Digital Power and Energy Meter with DSP TMS320C6711

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SPRP504

Agenda

- **Digital electricity meters**
- **Designed electricity meter**
  - voltage/current input board
  - analogue board
  - DSP board
  - main control board
- **Error sources**
- **Error correction**
- **Conclusions**

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Digital Electricity Meters

Advantages

- high accuracy,
- short-term and long-term stability,
- complex net parameters measurements,
- possibility of remote automated data processing,
- auto-calibration, self-test,
- many other functions resulting from the microprocessor-based digital system possibilities.

Measured quantities

- rms values of voltages and currents,
- active, reactive and apparent power,
- energy delivered into a load,
- phase shift, power factor,
- frequency spectrum of the power network signals.

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Digital Electricity Meters

Equations used to calculate the power network parameters:

- Voltage (RMS)

$$U = k_u \sqrt{\frac{1}{N} \sum_{i=1}^{N} u_i^2}$$

- Current (RMS)

$$I = k_i \sqrt{\frac{1}{N} \sum_{i=1}^{N} i_i^2}$$

- Active power

$$P = \frac{k_u k_i}{N} \sum_{i=1}^{N} u_i i_i$$

- Apparent power

$$S = UI$$

- Reactive power

$$Q = \sqrt{S^2 - P^2}$$

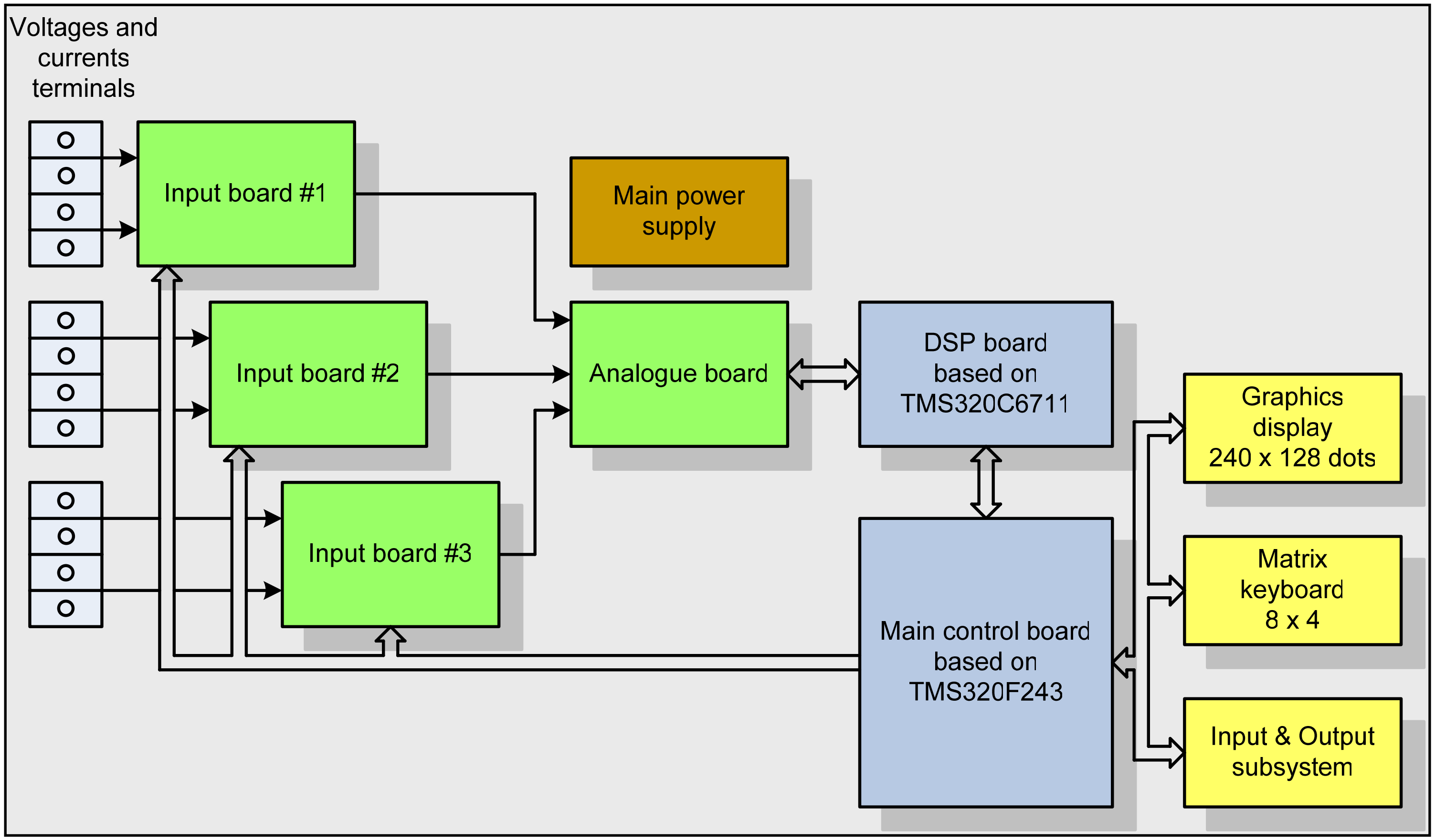
- Power factor

$$PF = \frac{P}{S}$$

- Frequency

$$f = \frac{f_s}{N}$$

Designed Electricity Meter



Two modes of operation:

- calibration mode – the measured and calculated parameters are displayed continuously on the display, calibration procedure can take place,
- registration mode - the measured and calculated parameters are periodically stored in the memory.

The period of averaging and storing the results is optional.

The duration of energy measurement is optional.

