*Analog Engineer's Circuit*

# *Three-Phase Isolated Voltage-Sensing Circuit Using AMC1350*

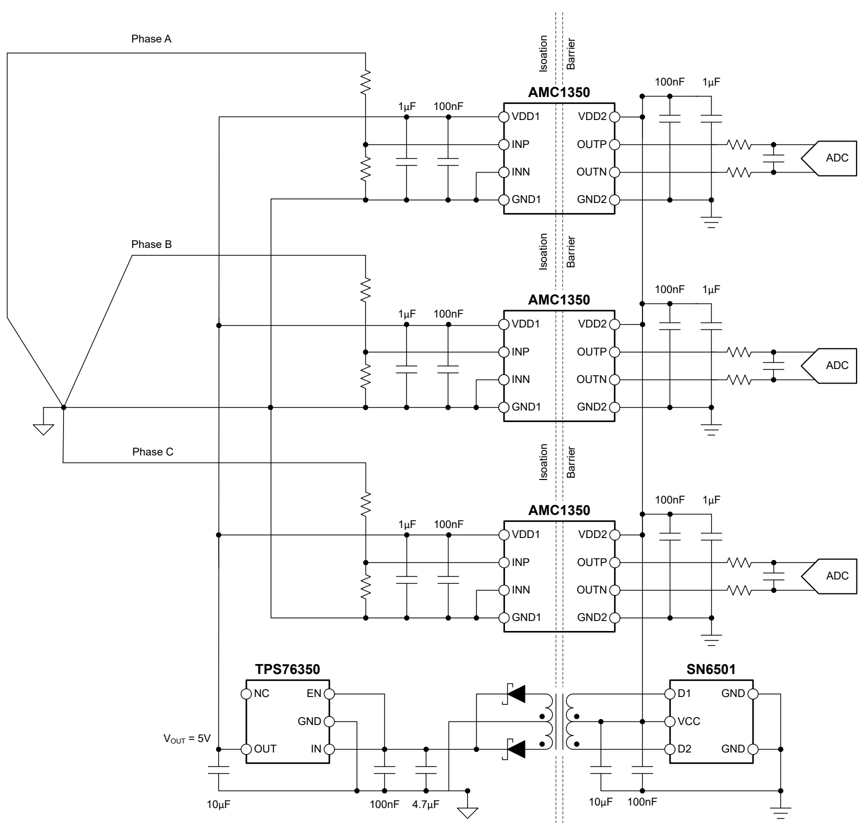
*Amplifiers*

## Design Goals

| Voltage Source | | AMC1350 Input Voltage | | AMC1350 Output Voltage VDD2 / 2 Common Mode ($V_{OUTP} - V_{OUTN}$) | | Power Supplies | |
|---|---|---|---|---|---|---|---|
| $V_{MAX}$ | $V_{MIN}$ | $V_{IN, MAX}$ | $V_{IN, MIN}$ | $V_{OUT, MAX}$ | $V_{OUT, MIN}$ | VDD1 | VDD2 |
| 480V | –480V | 5V | 5V | 4V | –4V | 3V–5.5V | 3V–5.5V |

## Design Description

This circuit performs three-phase line-to-neutral, isolated, voltage-sensing measurements utilizing the AMC1350 isolated amplifier and a voltage-divider circuit. The voltage-divider circuit reduces the voltage from ±480V to ±5V which matches the input range of the AMC1350. The AMC1350 is powered from both a high- and low-side power supply. Typically, the high-side supply is generated using a floating supply or from the low-side using an isolated transformer or isolated DC/DC converter. The AMC1350 can measure differential signals of ±5V with a fixed gain of 0.4V/V. The AMC1350 has a differential input impedance of 1.25MΩ which supports low gain-error and low offset-error signal-sensing in high-voltage applications.



**Design Notes**

1. The AMC1350 is an excellent choice for voltage-sensing applications due to the high input impedance and low input bias current, both of which minimize the DC errors.
2. Verify the linear operation of the system for the desired input signal range. This is verified using simulation in the *DC Transfer Characteristics* section.
3. Make sure the resistors used in the resistor divider circuit are capable of reducing the source input voltage to the AMC1350 input voltage range of ±5V.
4. Make sure the resistors in the resistor divider circuit have sufficient operating current and voltage ratings.
5. Verify that the AMC1350 input current is less than ±10mA as stated in the absolute maximum ratings table of the data sheet.

