A Differential Measurement Probe with High Common Mode Rejection

Master's Thesis in Electrical Engineering

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Abstract – This thesis presents a design idea for a fiber-optically isolated measurement probe. The measurement probe is intended to measure low voltage, high frequency signals on top of high frequency common mode voltages. In addition to developing the necessary theory, a prototype is also constructed.

When electrical signals are measured there are always errors. One of these errors is related to the difference in voltage between the measurement system and the signal being measured. If the voltage difference is large, care must be taken to limit the amount current that is allowed to flow between the two systems. Typically, this is done by use of an isolation transformer. However, if the voltage difference is also of high frequency, the amount of isolation the transformer can provide is greatly diminished. This is mainly because of how close the windings in the transformer are to each other. Increasing the distance between the windings means that leakage currents are lowered, and thus isolation improved, but also implies a less efficient transformer. Since these are contradictory requirements, an isolation transformer is limited to moderate frequencies. A way around the problem is to replace the isolation transformer with a fiber optic cable. Then, the separation distance can be made as long as the optical fiber itself.

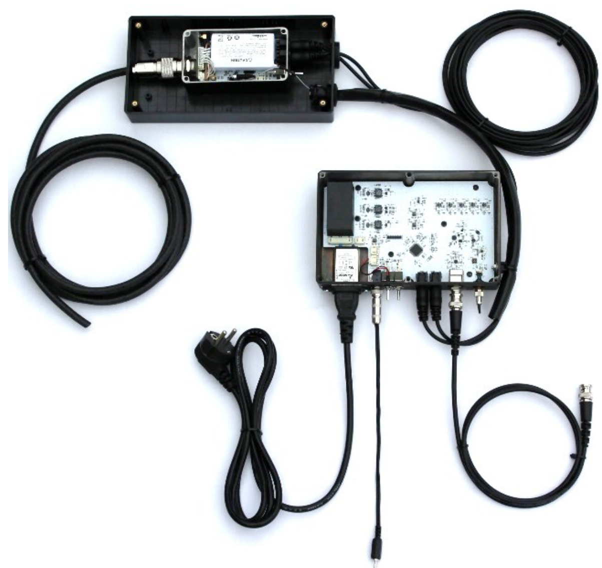

Figure 1 – The constructed prototype.

In this thesis, a prototype is constructed, and the theory used in its construction is derived. The designed prototype can be seen in Figure 1. The prototype consists of two devices, a sensor head (top left) and a receiver (center). The sensor head is connected (through cable in center left) to the signal that is to be measured, and the receiver is connected to an external measurement system (through cable in bottom right), for example, an oscilloscope. The two devices are interconnected by optical fibers. By doing so, it is expected that small, high frequency signals can be measured even when the voltage difference between the signal, and the system measuring it, is both large, and of high frequency.

In addition to fiber-optic isolation, the proposed system has a specially designed input stage. The signal to be measured is connected to the sensor head by a shielded balanced pair. The balanced pair is connected over the measurement point, and the shield is connected to either side of it. At the sensor head, the shield is connected to the enclosure, but not the circuit board. By doing so, the shield acts as a drain, shunting the inevitable leakage currents away from the amplifier which amplifies the measured signal. Since the leakage currents no longer flows through the amplifier, errors are minimized.

To transmit the measured signal over the optical fibers, two techniques are used. Low frequencies (DC – 1 kHz) are sampled by a digital converter and sent through an optical digital link, to be reconverted to an analog signal in the receiver. High frequencies (up to 100 MHz) are frequency modulated and transmitted by an analog laser. In the receiver, the frequency modulated signal is demodulated by a phase-locked loop. Figure 2 shows the response in the frequency domain as the two paths are joined.

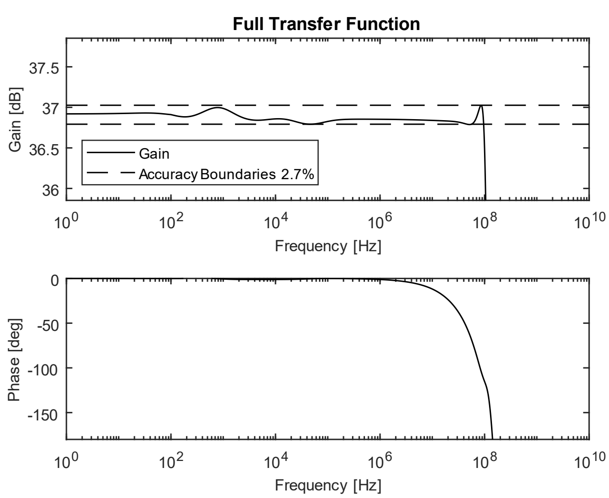

Figure 2 – Frequency domain response of the full signal chain.

While a prototype has been constructed, it is not fully functional. It is not believed that this is due to any fundamental flaw in the design, but it is rather an unfortunate consequence of the finite time that could be spent on troubleshooting.

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