

# Application of isolation amplifier in measurement of floating AC signal

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**Abstract** – Measuring procedures in some cases require connection of two measuring objects or parts of equipment which terminals should not have common potential. Achievement of these requirements is inappropriate by using the transformer coupling because of its non-linear transfer function. Optical transfer of digital signals by using optocoupler provides the precision and stability needed to accurately signal monitoring.

## I. Introduction

The essential requests on every transfer system are: precision and minimum of influence on measured signal. At optocoupler devices we define following parameters of influence:

- transfer function i.e. amplification factor:  $A = U_o/U_i$
- temperature coefficient of amplification factor:  $\Delta A/\Delta T$
- nonlinearity of  $A$
- signal delay  $t_D$

In this specific case, the optocoupler was used as analogue signal isolation stage in our *Three Phase Calibrator*. It requires floating potential of output terminals and high accuracy, stability and linearity even under severe noise conditions.

## II. Theory of operation

The basis of the isolation transfer system is an isolation amplifier HCPL-7800 which utilises analogue to digital conversion and linear optocoupler (LOC), Fig.1.

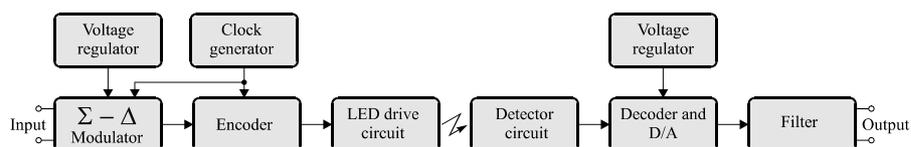


Fig. 1. HCPL-7800 Block Diagram

In circuit operation the sigma-delta analogue to digital converter converts the analogue input signal into a high speed serial bit stream, which time average is directly proportional to the input signal. This high speed stream of digital data is encoded and optically transmitted to detector circuit. Detected signal is decoded and converted into accurate analogue voltage levels and then filtered to produce the final output signal.

Sigma-delta converter possesses high resolution up to 24 bits, but also has the somewhat narrow frequency bandwidth of about 10 kHz. In accordance with Nyquist theorem, the sampling frequency  $f_s$  must be at least twice as high as bandwidth  $f_A$  of analogue input signal ( $f_s \geq 2 \cdot f_A$ ). Typically, the sigma-delta converter is *oversampled*, i.e. has several times higher sampling frequency than requested by Nyquist theorem. Increasing of sampling frequency  $f_s$  results with higher signal to noise ratio, because the effective value of quantisation noise (which remains constant), is now distributed on wider frequency band. Converter input consists of *antialiasing filter* which is not necessary of high order like those in non-oversampled A/D converters.

One of the main performance obstacles of isolation amplifiers is a large-signal nonlinearity or *distortion*. So the high-performance isolation amplifiers apply differentially linear optocouplers (LOCs)

to increase linearity over a large signal range. The challenge in isolation amplifier design is to minimise *drift*. As temperature rises, for constant LED current, photocurrents decrease, causing its feedback voltage to change in a direction that servos the LED-driver op-amp output to produce more photocurrent to maintain a nulled error at the input.

### III. Specific application

This solution of signal isolation was used in development of our *Three-Phase Calibrator*. The purpose of this special instrument is monitoring of accounting system in high-voltage electro energetic networks. Monitoring of measuring system is based on regularly inspections of parameters which have influence on measurement uncertainty, e.g. loads connected on secondary side of voltage and current transformers, and impedance in connection line between voltage transformers and electricity meters. In consideration of the fact that calibrator must be adapted to working conditions in accounting system and connected instead of voltage and current transformers, all six outputs of calibrator must be fully galvanic isolated.

In the actually circuit (Fig.2) the input of isolation amplifier is connected directly to a sense terminal of circuit. The differential output of the isolation amplifier is converted to a ground referenced single-ended output voltage with a simple differential amplifier circuit. As a consequence of high sensitivity, it is necessary to insure appropriate shielding to minimise electromagnetic interference of the sense signal.

