A new compact isolated power supply for electrical Metrology at low signal levels

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Abstract

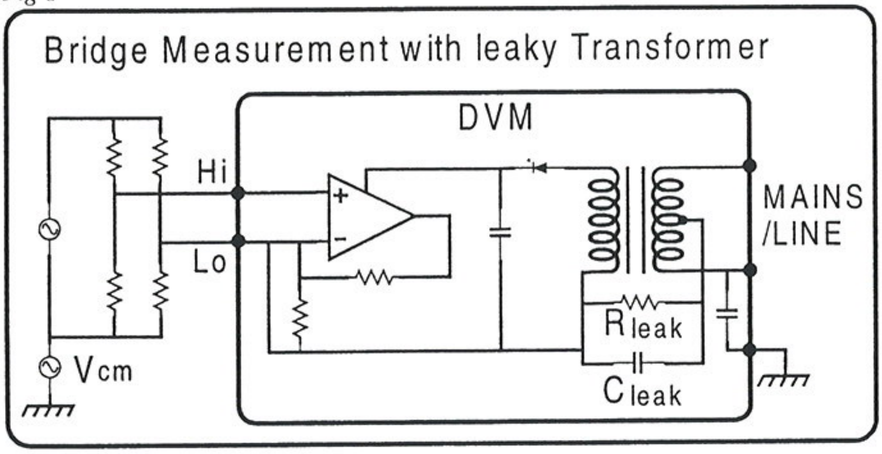
Many measurement situations call for true galvanic isolation between the measurer and the measurand (source). There are two basic reasons for isolation. For better measurements it is necessary to ensure that leakage currents that flow to power supply ground do not mix with signal currents and from the safety point of view that such leakage currents do not cause damage or injury. In these situations both DC and AC leakage can cause problems and whilst DC is relatively easy to control, AC leakage inevitably passes through the stray coupling capacitances in the Power Supply, particularly its transformer. In order to minimise this AC current 50/60 Hz linear supplies are the virtually exclusive choice of power supply technology in metrology applications.

This paper reports on the requirements, design and performance of a low power (7 W output) DC-DC converter capable of achieving leakage currents at its AC switching frequency of a few nanoAmps or less. It has the advantages of small size, lower capacitance and much higher efficiency than its counterpart. Early 2 W versions are used in a precision current source for the Large Hadron Collider project at CERN and in a new Wavetek Voltage reference source [1] and more recently it is being developed at somewhat higher power levels for general metrology applications at NPL.

The Importance of Isolation

The importance of power supply isolation has been covered extensively elsewhere but notably in NPL report DES 129 [2]. A common example of problems can be seen with the use of a mains powered digital voltmeter (DVM) as in Figure 1 where the presence of transformer leakage components clearly affects the voltage being measured in the bridge circuit.

Fig 1



The Hi terminal of the DVM feeds a very high impedance internal amplifier and negligible current flows through it. However, the Lo terminal is typically connected to the instrument's power supply and mains (line) transformer and on through the leakage components of that transformer, R_{leak} and C_{leak}, together with any other leakage paths to mains earth. The magnitude of the error is determined by the source impedance of the bridge, divided by the effective leakage impedance and this ratio constitutes the true common mode rejection ratio (CMRR) of the DVM, usually stated for a 1kΩ source impedance. The error current can be both AC and DC and will effect the measurement accordingly. It is also clear from Figure 1 that AC current from the mains, electrostatically coupled in the transformer can also flow back through the bridge causing additional errors.

