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# A New Wideband High Voltage Measurement System With An Integrated Optical Link

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**ABSTRACT** : *A wideband high voltage measurement system, which is free from electrical insulation and electromagnetic interference in signal transmission, is necessary to monitor the condition of power facilities in substations. This paper described a voltage measurement system (VMS) which is composed of a capacitive voltage probe, an impedance converter, and an optical linker. A high speed voltage follower is used to get a wideband characteristic of the VMS, and the output impedance of the VMS is set at 50[Ω] to be matched any type of observing instruments. The performance of the VMS is estimated by application of a step-like pulse, a commercial frequency voltage, and an impulse voltage. From the results, the frequency bandwidth of the VMS ranges from 11[Hz] to 14[MHz], and the VMS showed an advanced response characteristics from the commercial frequency voltage to impulse voltage*

**KEY WORDS :** voltage measurement system(VMS), capacitive voltage probe, impedance converter, electromagnetic Interference, optical linker, impulse voltages

## 1. INTRODUCTION

The requirement for optical isolation between high voltage test areas and the measurement and control areas so that operators can work safely is now becoming compulsory because of the more stringent safety work regulations[1][2][3]. In addition, transmitting small signals over long distances in noisy environments such as those in high voltage substations imposes limitations on existing measurement systems. Generally, high voltage measurement devices in substations are very large in size, and are exclusively used for measuring power-frequency voltages.

In this paper, we describe a new voltage measurement system that has the advantage of having no contact with the high voltage terminal and offering a cheap optically-isolated transmission of the low-voltage signal over long distances. The optical link is analogue, hence offering significant advantages over the more common digital and frequency converter systems. Laboratory calibration tests were conducted on a prototype designed

response ranging from 11 [Hz] to 14 [MHz] and stable voltage ratio over the frequency range.

## 2. VOLTAGE MEASUREMENT SYSTEM

### 2.1 Principle of Voltage Measurement

Figure 1 shows the principle of voltage measurement by a planar-type capacitive voltage probe under a high voltage conductor. Voltage division is formed by a capacitance $C_h$ between the high voltage conductor and the sensing plate of the voltage probe, and by a parasitic capacitance $C_s$ between the sensing plate and the grounding plate of the VMS[4][5].

The parasitic capacitance $C_s$ is very small and is unstably changed depending on the set-up condition. A capacitor $C_p$ with a few [nF] is connected to the $C_s$ in parallel for a stable and large dividing ratio.

The voltage probe was fabricated with two separated aluminum plates which has a thickness of 6 [mm], a

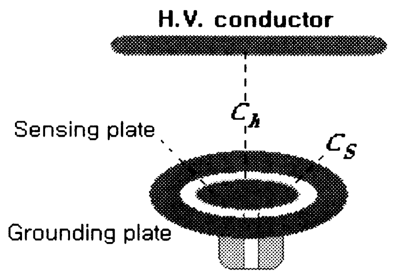



Fig. 1 Principle of voltage measurement by a capacitive probe

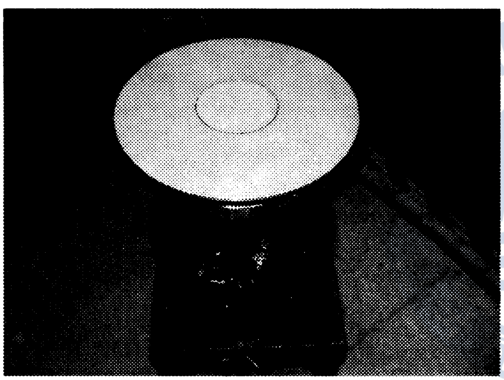


Fig. 2 Photograph of the capacitive voltage probe

Figure 3 shows a basic circuit for measuring high voltage under a high voltage conductor by using the principle mentioned before. A coaxial cable (RG 58A/U) of 50[Ω]-characteristic impedance is used to transmit voltage signal from the voltage probe to a transmitter

