Measurements with the ISOVP Probe Guide

Advantages of optically isolated probes

Optical isolation has become a reality in research, industrial measurements and control systems. The advantages offered by such approach mainly benefit floating and high voltage measurements due to the inherent isolation offered. Main advantages of the ISOVP probe are:

▶ Meaurements in high EMI environments. Fiber optic cables cannot pick-up electromagnetic interference, be it from pulsed currents or high dV/dt voltages.

▶ High isolation. Fiber cables present zero capacitance and infinite resistance across terminals for all practical purposes. This provides total safety when making measurements in high voltage areas for example.

▶ Low tip capacitance. The ISOVP probe was designed to minimize tip capacitance since that is what hurts most high frequency measurements. For a given source impedance, the tip capacitance forms a low pass filter that lowers the output signal at high frequencies. Thus tip capacitance should be as an important selection parameter as bandwidth when choosing a probe.

▶ Low common mode loading. Since the optical probe is completely isolated from the environment the only common mode capacitance is the parasitic capacitance from probe to the environment. It is important to obtain keep common mode capacitance as small as possible since voltage transients will produce common mode currents. Due to the small size of the ISOVP probe, this capacitance was measured at around 1.5pF from probe to a ground plane 10cm apart. This capacitance can even made smaller if the user chooses a different setup.

▶ Floating measurements. Floating measurements have become and important part of modern and power electronics, since for the reliable working of switching elements (IGBTs, Mosfets, thyristors...) their gate voltages must be measured, and modern topologies usually stack these semiconductors in order to handle higher voltages. Given appropriate clearance distances between probe head and chassis, optical probes can be safely floated to tens of kV.

▶ High common mode rejection. In power electronics not only it is the norm to find high common mode voltages but also quickly changing ones. And here is where the common mode loading and fiber isolation advantages of optical probes comes into play. Differential probes do have a limited and rapidly decreasing rejection ratio as frequency increases whereas optical probes offer an improved rejection.

▶ Selectable cable length. Up to 15m of fiber cable can be fitted between probe head and receiver.

▶ Hot zero and gain calibration. Due to drifts and temperature changes it is necessary to calibrate optical links. The ISOVP does calibrate the offset and amplitude of the signal and does it while the source is still connected. This increases user safety since there is no need to reach into potentially hazardous areas.

▶ Remote standby and power-off. To increase user safety and battery duration it is possible to put both probe head and receiver into standby mode by pressing a button.

▶ Compatibility with all oscilloscopes. The ISOVP probe can be connected to any scope via a BNC cable. A internal 50 Ohm termination is necessary for proper functioning of the probe but even scopes that do not have this feature can use the probe with an external 50 Ohm feedthrough. An optional external termination (code ISOVPTERM) can be obtained.

Differential probes have been the staple in the measurement of floating voltages. However they are not true isolated devices, their bandwidth is modest and common mode rejection is limited both by high frequency signals and sources with mismatched impedance. Also they are usually noisy and no apt for measuring low voltage values. As an additional remark it should be noted that some high voltage differential probes can show a highly degraded common mode rejection after some time from their manufacture. This is due to poor choice of substrate in the high impedance divider section that may change its dielectric properties without provision for the user to adjust it.

Typical Measurements with the ISOVP probe

The maximum differential voltage input voltage of the ISOVP is specified as ±2.5V although it will not saturate for slightly higher inputs. The included attenuators, x10 and x50 extend the input range to cover most practical measurement needs.

The input connector in the ISOVP probe and attenuators is a SMB RF type, which is convenient for its ease of use, as it is widely available, requires no torque wrench and can be connected to common RG174 or similar coaxial cables. Saker recommends the use of good quality SMB connectors, for example reference R114082000 from Radiall.

When manually positioning the probe head keep in mind the unit is physically joined to the receiver unit, so that when pulling the probe head you may accidentally throw the receiver into the floor. Also care must be taken not to trip over the fiber cable that joins both receiver and probe head as this will probably send both units to the floor possibly causing a unit fault.