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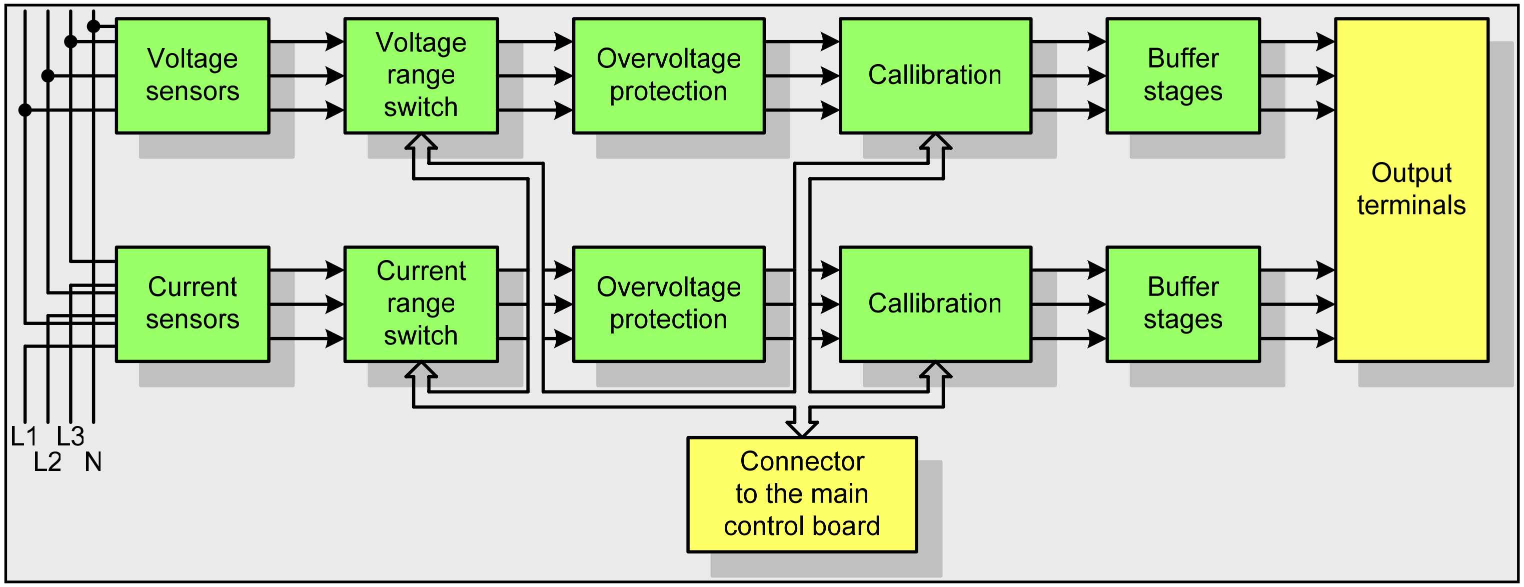
