Analog Engineer's Circuit

Half-Wave Rectifier Circuit With MSP430 Smart Analog Combo

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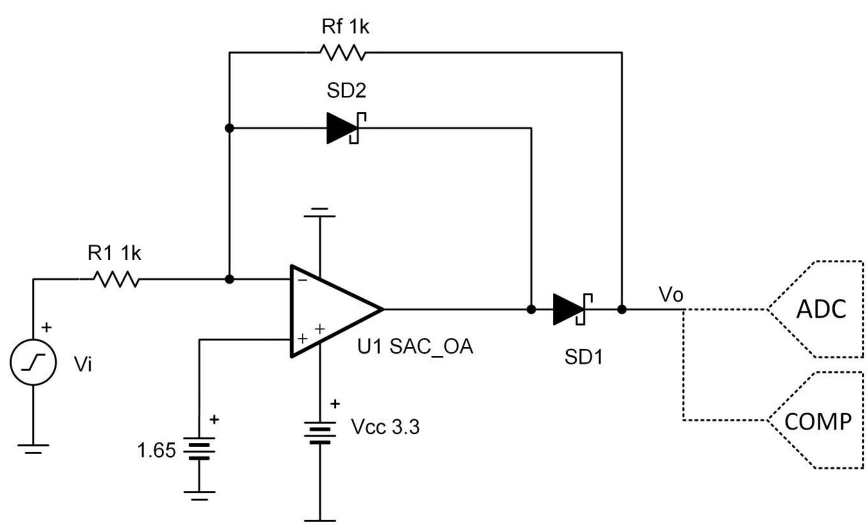
Design Goals

Input		Output		Supply	
V_{iMin}	V_{iMax}	V_{oMin}	V_{oMax}	V_{cc}	V_{ee}
$0.2V_{pp}$	$2V_{pp}$	$0.1V_p$	$1V_p$	3.3V	0V

Design Description

Some MSP430™ microcontrollers (MCUs) contain configurable integrated signal chain elements such as op-amps, DACs, and programmable gain stages. These elements make up a peripheral called the Smart Analog Combo (SAC). For information on the different types of SACs and how to leverage the configurable analog signal chain capabilities, visit *MSP430 MCUs Smart Analog Combo Training*. To get started with your design, download the *Half-Wave Rectifier Circuit Design Files*.

The precision half-wave rectifier inverts and transfers only the negative-half input of a time varying input signal (preferably sinusoidal) to the output. This circuit uses the MSP430FR2311 SAC_L1 op-amp in an inverting amplifier configuration with the appropriate diodes in place. There is room for further integration by using the integrated DAC in the MSP430FR2355 SAC_L3 block to provide the bias voltage on the non-inverting op-amp terminal. By appropriately selecting the feedback resistor values, different gains can be achieved. Precision half-wave rectifiers are commonly used with other op amp circuits such as a peak-detector or bandwidth limited non-inverting amplifier to produce a DC output voltage. The output of the SAC_L3 op-amp can be cascaded with the other 3 SAC_L3 blocks in the MSP430FR2355 to expand upon the analog signal chain functionality or sampled directly by the onboard ADC or monitored by the onboard comparator for further processing inside the MCU. This configuration has been designed to work for sinusoidal input signals between $0.2V_{pp}$ and $2V_{pp}$ at frequencies up to 50kHz.



Design Notes

- Set output range based on linear output swing (see A_{ol} specification).
- Use fast switching diodes. High-frequency input signals will be distorted depending on the speed by which the diodes can transition from blocking to forward conducting mode. Schottky diodes can be a preferable choice, since these have faster transitions than pn-junction diodes at the expense of higher reverse leakage.
- The resistor tolerance sets the circuit gain error.
- Minimize noise errors by selecting low-value resistors.
- If the fix is implemented using the MSP430FR2311, the circuit can be realized by the SAC_L1 op-amp in general purpose mode or the Transimpedance Amplifier (TIA). In both cases the bias voltage can be set using a resistor divider or external DAC.
- If the TIA op-amp is used, the input voltage would need to be kept below VCC/2 to operate within the peripheral's common-mode input specifications.
- If the fix is implemented using the MSP430FR2355, the circuit can be realized using any of the 4 on-board SAC_L3 peripherals in DAC mode in order to generate the bias voltage on the non-inverting op-amp terminal.
- When the input signal changes polarities, the amplifier output must slew two diode voltage drops. The MSP430 SAC and TIA op-amps can be configured in "High-Speed Mode" to achieve a higher slew rate.
- The *Half-Wave Rectifier Circuit Design Files* include code examples showing how to properly initialize the SAC peripherals.