**Design Steps**

1. Calculate the ratio from the voltage source to the input of the AMC1350 for the voltage-divider circuit.

$$\frac{5\mathrm{V}_{\mathrm{AMC1350,\,INPUT}}}{480\mathrm{V}} = 0.010417$$

2. The typical input impedance of the AMC1350 is 1.25MΩ. This impedance is in parallel with resistor $R_5$ and must be considered when designing the voltage-divider circuit. Select 1MΩ resistors for $R_1$, $R_2$, $R_3$, and $R_4$. Using the ratio from the previous step and the following voltage-divider equation, solve for the equivalent resistance required for the voltage-divider parallel combination ( || ) of $R_5$ and the AMC1350 input impedance.

$$\frac{\mathrm{R}_5||\mathrm{R}_{\mathrm{IN,\,AMC1350}}}{\mathrm{R}_1 + \mathrm{R}_2 + \mathrm{R}_3 + \mathrm{R}_4 + \mathrm{R}_5||\,\mathrm{R}_{\mathrm{IN,\,AMC1350}}} = 0.010417$$

$$\frac{\mathrm{R}_5||\mathrm{R}_{\mathrm{IN},\,AMC1350}}{4\mathrm{M\Omega} + \mathrm{R}_5||\,\mathrm{R}_{\mathrm{IN},\,AMC1350}} = 0.010417$$

$$\mathrm{R}_5||\,\mathrm{R}_{\mathrm{IN,\,AMC1350}} = 42{,}736.37\Omega = \mathrm{R}_{\mathrm{EQ}}$$

3. Substituting 1.25MΩ for the AMC1350 input impedance and using the following equation, solve for $R_5$. Use the analog engineer's calculator to determine the closest standard value for $R_5$.

$$\mathrm{R}_{\mathrm{EQ}} = 42{,}736.37\Omega = \frac{\mathrm{R}_5 \times \mathrm{R}_{\mathrm{IN,\,AMC1350}}}{\mathrm{R}_5 + \mathrm{R}_{\mathrm{IN},\,AMC1350}} = \frac{\mathrm{R}_5 \times 1.25\mathrm{M\Omega}}{\mathrm{R}_5 + 1.25\mathrm{M\Omega}}$$

$$42{,}736.37\Omega(\mathrm{R}_5 + 1.25\mathrm{M\Omega}) = \mathrm{R}_5 \times 1.25\mathrm{M\Omega}$$

$$\mathrm{R}_5 = 44.249\mathrm{k\Omega};\quad \text{closest standard value} = 44\mathrm{k\Omega}$$

4. Verify that the equivalent resistance is close to the calculated resistance from step 2.

$$\mathrm{R}_{\mathrm{EQ}} = \frac{\mathrm{R}_5 \times \mathrm{R}_{\mathrm{IN,\,AMC1350}}}{\mathrm{R}_5 + \mathrm{R}_{\mathrm{IN,\,AMC1350}}} = \frac{44\mathrm{k\Omega} \times 1.25\mathrm{M\Omega}}{44\mathrm{k\Omega} + 1.25\mathrm{M\Omega}} = 42.503\mathrm{k\Omega}$$

5. Verify that the voltage-divider circuit is within a reasonable error tolerance. For the following calculation, the input resistance of the AMC1350 is assumed to be the typical value of 1.25MΩ and this results in an error of 5.1%. However, consider that the input resistance varies from device to device due to variations in manufacturing tolerance. If this error range is unacceptable then either a calibration must be performed or the resistance of the voltage-divider circuit can be scaled down.

$$\frac{42.503\mathrm{k\Omega}}{4.042503\mathrm{M\Omega}} = 0.01051$$

$$\mathrm{Error\%} = \frac{|\mathrm{Actual} - \mathrm{Calculated}|}{\mathrm{Calculated}} \times 100 = \frac{|0.01051 - 0.010417|}{0.010417} \times 100 = 0.9\%$$

6. Calculate the current flowing through the voltage-divider circuit from the voltage source to make sure that the power dissipation does not exceed the ratings of the resistor. For additional details, see *Considerations for High Voltage Measurements*.

