Frequency modulation to deliver precise analog signal to long distances without retransmitters

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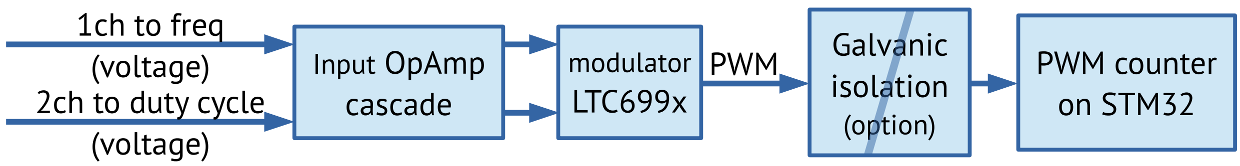
We have developed measurement channel based on LTC6990/LTC6992 and STM32 microcontroller. We enjoy our results and believe they could become interesting to engineer community.

Prehistory

Often we need to measure and monitor various parameters of different machines. There are a lot of sensors and sensing elements, and most of them produce voltage. To transfer measured value without distortion errors we need a defended transmission environment. The most popular variant is 4..20 mA current loop. We use it usually. Our look to the field line was changed after meeting Linear's frequency and pulse-width modulators LTC699x. The field line, which has two states is more defended, then analog. Current PWM signal showed itself quite well, in other words perfectly. Let's consider principals.

Brief description

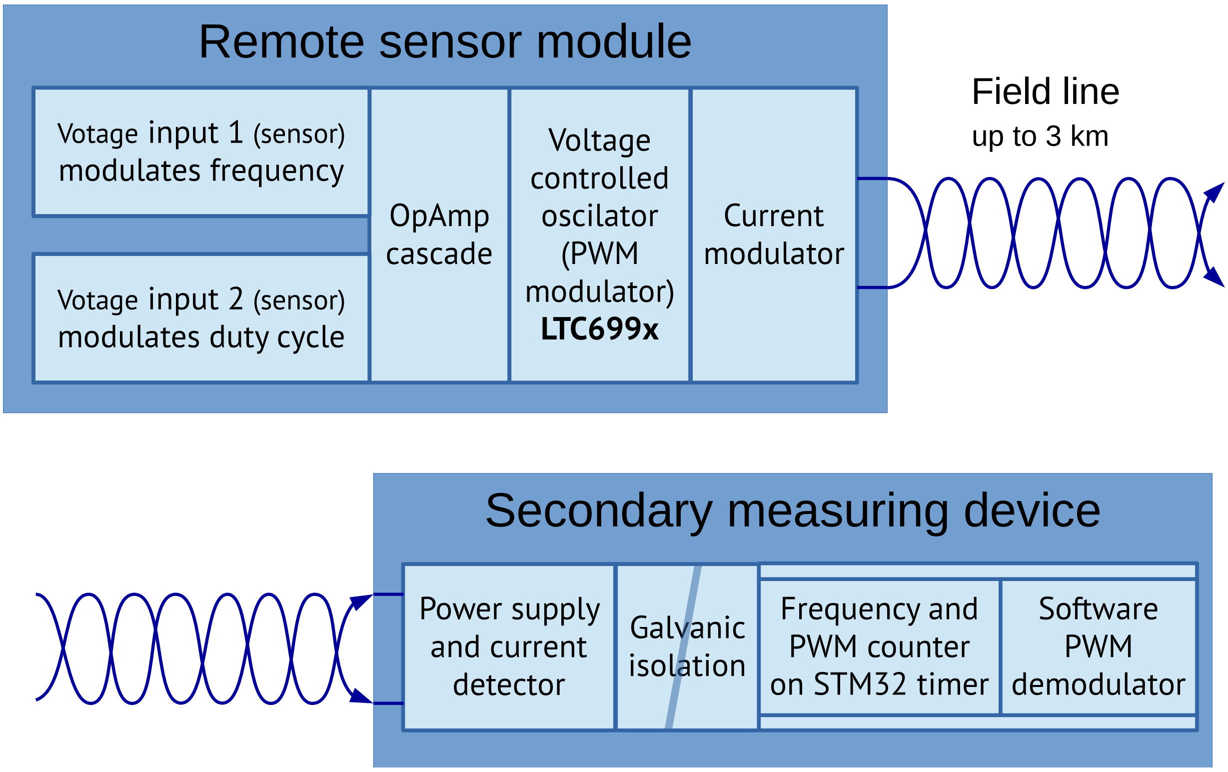
LTC699x in conjunction with precise PWM counter can be used as a very good ADC. In our case PWM counter is STM32 microcontroller with its feature-rich timers. The precision depends on core frequency of uC, sample rate and, of course, on input circuit's and LTC's inaccuracies. All our calculated estimations were tested and coincided with reality. Galvanic isolation is important for most field buses, and ours is not an exception, to provide galvanic isolation we need only one very cheap 1-line optocoupler like 6N137 or something more modern, e. g. ADUMxxxx.