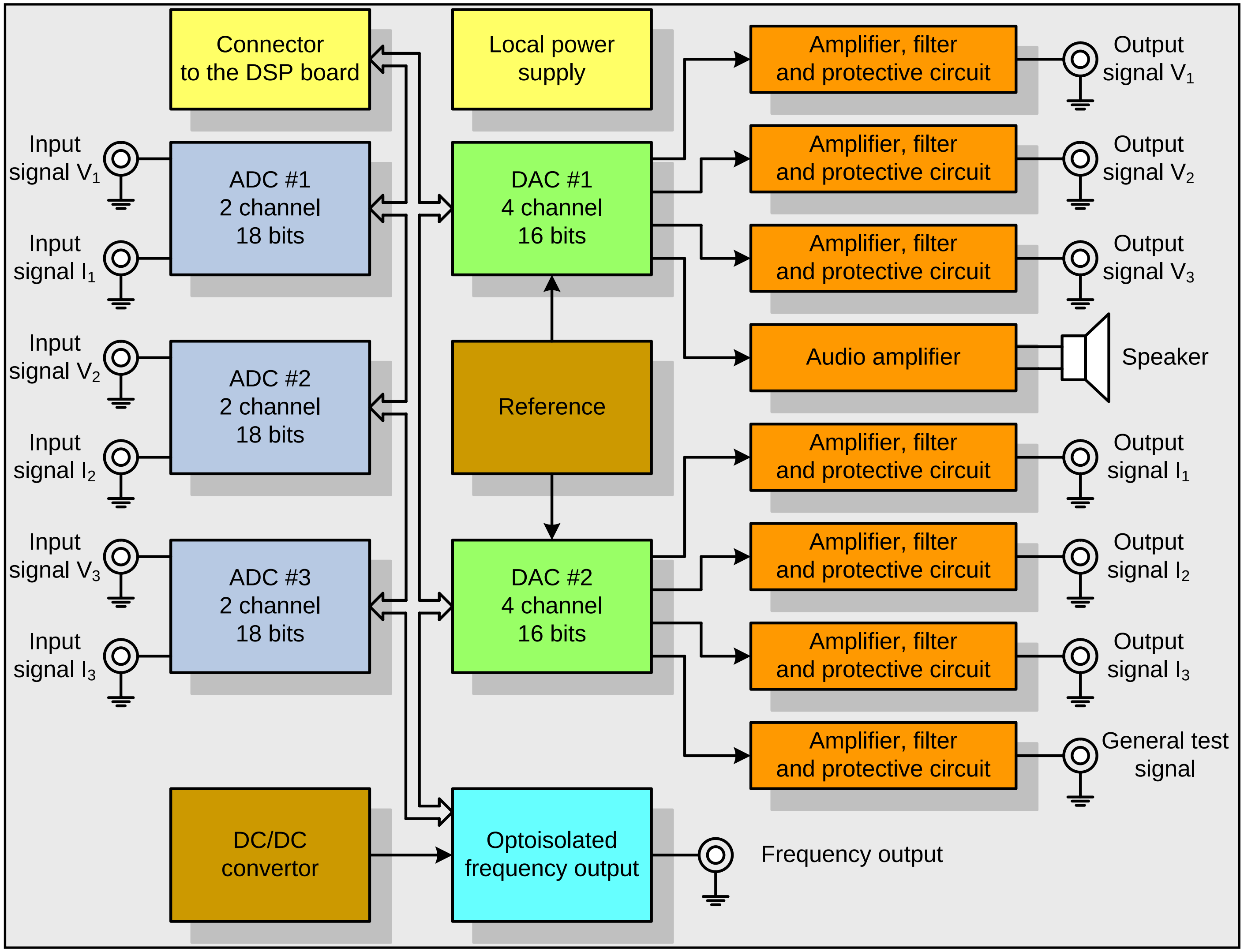
Voltage/Current Input Board



