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# A High-Impedance Precision Full-Wave Rectifier

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*A novel electronic circuit that produces precise full-wave rectification for frequencies up to and beyond 100kHz without waveform distortion is described. The circuit utilises basic op amps such as the LM741 along with a current conveyor to improve the rectifying process. The configuration has the additional advantage of a high input impedance.*

## 1. Introduction

A standard signal processing function that is usually implemented using operational amplifiers is precise rectification [1,2]. The use of the operational amplifier in these circuits ensures that the threshold voltage of the rectifying diodes is overcome particularly for low-level signals. These circuits generally function well at low frequencies but for frequencies above 1kHz, moderate to severe waveform distortion results [3]. This occurs because as the input signal passes through cross-over, there is a period when the diodes in the circuit are turned off and hence the op amp is operating in essentially an open-loop configuration. At low frequencies, the problem is insignificant since at these frequencies the op amp is able to respond relatively rapidly in turning on the diodes. At higher frequencies however, the op amp is unable to respond sufficiently fast to turn on the diodes and severe distortion results. Various circuits employing different methods have been reported [4,5] but they generally perform poorly at medium to high frequencies.

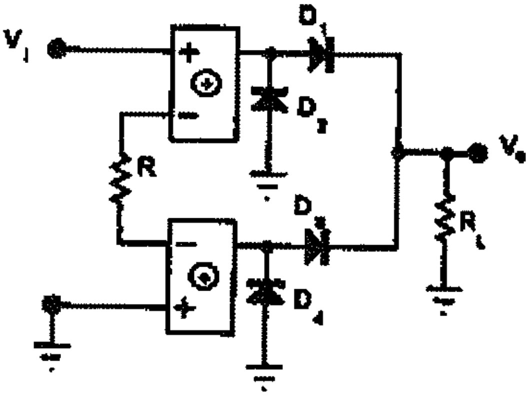

**FIGURE 1:** *Precision Full-wave Rectifier Circuit described by* ***Khan et al*** [6]

Recently, **Khan *et. al.*** [6] have described a circuit which utilises two current conveyors driving rectifying diodes (**Figure 1**). The high output impedance of the current conveyors overcomes the turn-on resistance of the diodes and allows this circuit to function above 100 kHz. The transfer function for this circuit is given by

$$\frac{V_0}{V_i} = \frac{R_L}{R+2R_x} \qquad \text{..........(1)}$$

This involves the resistor $R_x$ which is internal to the current conveyors and is a low-precision component. As a result, accuracy is impaired in this circuit as compared with the op amp-based circuits.

In this paper, our objective is to improve the op amp-based circuit. We therefore review these circuits, then propose a new precise full-wave rectifying configuration that is able to produce an undistorted rectified signal up to relatively high frequencies using basic op amps such as the LM741. The circuit has the additional advantage of a high input impedance.

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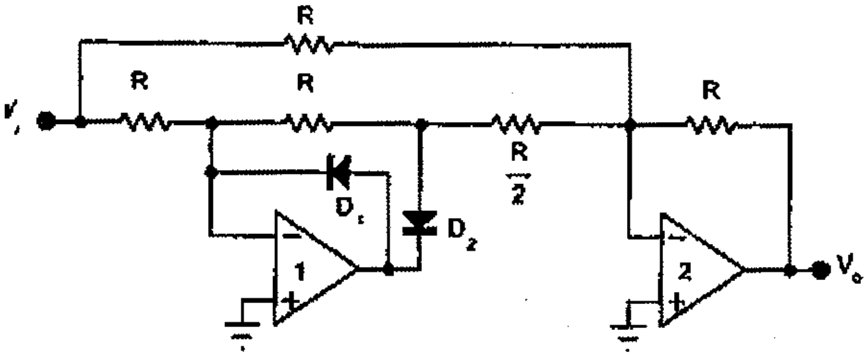

**FIGURE 2:** *Precise Full-wave Rectifier using a Precise Half-wave Rectifier and a Summing Amplifier*

## 2. Conventional Op-Amp-Based Circuits [1]

The circuit shown in **Figure 2** is widely used for precise rectification. It consists of a half-wave rectifier involving op amp 1 driving a summing amplifier involving op amp2. For a positive going input signal $V_i$, the weighted output of the half-wave rectifier is summed with the input signal giving $V_o = |V_i|$. For a negative going input signal, the half-wave rectifier gives a null output (since $D_1$ is on and $D_2$ is off) and the summer performs as an inverter again giving $V_o = |V_i|$.