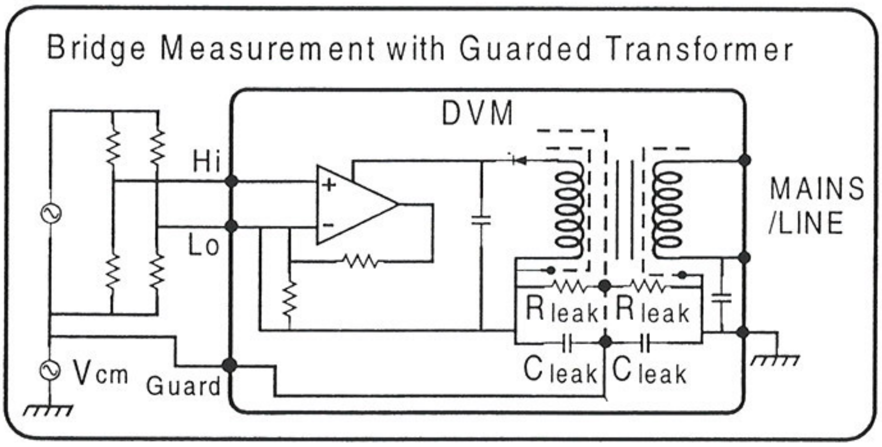
Techniques used to limit problems

There are several ways of overcoming the problems but all have their own characteristic shortcomings.

1. Actively Balance High and Low impedances. This can be done well with an active "Instrumentation Amplifier". However, the CMR (common mode rejection) of such circuits is limited by component matching and it may be impossible to handle the required voltage swing or to meet safety requirements.

2. Use Guarding techniques. Guarding techniques are well known to metrologists and essentially attempt to sink some of the leakage currents to a low impedance point at an appropriate, non interfering, potential. Sometimes circuit topology makes this impossible. The most effective place for guarding (and shielding) is in the transformer(s) using conductive electrostatic screens. Figure 2 shows the schematic of the DVM with an "ideal" screened and guarded transformer. Each winding is fully enclosed in its own screen and a guard screen is placed between the other two screens. The guard is connected to the source of common mode potential at the signal source and interrupts any leakage paths in the DVM's mains transformer forcing leakage current to flow through the guard back to earth rather than through the signal low as before. In effect it is an attempt to contain both source and measurer within a Faraday cage formed by the guard.

Fig 2



However, it is difficult to make the Guard interrupt 100% of the leakage paths. It is also often not possible to find an ideal connection point for the guard and measurements without a guard are made worse by the increased transformer capacitance and leakage to the Guard screen.

3. Battery Power! Perhaps the ideal situation is to have both measurer and measurand battery powered and this is practical for sub 50 mW consumption. However, this is not always perfect, particularly where high frequencies are concerned since they could be coupling asymmetrically to the outside universal "ground". It is also impossible to have continuous operation.

4. Make leakage components negligible. Lowering frequency in a given capacitance reduces AC current flow which is why (until now) 50/60 Hz transformers dominate measuring applications. However, the 50/60 Hz transformer tends to be large and inefficient, especially when screened sufficiently well for measurement applications. The large size leads to lower leakage resistance and high capacitance for a given insulation thickness so it would appear that small transformers could offer better leakage performance. Switching supplies are also much more efficient in the range of power (1 W to 30 W) most common in instrumentation, thus running cooler and reducing thermal errors.

High Frequency AC Leakage Currents in Switching Supplies

In order to benefit from switching it is necessary to operate at frequencies high compared with 50 Hz, together with still higher harmonics. These high frequency components then couple more readily through capacitance in the transformers. The leakage current can be measured using an oscilloscope or ammeter as shown in Figure 3. An example of the results obtained can be seen in figures 4 and 5 which show the measured leakage current across the isolation barrier of two so-called "medical" supplies.

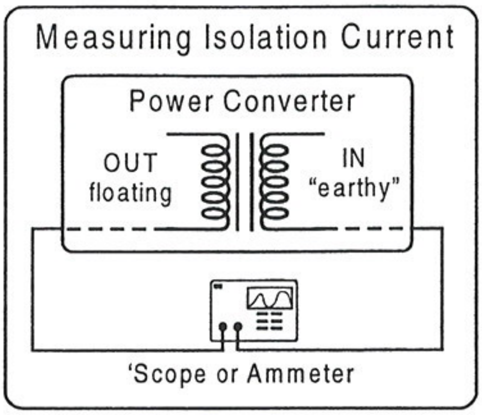


fig 3