# ELECTRICAL ENERGY MEASURING MODUL WITH GALVANOMAGNETIC CURRENT TRANSDUCER

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**Abstract:** In our time, electrical energy has been used in all household and industrial settings. This is achieved by the ability of the device to convert it into another form of energy – mechanical, lifting, light, heat, and many more. etc., and vice versa. Exactly this variety of energy converters enables the development of electronics, communications, transport, health, energy, but also the search for and the creation of new sources and converters known as alternative sources of energy.

The generation and consumption of electrical energy does not end there. In order to assess the quantity and quality of the generated electrical energy, special devices known as electric meters are needed. Measurement of electrical energy is important for both households and industry, as well as for its production and efficient use. There are different methods and means for electrical energy measurement. They work on the basis of different physical principles – induction, electromagnetic, galvanomagnetic, etc., but the task of all of them is to show the result of the current and voltage integrated in time.

Various methods are known for the basic parameters measurement defining the value of electrical energy (electrical current and voltage). With the development of microelectronics, and in particular of sensor technology, various sensor transducers have been developed to measure electrical energy through a high precision electric circuit using a contact and/or contactless method. One of the most commonly used sensor transducers for measurement of electrical current in modern energy meters are magneto-sensitive ICs. They are characterized by high reliability of the output signal, temperature and electrostatic steadiness and not least a long period of trouble-free operation[1]. The sensible element in magneto-sensitive ICs is most often a Hall element or a magnetoresistor. It measures the current flowing through the conductor by converting the magnetic field around it into electrical voltage. The advantage of magneto-sensitive ICs is possibility in a semiconductor chip to create sensitive element and a processing and forming signal circuit. This makes the measuring channel more secure and compatible with integrated circuits for processing and transmitting measurement data.

The article presents an experimental model of an electronic module for electrical energy measurement in a single phase AC current circuit. The measuring module is realized on the basis of a specialized integrated circuit ADE series of the Analog Device Company for electrical energy measurement and a current channel, realized by a magnetic-sensitive integrated circuit ACS of the Allegro MicroSistem Inc. for electrical current measurement. Presented are a block and schematic circuit diagrams, experimental design and experimental results showing the performance of the device.

**Keywords:** measurement of electricity, magnetic sensing integrated circuits, electronic meters, contactless measurement of electric current

## INTRODUCTION

The measurement of electrical energy consumption is crucial not only for households and industry, but also for its production and efficient use. From its correct measurement depends the formation of its price and the price of every electric consumer admitted to the market.

Various methods and means for electrical energy measurement are known. More common are electric meters. The action of induction electric meters is well known in theory and in practice. However, their constructional and metrological features do not allow them to take into account other parameters of the measured quantity. This does not downplay them, but makes them more inaccurate and unreliable in time.

Today, in order to increase the accuracy of reading, accompanied by increased reliability of the information obtained at measurement, digital meters have found a wide application (Hinova, 2019; Rankovska, 2013).

The development of modern microelectronic technologies allows the development of specialized programmable integrated circuits integrating in one chip a number of functional blocks that allow the construction of digital power

[1] Draganov, N. (2014). *Sensors. Principles, device technology, performance, parameters and applications.* (First part). (I. Kolev, Ed.) Gabrovo, Gabrovo, Bulgaria: EXPRES.

meters only within a monolithic integrated circuit. This significantly increases the reliability of the meter, the accuracy of the processing and the indication of the data as the whole processing of the signal from the device terminals to the indicator is done in one chip (Draganov, Sensors. Principles, device technology, performance, parameters and applications., 2014, p. 235).

Of great importance is how to measure the electrical current in the electrical grid. Its measurement by magneto-sensitive integrated circuits allows high accuracy and reliability of the received signal.

The purpose of this article is to describe a real practical development of an electronic module that allows electrical energy measurement in a single phase electric network by contactless current measurement in the current circuit and digital conversion of the power components.

**EXPLANATION**

The block diagram of the implemented device is shown in fig. 1. The main unit in it is the integral electric meter IE. Its task is to process the received signals from the voltage VC and the current CC channels and to form an output signal with a frequency proportional to the electrical energy consumed by the load. IE accuracy is factory set. The conversion constant is also invariable, but by the output frequency control circuit OFC, this frequency can be changed. The indicator I counts a number of pulses for 1kWh depending on the OFC's assignment. IE information can be directly processed by a microcontroller. It allows rating, collecting, storing and displaying the measurement information and can also drive an electromagnetic counter C. In this work C is used as the emphasis is focused to the electrical energy converter.