Picture 1 – PWM modulation/demodulation operates as an ADC. Simplified structural-functional scheme

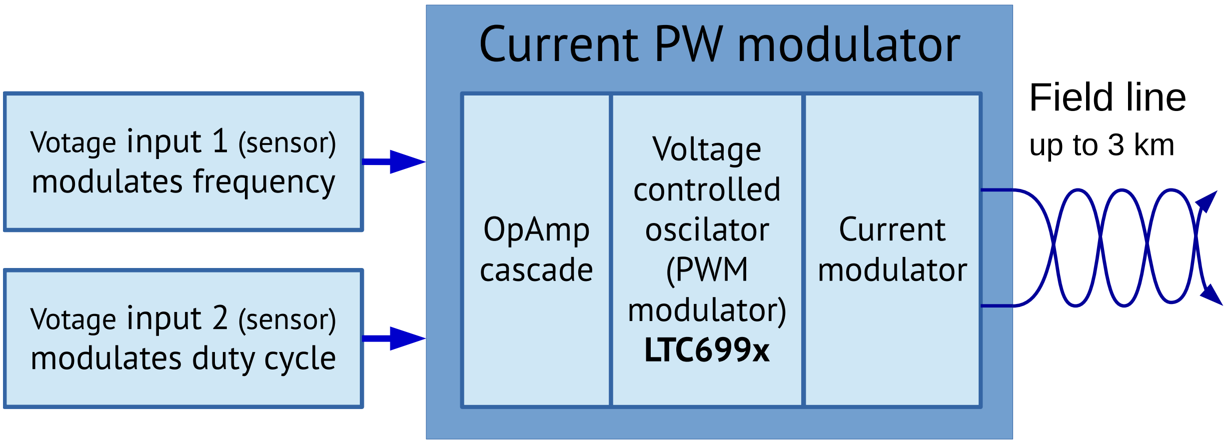
PWM measurement channel

Measurement channel consist of **primary measurement device** (remote sensor module), two-wire **field line** and **secondary measurement device**. Let's consider picture 2. Remote sensor module can have 1 or 2 input analog channels. First modulates frequency and second modulates duty cycle. Only LTC6992 can modulate duty cycle. Current modulator controls consumption current of sensor module. Since the current in the field line discrete, it is less susceptible to the effects of interference. The field line could have length of 3 km and that is not the limit. Secondary measurement device detects consumption of sensor module and PWM signal without errors goes through optocoupler to the uC's input. Than it is counted using STM32 timers. Demodulation is quite simple due to LTC699x is linear modulator. Input voltage is calculated from counted frequency via linear formula $v=k \cdot f+b$, where v – sensor voltage, k – multiplier, f – counted frequency, b – offset.



Picture 2 – Simplified structural scheme of measurement channel with current pulse-width modulated signal in field line.

Input signals could be dedicated from sensor module. So sensor module will be divided into 2 parts: sensor itself and current PW modulator (pic.3).



Picture 3 – Sensor module divided into 2 parts

The effort of using such measurement channel:

- 2-in-1 – two signals in one line;
- chipper, when using external ADC with galvanic isolation;
- very long field lines;
- noise immunity;
- power supply voltage can be varied to specify operating mode of sensor, e. g. self-test.

