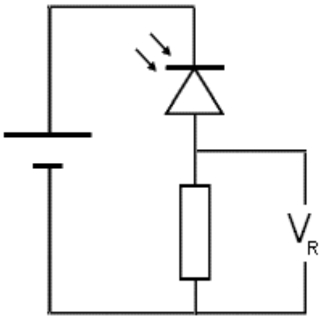
# Flash Rate Monitor

The aim of this project is to create a device which measures the rate at which a computer monitor refreshes. More broadly, the device will hopefully be able to measure the flash rate of anything that emits light at a slower rate and at a higher intensity than a computer monitor.

I did make the assumption that a computer monitor does actually flash, that is, it emits light then emits no light etc. A video-camera phone, presumably with a similar frequency to the monitor I was looking at, showed a black band across the monitor when pointed at it meaning that there was this ‘light on’, ‘light off’ effect on the monitor. This is not the case with certain monitors, notably TFT monitors for which my device will not work.

The response time of a light-dependent resistor is too slow for the every-hundredth-of-a-second flashes I will be detecting so I will be using a photodiode in reverse bias. According to its datasheet, the response time of the photodiode is 50ns so it should work for the rates at which a monitor will refresh. It will act as the variable resistor part of a potential divider circuit.



I will tap off the voltage across the fixed resistor (as the output, $V_{OUT}$) rather than the photodiode because I want the voltage output going up as light falls on the photodiode. The photodiode’s resistance, and so the voltage across it, decreases as the light falling on it intensifies.

I only came to use the photodiode with a computer monitor at the very end of the project. In the mean time I used a strobe and the 60W bulb. ‘Light on’ will mean a 60W bulb in contact and facing towards the photodiode. ‘Light off’ means the photodiode in complete darkness. $V_R$ is the voltage across the resistor; $R_R$ is the resistance across it. The subscript $_P$ indicates the photodiode.

The resistance off the photodiode ($R_P$) when the light was on was 3MΩ; when it was off, 20MΩ. These numbers are rough averages but are sufficient for the calculations to show why I chose the components I did. The voltage across the photodiode ($V_P$) was proportional to the change from 3MΩ to 20MΩ, i.e., going from 0V when the light was on to a large chunk of the supply ($V_S$ = 6V) when it was off. $V_R$ did the opposite.

**$R_R$ = 1MΩ**

Light ON
($R_P$ = 3MΩ)

$$V_R = \frac{10^6}{3(10^6)+10^6} \times 6 = 1.5\text{V}$$

Light OFF
($R_P$ = 20MΩ)

$$V_R = \frac{10^6}{20(10^6)+10^6} \times 6 = 0.29\text{V}$$

**$R_R$ = 1kΩ**

Light ON
($R_P$ = 3MΩ)

$$V_R = \frac{10^3}{3(10^6)+10^3} \times 6 = 2\text{mV}$$

Light OFF
($R_P$ = 20MΩ)

$$V_R = \frac{10^3}{20(10^6)+10^3} \times 6 = 0.29\text{mV}$$

As the photodiode allows only such a small current through (i.e., it has a large resistance), I will need a large resistor below it so the voltage output ($V_R$) varies considerably from ‘light on’ and ‘light off’. I am ‘matching’ the resistances so a larger chunk of the supply works in getting the current across the resistor rather than across the large resistance of the photodiode. This keeps $V_R$ as high as possible making the job of the frequency-meter easier and the amplitude of the wave as large as possible so it shows up against any noise.

$$V_R = \frac{R_R}{R_P + R_R} \times V_S$$

Using a formula to calculate $V_R$, I can show why I need to use a high value resistor. The calculations to the right show that the voltage across a 1kΩ resistor does not have as big a difference as that across a 1MΩ resistor.

Any components I find I need to place in parallel with the bottom resistor, such as an amplifier, will have to have an even higher resistance (than 1MΩ) because of the way resistances add up in a parallel set-up. (Adding another 1MΩ resistor in parallel would make the voltage across the lower part of my potential divider circuit equal 500kΩ.)

