

Precision Rectifiers

And RMS-DC Circuit Design

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Abstract—Design a full full-wave precision rectifier to given specs and simulate it using LTSpice. Build and RMS-DC converter and characterize it.

I. PRECISION RECTIFIER

Traditional Half-wave and Full-wave rectifiers have an error in their output equal to approximately the cut-in voltage (V_γ) of the diode (typically 0.6 V). The objective of this document is to is to design a precision rectifier which gives an output approximately equal to the absolute value of the input.

A precision rectifier [Fig. 1a], also known as a super diode can be used to overcome this issue.

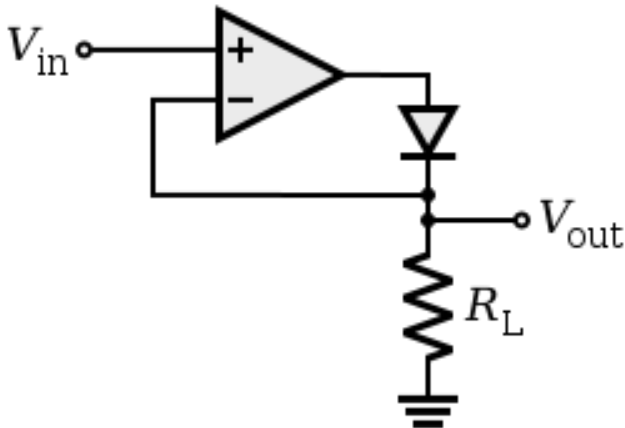


Fig. 1a – Precision Rectifier [1]

When the input is positive, it is amplified by the operational amplifier, which switches the diode on. Current flows through the load and, because of the feedback, the output voltage is equal to the input voltage. [1]

When the input voltage is negative, there is a negative voltage on the diode, so it works like an open circuit, no current flows through the load, and the output voltage is zero. [1]

The actual threshold of the super diode is very close to zero, but is not zero. It equals the actual threshold of the diode, divided by the gain of the operational amplifier. [1]

However, this basic configuration has a few problems. When the input becomes (even slightly) negative, the operational

amplifier runs open-loop, as there is no feedback signal through the diode. For a typical operational amplifier with high open-loop gain, the output saturates. If the input then becomes positive again, the op-amp has to get out of the saturated state before positive amplification can take place again. This change generates some ringing and takes some time, greatly reducing the frequency response of the circuit. [1]

II. IMPROVED CIRCUIT

An improved alternative is used to overcome the said drawbacks of the basic configuration [Fig. 2a]

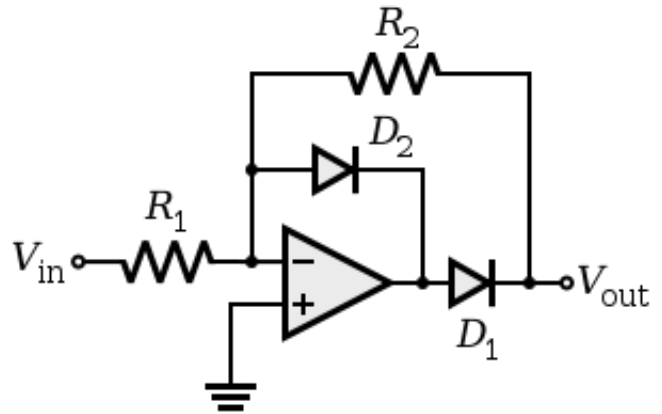


Fig. 2a – Improved Precision Rectifier [1]

In this case, when the input is greater than zero, D1 is off, and D2 is on, so the output is zero because one side of R_2 is connected to the virtual ground, and there is no current through it. and there is no current through it.

When the input is less than zero, D1 is on, and D2 is off, so the output is like the input with an amplification of $-R_2 / R_1$. [1]

III. PRECISION FULL-WAVE RECTIFIER

A precision full-wave rectifier circuit [Fig. 3a] is described in book Design with Operational Amplifiers and Analog Integrated Circuits by Sergio Franco [2].