Attenuators included with the ISOVP probe

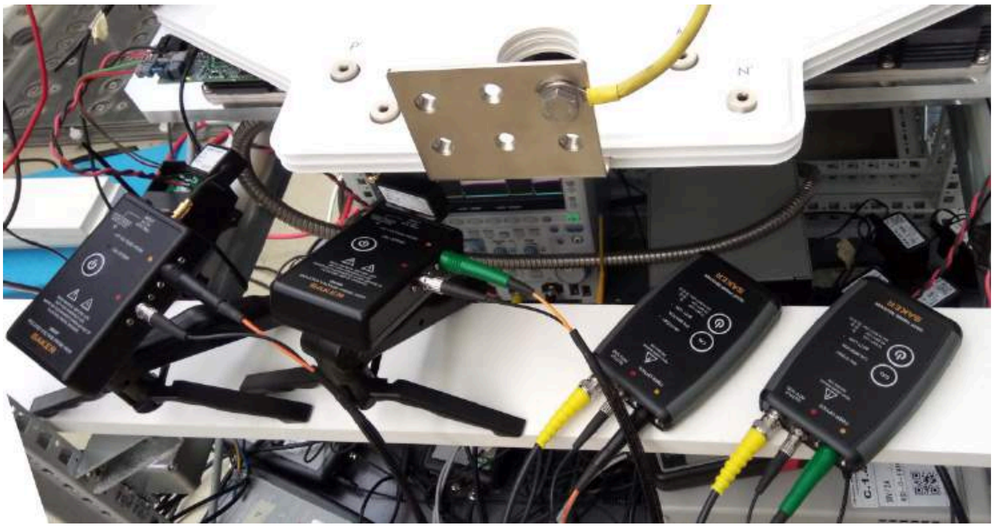
SMB type input connector

It is always recommended that the probe head be installed over a tripod mount. This will give the probe some mechanical stability and assure clearance between the probe and its surroundings. Always remember that all metallic parts in the probe head are at the same potential.

The ISOVP unit comes with two adapter cables, one with mini grabbers, the other unterminated so the user can make the appropriate connection to the particular setup. The mini-grabbers will easily connect to thin wires or small IC pins like the SO-8 package. The unterminated SMB cable leaves freedom of choice for the user to make additional terminations. In most measurement cases a typical straight 2,54mm 2 pin header installed in the board will make for a good enough connection. Additional SMB unterminated cables can be obtained (code ISOVPUC).

Top and middle: SMB cable with mini-grabbers and unterminated SMD cable (included with the ISOVP probe). Bottom: customer adaptation of an SMB to 2,54mm straight pin cable

Place the probe head firmly in a surface so that it won't accidentally fall, use plastic tie straps if necessary. Once all electrical connections are made, turn-on both probes. The receiver can be placed in the low-voltage safe-area. To save battery it is recommended to place the probe and receiver in standby from the receiver whenever measures are not necessary, this can be done with just a key press in the receiver. Also before taking scope measurements calibrate the probe with the CAL button, and do so from time to time if



Two ISOVP probes with x10 attenuators measuring IGBT gate voltages in a medium voltage multilevel inverter. Note the use of tripods in the probe heads (client provided image)

ambient temperature changes quickly. The ISOVP supports hot calibrations so that you don't need to disconnect the DUT (Device Under Test).

Probing an optocoupler with the supplied mini-grabbers

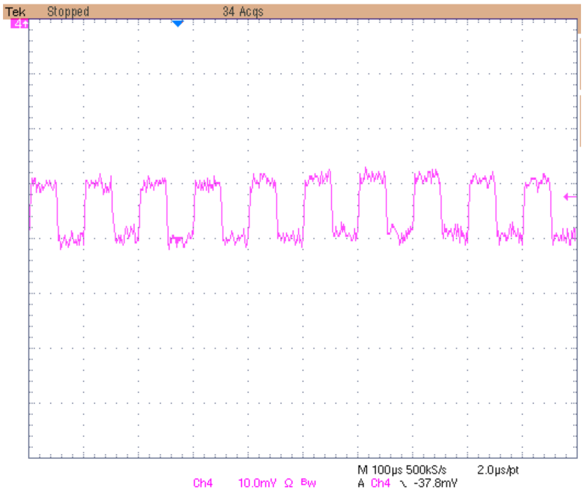
Remember that the receiver requires a 50 Ohm load for the probe to calibrate. If calibration fails check if the center pin of the oscilloscope input BNC is making proper contact with the provided BNC cable.

