Contactless Opto-Electronic Area Meters and Their Attainable Measuring Accuracy

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Abstract

This paper deals with the problems of the contactless area measurement on the principle of video signal processing. This video signal generates TV camera, which scans the measured object. Basic principle of these meters is explained and attainable measurement accuracy and factors influencing this accuracy are analysed.

Keywords
area meter, signal processing, measurement accuracy

1. Introduction

TV camera scans the square projection of the object with whatever form, whose area is measured. Principle of this method makes possible to measure the overall area of the more objects in the visual field of camera, prospective choosing of the measured object by means of the adjustable frame (see Fig. 2). This measurement is relative. Absolute values of these measurements are dependent on the used objective. There is possible to measure macro as well as micro-dimensional areas by mean of this method. Basic calibrations is performed by means of measurement of the known area. Absolute values of measured surfaces are subsequently automatically recounted. Application possibilities in the technical practice (e.g., in the machine, electrical and building industry, in the biochemistry, medical and industrial radio-logistic etc.) have direct connection with the attainable accuracy of measurement.

Principle of area meter with analog signal processing will be described in following text, because the digitisation of the analog (in time sampled) video signal of the actual monolithic image sensors CCD do not bring important advantages for attainable accuracy of measurement. This fact does not preclusive of employment of digital circuits and control microprocessor in the block diagram of the analog area meter, which is apparent on Fig. 1. Video signal, corresponding to the scanned image, is generated usually by means of the monochromatic TV camera with image sensor CCD (BCCD). It will be demonstrated, that the resolution capability and other characteristics of this sensor have the basic influence on the attainable measurement accuracy.

Composite monochromatic video signal V_{vs1} is amplified in the amplifier A1 and is restored its DC component in the direct-current (DC) restorer DCR (clamping circuit). So modified signal V_{vs} makes, together with the signals of the adjustable frame and measured value notation, input signals for multiplexer MUX. The output signal of this multiplexer is amplified in the amplifier A2 and displayed by means of the monitor MON. Video signal V_{vs} is compared with the comparison voltage V_{comp} in the comparator COMP. This level answers to the video signal (brightness level) of the measured area. This voltage is adjustable either manually or automatically from the peak-to-peak voltage of video signal, which is generated by means of peak-to-peak detector PPD. Output signal V_C of the comparator opens the electronic gate EG. The second signal of this gate is the continual sequence of clock pulses from the accurate and stable generator GCC controlled by the crystal. Number of pulses p_x transmitted through gate during the one picture (or two sequential fields in the course of inter-lacing scanning of used camera) is counted by means of the asynchronous counter ASC and this number is proportional to the measured surface.

Microprocessor μP is fundamental part of the surface meter. This digital integrated circuit is controlled by the synchronisation pulses H, V and E-O defined even and odd fields of the picture. These pulses are separated by the synchro-pulses separator SPS. Another input signal of the microprocessor is sequence of pulses of the gate EG and their total number answers to the size of measured area. Microprocessor executes these functions: generation of the adjustable frame signal, numerical conversion of the absolute value of measured surface pursuant to the measurements of the unknown and known reference surface, averaging of results of measurements for the given time interval and control their numerical representation (display), inserting of the rated results (incl. measuring unit) into defined position, control of the multiplexer MUX and display unit, etc.

