versatile and thus very common component used in a variety of consumer products (e.g. radios, pre-amps, graphic equalizers, etc.). The Color Organ circuit uses the individual amplifiers in the LM324 to form three distinct audio filter sections, which separate the input audio into three specific bands: Low range (around ~75 "cycles per second", or "Hertz"), Mid range (~400 Hz), and High range (~1100 Hz). The output from each section is amplified slightly and then used to drive three separate LED (Light Emitting Diode) strings.

Note that the LM324 can be configured in either a dual supply mode (e.g. +6v on pin 4 and -6v on pin 11), or in a single supply configuration (e.g. 12v on pin 4 and ground on pin 11). Since we are using this latter option, we must shift the signal DC level up a few volts or we will chop off the bottom alternations of our audio signal (we accomplish this DC biasing using the voltage divider resistors shown on all of the "+" amp inputs, i.e. pins 3,5,10,12).

Construction:

This document assumes the reader has some basic experience with electronic parts and can (for example) read a resistor color code (if not, we suggest reading some introductory material first, such as a Boy Scout electronics merit badge handbook [which is well worth the investment]; these handbooks can be obtained by contacting your local Boy Scout office, etc.). Before beginning construction, first accumulate and inventory all the required parts. This will make it much easier to complete the project once you start, plus it will get you familiar with each of the components used in this circuit.

As you assemble the project, place the components on the board in the layout shown in Figure 1, keeping all the parts as well separated as possible to make it easier to troubleshoot later. *Work only one section at a time* testing each before proceeding (see below).

To avoid damaging the LM324 when soldering, and to make troubleshooting / replacement of the chip *much* less *painful* down the road, we *strongly* recommended using a 14 pin socket to hold the chip (rather than soldering directly to the chip – *bad idea*). Please note that the chip and socket have an index notch to mark pin 1. Mount the socket and later (after all soldering is done) the chip *exactly* as shown in the figure. *If you put the chip in upside down and apply power, the chip will most probably be destroyed*. Before inserting the chip, double check that 12v DC is present on pin 4, and ground is connected to pin 11.

A common practice in building and troubleshooting all complex projects, is to divide the overall project into functional sections. In this project, the circuit can be broken down into FIVE distinct sections: the Power Supply, Audio Input/pre-amp, Low range filter (L), Mid

1 See "EpiphanyBySteveLee.com" for additional information to be added over time.

range filter (M), and the High range filter (H) sections. We therefore recommend building this project by sections, starting with the easiest section (i.e. the Power Supply), followed by the Audio Input/pre-amp section, etc, testing and debugging each section *before* proceeding to work on the next. A Digital Volt Meter (DVM) should suffice for testing, or better yet an Oscilloscope (if you have one).

As for the placement of the LED's themselves, you may want to randomize the location of each LED a little (rather than place them in a straight line), for visual effect. Just make sure they are wired as shown, and that wires from one string do not short to any other string.

