An Open-Lead Detection Voltmeter Circuit

A novel voltmeter design that can automatically detect open leads.

Nicholas Mann[1]

Introduction

Introducing the Mann Voltmeter Bridge Circuit[2]. This is a voltmeter circuit that allows a voltmeter to distinguish quickly and safely between when a zero volt reading means "the probes are on the same net" and "current cannot flow between these two points."

The primary application of this circuit is to speed up the testing and troubleshooting process by allowing the user to quickly determine on live circuits if two points with zero voltage potential are on the same net or isolated from each other.

Design

Concept

The Mann Voltmeter Bridge works by putting a MOSFET in a differential voltmeter bridge. This bridge uses two ADC connections on either side of a resistor to track and compare the voltage on either side. One side is always a fixed voltage, while the other side varies in direct ratio to the input voltage. The test leads connect to either side of the bridge in series with high value resistors. These both form a divider network and limit current (see figure 1).

Truth Table of Conditions		
Condition	**MOSFET OPEN**	**MOSFET CLOSED**
Voltage Probes Floating	Lower Voltage on far ADC	No Differential Voltage
Voltage Actual 0 (same net)	Similar Voltage on Both ADCs	No Differential Voltage
Voltage on Contacts	Voltage goes to diode limit	Normal Voltmeter

[1] Nick@OIHDesigns.com; Electronics Technician, Private Industry. This paper is written in a personal capacity.

[2] *Research indicates this is a novel circuit design and function. If this is a mistake and someone has already designed this please reach out.*