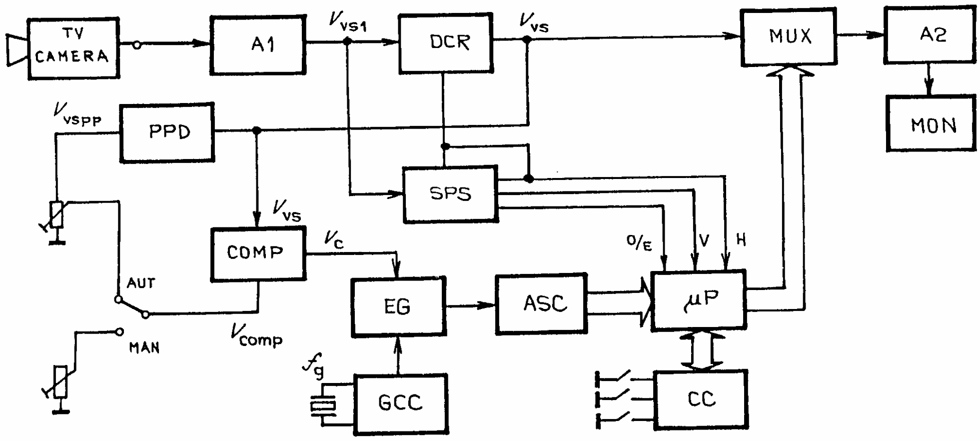

Fig. 1 Block diagram of the area meter with analog processing of the video signal

2. Systematic measurement errors

Principle of surface measurement is based on the sequential measurement of the time intervals (in the active line period), in which the voltage of video signal V_{vs} is equal or smaller (greater) than comparison voltage V_{comp}, whom value answers to the bright level of the measured area. Therefore the systematic relative error δ_V of measurement, due to the line scanning in vertical direction (for the measured object occupied the maximum height V of the scanned image) is expressed by the formula

$$\delta_v = \Delta V/V = n_v^{-1}, \quad (1)$$

where n_v.means number of active (visible) lines in the complete picture. For TV standards CCIR D is $n_v = 575$ lines.

Systematic relative error δ_H is evoked by means of the camera resolution in the horizontal direction (for the measured object occupied the whole horizontal size H of scanned image) is expressed by the formula

$$\delta_H = \Delta H/H = m^{-1}, \quad (2)$$

where m means number of picture elements (pixels) of the sensor in the horizontal direction.

Systematic errors δ_H and δ_V are not dependent. Therefore it can be to express the resultant relative systematic error δ_S (for measurement of the greatest measurable rectangular area $S_{max} = V.\,H$) by the formula

$$\delta_S = \frac{\Delta S}{S_{max}} = \frac{\sqrt{n_v^2 + m^2}}{m \cdot n_v} \,. \quad (3)$$

E.g., for $n_v = 575$ and used sensor with $m = 1000$, we can get $\delta_S = 2.10^{-3}$.

It can be anticipate smaller factual relative systematic error of the measurement of common large areas. Its value will be dependent on the form and orientation of measured area toward to the scanning pattern. On the contrary, its value can be increased for the measurement of the smaller areas $S < S_{max}$.

3. Analysis of partial functional blocks properties and their influences on the resultant measuring accuracy

From the previous description of the principle of the area meter results, that the properties of the partial functional block have the great influence on the resultant measuring accuracy It is necessary to investigate these factors especially:

- geometrical distortions of used sensor and objective,
- frequency fluctuations Δf_g of the generator GCC,
- fluctuations (V_{comp} of the comparison voltage,
- DC component fluctuations (V_{dc} of the video signal on the output of DC restorer DCR,
- finite rise and fall times t_r, t_f corresponding to the bandwidth of the amplifier A1 and DC restorer,
- time delay of the signal in the comparator COM, electronic gate G and asynchronous counter ASC.

Verification of these factors values were realised on the functional specimen of area meter.

3.1 Influence of the relative geometrical distortions of the used sensor and objective

These distortions are in the rank 10^{-6} case of monolithic image sensors CCD (BCCD) and top objectives and they are negligible against to the systematic errors mentioned above.

3.2 Influence of the frequency fluctuations Δf_g of the generator GCC

For the frequency f_g of this generator, the formula has to hold

$$f_g \geq 2 \cdot \frac{\mathrm{m}}{t_{al}} \ . \qquad (4)$$

TV standards CCIR D,B indicate for the active time of the line scanning $t_{al} = 52.10^{-6}$ s. E.g., for $m = 1000$ it is $f_g \geq 38{,}4$ MHz. With respect to the application of the generator GCC controlled by crystal it can be to anticipate the relative frequency stability $\Delta f_g/f_g \leq \pm 5.10^5$. This assumption was confirmed by the measurement on the functional specimen of the area meter.