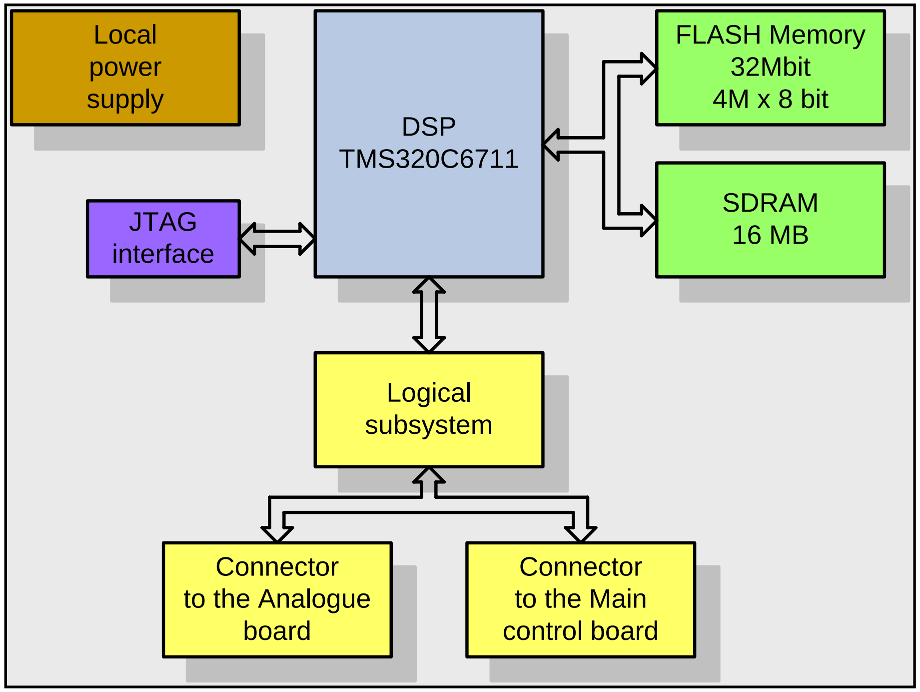
- 3-phase four-stage resistive voltage dividers, 20 V...500 V,
- three current transformers, 6 ranges, 40 mA...120A,
- signal conditioning and protection circuits.

Analogue Board

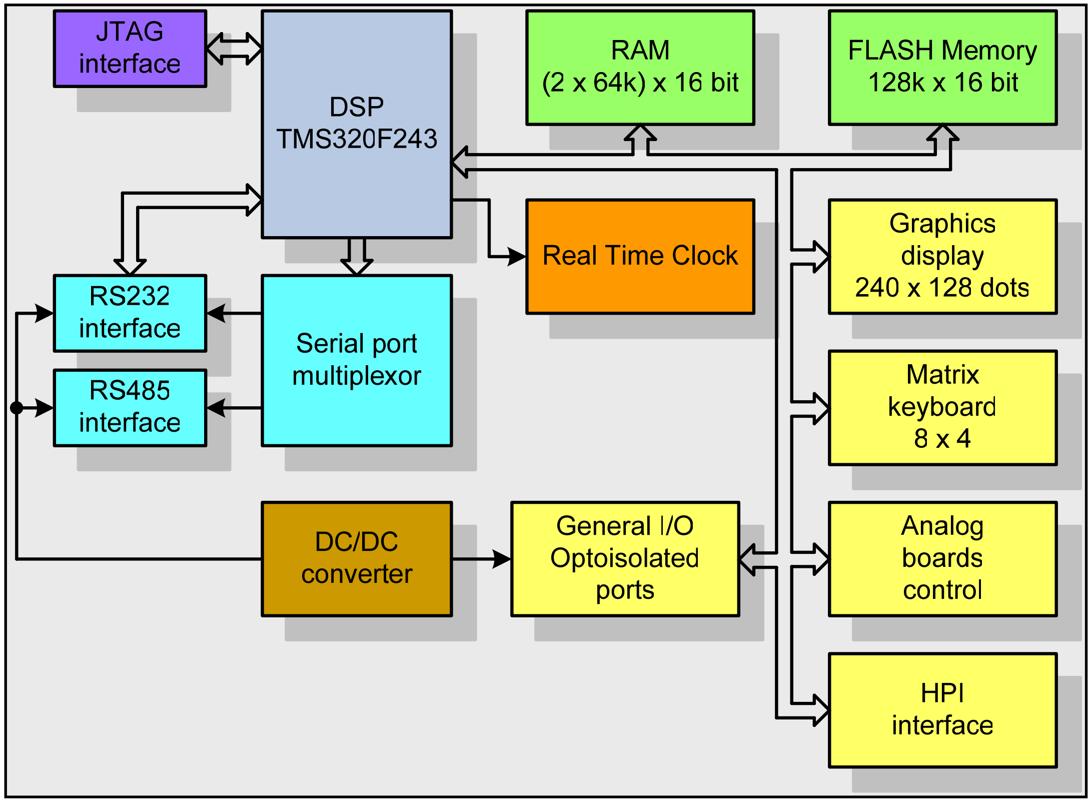


DSP Board

- powerful floating-point Texas Instruments TMS320C6711 processor,
- high speed temporary data memory (16 MB SDRAM),
- large low-cost program and data memory (32 Mbit FLASH ROM),
- necessary calculations and signal processing in digital form,
- frequency output with the frequency proportional to the measured power,
- 3-phase voltage and current signal generation, outputs through D/A converters,
- simple control signals and data transfer from three A/D converters at sampling rate up to 100 kHz,
- simple communication between DSP and microcontroller (HPI interface),
- watch-dog security system,
- JTEG emulation for software development.