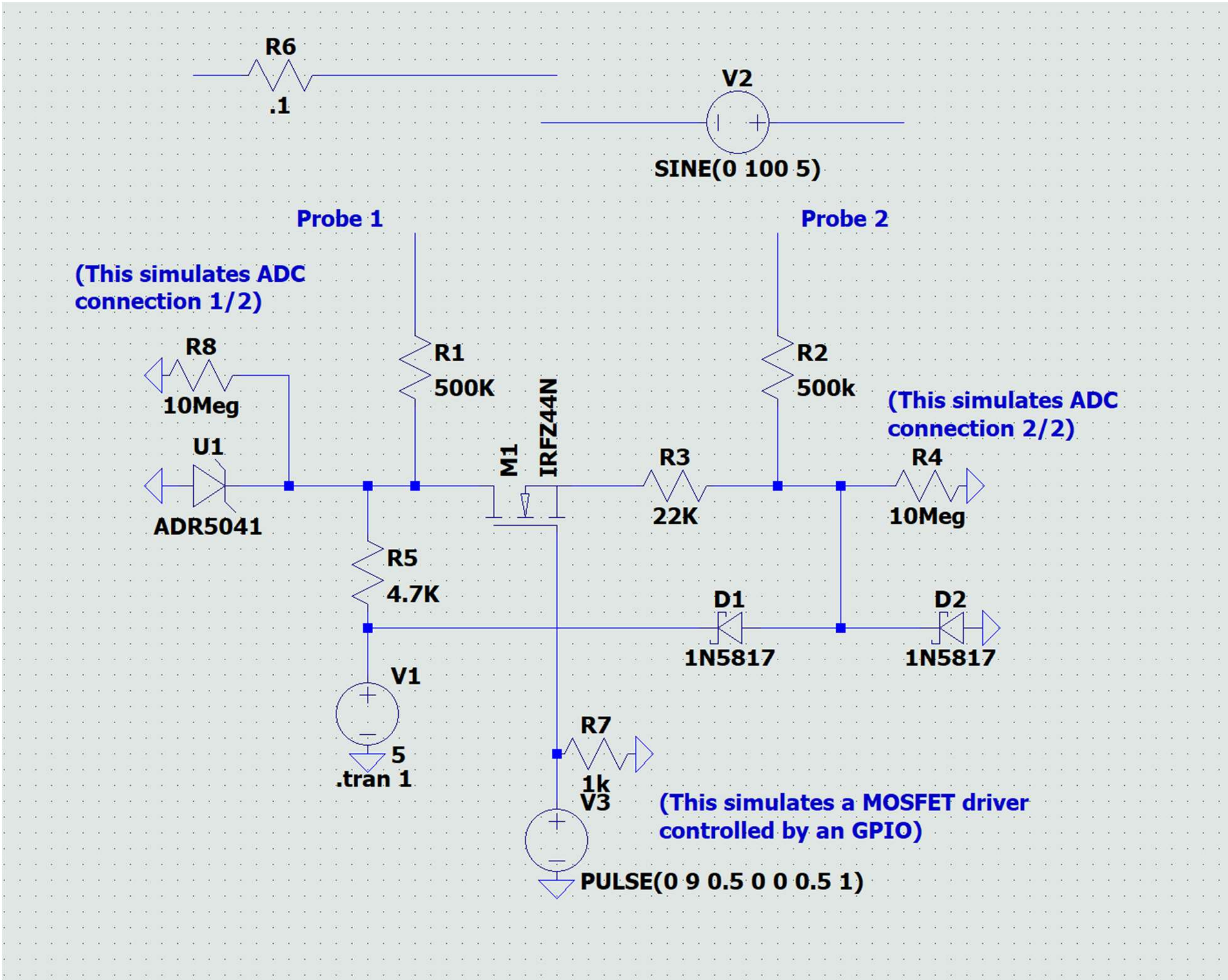

Figure 1 Schematic of the Voltmeter Bridge

The MOSFET is placed in series with the bridge resistor, is normally on (conducting), and does not affect voltmeter operation. The MOSFET is turned off when the differential ADC measurement is ~0v, breaking the bridge, and then a single-ended measurement is taken by the ADC on the far side of the bridge. If the voltage is approximately the same (~2.2vdc above ground in my example) that indicates the probes forming a closed circuit. If the ADC measures close to zero (~0.25vdv) that indications the probes are floating. A value in between indicates either a high impedance or a very low voltage on the probes.

Note that two protective Schottky diodes are used on the varying side of the bridge to prevent damage when the bridge is broken (or from over voltage in general), as there is no longer a voltage divider network.

Design Variations

The maximum potential current sourced from the probes can be further limited by adding a resistor in parallel with both the MOSFET and sense resistor (see figure 3). For the circuity values in the schematic, adding a 1MOhm resistor (R9 in schematic) here cuts the maximum potential current through the probe tips by approximately half (from ~240 to ~120nA), as well as dramatically cuts the potential voltage on from one side to the other (from an approximately 2vdc maximum potential difference to a maximum potential of ~600mV[3]). This reduces the risk of the voltmeter probes causing harm to a circuit under test, but also but reduces the potential to learn useful information from an intermediate state. The more desirable configuration may depend on the end user's desire between protection and greater information.