**Figure 3** shows an alternate full-wave rectifier comprising two op amps and two diodes that offers some advantages over that in **Figure 2**. For a positive going input signal $V_i$, diode $D_2$ turns off resulting in zero potential at the non-inverting input of op amp 2 since there is no current flow in resistor $R_3$. Diode $D_1$ turns on causing a current $V_i/R$ to flow through the feedback resistor $R_5$ of op amp 2. This results in $V_o = |V_i|$. For a negative going input signal $V_i$, diode $D_2$ turns on and a current $2V_i/3R$ flows from op amp 1 through $D_2$ and $R_3$ into $R_1$ resulting in a potential of $2V_i/3$ at the non-inverting input of op amp 2. Diode $D_1$ turns off and a current $V_i/3R$ flows from op amp 2 through the resistor chain $R_5$, $R_4$, $R_2$ into $R_1$. This creates a potential drop of $V_i/3$ across $R_5$ which results in $V_o = |V_i|$. Unlike the circuit in **Figure 2**, this circuit utilises equal resistors throughout and has a higher though still relatively low input impedance.

The full-wave rectifier in **Figure 4** has the advantage over the other two of having a high input impedance since the signal input is at the non-inverting inputs of the two op amps. It also uses one less matched resistor. A positive going input signal $V_i$ appears at the non-inverting and inverting inputs of both op amps. The result is that op amp 2 acts as a follower giving $V_o = |V_i|$. When $V_i$ goes negative, $-V_i$ is established at the inverting input of op amp 2. $D_1$ turns off and $D_2$ turns on and a current $V_i/R$ flows through $R_1$ and $R_2$ into $D_2$ establishing a potential $-2V_i$ at the junction of $R_2$ and $R_3$. As a result, a current $V_i/R$ flows from the output of op amp 2 through $R_4$ and $R_3$ into $D_2$ which, because $R_4 = 2R$ gives $V_o = |V_i|$.

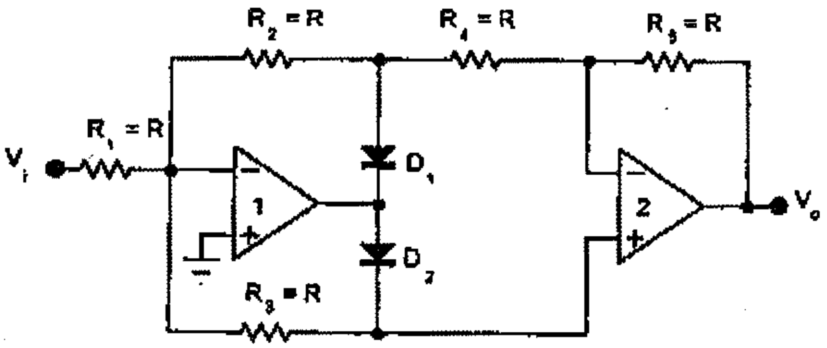

**FIGURE 3:** *Precise Full-wave Rectifier that utilises Equal Resistors throughout*

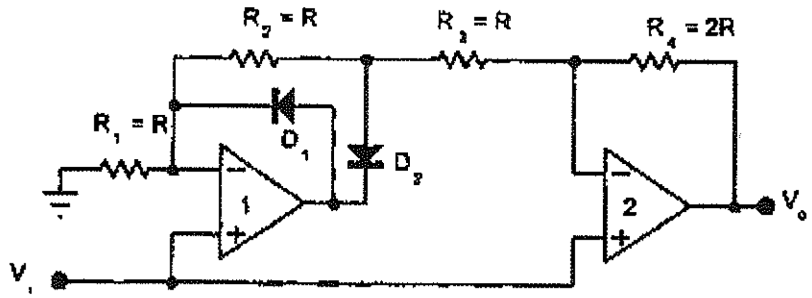

**FIGURE 4:** *Precision Full-wave Rectifier that has a High Input Impedance*

Like the others, this circuit exhibits waveform distortion at upper frequencies. To illustrate this, tests were done on this circuit using R = 10K and LM 741 op amps.An undistorted waveform was obtained for a frequency of 100 Hz as shown in **Figure 5**. At higher frequencies however, the waveform became increasingly distorted. This deterioration is illustrated in **Figures 6, 7** and **8** for frequencies of 1kHz, 10kHz and 100kHz respectively using a 1V pk-pk input signal. The distortion at 10kHz and 100kHz is particularly severe, rendering the waveform unusable at these frequencies.