3.3 Influence of the fluctuations (V_{comp} of the comparison voltage

Time periods of the compared video signal fluctuate in the course of the fluctuations ΔV_{comp} of the comparison voltage with respect to the finite rise and fall times t_r, t_f of the compared video signal pulses V_{vs} (see Fig. 2).

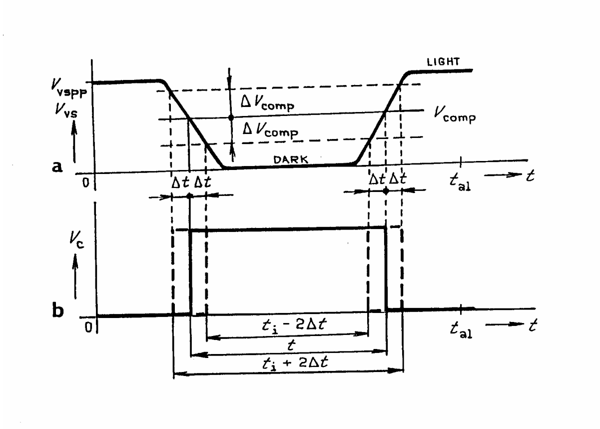

Fig. 2 Time response of the
a) video signal V_{vs}(t) on the comparator input,
b) compared signal V_c(t) on the comparator output

Providing the **linear** form of the rise and fall edge of pulses, we obtain for the variation Δt of each of time intervals (for each edge) this formula

$$\Delta t = -\frac{\Delta V_{comp}}{0{,}8 V_{vspp}} \cdot t_r \cong -\frac{\Delta V_{comp}}{0{,}8 V_{vsspp}} \cdot \frac{0{,}35}{f_0} \cong \cong -\frac{\Delta V_{comp}}{V_{vspp}} \cdot \frac{0{,}44}{f_0} \qquad (5)$$

where f_o. is the overhead frequency of the channel for video signal processing (camera, amplifier A1, DC restorer DCR), V_{vspp}.is peak-to-peak voltage of the video signal V_{vs} on the comparator output.

Value $\Delta V_{comp}/V_{vspp} \leq \pm 10^{-2}$ can be achieved providing the first-rate voltage stabilisation of the voltage V_{comp} .

3.4 Influence of the DC component fluctuations ΔV_{dc} on the DC restorer output

DC component fluctuations ΔV_{dc} of the video signal on the comparator input has identical results as ineligible fluctuations ΔV_{comp} of the comparison voltage and they are expressed by modified relation (5) - video signal moves, in contrast to the previous case, against to the level of comparison voltage. Providing that for the d.c. component restoration is used clamping circuit it can be achieved relative stability of the DC component $\Delta V_{dc}/V_{vspp} \leq \pm 10^{-2}$.

Notice: Fluctuations of peak-to-peak voltage (V_{vspp} of the compared video signal, appropriate to the fluctuation of the gain of amplifier A1, can have similar results as effect described in the paragraphs 3.3. and 3.4. This effect can be neglected, because in automatic mode of the area meter the comparison voltage V_{comp} is generated in dependence on the greatness of the peak-to-peak voltage V_{vspp} (see Fig. 1). Amplifier A1 is realised usually by means of broad-band operational amplifier with the passive negative feedback and accordingly the fluctuations of its gain are negligible.