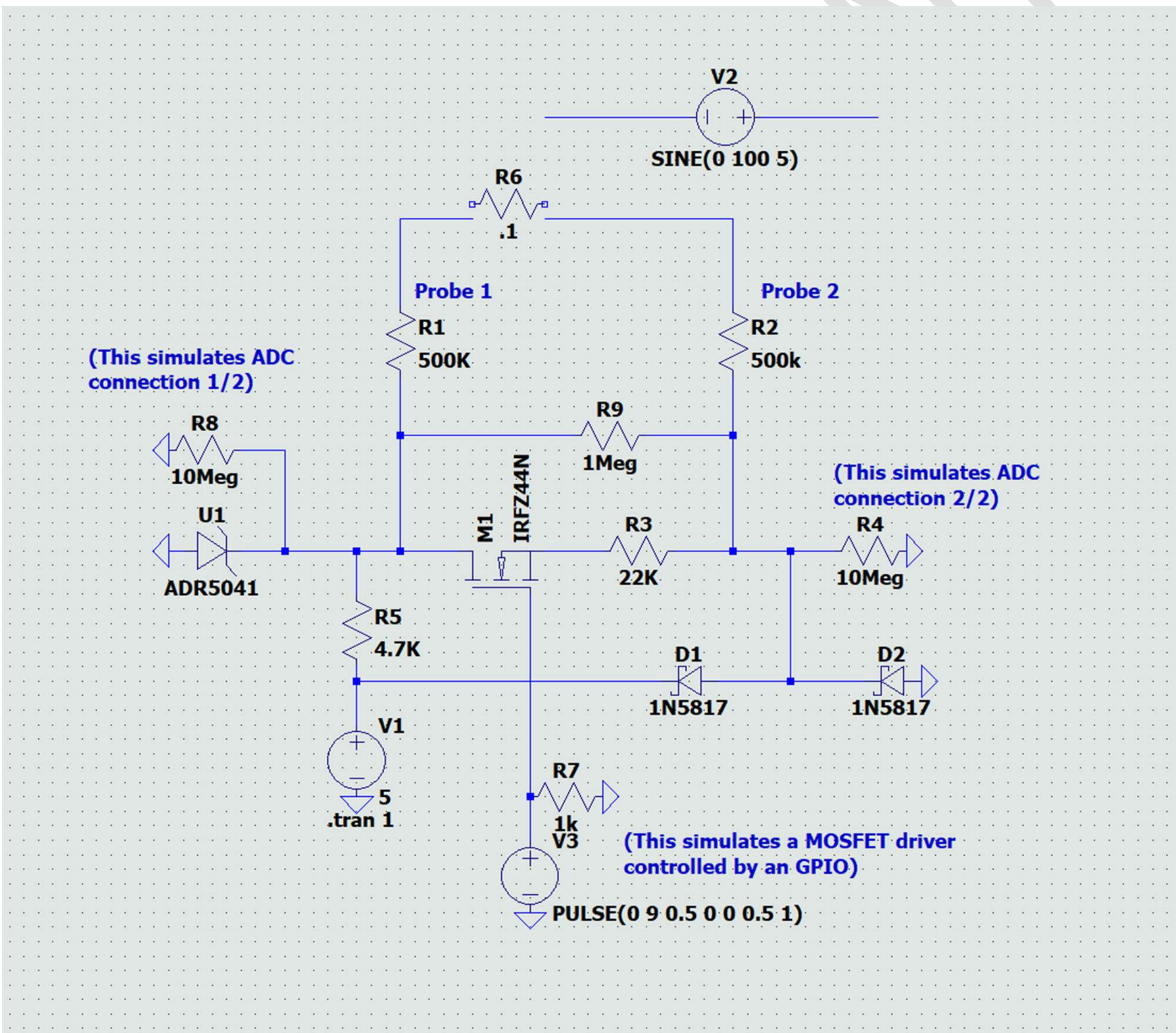

Figure 2 An alternate version where R9 reduces maximum probe voltage.

[3] Due to the low level nature of the signal the precise value is difficult to confirm against the simulation. The author has measured peaks of ~600mV across a 10M Ohm DMM, ~100mV across a 1M Ohm scope input, and <10mV across a 50 Ohm scope input.

Testing

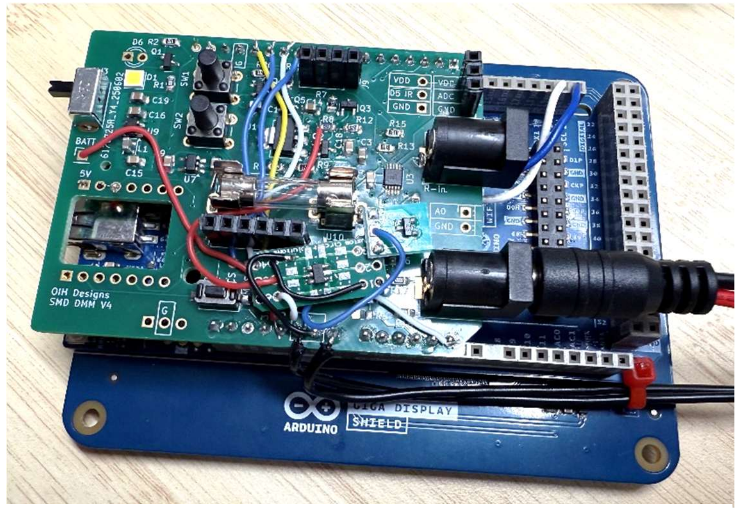

Figure 3 The Circuitry. The MOSFET and a driver IC are seen on breakout boards at bottom center

Both versions of this circuit have been tested as part of a broader custom instrumentation circuit (with a focus on multimeter function). This specific circuitry was installed on a Arduino Giga development board. The ADC used is a TI ADS1115.

Please note that while the schematic above uses an IRFZ44N, an SI2302 is used in application due to a much smaller footprint and similarly low Rds-On spec. Similarly, the 2.5vdc LM4040 is used instead of an ADR5041 due to specific parts on hand, the bridge resistor value was changed to 15K to adjust the divider network so the full North American mains power amplitude can be measured.

The author has tested the function up to standard North American 120VAC, and confirmed that the circuits functions as expected to automatically report voltage, open leads, or shorted leads on the fly.