**Current In Circuit**

Light ON
($R_P = 3\text{M}\Omega$)

$$I = \frac{6}{3(10^6) + 10^6} = 1.5\mu\text{A}$$

Light OFF
($R_P = 20\text{M}\Omega$)

$$I = \frac{10^6}{20(10^6) + 10^6} = 0.27\mu\text{A}$$

Incidentally, the voltage differences from the ‘light on’ and ‘light off’ of the computer monitor will be a small fraction of those from the ‘light on’ and ‘light off’ of the 60W bulb so voltage changes really do need to be as large as possible.

$$I = \frac{V_S}{R_P + R_R}$$

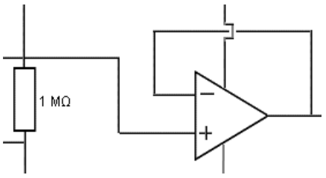
As is takes a million volts to ‘push’ a current of one amp through a 1MΩ resistor, the current flowing through my 6V circuit will be tiny. Resistance being inversely proportional to current shows up nicely in that the current flowing through my circuit when the light is on (and $R_R$ = 1MΩ, as it will be from now on) is 1.5μA and when it is off, 0.27μA.

$$P = I^2(R_P + R_R)$$

**Maximum Power Dissipated**

$$P = \left(1.5(10^{-6})\right)^2 \times 21(10^6) = 47.25\mu\text{W}$$

This is good in that my circuit, so far at least, will never get too hot as the power dissipated is proportional to the square of this tiny current (maximum $I^2$ is in the range $10^{-12}$). Even if we are multiplying $I^2$ by millions of ohms of resistance, the maximum power dissipated is in the range of micro-watts.

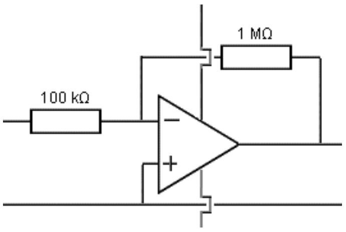


However, the voltage difference between the dark and light of the computer monitor is not enough to trigger the frequency-meter with all the background noise, but I know that there are voltage peaks when the light is on because the oscilloscope shows them. So I will need an amplifier. I know, though, that putting an amplifier onto the lower resistor will decrease the total resistance in the lower part of the circuit considerably, so will need to somehow buffer it from the resistor maintaining a high resistance. For this I will use an operational amplifier set up as what is known as a unity gain buffer. This essentially places a resistor with infinite resistance in parallel with the lower resistor, i.e., making a new $R_R$ that is just as high as before and that buffers the real amplifier’s huge load from the main circuit. There is no amplification at this point and no inversion as the non-inverting input of the op-amp is used.

$$V_{OUT} = V_{IN} \times -\left(\frac{R_f}{R_{IN}}\right)$$

**Gain of Amplifier**

$$\frac{V_{OUT}}{V_{IN}} = -\left(\frac{10^6}{10^5}\right) = -10$$



From the unity gain buffer I can connect another op-amp that actually works as an amplifier and amplifies my 1.23V, (minus) ten times. You will notice that ten times 1.23V is much greater than the supply voltage of 6V, so saturating the op-amp. However, my circuit only requires a ‘high or low’ reading so a 6V reading is as good as a 12.3V reading, both meaning ‘high’, light on. It is likely that the op-amp is not saturated though, or at least not to over 10V; it depends on whether the ‘light on’ intensity of the monitor is great enough to give a $V_{OUT}$ greater than 0.6V before it reaches the amplifier.