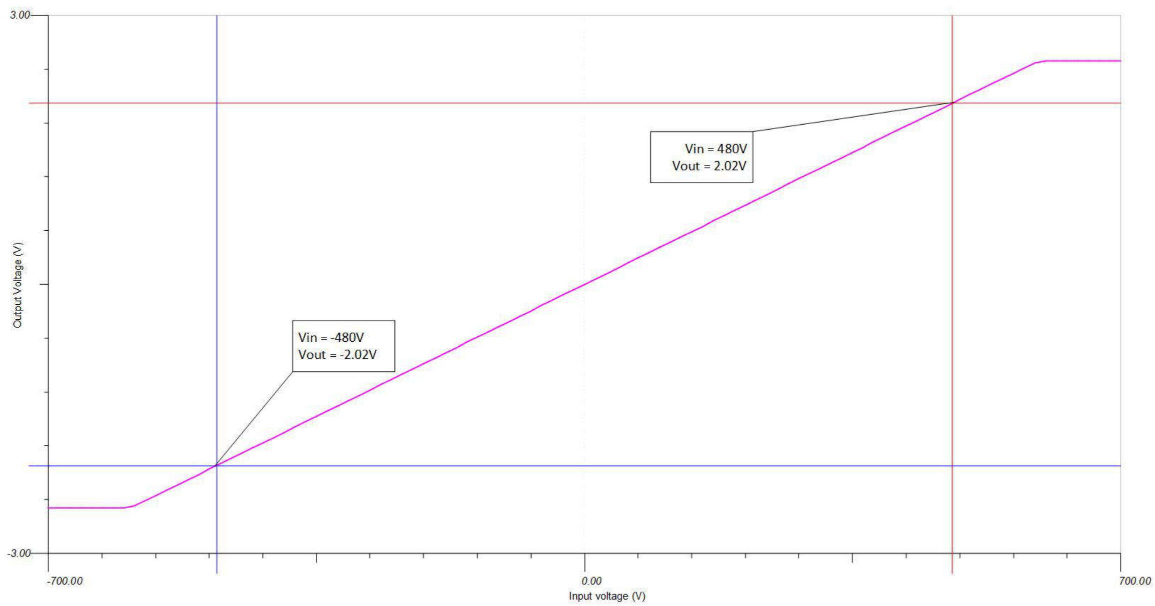
$$V = IR; \frac{V}{R} = \frac{480V}{4M\Omega + 42k\Omega} = 118.69\mu A$$

7. Since the gain of the voltage divider is 0.010417 and the gain of the AMC1350 is 0.4V/V, the output voltage can be calculated for an input voltage of 480V using the transfer function equation, $V_{OUT}$ = Gain × $V_{IN}$.

$$V_{OUT} = \frac{5}{480} \times 0.4 \times 480 = 2V$$

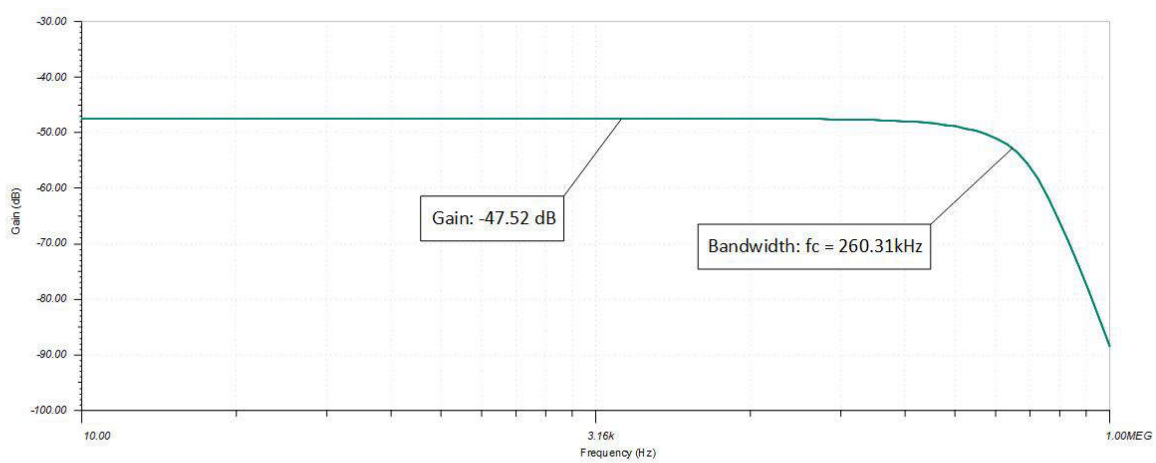
## DC Transfer Characteristics

The following graph shows the simulated output of the AMC1350 for a ±480V input. The output voltage is about 2.02V for an input voltage of 480V, as calculated in step 7.