Design Steps

1. Set the desired gain of the half-wave rectifier to select the feedback resistors.

$$V_o = \text{Gain} \times V_i$$

$$\text{Gain} = -\frac{R_f}{R_1} = -1$$

$$R_f = R_1 = 2 \times R_{eq}$$

   - Where R_{eq} is the parallel combination of R_1 and R_f

2. Select the resistors such that the resistor noise is negligible compared to the voltage broadband noise of the op amp.

$$E_{nr} = \sqrt{4 \times k_b \times T \times R_{eq}}$$

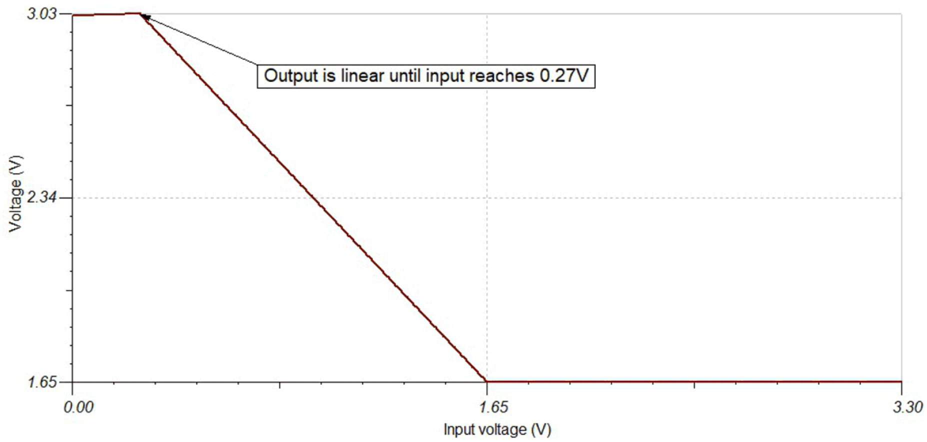
$$R_{eq} \le \frac{E_{nbb}^2}{4 \times k_b \times T \times 3^2} = (\text{Enbb})$$

$$= 20\frac{\text{nV}}{\sqrt{\text{Hz}}} = \frac{\left(20 \times 10^{-9}\right)^2}{4 \times 1.381 \times 10^{-23} \times 298 \times 3^2} = 2.7k\Omega$$

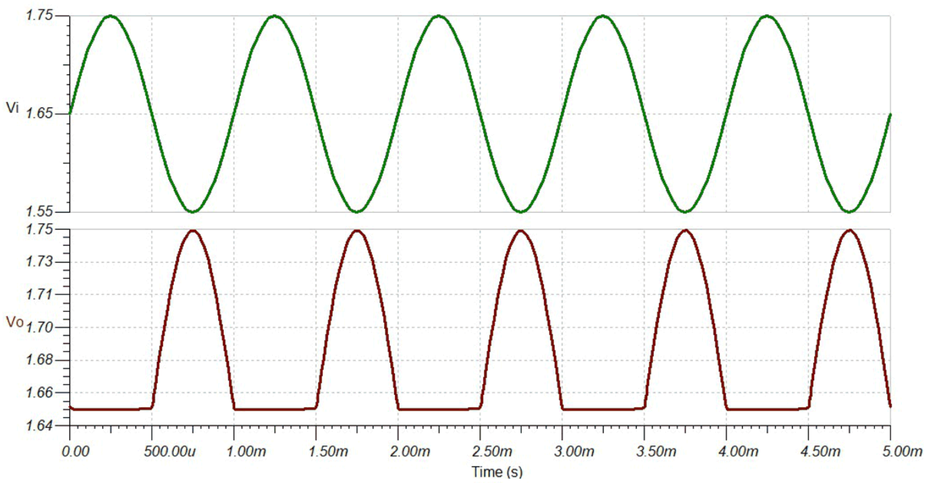
$$R_f = R_1 \le 5.4k\Omega \rightarrow 1k\Omega \text{ (Standard Value)}$$