Low level measurements

The ISOVP probe is well suited to the measurement of low level signals specially if a digital scope with excess bandwidth and sample rate is used.

The inherent x10 attenuation of the ISOVP probe increases noise seen in the scope relative to the signal. However modern digital scopes feature a useful High-Resolution mode that will remove most of the noise from the signal. Moreover, although traditionally 8-bit digital scopes have been the norm, scopes with 12 and 14-bit ADCs are starting to be common in the marketplace. All of this features translate into clearer signals and more noise removed.

As an example we generated a 10mVpp 10kHz square wave and fed it into the ISOVP head with no attenuator. The 8-bit scope was set to High-Res mode, the result of the measurement can be seen in the next image. With 10, 12 or 14 bit scopes the improvement would be more appreciable. The measurement of low levels like this can be useful in noise and ripple measurements.



10kHz 10mVpp signal fed into ISOVP probe with oscilloscope into Hi-Res mode

Ripple measurements

Ripple can be a sign of potential design and reliability problems in some systems. Usually ripple is riding on top of a DC level and most scopes have limited DC offsetting capability when the vertical scale is set to a more sensitive setting. Power supply lines or lines into which switching spikes do interfere could be the target for ripple measurements.

To aid in these measurements, Saker offers an external DC blocking capacitor (ordering code ISOVPDC) with SMB input/connectors. It has a 500V rated 1uF capacitor inside, DC voltage rating that is enough for most practical applications. The AC voltage limit for this accessory is 20Vpk and is there to protect the input of the next stage.

Measurement of high voltages using commercial probes and ISOVP

The maximum measurable voltage with the ISOVP using the included attenuators is limited to about 130V. However there are practical situations where a user may need to measure higher voltages such us those found in bus capacitors, Vce from IGBTs or floating inductors.

The input impedance of the ISOVP probe is specified as 1MOhm with a small capacitance in parallel. This mimics the impedance seen in oscilloscopes and thus the probe is well suited to the use of third-party probes such as common x10, x100 and x1000 passive probes found in the market. The use of x1000 high voltage probes is of special interest due the ample measurement range that they provide.

A well known x1000 probe in the market is the Tektronix P6015A, with a 100MOhm and 3pF input impedance and 75MHz in bandwidth. The use of this probe also adds some delay, 15ns for a 10ft cable. The output compensation box can support scopes with an input capacitance from 7 to 49 pF. For proper pulse accuracy it is of utmost importance to perform the adjustment of the compensation probe box in pulse response for the particular scope that the user is going to make measurements with. A 1000V or higher square pulse should be used to perform such adjustment.

A probe like the P6015A can be connected directly to either the ISOVP probe or through the x10 or x50 attenuators. Together they will allow the user to make safe floating and high voltage measurements. The 6pF input capacitance of the ISOVP probe plus the around 4pF that a BNC RF Tee adaptor adds will bring the P6015A compensation box into adjustment range.

Connection of a 1000x probe through a BNC T. Other types of probes can be connected in the same way. The additional BNC port can be used to add extra compensation capacitance in case the probe needs it.

Measurement of floating signals with high common mode voltages

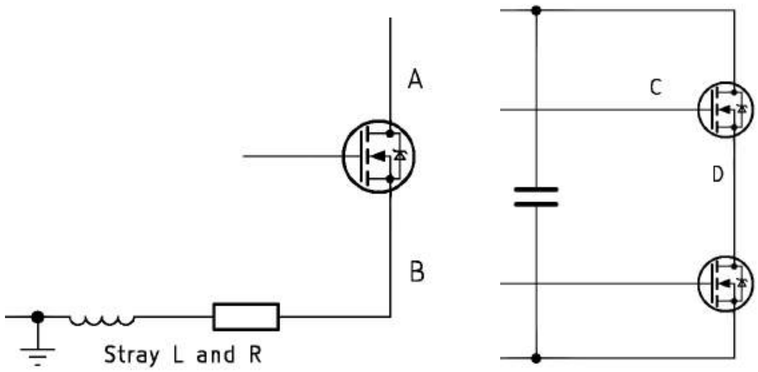
Measurements with differences between grounds, or common mode voltages, are called floating measurements and are said to float by the amount of common mode voltage. An ideal floating measurement would be insensitive to the common mode signals. Common mode voltages can be fairly constant over time or fast varying, the latter happening in modern switched converters.