Main Control Board

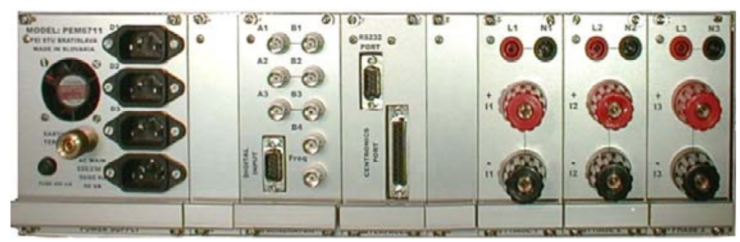


- Texas Instruments TMS320F243 DSP microcontroller,
- control of the operation of the device,
- displaying of the results on the graphical LCD display with the resolution of 240x128 dots,
- communication via IrDA or RS 232 interfaces.

PEM6711

Front view

Rear view



Calibration Station

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Calibration Station

Error Sources

Analogue input circuits

- inaccurate adjustment of voltage and current sensors,
- instability and noise of circuits handling the input signals.

Sampling process

- approximation of the waveform by a staircase or a piecewise linear function,
- asynchronous sampling – long averaging time (large number of samples),
- approximately synchronous sampling – start of sampling synchronized,
- synchronous sampling – the best accuracy, complicated construction,
- number of samples, N, sampling rate.

A/D conversion

- multiplexed inputs – error caused by time shift between samples,
- separate A/D converters – higher accuracy, expensive,
- resolution and accuracy of A/D converters.

Digital calculations

- some calculation time necessary,
- error correction of the results, not single samples.

Error Correction

Analogue input circuits

- not necessary to be accurate (error correction in digital part),
- importance of stability of parameters.

Sampling process

- staircase approximation used – simplicity of calculations,
- approximately synchronous sampling with starting point in the instant of zero crossing of the sampled signal used – simplicity, low error if N is high.

A/D conversion

- sigma-delta A/D converters:
  - **high resolution (over 16 bits),**
  - **high sampling rate (tens kSPS),**
- averaging during longer summation interval (many periods) to get higher measurement accuracy.

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Error Correction

Digital calculations

- the error of calculation when only the final calculated values are corrected:

Linear correction function of the type $y = ax + b$ was used,
a – gain error,
b – offset error;
1000 samples of the voltage and current per period were calculated using the equations

$$u_i = a_1 U_m \sin(2\pi i / 1000) + b_1 \qquad (1)$$

$$i_i = a_2 I_m \sin(2\pi i / 1000) + b_2 \qquad (2)$$

i = 1,2,...,1000,
U_m and I_m considered to be unity.

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Error Correction

Digital calculations

• the error of calculation when only the final calculated values are corrected:

Equations for the correct use of the correction function (U_1, I_1 – rms values, P_1 – power)

$$U_1 = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{1}{a_1}u_i - \frac{b_1}{a_1}\right)^2} \qquad (3)$$

$$I_1 = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{1}{a_2}i_i - \frac{b_2}{a_2}\right)^2} \qquad (4)$$

$$P_1 = \frac{1}{N}\sum_{i=1}^{N}\left[\left(\frac{1}{a_1}u_i - \frac{b_1}{a_1}\right)\left(\frac{1}{a_2}i_i - \frac{b_2}{a_2}\right)\right] \qquad (5)$$

Error Correction

Digital calculations

• the error of calculation when only the final calculated values are corrected:

Equations for simplified calculation of the final corrected values

$$U_2 = \frac{1}{a_1}\sqrt{\frac{1}{N}\sum_{i=1}^{N} u_i^2 + b_1^2} \quad (6)$$

$$I_2 = \frac{1}{a_2}\sqrt{\frac{1}{N}\sum_{i=1}^{N} i_i^2 + b_2^2} \quad (7)$$

$$P_2 = \frac{1}{a_1 a_2}\frac{1}{N}\sum_{i=1}^{N} u_i i_i + \frac{b_1 b_2}{a_1 a_2} \quad (8)$$

Error Correction

Digital calculations

• the error of calculation when only the final calculated values are corrected:

Calculation errors expressed by equations

$$\delta_u = \frac{U_2 - U_1}{U_1} \times 100 \quad (9)$$

$$\delta_i = \frac{I_2 - I_1}{I_1} \times 100 \quad (10)$$

$$\delta_P = \frac{P_2 - P_1}{P_1} \times 100 \quad (11)$$

These errors are plotted in following figures ($a_1 = a_2$, $b_1 = b_2$).