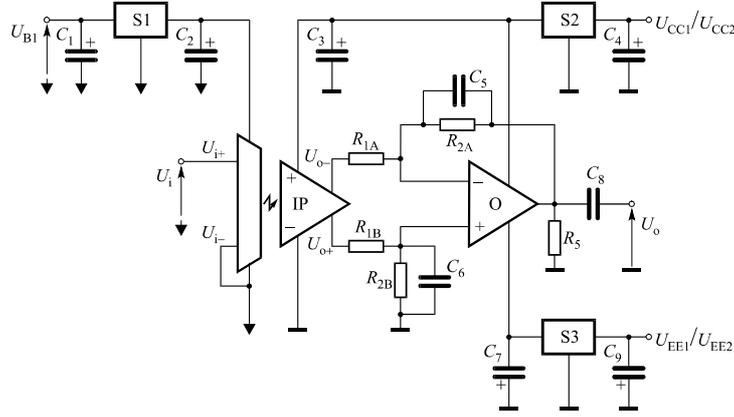


Fig. 2. Electrical circuit of single-phase isolation stage

The operational amplifier used in the output stage of circuit should be of sufficiently high precision so it doesn't contribute a significant amount of offset or offset drift relative to the contribution from isolation amplifier. The pair of capacitors  $C_5$  and  $C_6$  in the output allows the bandwidth adjusting independently of the gain which can reduce the output noise from D/A converter. In case of offset voltage appearing, the output coupling capacitance  $C_8$  is added. With input resistance  $R_i$  of next stage, this capacitance produces low-pass filter whose phase shift must be negligible on working frequency  $f = 50$  Hz. Hence this  $\tau$  constant must be

$$\tau = C_8 \cdot R_i \gg (2\pi f)^{-1} \quad (1)$$

With  $R_{1A}=R_{1B}=R_1=1.69$  k $\Omega$  and  $R_{2A}=R_{2B}=R_2=10$  k $\Omega$ , the amplification factor is

$$A_1 = A_{IP} \cdot (R_2/R_1) \approx 47 \quad (2)$$

, where  $A_{IP}$  marks the amplification factor of isolation amplifier HCPL-7800A with typical value of  $A_{IP} = 8$ , and worst-case temperature coefficient of  $\Delta A_{IP}/\Delta T = 2.5 \cdot 10^{-4}/^\circ\text{C}$ . The gain-setting resistors  $R_{1A}$ ,  $R_{1B}$ ,  $R_{2A}$  and  $R_{2B}$  have the same temperature coefficient of  $-10$  ppm/ $^\circ\text{C}$  and insure adequate CMRR and gain tolerances. Their close thermal interconnection insure very small temperature coefficient of  $A_1$ . In relation to input signal, the isolation amplifier introduces time delay  $t_D$ , so frequency-depended phase shift is present. With typical delay of  $t_D \approx 6$   $\mu\text{s}$  and frequency of 50 Hz this phase shift is

$$\varphi = 2\pi \cdot f \cdot t_D = 1.9 \cdot 10^{-3} \text{ rad} \quad (3)$$

In consideration that electrical topology is symmetrical, this delay is equal in all phases. Exceptionally, only as result of infinitesimal dispersion in amplifiers initial delays, the certain deviation may occur. The estimated value of this deviation is lesser than quoted in (3) by an order of magnitude. The physical view of three-phase isolation stage is shown on Fig.3.

