Contactless Voltage Probe Technology: Measuring Voltage Waveforms from Outside Signal Cables

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***Development Background*—Engineers are often called upon to measure pulse signals used to control industrial robots and output waveforms from automotive sensors using oscilloscopes and data recorders. Examining disturbances at the edges of waveforms to ascertain signs of impending failure or investigate the causes of issues is essential in maintaining and managing such devices. However, connecting voltage probes to the signal terminals being measured often proves to be an exercise in frustration because the devices in question use high-density connectors and cable ends that are buried deep inside the hardware, making it a tricky proposition to establish reliable electrical contact.**

The ability to obtain a voltage waveform from outside the cable—as is possible with many current sensors—would resolve most of these issues. To make possible this type of measurement, a revolutionary technology for acquiring voltage waveforms and levels with a high degree of precision, without regard to cable diameter or insulating material, would be ideal. This paper introduces state-of-the-art technology for acquiring AC voltage waveforms in a manner that requires no contact with metal terminals.

I. Technical Issues and Their Resolution

Imagine placing the tip of an oscilloscope probe that has a high impedance, for example 100MΩ, close to the insulation of a voltage signal cable. As you do so, you should be able to obtain a signal waveform that differentiates the source voltage waveform, albeit in an unstable manner. This voltage signal is being captured via capacitive coupling, facilitated by an equivalent capacitor that forms between the conductor inside the insulated cable and the metal terminal on the tip of the probe. To obtain the voltage waveform that you desire, you need to pass the differentiated signal waveform that you've acquired through an integrator. Doing so would also allow you to suppress external noise.

However, the voltage levels characterizing a waveform acquired in this manner remain undefined because the magnitude of the capacitive coupling that forms varies as the cable's diameter and insulation change. Furthermore, that magnitude also changes over time due to environmental factors such as temperature and humidity, posing other challenges. That fluctuations in capacitive coupling are significantly influenced not only by the voltage level, but also by the frequency only makes it more difficult to acquire a stable voltage waveform.

To resolve these issues, we took the approach of generating a signal that is the same as the measured voltage waveform inside the probe and then canceling out the coupling capacitance. When the probe is kept at the same potential as the conductor inside the insulated cable that is being measured, no current flows to the capacitive-coupled conductor, regardless of the magnitude of the coupling capacitance. In short, it is as if the equivalent capacitor has been eliminated. Moreover, since the probe's potential is the same as that of the cable conductor, we can measure the voltage without needing to establish contact with any metal terminals, simply by measuring the probe's potential with a suitable instrument.

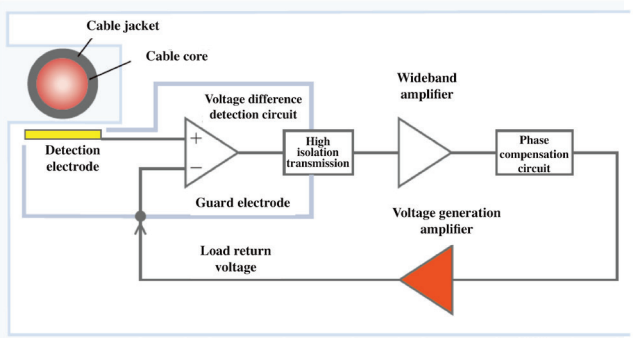


Fig. 1 Block Diagram

Fig. 1 provides a block diagram of a non-contact voltage probe. The probe's detection electrode undergoes capacitive coupling with the cable conductor. The potential difference between the electrode and the reference potential is then detected using an integrating trans-impedance amplifier (I-TIA) in the potential differential detection block, which has a power supply that is independent of the external circuitry. The detected potential difference signal is transmitted in an insulated manner out of the potential difference detection block, subjected to signal amplitude and phase correction, and applied to the potential difference detection block's reference potential via a voltage generation amplifier. As a result, this circuit design serves to minimize the potential difference between the cable and the reference potential, causing the current flowing to the detection electrode to approach zero.

II. Example Characteristics

The probe's design embodies a negative feedback circuit. Given suitable loop gain, it allows contactless voltage detection that is not affected by fluctuations in coupling capacitance. Furthermore, as a result of its use of negative feedback, the circuit delivers very flat frequency characteristics, from low to high frequencies. In fact, the non-contact voltage probe (Fig. 2) has a frequency band that exhibits -3 dB characteristics from 1 Hz to 100 kHz (Fig. 3).