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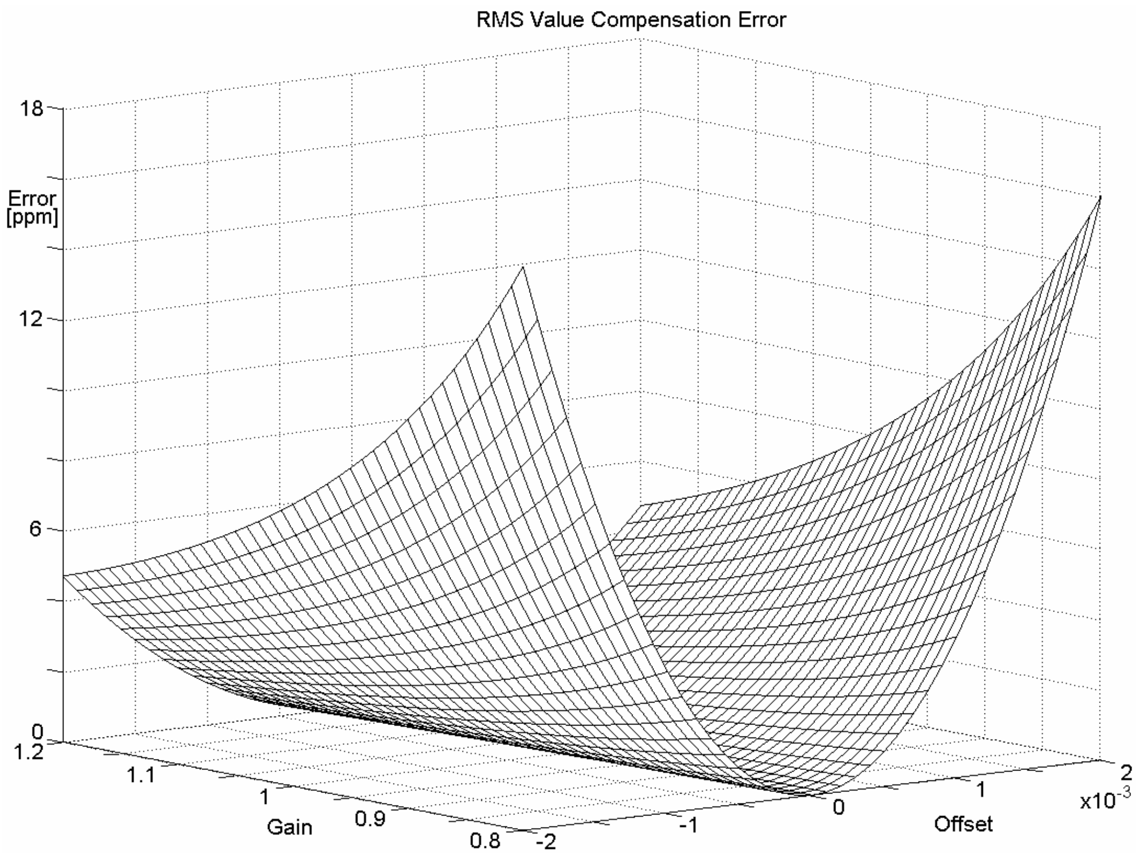
Error Correction

<u>Digital calculations</u>

- the error of calculation when only the final calculated values are corrected:



The errors of such simplified calculations are of the order of 10 ppm.

RMS value correction error of the simplified calculation procedure.