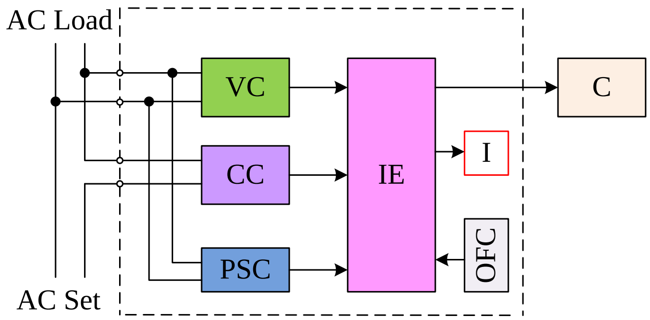


*Fig. 1. Block diagram of the electricity metering module*

The principle electrical diagram of the device is shown in fig. 4. To the current channel of the integral electric meter $IC_4$ (pins 4 and 5) a consumed by a load current signal is fed. The integral electric meter is realized by an special integrated circuit of Analog Device ADE7757 (Analog Device, 2019). The electrical current is measured simultaneously in the phase conductor circuit and in the zero conductor loop. Both $IC_2$ and $IC_3$ are magnetosensitive integrated circuits ACS712 manufactured by Alcegro MicroSistem Inc. (Allegro Microsistems Inc., 2019).

The voltage channel is implemented with the elements $L_1$, $R_3$, $R_4$, $R_6$ and $C1_2$, providing a maximum input voltage between $IC_4$ pins 2 and 3 about 165mV.

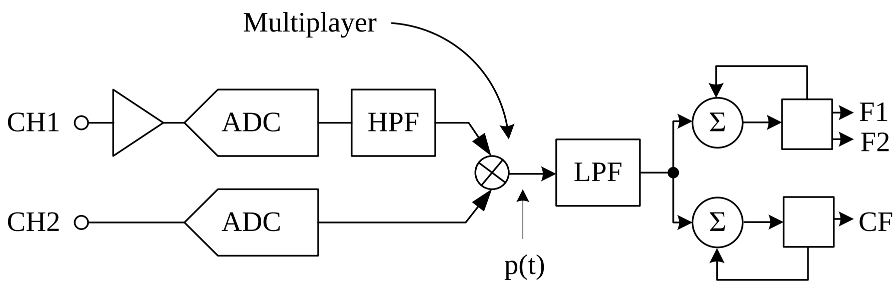


*Fig. 2. Functional block diagram of the integral energy meter*[2]

[2] Analog Device. (2019, Mart). *Application note and part information.* Retrieved from www.analog.com.

The power circuit is implemented by the elements: $C_3$, $R_1$, $D_1$, $DZ_1$, $IC_1$, $C_1$ and $C_2$. Voltage stabilization is done by the integral stabilizer $IC_1$ (LM7805). At the input of the $IC_1$ a voltage stabilized by referent diode $DZ_1$ is 15V. The power circuit is not galvanically separated from the measured circuit (grid). This is a great assets because it saves materials and additional components in the workmanship.

The elements $R_2$, $R_4$, $R_6$ and $R_3$ provide the initial calibration of the measuring module. They are selected so that $R_3 >> R_4 + R_6$. In this case the values are selected as follows: $R_2 = 1\text{M}\Omega$, $R_4 = 500\text{k}\Omega$, $R_6 = 500\Omega$.

Output signals are received at pins 14, 15 and 16. Output 14 (CF) receives direct information about instantaneous full power. This terminal is intended for calibration of the meter. Its frequency can be selected according to application and operating mode by selecting a combination of logic input levels S0 and S1. At pins 15 and 16 (respectively F1 and F2), two low-frequency signals are generated. They are rectangular pulses dephased to one another. F1 and F2 are designed to control an electromagnetic counter C. It is powered by a voltage of 15V, which is controlled by a transistor VT1 (fig. 4).

When the device is switched on to the single-phase loaded grid, signals are sent to the voltage inputs (V2P, V2N) and the current inputs (V1P, V1N) of the IC4 integrated circuit via the voltage and current channels (fig. 2). Both signals are digitized by two 16-bit analogue-to-digital converters of the Σ-Δ type. The dynamics of the two inputs and simplified circuits of the two measuring channels are achieved by the integrated IC4 analog input blocks. A high-pass filter HPF filtering any fluctuations and DC components is included in each channel. It eliminates any inaccuracies in the full power calculation, which are manifested by compensation of the current and power components in the cases of PF<1 (fig. 2). Determination of full power is obtained from the instantaneous power signal. It is derived from the direct multiplication of instantaneous digital values of current and voltage. The value obtained after multiplication is the instantaneous power consumed by the load. Using the low-pass filter LPF the full power value is derived. The integrated circuit correctly calculates full power with high accuracy (0,5%) due to the digital processing of high-resolution information.