Design Simulations

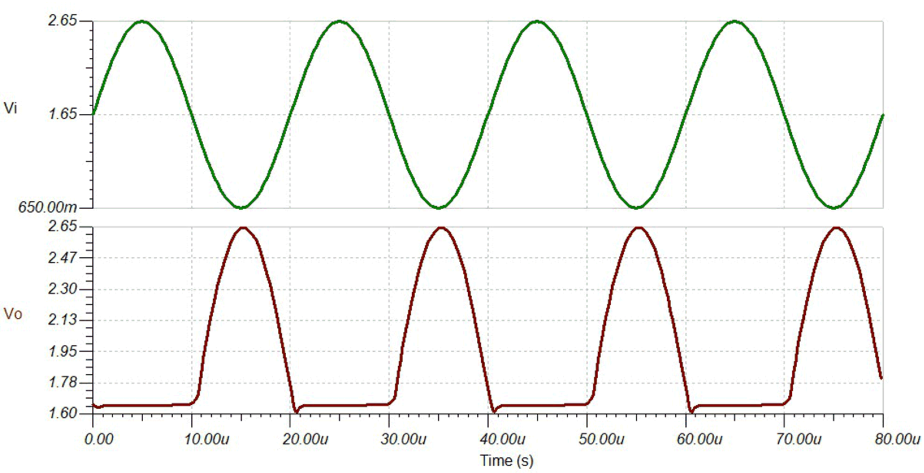
DC Simulation Results



Transient Simulation Results



200 mV$_{pp}$ at 1 kHz



2 V$_{pp}$ at 50 kHz

Target Applications

- *Battery charger*
- *Waveform generator*

References

1. Texas Instruments, *MSP430 Half-Wave Rectifier Circuit*, design file
2. Texas Instruments, *MSP430 MCUs Smart Analog Combo Training*, video

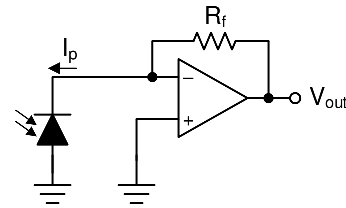
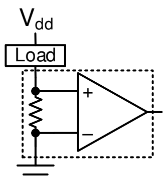
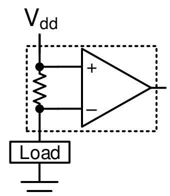
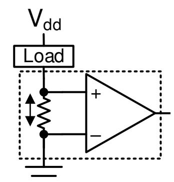
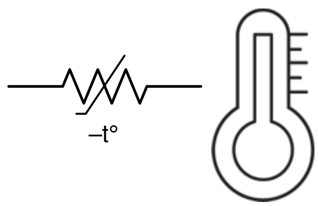
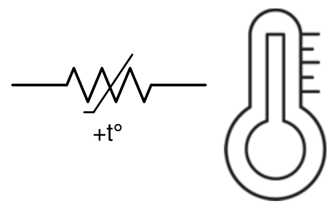
Design Featured Op Amp

MSP430FRxx Smart Analog Combo		
	MSP430FR2311 SAC_L1	MSP430FR2355 SAC_L3
V_{cc}	2.0V to 3.6V	
V_{CM}	-0.1V to V_{CC} + 0.1V	
V_{out}	Rail-to-rail	
V_{os}	±5mV	
A_{OL}	100dB	
I_q	350µA (high-speed mode)	
	120µA (low-power mode)	
I_b	50pA	
UGBW	4MHz (high-speed mode)	2.8MHz (high-speed mode)
	1.4MHz (low-power mode)	1MHz (low-power mode)
SR	3V/µs (high-speed mode)	
	1V/µs (low-power mode)	
Number of channels	1	4
MSP430FR2311		
MSP430FR2355		

Design Alternate Op Amp

MSP430FR2311 Transimpedance Amplifier	
V_{cc}	2.0V to 3.6V
V_{CM}	-0.1V to V_{CC}/2V
V_{out}	Rail-to-rail
V_{os}	±5mV
A_{OL}	100dB
I_q	350µA (high-speed mode)
	120µA (low-power mode)
I_b	5pA (TSSOP-16 with OA-dedicated pin input)
	50pA (TSSOP-20 and VQFN-16)
UGBW	5MHz (high-speed mode)
	1.8MHz (low-power mode)
SR	4V/µs (high-speed mode)
	1V/µs (low-power mode)
Number of channels	1
MSP430FR2311	

Related MSP430 Circuits

Low-noise and long-range PIR sensor conditioner circuit 	Bridge amplifier circuit 	Transimpedance amplifier circuit 
Single-supply, low-side, unidirectional current-sensing circuit 	High-side current sensing with discrete difference amplifier circuit 	Low-side, bidirectional current-sensing circuit 
Half-wave rectifier circuit 	Temperature sensing with NTC thermistor circuit 	Temperature sensing with PTC thermistor circuit 

Trademarks

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Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision A (March 2020) to Revision B (October 2024)	Page
• Updated the format for tables, figures, and cross-references throughout the document.	1

Changes from Revision * (December 2019) to Revision A (March 2020)	Page
• Added *Related MSP430 Circuits* section.	1

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