AC Voltage Sensing

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## # **AC Voltage Sensing Hardware**

To achieve the sensing of the AC voltage at the output of the power inverter, the approach is more involved than the DC voltage sensing methodology. Not only does a step down mechanism need to be implemented to provide a low power sensed signal to a processing device, but also a method to handle or correct for the the bipolar nature of the AC wave, namely the negative swing. More specifically, the AC voltage sensing network needs to be able to scale a 12V-48Vpk signal to 0-5V signal in order to be compatible with the ADC122S021, which is used for output voltage and current sampling. The ADC122S021 serves as the intermediary between the ATMEGA328P and the AC sensed signal. It samples the output produced by the AC voltage sensing network and transmits the data to the ATMEGA328P via SPI communication. The ATMEGA328P receives the sensed data by requesting channel 1 of the ADC122S021 and uses it to compute the RMS reading of the voltage.

<h7><b>Figure X.</b> AC Voltage Sensing Block Diagram </h7>

This section covers the hardware implementation for the AC sensing framework as illustrated above. To learn more about how the voltage RMS computation is performed and other key considerations for the software design, see the section [AC Voltage Sensing](../software/modules/ac_voltage_sensing).

## **AC Voltage Sensing Network**

<h7><b>Figure X.</b> AC Voltage Sensing Network </h7>

The design is comprised of two main stages: 1. **ZMPT101B Transformer** - Voltage step-down using 1:1 isolation transformer - Well known and documented for projects that interface with Arduino/ESP/RaspberryPi devices 2. **Signal Conditioning and Amplification** - A cascaded pair of inverting op-amp configurations to amplify the low-voltage sensed signal - Tunable gain set by a potentiometer that aims to reduce potential saturation or improve resolution at AC sensing output - Active low-pass filter attenuates high frequecy noise and improve signal integrity

## ZMPT101B Transformer

The first stage is based on the ZMPT101B current transformer. It is a 1:1, 1000V, 2mA rated transformer. For a more thorough documentation of the component, please review the [ZMPT101B datasheet](https://5nrorwxhmqqijik.leadongcdn.com/attachment/kjilKBmoioSRqlkqjoipSR7ww7fgzb73m/ZMPT101B-specification.pdf).

The input to output voltage relation describing the transformer operation is stated in ***Figure II***:

where: - is the input voltage - is the output voltage - is the current limiting resistor - is the voltage sampling resistor

In efforts to maintain consistency with the previous AC Voltage Circuit diagram, we will denote , , , as , , , respectively. Therefore, the newly denoted equation is

## 🔢 Calculating

To achieve higher levels of Signal-to-Noise Ratio (SNR), better ADC range, and noise immunity, a current limiting resistor should be selected such that the magnitude is near the rated current but not exceeding. Choosing a current limiting resistor is based on the highest expected voltage that will be delivered to the input primary side of the transformer. Recalling that the maximum peak voltage for the power inverter is 48V, and considering that the transformer has a rated current of 2mA, a max current value of 1.5mA is chosen. This ensures that is maximized in signal strength to improve resolution, but also provides buffer from operating the part at rated conditions.

* Choose based on standard resistor values

## 🔢 Calculating

The sampling resistance linearly influences the transformer AC voltage output as per the equation in ***Figure II***. By rearragning the ZMPT101B expression, this renders the following equation usable for solving the sampling resistor in a passive configuration where no amplication is present.

However, this expression is not directly applicable since it makes use of an active configuration. Nonetheless, it can be adapted to suit the needs of the current design as detailed in the next section.

## Signal Conditioning and Amplification

The second stage of the **AC Voltage Sensing Network** is a combination of two inverting amplication phases that serve the purpose of amplifying the low voltage signal produced across the sampling resistor. Each level provides an amplication factor of 10, yielding a net gain of 100. To develop a transfer function that accounts for this two op-amp amplification chain in the AC voltage sensing network, this gain stage can be modeled by a variable . This net gain is also equivalent to the product of the two intermediate gains .

The AC voltage from output to input then can be described as:

It is important to note that refers to the desired AC magnitude that will be provided to the ADC122S021 after the two op amp chain whereas is the AC magnitude at the secondary of the transformer.

The amplification phases are also designed to attenuate high frequency noise, as they are based on the active low pass filter topology. This is necessary because although the output of the transformer is being amplified in two segments, the noise present at the op-amp inputs can also amplified. It is beneficial to have this embedded into the design since needs to be a clean waveform for accurate readings from the ADC122S021.

The cutoff frequency of this 1st order low-pass filter can be calculated using the following formula:

Another key feature of the AC Voltage Sensing Network is the potentiometer, as it also impacts the magnitude of . Since the potentiometer functions as a voltage divider, it can be modeled by introducing two resistors: , the resistor in series with the signal path, and , the resistor connected to ground. Therefore, the divider ratio is:

Since the divider ratio is effectively a gain constant between the first and second op amp chain, both of which are linearly combined, the specific placement of this term has no effect on the computation.

To obtain the final sampling resistor equation that, we can isolate for the sampling resistor:

The AC portion of the signal must remain within the saturation limits of the LM358 op-amp due to resulting amplified signal being centered around a 2.5V DC offset, which is caused by the resistors.

Since the LM358 op amp saturates at about 1.5V from the supply voltage (i.e. 5V - 1.5V = 3.5V), then the maximum permissible swing is .

The worst case scenario for potential saturation occurs when the potentiometer provides no gain attenuation (i.e ), resulting in an amplification of = 100 applied to . Using this case to calculate the sampling resistor is performed for both ends of the inverter range.

**= 12V:**

**= 48V:**

* Choose based on standard resistor values, as this accomodates for both 12V and 48V . The effective resolution of the sensed signal can then be improved by reducing , as this increases the output swing without exceeding the op-amp’s output swing range.

## Simulation

The AC voltage sensing topology was simulated using LTSpice to verify operation. Since the LM358 is not an available in the component library, the OP07 amplifier was used as a suitable substitute.

<h7><b>Figure X.</b> AC Voltage Sensor Network Simulation Circuit </h7>

<h7><b>Figure X.</b> AC Voltage Sensor Network Simulation Signals Plot </h7>