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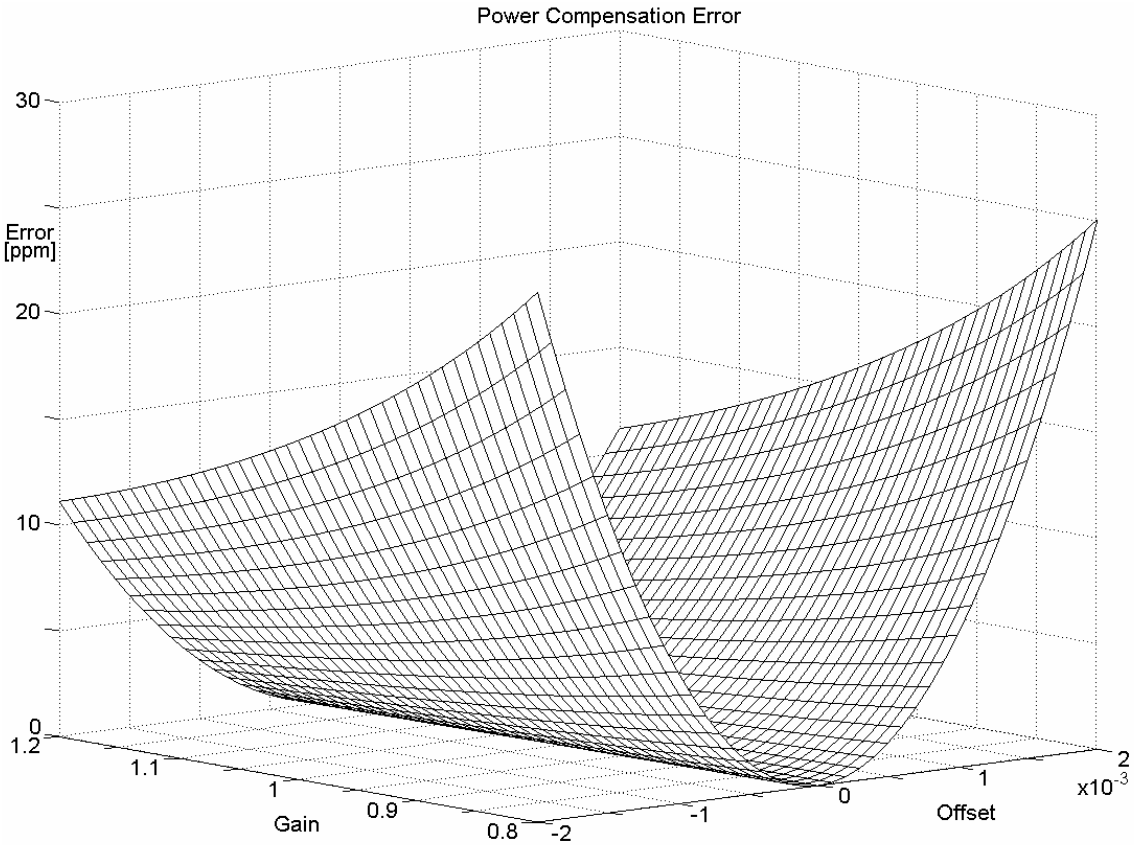
Error Correction

Digital calculations

- the error of calculation when only the final calculated values are corrected:



The errors of such simplified calculations are of the order of 10 ppm.

Power correction error of the simplified calculation procedure.

Calibration Problems

Calibrated quantities

- voltage *U*, current *I*,
- correction of the parasitic phase shift φ_p between *U* and *I*.

Computer controlled calibration

- controlled signal source, calibrated and reference instrument,
- calibration constants calculation and storing in the memory of the calibrated instrument.

Calculation speed disables the correction of every sample

- corrected only resulting values of voltages and currents,
- problems with power measurement accuracy: calculated from uncorrected samples.

Calibration Problems

Voltage calibration

- least squares method.

Current calibration

- problems with the stability of generated current,
- average values must be used,
- frequency output based on the apparent or active power can be used to calibrate current, current calibration based on the active power value influenced by phase shift correction,
- calibration procedure for the corrections of the measured current and parasitic phase shift between the measured voltage and current based on the active power measurement was designed.

Parasitic phase shift correction

- based on the active power values,
- shifting of the current samples against the voltage samples before multiplication.

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Conclusions

- The description of the designed digital three-phase electricity meter is given.
- Modern Texas Instruments processors TMS320F243 and TMS320C6711 were used to get a powerful measuring system.
- Error sources, error corrections and calibration problems are briefly discussed.
- The errors of corrections of rms values and active power when only the final calculated values were corrected, were verified.
- MATLAB calculations were used to simplify this verification.
- The errors of such corrections were of the order of 10 ppm.

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