$$C = \frac{1}{f \times R_R}$$

**Choice of Capacitor**

$$C = \left(5(10^3) \times 10^6\right)^{-1} \approx 220\text{pF}$$

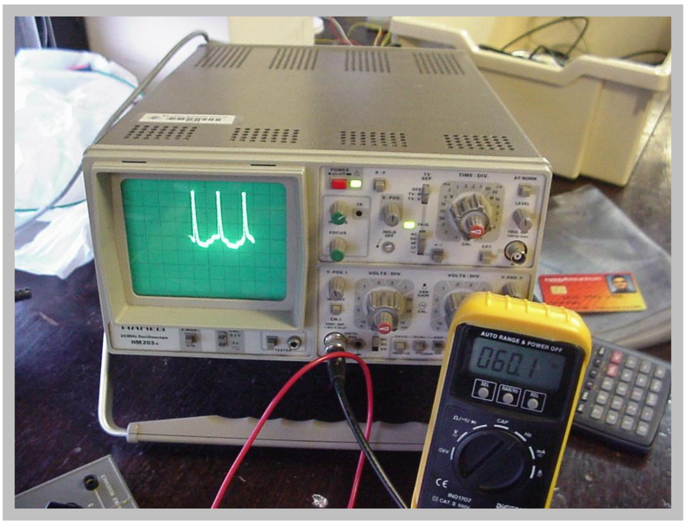
However, I found that the amplifier also amplified the noise that was coming from my main circuit and added a lot of its own. This was overcome by placing a capacitor in parallel with the lower resistor of the main circuit. This has the effect of smoothing out the waveform of the high frequency noise. I chose a 220pF capacitor as this tied in with the main frequency of the noise, 5 kHz, I was getting. The capacitor does not only cancel out noise at 5 kHz so the calculation above is a very rough one, i.e., the 5 kHz value for the noise is inaccurate.

I was lucky in having the photodiode already mounted so I didn't have to play with crocodile clips. This is one safety aspect. I also kept dangling wires to a minimum and the strobe and 60W bulb off when they were not needed.

While setting up the circuit I used a strobe for my flashing which is of course much more intense than the monitor. It took me a while to realise how inaccurate the frequency scale on the strobe was. This threw me before I noticed that both the oscilloscope and frequency-meter were giving equal readings. Turning the strobe down to 1 Hz it was clear without even a stopwatch that the actual frequency was not 1 Hz.

I also had problems with the voltmeters, which is one of the reasons I don't have any accurate voltage readings, not that they are required though. The readings fluctuated far too greatly to take down. This is probably down to the high sensitivity of my photodiode and relatively low accuracy, compared to the photodiode, of the voltmeters.

The frequency-meter worked well enough, sticking to a frequency when it was receiving a steady one. However, the oscilloscope was the most useful device, showing me the waveforms, their frequency and their voltage etc. and also proving to be the most accurate piece of equipment by far. The frequency-meter, if it didn't have a steady frequency, tended to fluctuate quite wildly.



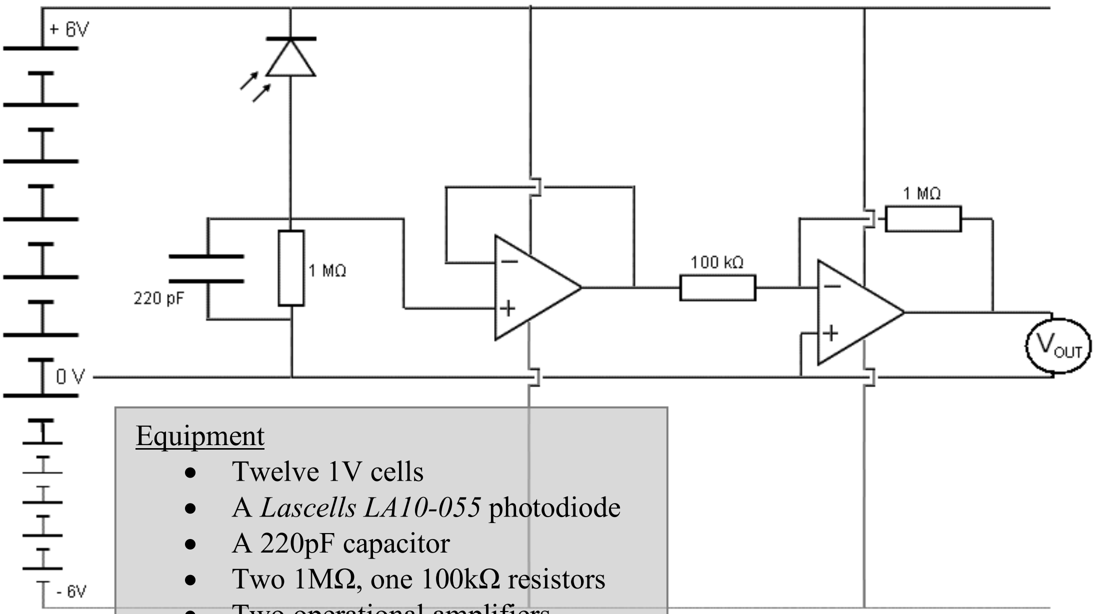
I did try using a NOT gate to square out the waves, however, the noise was too great and the voltage too low for the voltage changes to be over the threshold giving a 'high' or 'low' so the NOT gate was abandoned. It may have worked with the capacitor in place though.