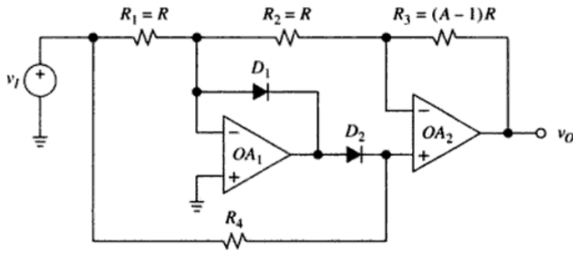


Fig. 3a – FWR using only 2 matched resistors

This circuit also provides a gain to the rectified output.

Positive gain:

$$A_p = 1 + \frac{R_3}{R_2}$$

Negative gain:

$$A_n = \frac{R_2 + R_3}{R_1}$$

Requiring equal gain on both rectified cycles would make

$$R_1 = R_2 = R$$

and

$$R_3 = (A - 1)R$$

IV. RMS-DC CONVERTER

An RMS-DC converter generates a DC voltage proportional to the amplitude of a given AC signal. The AC signal is first full-wave rectified and the low-pass filtered to synthesize a DC voltage. [2] This voltage is the average of the rectified wave. [Eq. 4a]

$$V_{avg} = \frac{1}{T} \int_0^T |v(t)| dt$$

Where, $v(t)$ is the AC wave and T is its period.

We need to design a RMS-DC converter using a precision FWR that accepts an input of up to 2V sine and rectifies it to give 2X gain. The output of which should be equal to the RMS value.

For a sinusoidal input, say a sine wave, [Eq. 4b]

$$v(t) = V_m \sin 2\pi f t$$

V_m is the peak amplitude and $f = 1/T$ is the frequency

Substituting this in previous equation Eq. 4a gives [Eq. 4c]

$$V_{avg} = (2/\pi)V_m = 0.637 V_m$$

An AC-DC converter is calibrated so that, when fed with an AC signal, it gives its RMS value [Eq. 4d]

$$V_{rms} = \left[\frac{1}{T} \int_0^T V^2(t) dt \right]^{1/2}$$

Substituting Eq. 4b in this, we get

$$V_{rms} = \frac{V_m}{\sqrt{2}} = 0.707 V_m$$

Therefore, in order to obtain V_{RMS} from V_{AVG} , we need to multiply the latter by

$$\frac{\left(\frac{1}{\sqrt{2}} \right)}{\frac{2}{\pi}} = 1.11$$

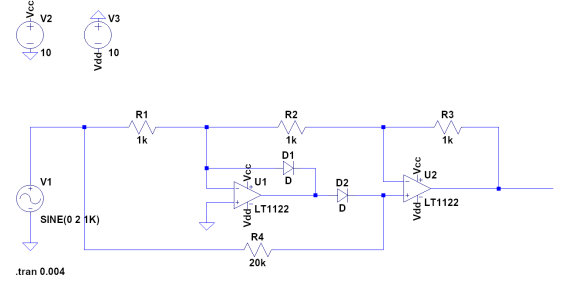


Fig. 3b – Full-wave rectifier

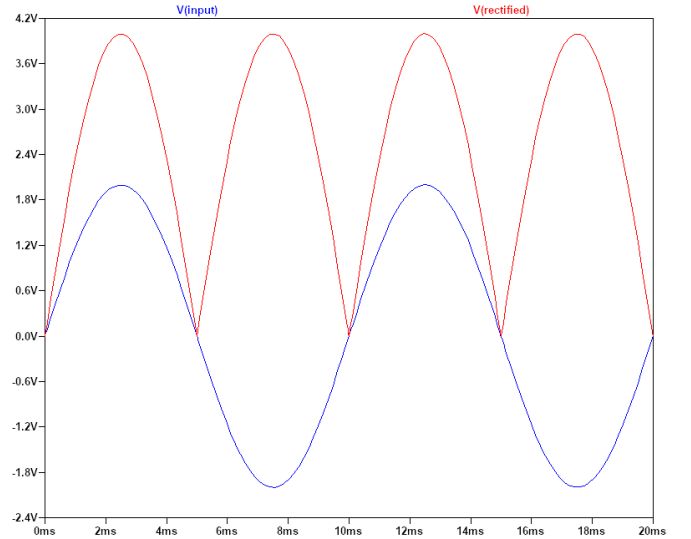


Fig. 3c – FWR output

The frequency of the FWR output is double the AC frequency. A low-pass filter acts like an integrator and can be placed at the output to get the average of the rectified signal.