3.5 Influence of the rise and fall times t_r, t_f of the compared video signal pulses V_{vs}

Finite rise and fall times have considerable influence on the measurement accuracy also. Influence of the DC component and comparison voltage fluctuations on the accuracy measurement of compared time intervals (described by formula (5) in the paragraphs 3.3 and 3.4) grows in the case of their enhancement. Therefore the equivalent cut-off frequency f_o, according to the **modulation transfer function (MTF)** of opto-electric transformation in the image CCD sensor and to the bandwidth of video channel (amplifier A1 and d.c. restorer DCR), must be high. Numerical expression of the influence of the rise and fall times on the resultant measurement accuracy is very difficult. This influence depends on the number of the partial compared time intervals in lines, which fall into the measured area (number of these intervals can be $p_x \geq n_v$ in the case of the large area). Common numerical values of the rise and fall times in the TV systems are t_r, $t_f \leq 50.10^{-9}$s.

3.6 Influence of the time delays in comparator, electronic gate and asynchronous counter

Influence of these time delays in these circuits can be usually failed. These time delays are small (under 10 ns), constant and almost equal for rise and fall edge and do not influence number of pulses p_x on electronic gate output.

4. Conclusions

Absolute value of the additional summary relative error $|\delta_{asr}|$, appropriate to the factors (with round uncorrelated actions), described in the paragraphs 3.1 - 3.6, can be expressed for the greatest measurable surface (non-essential factors are neglected) by the formula

$$|\delta_{asr}| = \sqrt{(\delta_f)^2 + (\delta_{tcomp})^2 + (\delta_{tdc})^2}\ , \qquad (6)$$

where δ_f.is the relative frequency stability of the generator GCC - $\delta_f = \Delta f_g / f_g = \pm\ 5.10^{-5}$, δ_{tcomp}.is the summary relative error of measured time interval appropriate to the comparison level fluctuations ΔV_{comp}. It can be expressed in the case of the **greatest measured area** by the formula

$$\delta_{tcomp} = \sum \Delta t / \sum t \cong \frac{-2n_v \left(\frac{\Delta V_{comp}}{V_{vspp}} \cdot \frac{0,44}{f_o} \right)}{n_v \cdot t_{al}}\ . \qquad (7)$$

E.g., for TV standard CCIR D ($n_v = 575$, $t_{al} = 52.10^{-6}$ s), $f_o = 10$ MHz and $\Delta V_{comp}/V_{vspp} = \pm\ 10^{-2}$, we obtain after the substitution in the formula (7)

$$|\delta_{tcomp}| \cong 1{,}7.10^{-5}$$

δ_{tdc}.is the summary relative error of the measured time interval appropriate to the DC component fluctuations ΔV_{dc} of the compared video signal. It is expressed in the case of **greatest measurable area** by the modified formula (7). In this formula it is substituted the $\Delta V_{comp}/V_{vspp}$ by the rate $\Delta V_{dc}/V_{vspp}$. For the same value of the rate $\Delta V_{dc}/V_{vspp} \leq \pm 10^{-2}$ we obtain also the same value of the error $|\delta_{ar}| \cong 1{,}7.10^{-5}$.

Then by means of the substitution into the formula (6)

$$|\delta_{asr}| = \sqrt{(5.10^{-5})^2 + (1{,}7.10^{-5})^2 + (1{,}7.10^{-5})^2} = $$
$$= 7{,}6.10^{-5}$$

So expressed and calculated additional summary relative error δ_{asr} is increasing evidently in the course of downsizing of the measured area. However this error is for the greatest measurable areas than hundred fold under the systematic relative error δ_S, expressed by the formula (3). Optical magnification of the area meter is presented by means of advisable objective in the real conditions so that the measured surface must cover fully 50% of the raster of scanned image. In these conditions the systematic relative error δ_S poses, evidently, the limit of the attainable measurement accuracy of the area meter. Desirable enhancement of measurement accuracy can be achieved only by application of the special opto-electronic sensors with high resolution.

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Václav ŘÍČNÝ was born in 1937. He is professor and vice-dean at the Faculty of Electrical Engineering and Computer Sciences of Technical University in Brno. His research interests include TV technology, video signal processing and applications of the light sensitive CCD sensors for measuring techniques.