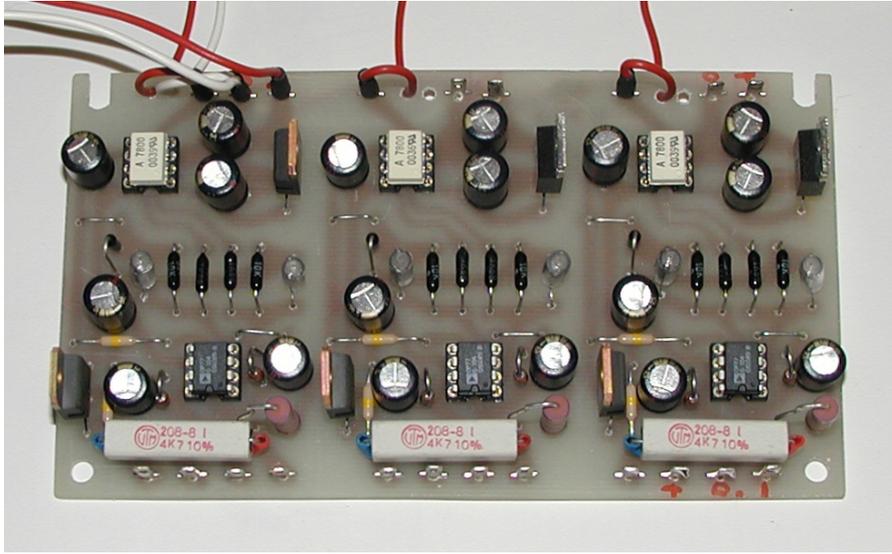


Fig. 3. Physical view to a three-phase isolation stage

### III. Conclusion

Measurements are obtained with Fluke 5700A Calibrator as voltage source on circuit input, HP 3458A multimeter as AC voltmeter, HP 3581C spectral analyser and Tektronix 2432A digital oscilloscope on output. The frequency of sinusoidal input signal was set to  $f = 50$  Hz. Output signal harmonic distortion  $k$  (up to 10<sup>th</sup> harmonic) in depending of input signal level  $U_i$  is represented on Fig.4.

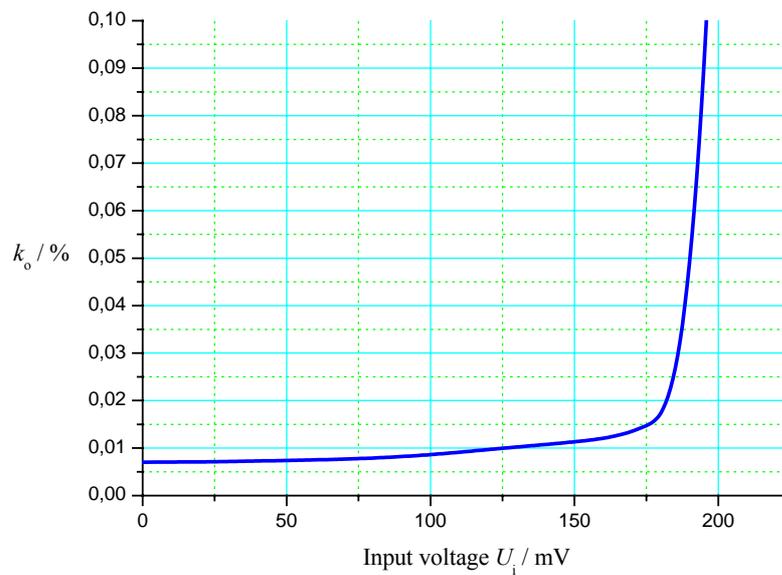


Fig. 4. Distortion of output signal ( $THD_o$ ) versus input signal  $U_i$

The obtained curve shows that harmonic distortion in order of 0.01 % is present for input levels up to 150 mV<sub>eff</sub>. With frequency  $f = 50$  Hz and the same input signal (up to 150 mV<sub>eff</sub>) on all inputs, mutual phase differences between output signals were not exceeded  $3.5 \cdot 10^{-4}$  rad. In laboratory conditions, at temperature within  $23^{\circ} \text{C} \pm 1^{\circ} \text{C}$  and without additional thermostating, the relative uncertainty of overall gain was better than  $3 \cdot 10^{-4}$ . With thermostating we expect uncertainty better than  $10^{-4}$ . In accordance with technical specification of isolation amplifier the maximum working isolation voltage is 890 V<sub>p</sub>.

### References

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