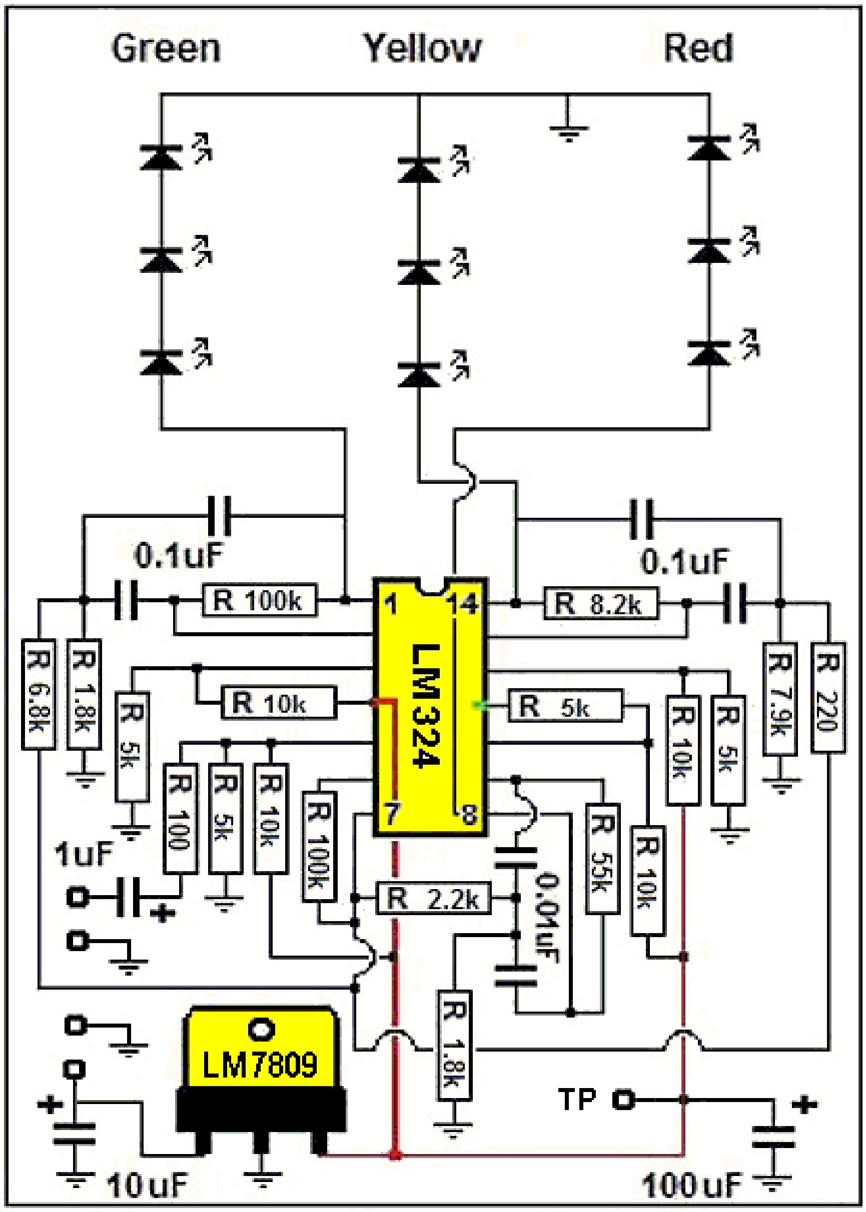


Figure 1: Color Organ board layout.

Power Supply: The primary component in the Power Supply is the LM7809 chip. The LM78xx family of power chips are cheap, very easy to use, highly effective and thus widely used in a large number of consumer electronic devices on the market. An LM78xx takes a rough DC input on its left-most pin (when viewed from the front) – for example from a “wall wart" power transformer – and produces a smooth DC voltage on its output (its right most pin) at the specified value (12 volts in this project; the raw DC input used should be ~3v higher, or in this case roughly 15v DC).

Audio Input Section: Since this project uses only three of the four Op Amps in the LM324, we will use the unused amp on pins 5, 6, and 7 to buffer the input audio. This will allow us to easily match the impedance of the audio source you choose to use (e.g. pocket radio, cassette tape player, MP3 player, etc.), as well as help minimize any affects this circuit might have on your audio input device.

Filter Sections: All three audio filters use the same basic design, making the component placements around each of the three filters very similar. Each filter is fed audio from the output of the Audio pre-amp (pin 7) via one input resistor per filter. The fluctuating output of each filter is then used to drive each of the three LED strings (via pins 1, 8, and 14).

How the Color Organ works:

The heart of the Color Organ is the LM324 Quad op amp IC, with three of the four amps in the IC configured to function as audio filters. An Op Amp is basically a modular amplifier in an integrated circuit ("IC") package, with most Op Amps designed to provide extremely high amplification ("gain"). In most cases, max gain is typically well above a factor of 10,000 (gain is usually expressed in spec sheets in "decibels" or "dB"; where 3dB = 2x, 10dB = 10x, 20dB = 100x, 30dB = 1000x, etc.). Most basic Op Amps typically have two inputs: the inverting input ("-") (i.e. any signal applied to this input is amplified and *flipped* before it reaches the output), and the non-inverting input ("+") (i.e. any signal applied to this input is amplified but not inverted).

Since Op Amps come pre-designed with the full gain already built in, we must reduce that gain down to the level we need by feeding back some of the signal from the output into the inverting input. Gain is inversely related to I_{FB}. In other words, the smaller the feedback resistor, the more signal current we feed back, and therefore the more we reduce the gain.

If instead of using only a resistor in the feedback path, we place some frequency sensitive components (e.g. a capacitor, which "blocks" low frequencies while offering a decreasing impedance to progressively higher frequencies), we can make the Op Amp selectively amplify a certain range of frequencies while rejecting others. In other words, we can turn the Op Amp into a frequency selective filter. A simple "low-pass" filter example is shown in Figure 2. This circuit will amplify frequencies up to about 1600 Hz (cycles per second), while frequencies higher than 1600 Hz will be attenuated. We can increase that cutoff frequency either by decreasing the capacitor or the resistor in the feedback loop.