## 3. New High-Impedance Precision Rectifier

The new circuit is shown in **Figure 9** and bears some resemblance to the circuit of **Figure 4**. It consists of op amp1 driving the non-inverting input of a current conveyor. The inverting terminal of the current conveyor is connected to the inverting input of op amp1 thereby placing the input circuit of the current conveyor within the feedback loop of the op amp. The effect of this is that the output current $I_o$ of the current conveyor is defined precisely by the op amp as

$$I_0 = \frac{V_i}{R_1} = \frac{V_i}{R} \qquad \text{..........(2)}$$

and is independent of the current conveyor resistor $R_x$. The output of the current conveyor is connected through $D_1$ and $D_2$ to the inverting input of op amp2 which has a feedback resistor $R_2$ = 2R. During operation, the high output impedance of the current conveyor readily overcomes the diode turn-on resistance and this increases the linearity and operating

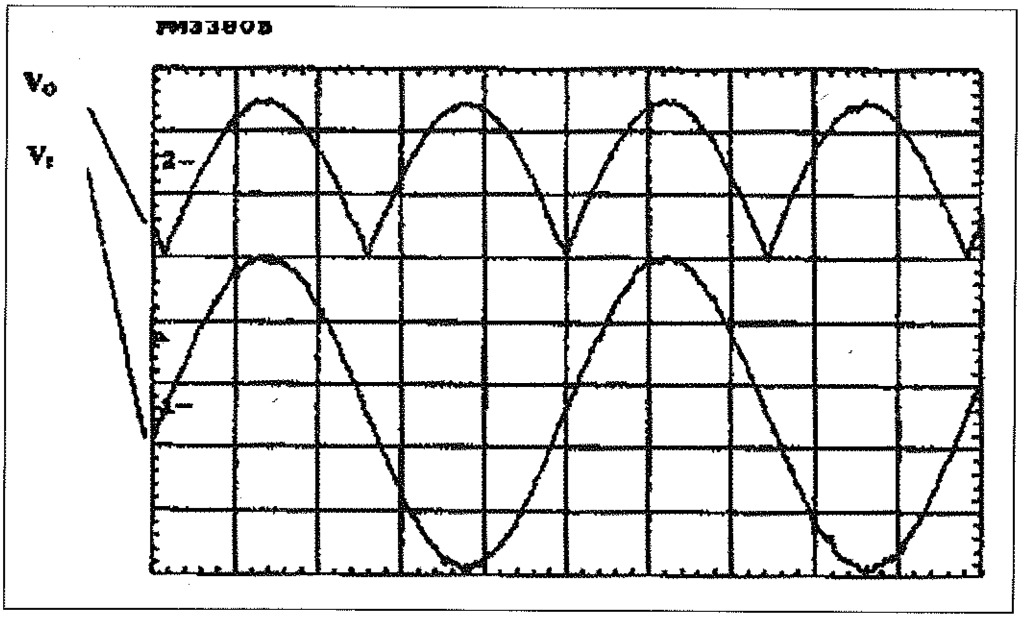

**FIGURE 5:** *Output Waveform of the Circuit of Figure 4 for a Frequency of 100Hz (0.2V/div, 2 msec/div)*

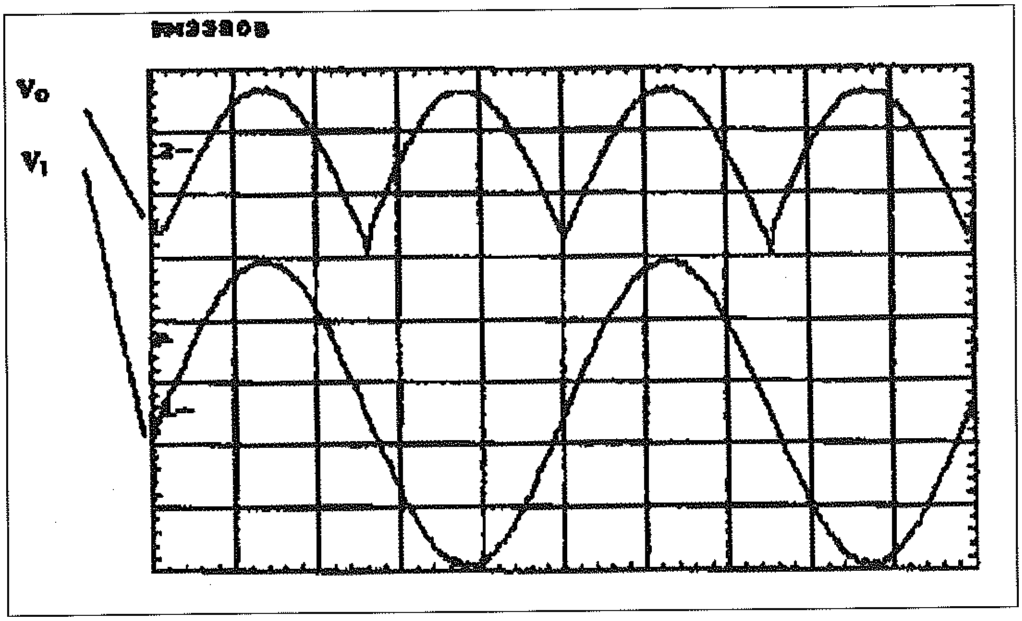

**FIGURE 6:** *Output Waveform of the Circuit of Figure 4 for a Frequency of 1kHz (0.2V/div, 200μsec/div)*

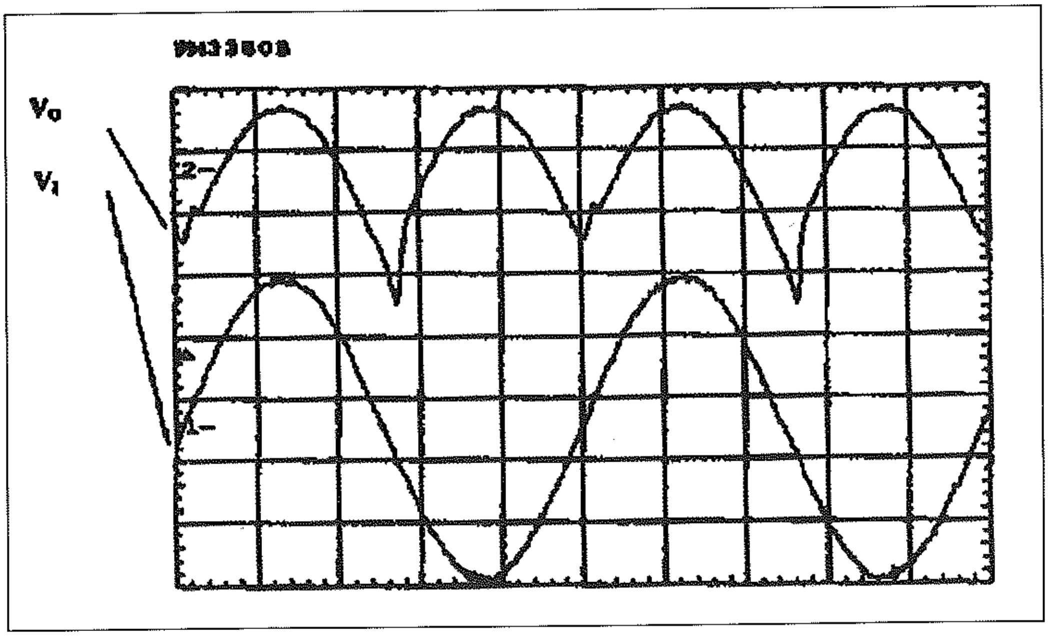

**FIGURE 7:** *Output Waveform of the Circuit of Figure 4 for a Frequency of 10kHz (0.2V/div, 20μsec/div)*

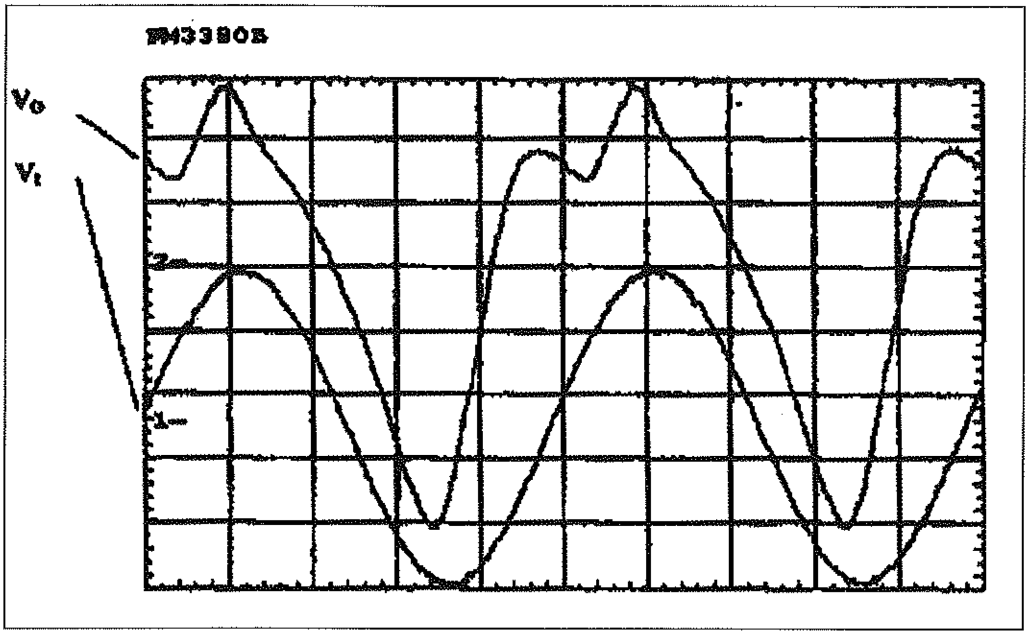

**FIGURE 8:** *Output Waveform of the Circuit of Figure 4 for a Frequency of 100kHz (0.2V/div, 2μsec/div)*

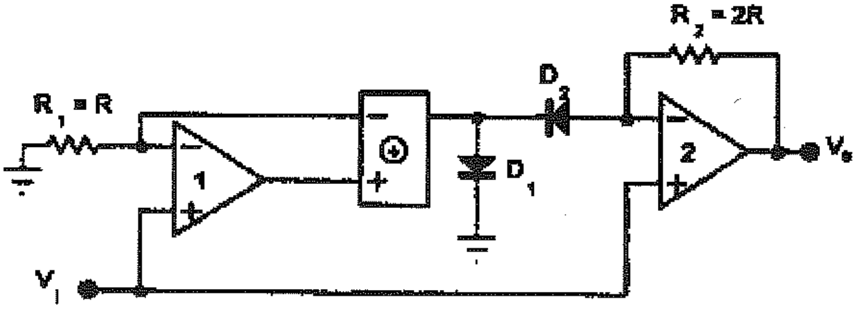

**FIGURE 9:** *New High-Impedance Precision Rectifier*

frequency of the circuit and allows the use of op amps with quite modest characteristics such as the LM741. Finally, the non-inverting input of op amp2 is connected to the non-inverting input of op amp1.

Consider first a negative going input signal $-V_i$. This causes a current $I_o = V_i/R$ defined by the hybrid arrangement of op amp 1 and the current conveyor, to flow in through $D_2$ into the output terminal of the current conveyor. At this time, $D_1$ is off. This current flows from the output of op amp2 through $R_2 = 2R$ developing a potential difference of $2V_i$ across $R_2$. Since the non-inverting input is at $-V_i$, then $V_o = |V_i|$.

When $V_i$ goes positive, all of the output current of the current conveyor flows through $D_1$ to ground while $D_2$ is off. Op amp2 therefore operates simply as a voltage follower giving $V_o = |V_i|$. The overall result is a full-wave rectified signal satisfying

$$V_o = |V_i| \qquad \text{.............(3)}$$

Only two matched resistors are used and the high impedance associated with op amp non-inverting terminals gives the circuit its high input impedance.