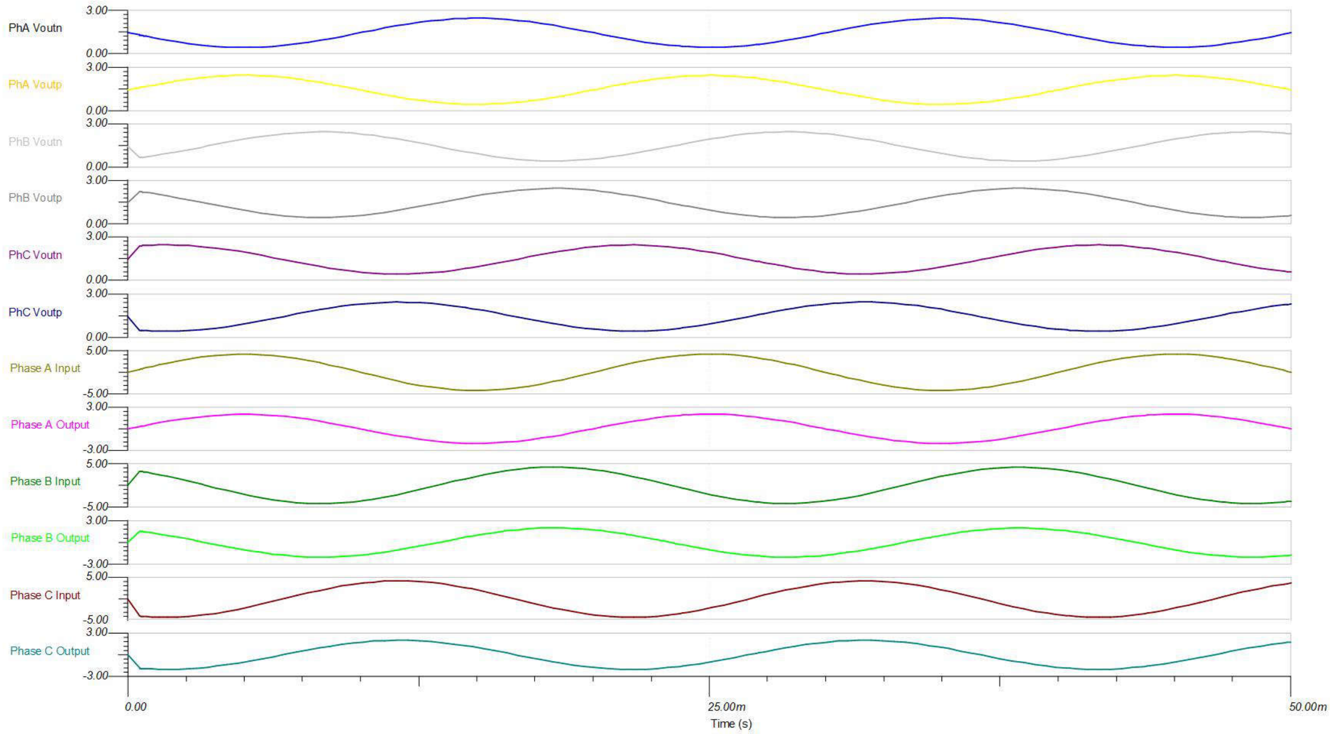

## AC Transfer Characteristics

The simulated gain is –47.52dB (or 0.0041V/V) which closely matches the expected gain for the voltage divider and AMC1350.



### Transient

The following simulation shows the input and output signals of the AMC1350.