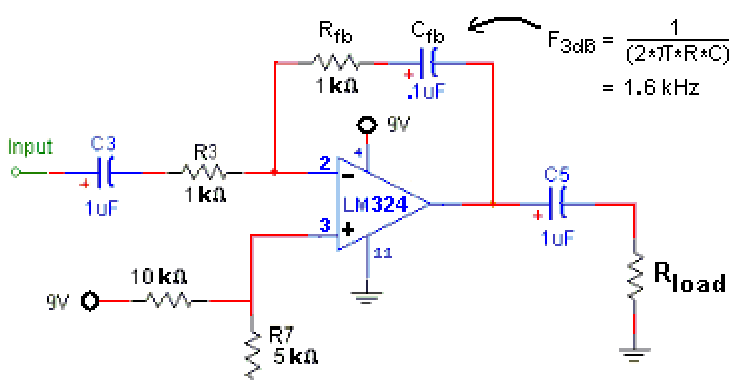
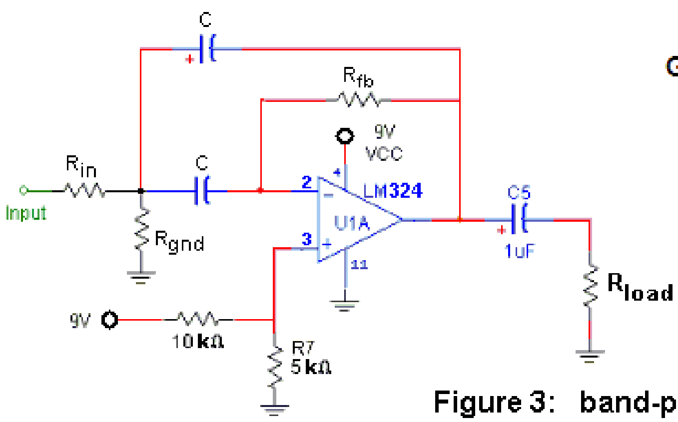


Figure 2: simple low pass filter

In the filters used in the Color Organ circuit, both the input paths and the feedback paths are frequency selective, allowing us to affect frequencies above and below the filter's center frequency, making the filter a “band-pass” filter. By adjusting the RC component values used in each path, we can change a number of characteristics of these band-pass filters, including their center frequency, their bandwidth and their gain. The basic configuration and the equations needed to design this type of band-pass filter with the desired characteristics (i.e. Gain, Center Frequency, BandWidth and Q) are shown in Figure 3:

One problem that may affect performance is the level of audio signal injected into the circuit. If it is too loud or any of the amplifiers apply too much gain, the signal will become distorted. These distortions will manifest as additional frequency components (e.g. over-driving a low frequency tone, say from a drum, will generate distortions that will appear as the MF Yellow and HF Red LEDs flashing when no high frequency audio is present in the music). Though this is obviously not a fatal problem, if you encounter it and wonder why, now you know. To mitigate this problem, turn down the input signal and if it still persists, you can adjust the Op Amp gains (increasing Rin will lower the gain, but will also affect the Fcntr).



Given: A_V **(gain),** F_{cntr}**, BW, Q (=** F_{cntr}**/BW)**

$R_{fb} = Q / (2 \text{ Pi } F_{cntr} C)$

$R_{in} = R_{fb} / 2 A_V$

$R_{gnd} = (R_{fb}/2) / (2 Q^2 - A_V)$

Figure 3: band-pass filter

Troubleshooting:

Treating the overall project as a collection of five distinct sections simplifies the troubleshooting by allowing us to use any symptoms to point to the problem section(s). For example, are all of the sections dead? If so, the problem is likely due to a section they have in common (e.g. the Power Supply, the Audio Input/pre-amp, etc.).

One of the most common failure points in any circuit is the supply voltage. In fact, if the circuit worked previously but is now dead, 90% of the time the problem is either with the supply voltage or the ground. If there is no voltage on the chip, start by checking the output of the Power Supply section. If there is no voltage at the output of the Power Supply, check the raw input supply voltage.

If the output from the Power Supply is good but the LED's are still not lighting up, verify that the Audio pre-amp section is feeding a good signal into each of the filter sections. If not, check the input signal feeding the Audio pre-amp section. If the audio pre-amp section is good, check that the output signal from the pre-amp section is getting to the filter inputs.

Is there a strong fluctuating signal on the output of the filter amps (pins 1, 8, and/or 14)? If there is a strong signal at the filter output, check that the LED's are all good and that each string is well grounded at its end; (etc.).

The Five key Op Amp design "rules":

There are five general characteristics or "rules" that define the operation of a theoretically "perfect" Op Amp:

1) The ideal Op Amp provides "Infinite" gain.
2) The two input pins (V_+ and V_-) follow each other (i. e. $V_+ = V_-$) via the feedback path.
3) Input current is zero (i.e. the Op Amp input pins draw virtually no current).
4) Output current is "infinite".
5) The V_+ input pin impedance is infinite, while the output impedance is zero.

Using these rules we can derive the equation that describes the output for Figure 2:

Let "s" = j 2 π F. With $I_{IN} = 0$, $V_{FB} = V_{out}$, and thus $I_{IN} = I_{FB}$:

Vin / Rin = Vfb / (R + 1/s C), multiply through by Rin / Vfb.

Vin / Vout = Rin / (R + 1/s C) now invert both sides:

Vout / Vin = (R + 1/s C) / Rin