Modern power electronic topologies rely heavily on switching semiconductors that are stacked to handle higher voltages. Topologies such and CHB, NPC or typical H bridges are examples of this type. In this environment floating measurements are a must for proper troubleshooting, but most probes are ground referenced leaving the user with the only option of differential probes and their limitations or floating a scope with its inherent hazards.

Although some measurements seem to be ground referenced they are best considered as floating measurements since stray inductance and resistance from one of the probing points to ground greatly affect the measurement in high current or fast pulsed systems.

In general the magnitudes that must be considered when making floating measurements are the following:

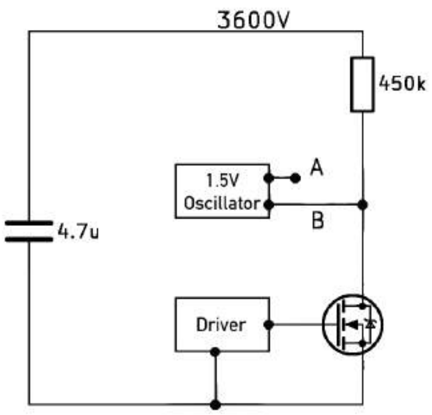
- Differential voltage between probing points
- Source impedance in the probing terminals
- Maximum common mode voltage
- Maximum slew rate of the common mode voltage



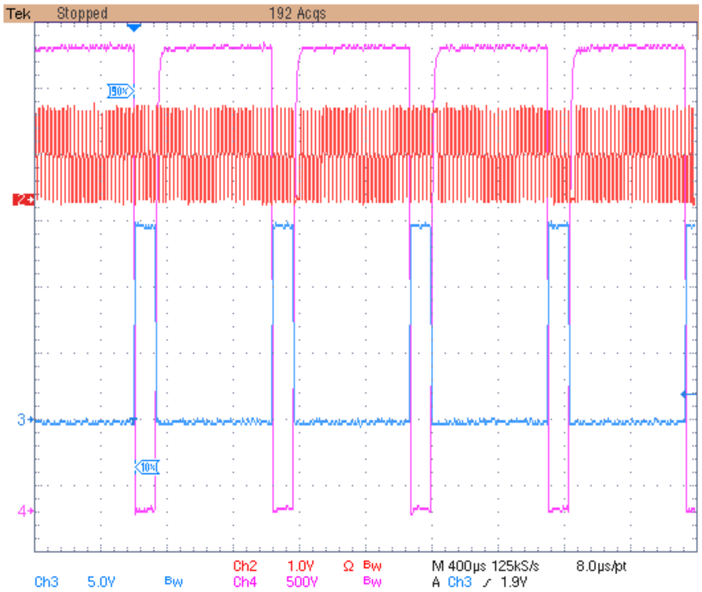
A to B measurement will be greatly affected by high currents and pulsed voltages by stray L and R if taken as a ground referenced measurement. High side gate voltage C to D measurement is typical in power electronics and will need a properly rated probe not only for that particular common mode voltage but also for the switching speeds created by the low side MOSFET.

Optical probes are specially useful when making floating measurements and the ISOVP probe can be safely floated to thousands of volts and will only slightly load the probing points.