Using a low-pass filter that has a f_{3dB} point at 5Hz. $R = 3.3$ M Ohm and $C = 10$ nF

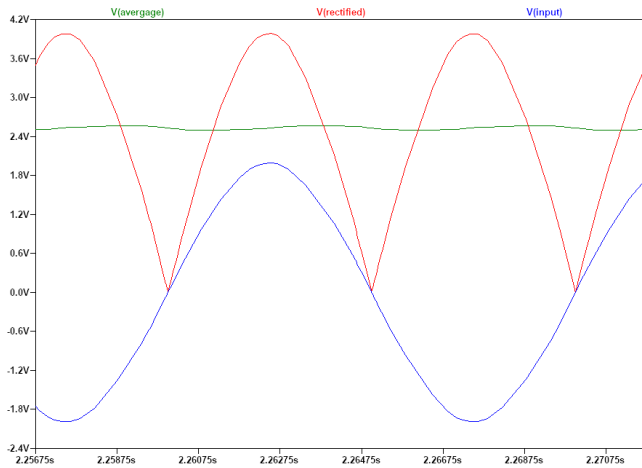


Fig. 3d – Average of AC input

We know that RMS voltage is about 1.11 times the Average voltage. To obtain the RMS voltage, amplify the output 1.11 times.

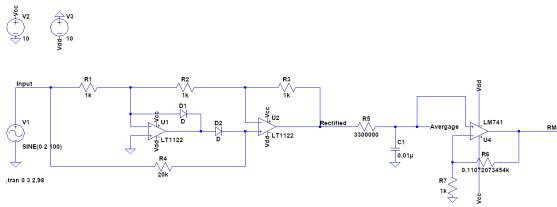


Fig. 3e – RMS-DC converter

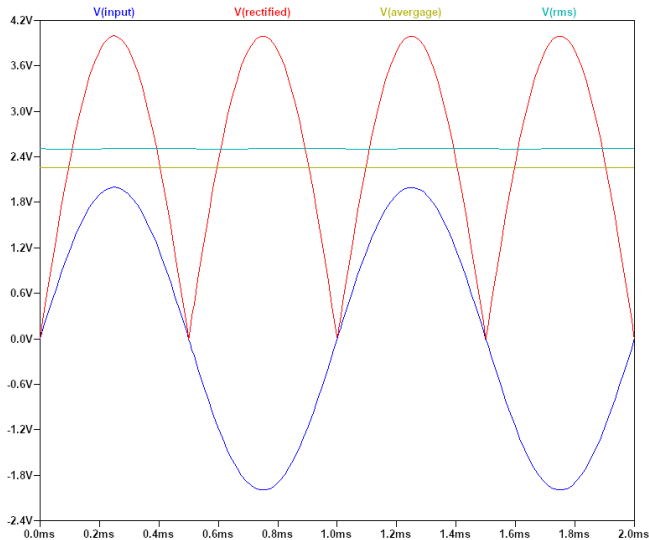


Fig. 3f – RMS-DC converter output

Average value of 4vpp rectified AC signal as from the graphs is 2.53 which is 63.25 percent. Error is 0.45 percent.

A. Worst case of mismatch

With 1% mismatch of each resistor, amplitudes of rectified signal are not the same for both the cycles.

The error is $|A_p - A_n|$.

$$|A_p - A_n| = |(R_3 + R_2) \left(\frac{1}{R_1} - \frac{1}{R_2} \right)|$$

Worst case scenario when R1 decreases by 1%, and R2 increases by 1%. Let the ratio change in resistance be e. So, $R_1 = R(1 - e)$, $R_2 = R(1 + e)$, $R_3 = (A - 1)$

$$|A_p - A_n| = |(A - 1 + 1 + e) \left(\frac{1}{(1 - e)} - \frac{1}{(1 + e)} \right)|$$

$$|A_p - A_n| = |(A + e) \frac{2e}{1 - e^2}|$$

As $e = 0.01$, the above result evaluates to 0.02A (approximately). So, the worst-case error is 2%.

B. Accuracy Requirement

The minimum frequency of AC is 50 Hz. The ripple voltage is minimum if capacitor doesn't discharge between two peaks of the FWR output. Frequency of FWR is 100 Hz which corresponds to 0.01 s. If the time constant of the RC filter is greater than this value, ripple voltage can be reduced.