As a result of the processing of outputs F1 and F2 (pins 15 and 16), accumulation pulses are generated at a low frequency proportional to the consumed power. These pulses are counted from a counter for a certain amount of time, thereby the value of the consumed electrical energy by load is obtained.

The frequency of the signal generated at the CF output (pin 14 which controls the LED) is proportional to the total instantaneous power consumed by the load. It is useful in cases where calibration needs to be done as it reduces measurement time.

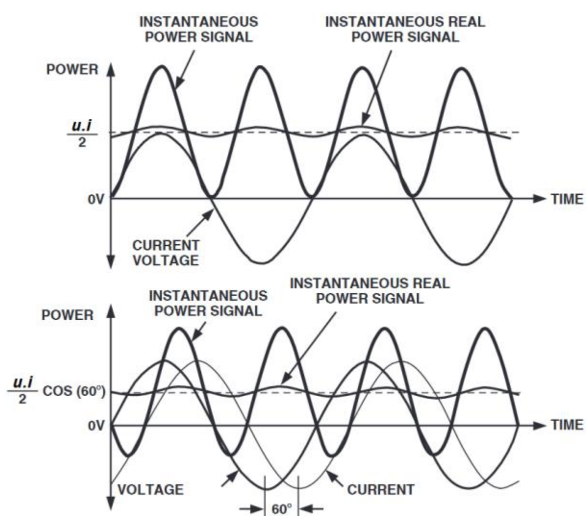


*Fig. 3. Diagrams reflecting the determination of the instantaneous power at a power factor PF <1*

When current and voltage signals are not in phase (PF<1), the same method is used by low-pass filtering to derive full power information. In fig. 3 are shown diagrams reflecting the determination of the instantaneous power at a 60% lagging current (AnalogDevice, 2019). If the ideal case is assumed that the voltage and current modes are sinusoidal, then for the correct determination of the actual power the equation will be used:

$$\left(\frac{u.1}{2}\right).\cos(60°) \quad . \tag{1}$$

In practice, however, current and voltage patterns always have harmonic constituents. The same algorithm is used for calculating the actual power for non-sinusoidal currents and voltages. Using Fourier transforms, instantaneous current and voltage values can be expressed by their harmonic contents:

$$u(t) = U_0 + \sqrt{2}.\sum_{h \neq 0}^{\infty} U_h.\sin(h\omega t + \alpha_h)\,, \tag{2}$$

$$i(t) = I_0 + \sqrt{2}.\sum_{h \neq 0}^{\infty} I_h.\sin(h\omega t + \beta_h)\,, \tag{3}$$

where: $u(t)$ and $i(t)$ are instantaneous voltage and current values and $U_0$ and $I_0$ are their mean values; $U_{hh}$ and $I_h$ are the effective values of harmonic $h$, respectively, of voltage and current; $\alpha_h$ and $\beta_h$ are the phase angles of the voltage and current harmonics.

Using the above two equations, the full power can be determined from the base value $P_1$ and that obtained from the harmonics $P_H$:

$$P = P_1 + P_H\,, \tag{4}$$

where:

$$P_1 = U_1.I_1.\cos\varphi_1; \tag{5}$$

$$\varphi_1 = \alpha_1 - \beta_1; \tag{6}$$

$$P_H = \sum_{h \neq 1}^{\infty} U_h.I_h.\cos\varphi_h\,; \tag{7}$$

$$\varphi_1 = \alpha_1 - \beta_1.$$

As can be seen from the last equation (7), the harmonic component of full power is generated for each harmonic provided that the harmonic exists both in the shape of the current and the voltage. The calculation of the power factor for sinusoidal form was presented above. For the actual power of the harmonics it is also appropriate to take into account the power factor as it is composed of a series of pure sinusoids.

The bandwidth of the analog inputs is 7 kHz at a nominal frequency of the 450 kHz internal generator. These parameters should be taken into account in the passporting and operation of the measuring module since harmonics with frequencies outside the given bandwidth will not be correctly transformed by the circuit.