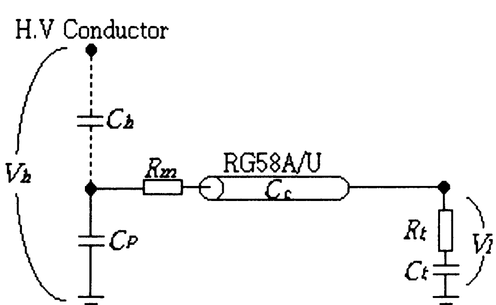



Fig. 3 Basic circuit for measuring high voltage

To remove signal distortion caused by the capacitance of on the frequency characteristics of input signal. The dividing ratio $U_L$ in low frequency ranges, such as commercial frequency voltage, can be expressed as Eq. (1)[6]:

$$U_L = \frac{(C_h + C_p + C_c + C_t)}{C_h} \tag{1}$$

The dividing ratio $U_h$ in high frequency ranges is also as follow :

$$U_h = \frac{(C_h + C_p)\cdot(R_m + R_t)}{(C_h \times R_t)} \tag{2}$$

In practical application, $C_p$ is 5~10 [nF] ( $C_h \ll C_p$ ), and $U_h$ must be equal to $U_L$ at any frequency range. The dividing ratio also changes as the input impedance of an instrument connected to the VMS. Therefore, the best signal transmission method between the VMS and an instrument has to be decided.

The complete the VMS was designed to solve these problems as shown in Fig. 4. The VMS can measure high voltages without any influence by the input impedance of observing instruments because the detected signal is transmitted through a voltage follower (LH0033) with 50 [MΩ] input impedance and 50 [Ω] output impedance

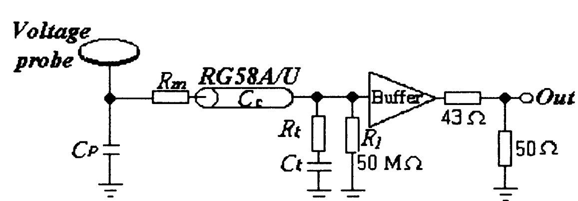


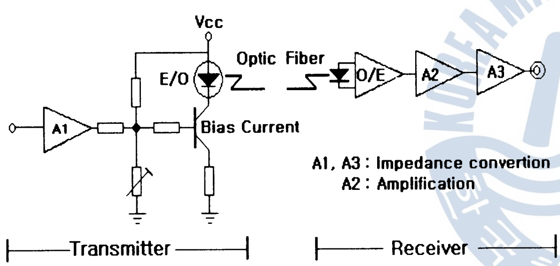

Fig. 4 Voltage measurement circuit

### 2.2 Optical Linker

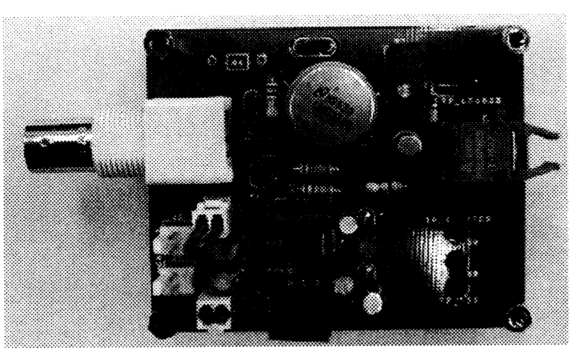
A high speed and wide-band optical linker is required to transmit the measured voltage signal to an observing instrument in ranges from commercial frequency voltage to impulse voltages without any distortion by electromagnetic interference.

Figure 5 shows the configuration and photographs of the

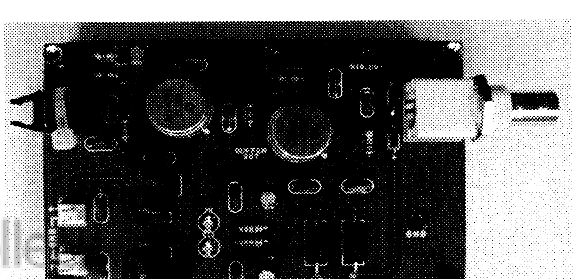
The receiver, optical to electrical (O/E) converter, is designed with PIN photo diode (HFBR 2526, built in amplifier, $t_r$ : 3.3 [ns]). The optical linker has two special features: One is to transmit and receive analog signal without a process of voltage to frequency (V/F) conversion or analog to digital (A/D) conversion, which make real-time signal transmission possible. The other is to transmit bi-polar voltage signal by only one unipolar light emitting diode (LED), which can be realized by flowing bias current to the LED. The magnitude of the bias current was set at 50 [%] of the rated forward current of the LED. Optical power increases by adding positive signal on the bias current or decreases by subtracting negative signal from the bias current.