### References

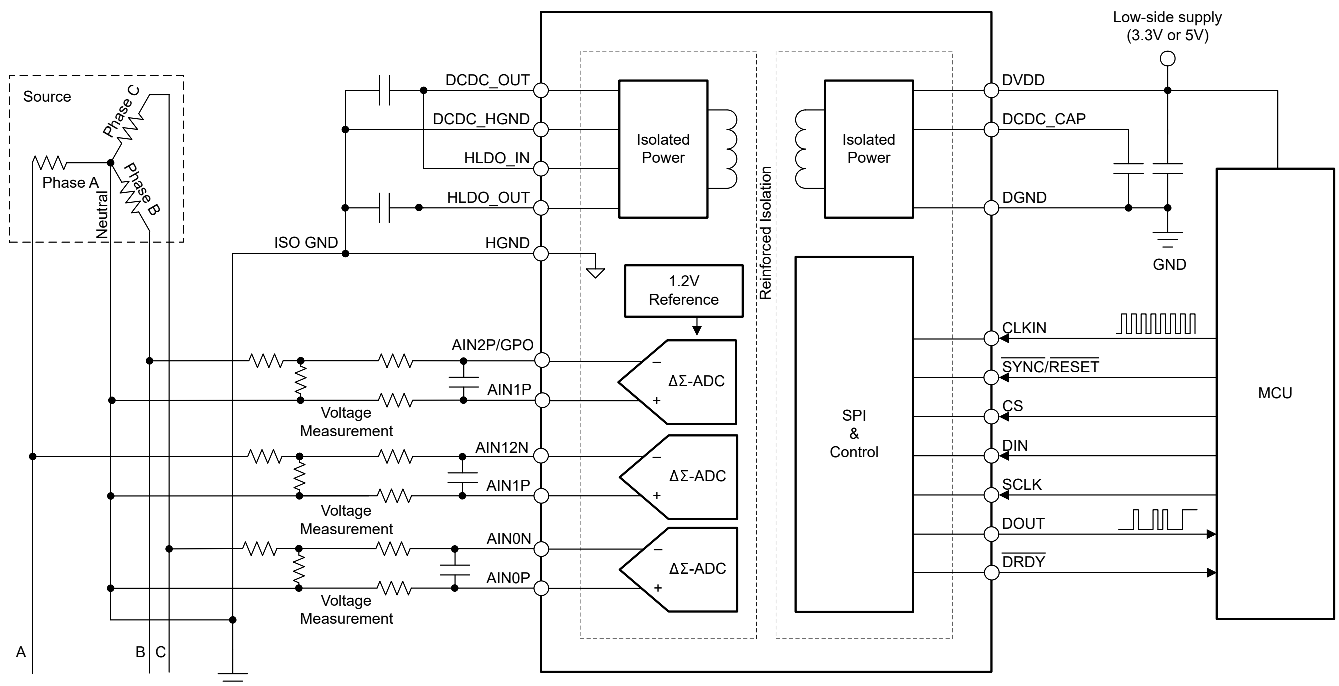
1. Texas Instruments, *An Engineer's Guide to Isolated Signal Chain Solutions E-Book*
2. Texas Instruments, *Split-Tap Connection for Line-to-Line Isolated Voltage Measurement Using AMC3330 Analog Engineer's Circuit*
3. Texas Instruments, *Analog Circuits Design and Development*
4. Texas Instruments, *TI Precision Labs*

### Design Featured AMC0330D, AMC0330R, AMC0330S

| AMC0330D | |
|---|---|
| VDD1 | 3V to 5.5V |
| VDD2 | 3V to5.5V |
| Input Voltage Range | ±1V |
| Nominal Gain | 2 |
| Input Resistance | 1GΩ (typical) |
| Output Bandwidth | 110kHz (typical) |
| Input Offset Voltage and Drift | ±1.5mV (maximum), ±10μV/°C (maximum) |
| Gain Error and Drift | ±0.25% (maximum), ±40ppm/°C (maximum) |
| Nonlinearity | 0.05% (maximum) |
| Isolation Transient Overvoltage | $7kV_{PEAK}$ |
| Working Voltage | $1kV_{RMS}$ |
| Common-Mode Transient Immunity, CMTI | 50V/ns (minimum) |
| AMC0330D, AMC0330R, AMC0330S | |

### Design Alternate AMC131M03

The AMC131M03 is a precision, low-power, isolated, three-channel delta-sigma (ΔΣ) analog-to-digital converter (ADC) with reinforced isolation that, in conjunction with a voltage divider, can also be used to perform three-phase, line-to-neutral, isolated, voltage-sensing measurements. Each channel of the AMC131M03 needs to connect to one of the three-phase voltages through a resistor divider to scale down to the input voltage range of the ADC. This device features a fully integrated isolated DC/DC converter that allows single-supply operation of 3.3V or 5V from the low-side of the device. When the measurements are conducted by the device, the ADC converts the three-phase measurements into digital data. The digitized data can be output by the device through serial peripheral interface (SPI) communication, allowing for direct communication to a microcontroller. The dynamic range, size, feature set, and power consumption are optimized for cost-sensitive applications requiring simultaneous sampling.




| AMC131M03 | |
|---|---|
| $V_{DVDD}$ | 3V to 5.5V |
| Input Voltage Range | Vref / Gain |
| Gain | Programmable gain up to 128 |
| Input Offset Error and Drift (Channel 0,1) | ±100μV (typical), ±0.5μV/°C (maximum) |
| Input Offset Error and Drift (Channel 2) | ±120μV (typical), ±0.5μV/°C (maximum) |
| Gain Error and Drift (Channel 0) | ±0.2% (maximum), ±25ppm/°C (maximum) |
| Gain Error and Drift (Channel 1,2) | ±1% (maximum), ±25ppm/°C (maximum) |
| Nonlinearity | 6ppm of FSR |
| Isolation Transient Overvoltage | $7070V_{PEAK}$ |
| Working Voltage | $1.2kV_{RMS}$ |
| Common-Mode Transient Immunity, CMTI | 100V/ns (minimum) |
| AMC131M03 | |

## Trademarks

All trademarks are the property of their respective owners.