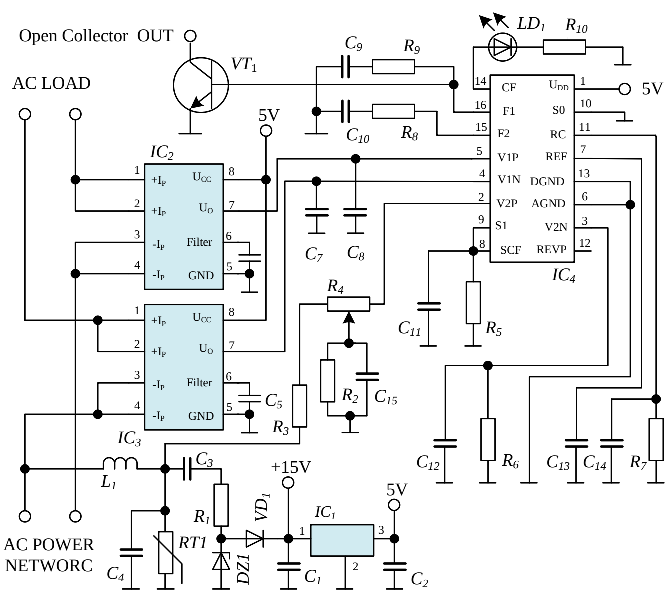


*Fig. 4. The electrical circuit diagram of a module for electrical energy measurement*

In practice, the operation of the module is limited to multiplying the voltages supplied to the two channels (V1P, V1N and V2P, V2N) and after filtering power consumption is converted to frequency. The pulse frequency is related to voltages fed at both inputs (current and voltage) through the following equation:

$$F_{F1-F2} = \frac{515{,}84.U_{RMSCH1}.U_{RMSCH2}.F_{OSC}}{U_{REF}^{\;2}}, \tag{8}$$

where: $U_{RMSCH1}$ and $U_{RMSHC2}$ – effective differential voltages fed to channel 1 and channel 2; $U_{REF}$ = 2,5V ± 8% – comparator voltage, $F_{OSC}$ – generator frequency defined by input levels S0 and S1, table. 1.

Tab. 1

| S1 | S0 | FF1-F2,Hz |
|---|---|---|
| 0 | 0 | 0,86 |
| 0 | 1 | 1,72 |
| 1 | 0 | 3,44 |
| 1 | 1 | 6,86 |

Tab. 2

| IMAX, A | F1-F2, Hz |
|---|---|
| 12,5 | 0,076 |
| 25 | 0,153 |
| 40 | 0,244 |
| 60 | 0,367 |
| 80 | 0,489 |
| 120 | 0,733 |

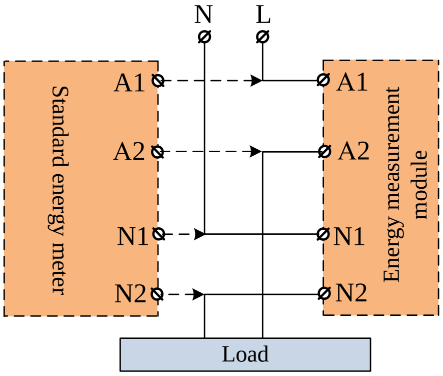


*Fig. 5. Schematic diagram of the experimental setup*

The operator can select one of the frequencies shown in Table 1. Depending on this frequency, the number of switching outputs F1 and F2 is determined. Since only four frequency values can be selected, they are selected to be optimized towards the 100imp / kWh constant. Table 2 shows the output frequency values for several load current values described by [9] and measured by the developed device for supplying a load with grid voltage. In any case, the device constant is invariable – 100imp / kWh.

**EXPERIMENTAL RESEARCH**

Experimental research has been carried out showing the performance of the device. In Fig. 5 is shown a schematic diagram of the experimental setup under which the test measurements were carried out. They are carried out using a water rheostat as a load, allowing for smooth adjustment of the current or the power in the measured circuit and a standardized one-phase single-tariff digital electric energy meter purchased from the market.