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Fig. 2 Appearance of Contactless Voltage Probe

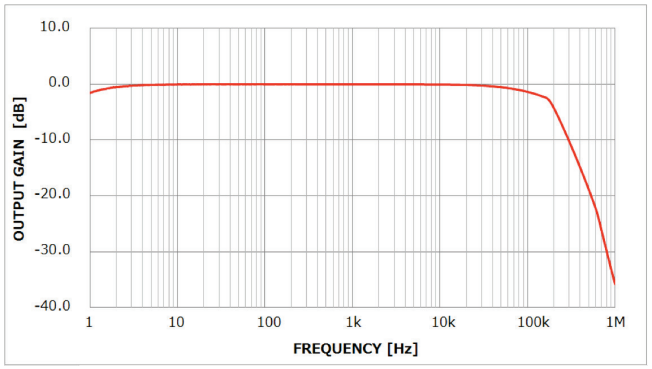


Fig. 3 Frequency Characteristics

The voltage dynamic range of this sensor probe is 14 Vpp, making it suitable for use with most machinery control signal levels. Fig. 4 illustrates an acquired pulse waveform with a duty ratio of 30:70. The waveform was acquired by applying a 5 Vpp signal to an insulated cable (with an outer diameter of 1.8 mm, including 0.3 mm of polyvinyl chloride insulation) using a waveform generator. Fig. 4(A) illustrates the waveform acquired at 100 Hz, and Fig. 4(B) at 10 kHz. At 100 Hz, the voltage probe reproduces the original signal with a high degree of faithfulness. Although not shown, the signal is similarly reproducible at 1 kHz. While there is slight rounding of the edges at 10 kHz, the waveform exhibits little delay and is sufficiently faithful to the source waveform to permit use of the probe in applications involving communications signals such as those used by LIN-bus systems in vehicles.

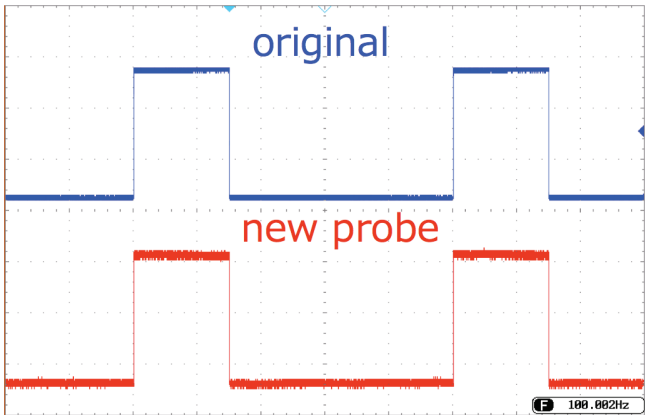


Fig. 4(A) Waveform Comparison (100 Hz)

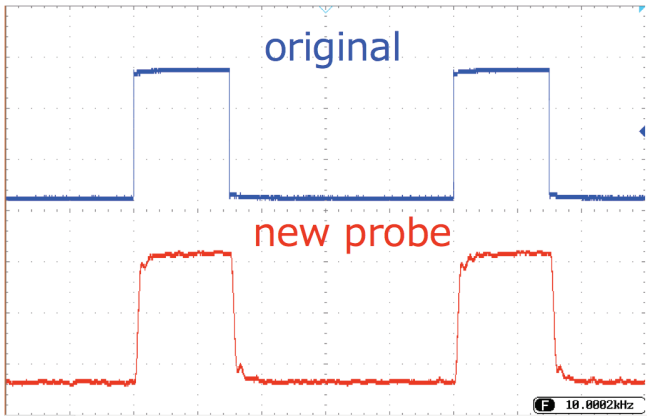


Fig. 4(B) Waveform Comparison (10 kHz)

III. Summary and Future Prospects

This paper has summarized the technology to realize a non-contact voltage waveform probe. Although the work it describes envisioned maintenance applications involving device control signals and sensor signals, the technology is likely to also prove effective as a tool for reverse-engineering hardware that lacks detailed technology drawings and specifications.

Future directions for related technological development include development of high-speed non-contact voltage waveform probes for capturing communications signals and development of probes for acquiring DC voltages.

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