## 4. Circuit Implementation

In order to examine the performance of the new rectifier, the circuit of **Figure 9** was tested with $R_1 = 1\text{k}$ and $R_2 = 2\text{k}$. Two LM741 op amps were used and the current conveyor was the AD844 in the current conveyor configuration.

The circuit performed as expected producing clean, precise, full-wave rectification according to equation (3) for frequencies exceeding 100kHz. Examples of the undistorted output signal for input signal frequencies of 1 kHz, 10 kHz and 100 kHz and input signal amplitude of 1V pk-pk are shown in **Figures 10, 11** and **12** respectively. There was slight distortion on the rectified waveform for the upper frequencies possibly due to falling current output of the current conveyor for increasing frequency. The inclusion of a small capacitor in parallel with resistor $R_1$ corrected this problem. It has the effect of increasing the drive to the current conveyor such that any falling output current is compensated. The value was experimentally determined to be about 200 pF with the resistor values used.

## 5. Conclusion

In this paper, a new precision full-wave rectifying circuit has been presented. The new circuit utilises two op amps and a current conveyor whose transfer function is made precise by the incorporation of its input circuit in the feedback loop of the input op amp. The high output impedance of the current conveyor is exploited in overcoming the diode resistance.

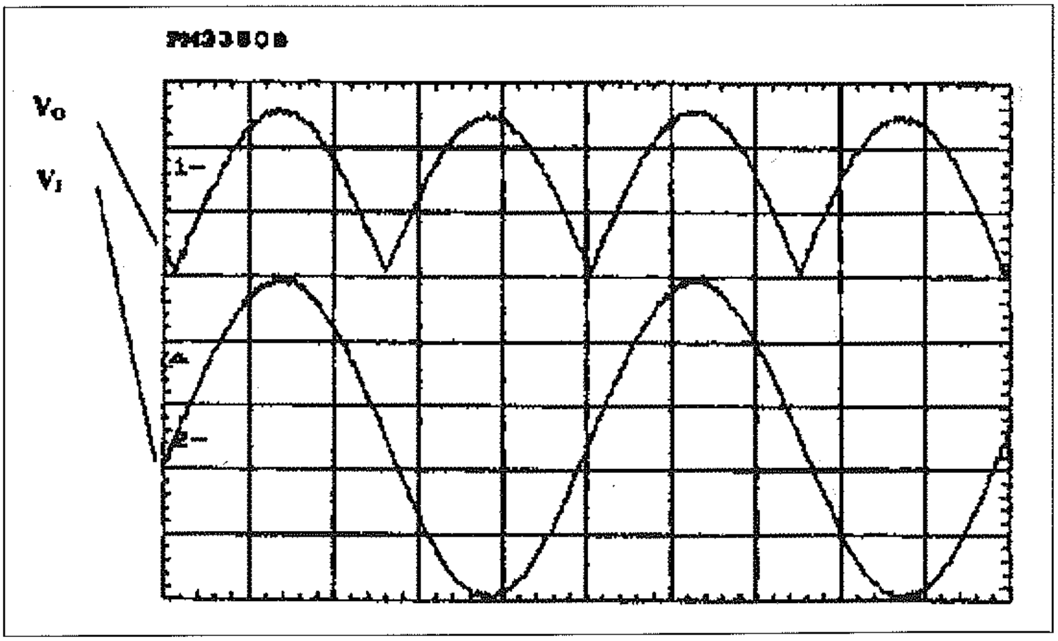

**FIGURE 10:** *Output Waveform of the New Circuit for a Frequency of 1kHz (0.2V/div, 200µsec/div)*

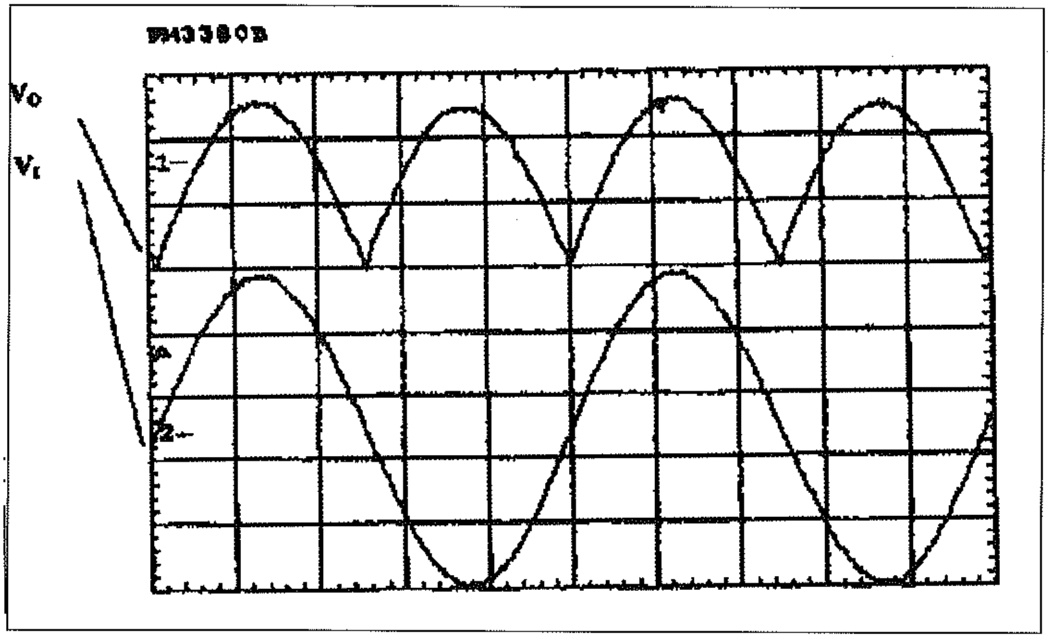

**FIGURE 11:** *Output Waveform of the New Circuit for a Frequency of 10kHz (0.2V/div, 20µsec/div)*

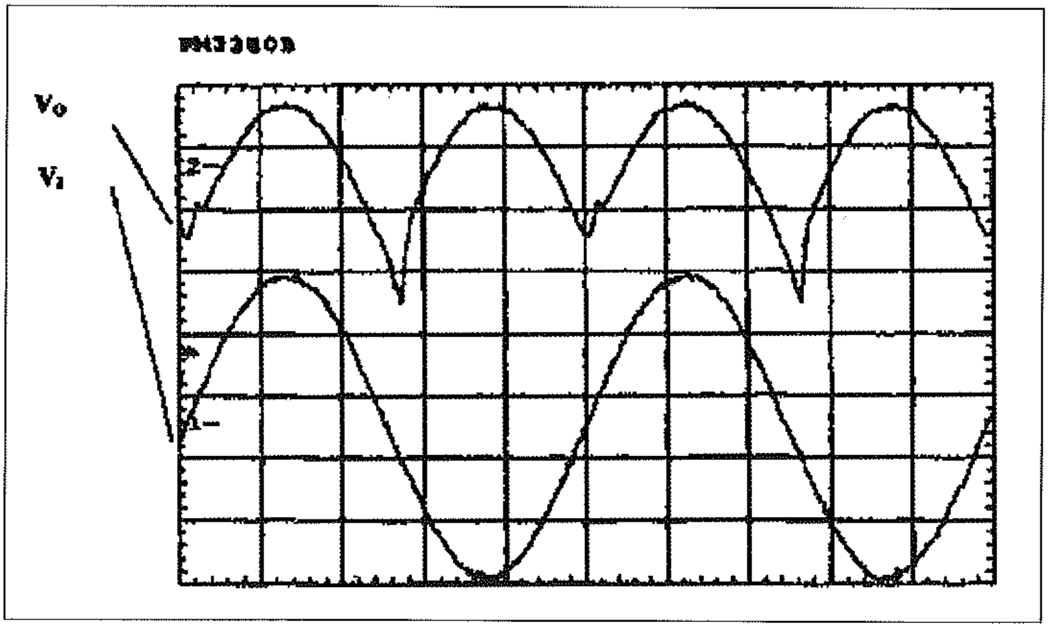

**FIGURE 12:** *Output Waveform of the New Circuit for a Frequency of 100kHz (0.2V/div, 2µsec/div)*

The configuration enjoys the advantages of precise rectification over a wide range of operating frequencies, a high input impedance and the ability to utilise basic op amps. It is a significant improvement over conventional op-amp-based rectifier circuits and should find wide utilisation in practice. An improved rectifier circuit employing principles similar to those embodied in the new circuit described in this paper has also been developed based on a modification of **Figure 2**. This has been presented elsewhere [7].

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