$R = 1$ Mega Ohm and $C = 0.01$ u give $RC = 0.01$

This produced a ripple voltage of 23 mV which corresponds to an attenuation of 44.8 dB.

C. Average and Error

Average value was 2.5299 V when input was 2 V.

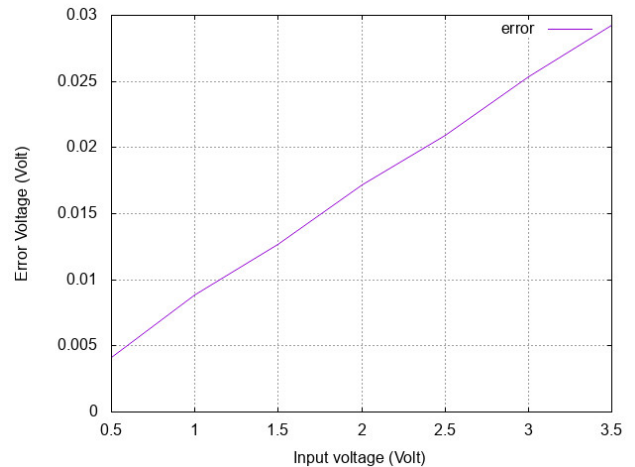


Fig. 4a – Error wrt input

D. Mismatched Error

According to datasheets, the DC offset is 600 micro volts.

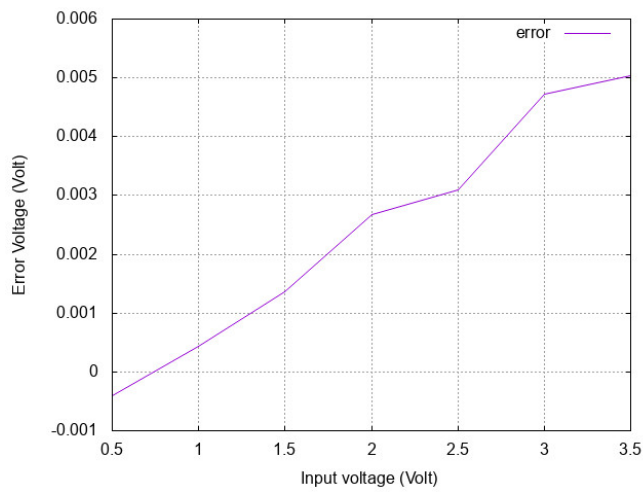


Fig. 4b – Error with capacitor mismatches

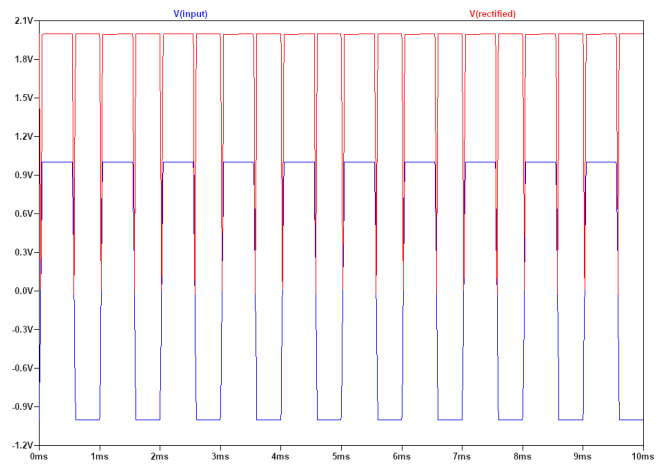


Fig. 5a – Pulse response

E. Pulsed Input

No instability was observed even on zooming in on the rectified output.

REFERENCES

- [1] https://en.wikipedia.org/wiki/Precision_rectifier
- [2] Sergio Franco: https://books.google.co.in/books?id=WbYjKaLeLwQC&pg=PA425&lp g=PA425&dq=Precision+FWR+using+only+two+matched+resistor&source=bl&ots=4YWd-wtqlK&sig=CIPbjV11DWMJretTNgCtfud5TWY&hl=en&sa=X&ved=0ahUKEwidw_bpl4fXAhWKpY8KHSmcCR4Q6AEILjAB#v=onepage&q&f=false