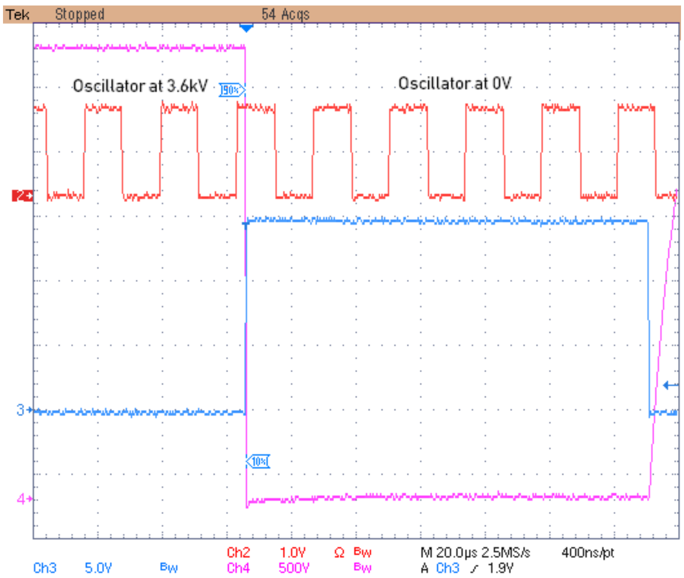
As as test platform for generating large and fast common modes the circuit in the next image was built. By limiting the MOSFET switch current with a large drain resistor it is possible to create varying common mode voltages with high slew rate. A 4.5kV MOSFET (IXTH02N450HV from Ixys) was used in these tests. A 1.5V battery powered 40kHz oscillator is floated at the drain of the MOSFET and the ISOVP probe is set up to measure this voltage directly with no attenuators attached.



Test circuit for generating fast varying medium voltage common modes. Measuring a 1.5Vpp signal riding in a 3.6kV voltage presents a challenge for any researcher. Oscillator and driver are not in sync.

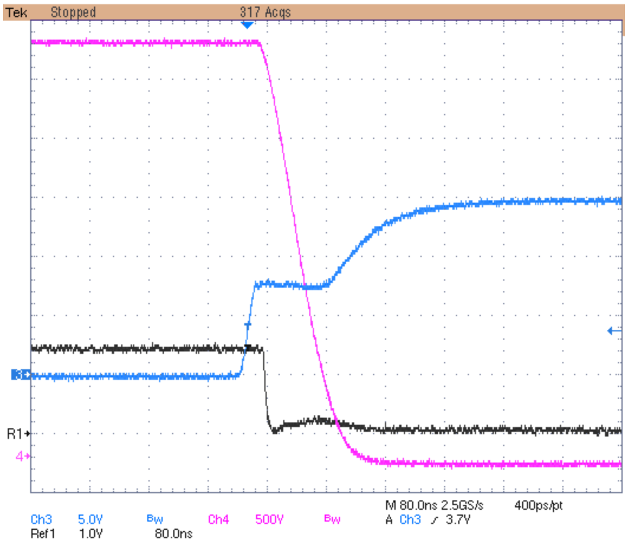


Test circuit measures. CH2: 1.5V oscillator output (A-B) measured with ISOVP probe. CH3: Mosfet Vgs. CH4: Mosfet Vds

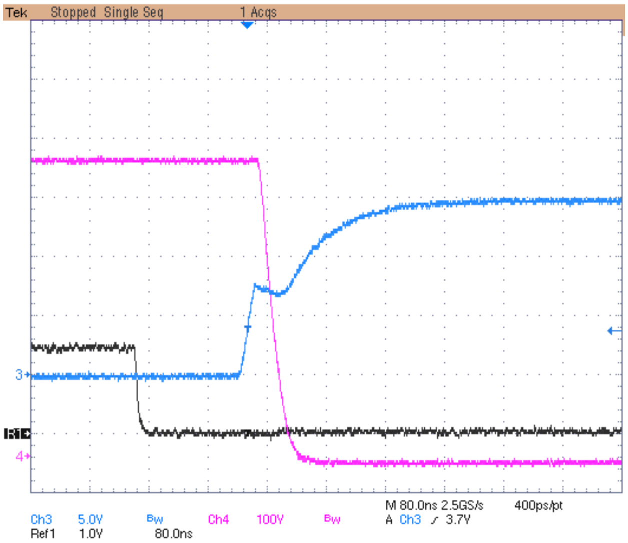


Detailed view of switching pulse. To the left of the CH4 falling edge, the oscillator (CH2) is floating at 3.6kV and at nearly 0 to its right. Such a low voltage measurement is nearly impossible to make with a differential probe given the high common mode of the signal, noise

In making this kind of measurement it is important to keep enough clearance from probe to any metallic part near the circuit. The faster the dV/dt the greater the leakage current will be for a given common mode capacitance.