Contrast with Traditional Voltmeter Designs

In contrast with traditional voltmeter designs that read and report voltage without automatic continuity checks, this design enables the meter give the user information about what the “0v” actually means:

Probes Separated By:	**Reading**	
	Normal Meter	**Mann Voltmeter Bridge**
Copper - Same Net	0v	“Leads Closed”
Air Gapped	0v	"Open Lead"
Open Relay	0v	"Open Lead"
Diode (unenergized)	0v	Reading is function of polarity and type
Autotransformer, primary to secondary, (unenergized)	0v	"Undefined" - Function of Impedance and Design
Isolation transformer, primary to secondary, (unenergized)	0v	"Undefined" or “Floating" - Function of Isolation and Design
DIO Contact, Output Low	0v	“Leads Closed”
Resistor, or other impedance, energized	Voltage	Voltage

Some current DMMs on the market offer a "Smart Mode" or similar where the meter switches to ohmmeter circuity after a 0v reading, and many bench DMMs offer the ability to run custom programs and can be commanded to switch modes after a 0vdc reading. Both of these are functionally the same as the operator manually changing modes, and are fundamentally different than this paper's voltmeter design. Switching modes exposes the ohmmeter circuity to damage, and generally requires the operator to pause and confirm a switch has been made, or more importantly, that the meter is switched back to voltmeter mode for further readings. This circuit is fundamentally different than these because it does not switch to ohmmeter circuitry, and therefore does not expose that circuitry to damage. All open-lead detection is done from behind the protective voltmeter inputs.

Applications

The Mann Voltmeter Bridge builds on common and useful multimeter features such as a continuity alert in ohmmeter mode and alarms that alert the user when a probe is inserted into the wrong jack for the current mode. These features, while not required for making measurements, allow the user to work more efficiently and safely.

The ability to quickly determine if a 0vdc reading is a true zero or an artifact of floating probes is useful for troubleshooting any electrical devices with relays, isolation, or components that can otherwise be brought in and out of circuit. It also allows immediate confirmation that a DIO commanded low is continuous with ground. Immediately knowing the difference between "these point are on the same net" and "current is neither attempting to, nor does it flow between these points" can dramatically increase the speed of testing and troubleshooting live circuits, while also reducing the chance for errors that cause damage to either the test equipment or the circuitry being tested.

Currently, a meter must be switched to ohmmeter circuitry to determine if a zero voltage reading is an actual zero. Best practice also dictates the device under test is de-energized to ensure that neither ohmmeter circuitry nor the device's circuitry are damaged if a probe accidentally contacts voltage. This may add significant time to troubleshooting, and attempts to save time by not de-energizing a circuit pose the risk that a probe slip in ohmmeter mode causes damage. This voltmeter design automatically checks continuity for the user, with a non-perceptible delay to useful readings, and can be implemented to alert the user in the same way as multimeters currently use for ohmmeter continuity checks.

In additional to manual circuit troubleshooting, this circuitry has the potential to simplify process monitoring. For example, the same two wires across a motor could report the voltage going to the motor and, when none, immediately report if the motor is still in circuit or not. Knowing immediately if a motor has failed open or short could save valuable troubleshooting time. A VFD or other process controller could also then refuse to reenable voltage without the expected low impedance measurement first, potentially preventing voltage when a wiring or other user error has occurred.

Areas for Further Development

Further experimentation and testing is needed to quantify the sets of resistor values that balance minimizing energy into the circuit against signal strength for any given application. The reading in the "Undefined" state contains information, which may be useful to quantify the degree and nature of impedance the circuit is encountering, and some users may prefer a greater degree of signal here[4], while other applications may call for minimizing the energy sourced from the probes to only the level required to identify an open circuit.

The test frequency in the current prototype is limited by the sample rate of the ADS1115 ADC (860Hz best case). A different ADC with a higher sample rate has the potential to dramatically increase the possible sampling speed.

Conclusion

The Mann Voltmeter Bridge is a novel circuit to speed the testing and troubleshooting of electronics, and is the first design that allows continuity to be measured on the fly without sacrificing regular voltmeter input protections, nor does it require the use of a relay or other mechanical switch to make or break contacts. This paper shows are two variations, one with a greater voltage drop between probes to give the user more information, and a second version with a smaller voltage drop to minimize the risk of damage to sensitive electronics.

Further Reading

This was developed as part of my broader custom DMM / voltmeter project. That project is documented in extensive detail here:

https://www.oihdesigns.com/arduino-multimeter-project

A video of the circuit functioning can be found:

https://www.youtube.com/watch?v=Hc1zJ1Zz5n8

[4] Particularly as to identifying between an inductive load or short circuit. This may also require pulsing the circuit.