I had not expected the device to work with a computer monitor as it had not done the last time I had placed the photodiode up to one, however, with the amplifiers in and the noise smoothed out I was getting closer. It did occur to me, though, that the 60 Hz reading I was getting may not have been due to light alone but the electromagnetic field of the monitor being so close to my circuit. I tested this by holding about a metre-long endoscope to the monitor with the other end on the photodiode. Then, knowing that the frequency was the result of the flashing light of the monitor, I could take the photo above. The endoscope also helped in blocking out external light from the photodiode which would have made it less sensitive.

That was my first reading, of a monitor refreshing at 60 Hz. I also tried my device on an old BBC computer. Apparently it had a refresh rate of 50 Hz. There is no way for me to verify this but I will assume that my device does work as I know the 60 Hz reading was correct.

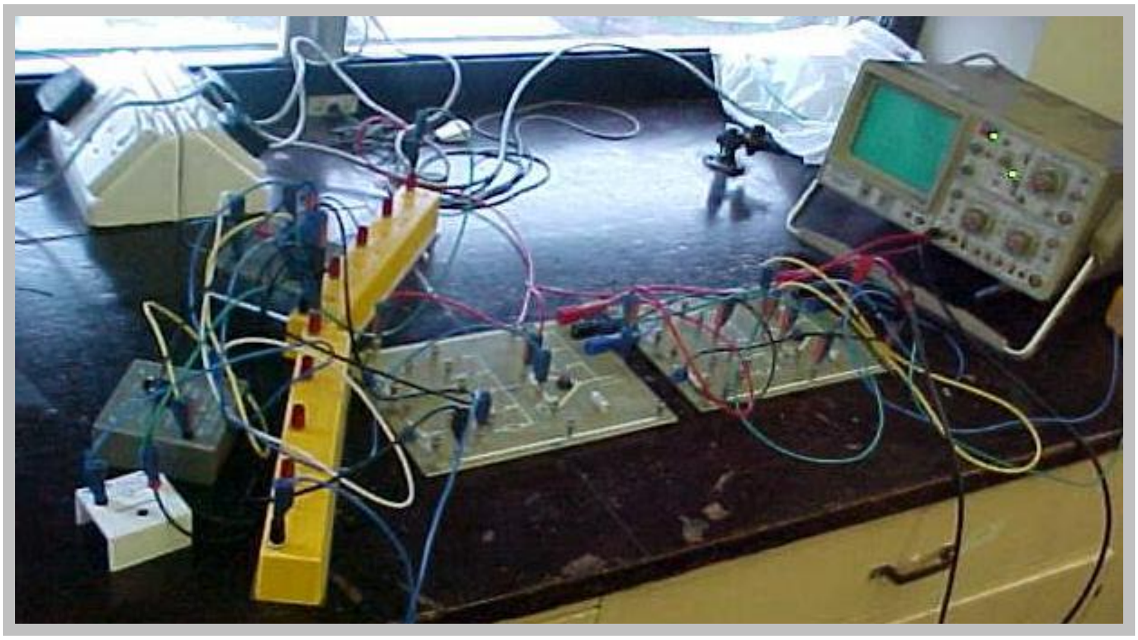
The voltages are positive on the oscilloscope only because I inverted the output on it; up looked better than down. The actual voltage output ($V_{OUT}$) from my circuit is negative because of the inverting op-amp, however, this makes no difference to the frequency-meter which detects only the change in voltage.

# Flash Rate Monitor



Equipment

- Twelve 1V cells
- A *Lascells LA10-055* photodiode
- A 220pF capacitor
- Two 1MΩ, one 100kΩ resistors
- Two operational amplifiers
- An oscilloscope
- A frequency-meter
- An endoscope



**Girish Gupta**

21st-23rd March 2004