Falling edge detail of Mosfet drain. CH3: Mosfet Vgs. CH4: Mosfet Vds, has a slew rate in excess of 35kV/us. R1: Oscillator output captured with slight 0.2V distortion from common mode interference at the time of switching



Same measurement as graph in left but with a 500V rail instead of 3600V

About CMRR of probes

A perfect probe would sense only the desired voltage component and reject the entire common mode voltage component. Usually ground referenced probes cannot be used where common modes are present unless the scope itself is isolated. Thus the traditional go to solution has been the differential probe.

Common Mode Rejection Ratio is a measure of how much the amplifier rejects the common mode voltage with respect to the differential voltage. Differential probes are known to have a less than admirable CMRR at high frequencies and the problem gets worse if the impedance of the source is unequal. In optical probes the amplifier is single-ended and since it is floating and there is no ground return an imbalance in source impedances does not imply a worsened CMRR.

Typically CMRR becomes smaller as frequency increases. For historic reasons and easiness CMRR has been measured with a varying frequency tone. However in real life applications no one is measuring pure sine waves but pulsed signals that have multiple frequency components. In reality a performance measure based on slew-rate would be more useful for the developer.

In practice CMRR vs frequency measurements are mostly used to compare performance against different manufacturers and as a marketing tool. However even for this application they are tools with shortcomings. For one, there is not a clear and standard test setup that manufacturers should adhere to, for example the power level of the tone applied as common mode signal. Also CMRR is dependant on the input voltage range of the probe, ie CMRRs would be different for probes with a ±0.5V, ±1 or ±10V input range. Finally some manufacturers include in the CMRR the inherent attenuation of the probe to make for better looking numbers.

General measurement tips and tricks

▶ *Remember the important magnitudes for each measurement*. Every time a measurement with the ISOVP probe is made the most relevant magnitudes should be kept in mind. These magnitudes are to be compared so that no maximum ratings of the attenuators and probe are exceeded and personnel safety is assured.

-Maximum differential voltage to be measured
-Common mode voltage of the source
-Switching frequency slew rate of the common mode voltage
-Source impedances

▶ *Keep probe head and receiver secured*. Both units are joined by the fiber optic cables so be careful when manually placing one of the units, as you may inadvertently throw the other unit to the floor. Also when both units are placed it is possible to trip with the fiber cables. It is thus advisable for example to secure the tripod of the probe head with a plastic, velcro tie or similar. Both units contain sensitive electrooptical components that may suffer if subjected to mechanical shock.

▶ *Maintain clearances*. The whole probe head is optically isolated and can be potentially floated to thousands of volts. A maximum of 50kV has been tested for the ISOVP. However the user should advise the proper clearance given the voltage and the switching frequency of the common mode voltage. Higher common mode frequencies will create larger leakage currents to ground. Always make use of a plastic non-conductive tripod to increase distances between probe and any conductive surface nearby.

▶ *Keep connections to probe short*. General probing techniques apply when making measurements with the ISOVP probe. The amount of care taken in making probe connections should rise when circuits generate large dI/dt or dV/dt swings. Electrical field couples into lines that are not shielded, and magnetic field creates voltage differences in electrical loops. Thus in general it is best to transmit the measured signal in a coaxial cable for the most part of the distance between probe points and attenuator input. The provided SMB to unterminated coaxial cable can be used to tailor specific coaxial to board terminations, like coaxial connectors, 2 pin headers or crimp ring terminals.

▶ *Don't forget about the stand-by mode*. When the probe is not in use make use of the stand-by feature that puts receiver and probe head in low power mode. Measurements are most of time only needed during shorts period of time. The probe head must run on batteries due to isolation requirements and its power consumption is higher than that of the receiver due to the optical transmission requirements.

▶ *Use the auto-calibration*. This feature takes care of the offset and gain adjustment of the probe. Use of these feature only takes a few second and can be run at any given time without disconnecting the input signal, so it is recommended to use it every few minutes and just before any important measure.