(a) Configuration of the optical linker



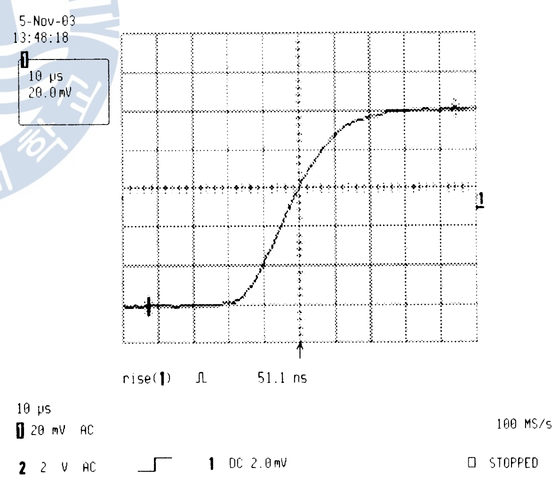
(b) Transmitter



In practical, an observing instrument with high input impedance is necessary to observe measured signal by the VMS without any change of dividing ratio, but the problem can be solved if the VMS has a low output impedance, typically below 50 [Ω], to be matched with any type of instruments. Therefore, a voltage follower with a high input and a low output impedance, which is a kind of impedance converter, was used in the optical receiver.

## 3. Results and Discussion

Dynamic characteristics of the VMS were estimated by using an unit step response in a test set-up shown in Fig. 6. The step-like voltage was applied by a function generator (Thandar, TG501) with a rise-time of 44.2 [ns].




(a) rise-time

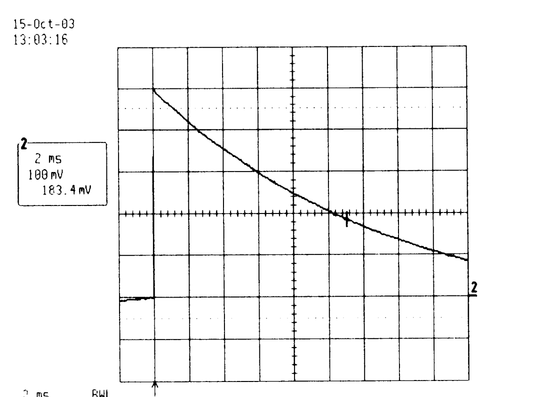


Figure 6 shows the step response waveforms of the VMS. The true rise-time of the measurement system can be calculated by the method of quadrature.

Let

$t_r$: Pure rise-time of the circuit,

$t_{ro}$: Total rise-time of signal path,

$t_{ri}$: Rise-time of the pulse generator

The method of quadrature gives[8]

$$t_r = \sqrt{t_{ro}^2 - r_{ri}^2} = 25.64\ [ns] \qquad (3)$$

If an observing instrument like an oscilloscope has the Gaussian response characteristic, it can be written as follow:

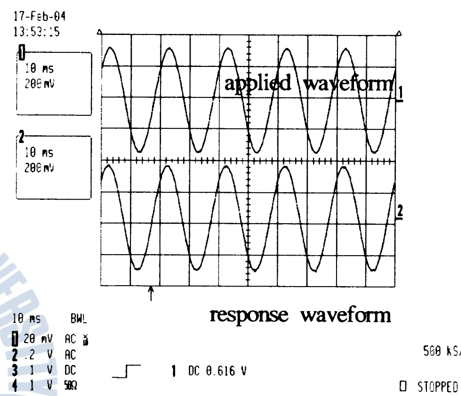
$$B_w \cdot t_r = 350 \qquad (4)$$

Where $B_w$ is a frequency bandwidth of [MHz] unit and $t_r$ is a rise-time of [ns] unit. The high cut-off frequency $f_h$ is approximately equal to the upper limit of the frequency bandwidth $B_w$. The response of the measurement system in the low frequency domain depends on the time constant of $C$ multiplied by $R$, and the low cut-off frequency $f_L$ at which a gain attenuates by -3 [dB] compared with that at the higher frequency domain is given by:

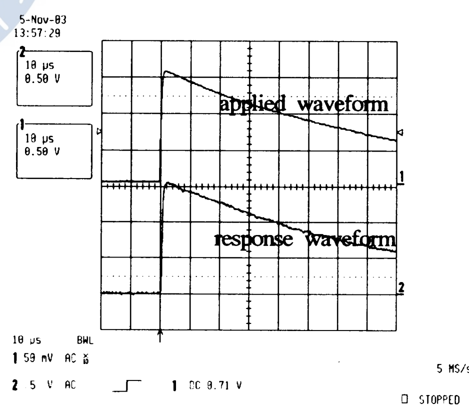
$$f_L = \frac{1}{2\pi RC}\ [Hz] \qquad (5)$$

The intrinsic rise-time of the oscilloscope(Lecroy 9354C ) used in this experiment is less than 1 [ns], and the measured rise-time to the input signal is about 51.1 [ns] as shown in Fig. 6(a). Therefore, we can calculate the true rise-time $t_r$ of the VMS from Eq. (3), and the rise-time is approximately 25.64 [ns]. The frequency bandwidth is determined by the transfer function of Eq. (4),the high cut-off frequency of the frequency bandwidth is approximately 13.65 [MHz]. The decay time of the VMS to the unit step input is 13.3 [ms] from Fig. 6(b), and the low cutoff frequency calculated from Eq. (5) is about 11.42 [Hz].Thus the frequency bandwidth of the developed VMS ranges from 11 [Hz] to 14 [MHz], and the VMS can produced by a high voltage transformer, and impulse voltages generated by a surge generator (Haefely, SG481).

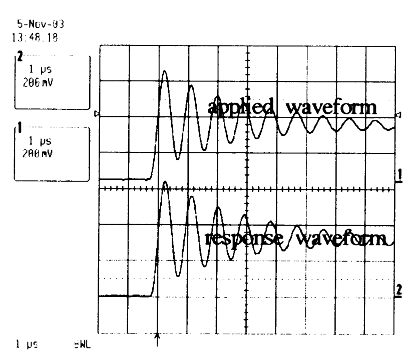
From the estimation, the deviation of dividing ratio in each measurement for commercial frequency voltages and for impulse voltages were 0.4 [%] and 1.7 [%], respectively. The error of dividing ratio between the commercial frequency voltages and the impulse voltages was 2.6 [%].

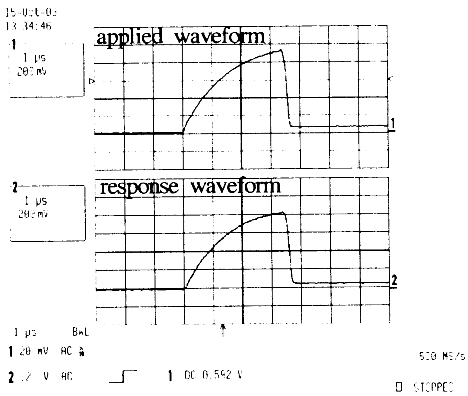



(a) Commercial frequency




(b) Impulse voltage






(d) Chopped impulse voltage

Fig. 7 Typical response waveforms measured by the VMS

## 4. Conclusions

This work concentrated on the development of a wideband VMS which can measures commercial frequency voltage as well as impulse voltage at the same dividing ratio. The VMS is free from electrical insulation and electromagnetic interference in signal transmission by using a capacitive voltage probe and an optical linker.

From the experimental results, the frequency bandwidth of the VMS ranges from 11[Hz] to 14[MHz], and the VMS showed an advanced response characteristics to the commercial frequency voltage and impulse voltages.

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