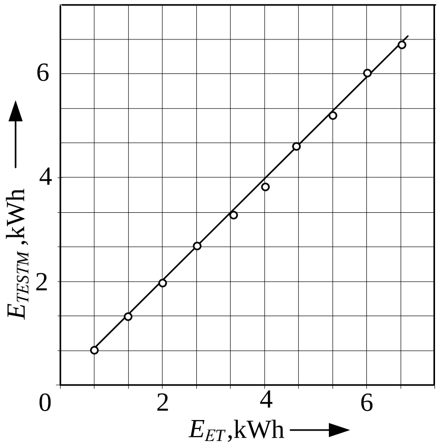


*Fig. 6. Graphics dependence $E_{TESTM}=f(E_{ET})$*

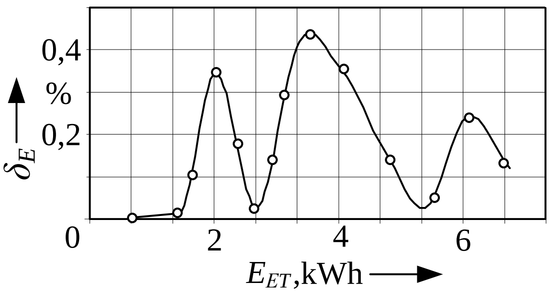


*Fig. 7. Graphics dependence $\delta_E=f(E_{ET})$*

The results for the electrical energy measured by the developed module are compared with those obtained with the standardized electric energy meter. The measurements are carried out in sequence, first with the standardized device then with the developed module. The results obtained are presented graphically in fig. 6. It reflects the dependency of the energy measured by the developed $E_{TESTM}$ module for electric energy measurement as a function of measured by standardized device. The error obtained by the comparison is:

$$\delta_E = \frac{E_{TESTM} - E_{ET}}{E_{ET}}.100 \qquad (9)$$

The $E_{ETESTM} = f\,(E_{ET})$ dependency analysis shows that it is almost linear, with very small differences between the readings of the two devices – the developed and comparing.

In order to illustrate the results by means of equation 9 is obtained the dependence $\delta_E = f\,(E_{ET})$ (fig. 7). It reflects the measurement error obtained by developed device in relation to the results obtained from the standardized. Since the latter also makes a mistake, the results are comparative and tentative. They show a maximum deviation of the actual value to 0,45%. The results are largely due to the tolerance of the electronic components, and the existence of parasitic signals with constant action in the set groups and others related to the structure of the developed device. Of course, here is an experimental measuring module!!! Its class is much lower than the one with which it is compared and certified according to Bulgarian State Standard BSS EN61000-3-2: 2006/A2 and BSS EN61000-4-5 (Bulgarian Institute for Standartization, 2019)!

**CONCLUSION**

An exemplary version of an electronic module for electrical energy measurement in a single phase electric network, realized on the basis of a specialized integrated circuit has been developed.

Proposed and described are a block and a general circuit diagrams. The mode of action is described and the algorithm for calculating the power is presented.

Experimental studies have been carried out demonstrating the functionality of the developed module and the maximum error of measurement was established $\delta_E = 0{,}45\%$.

The design does not claim the name "electric energy meter". The electric energy meter is a device with very good metrological performance. An experimental module for electrical energy measurement has been developed. By means of its work possibilities can be done various experimental measurements.

The developed module is characterized by simplified realization and the possibility of easy adjustment and processing of measured data. The minimum number of components and their accessibility make it an appropriate choice in various electronic systems and devices for monitoring and controlling the parameters of electrical networks and facilities.

The developed module for digital measurement of single-phase electric power is used both in measuring equipment and in engineering research. The circuitry configuration of the input channels and the control flexibility of the conversion function give to presented module not only measuring but also developmental applications.

**REFERENCES**

Allegro Microsistems Inc. (2019, Mart 22). *Application notes and part information.* Retrieved from www.allegro.com.

Analog Device. (2019, Mart). *Application note and part information.* Retrieved from www.analog.com.

Bulgarian Institute for Standartization. (2019, April). Retrieved from www.bds-bg.org.

Draganov, N. (2014). Contactless galvanomagnetic DC and AC ammeter. *The Journal of Machinebuilding and electrical engineering* (3), 40-43.

Draganov, N. (2012). Experimental Contactless Galvanomagnetic Residual Current Device. *Third International Scientific Congress Tehcnical university of Varna. II,* pp. 134-139. Varna: Tehcnical university of Varna.

Draganov, N. (2014). Experimental digital three-phase check electrical energy meter. Part 1. *ICEST* (pp. 429-432). Nish, Serbia: ICEST.

Draganov, N. (2015). Galvanomagnetic sensor unit for electric current measurement. *UNITECH* (pp. 260-264). Gabrovo: Technical university of Gabrovo.

Draganov, N. (2014). *Sensors. Principles, device technology, performance, parameters and applications.* (First part). (I. Kolev, Ed.) Gabrovo, Gabrovo, Bulgaria: EXPRES.

Hinova, A. (2019). Analytical assessment of logical risk rejection schemes. *Scientific Research of the SCO countries* (p. 166). Beijimg, China: Synergy and Integration.

Rankovska, V. (2013). Teaching FPGA-Based CPU Cores and Microcontrollerr. *ICEST. 2*, pp. 835-838. Ohrid, Macedonia: ICEST.