Cons:

- maximum good-working sample rate is tens of kHz

Theory of measure and calculations

Frequency is the number (*n*) of occurrences of a repeating event per unit time (*t*). Frequency may be expressed as

$$f=\frac{n}{t}$$

In our case event is input pulse, or strictly speaking edge of input pulse. In µC frequency is calculated according to the formula

$$f=F_{ref.tim.}\cdot\frac{N_{input.pulses}}{N_{ref.ticks}}$$

where $F_{ref.tim.}$ – timer frequency. Regular frequency of STM32F4xx core and timer is 168 MHz;

$N_{ref.ticks}$ – period of time given as number of reference ticks;

$N_{input.pulses}$ – number of pulses of measured signal. Timer fixes edges of PWM signal.

There are two sources of possible inaccuracy: 1) base *frequency of timer* depends on input clock (usually quartz crystal resonator) and µC's PLL block; 2) reference ticks may vary ±1 tick, because of input and internal clocks are not synchronized.

A **duty cycle** is the percentage of one period in which a signal is active. A period is the time it takes for a signal to complete an on-and-off cycle. As a formula, a duty cycle may be expressed as:

$$q=\frac{t_{high}}{T}\cdot 100\,\%$$

where t_{high} is the time the signal is high, and T is the total period of the signal. To achieve better accuracy consider more than one period:

$$q=\frac{\sum t_{high}}{\sum T}\cdot 100\,\%$$

In μC time is expressed in ticks, so duty cycle is calculated according to the formula

$$q=\frac{N_{high}}{N_{ref.ticks}}\cdot 100\,\%$$

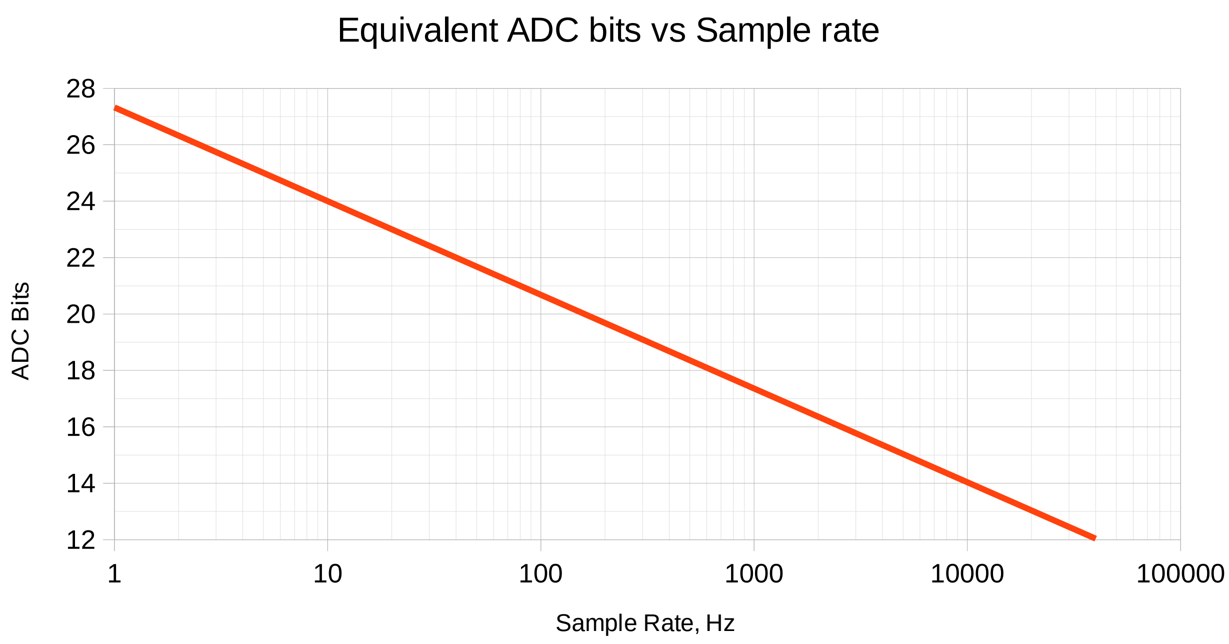
N_{high} – number of ticks of reference timer, when input signal was high (logic 1);

N_{period} – measure period, represented in ticks of reference timer.

Recommendations to increase precision. 1) Use 10..20 ppm resonator or better generator; 2) Migrate to STM32F7 to Increase reference frequency from 168 MHz to 216 MHz. STM32F4 also allows undocumented overclocking up to 250 MHz.

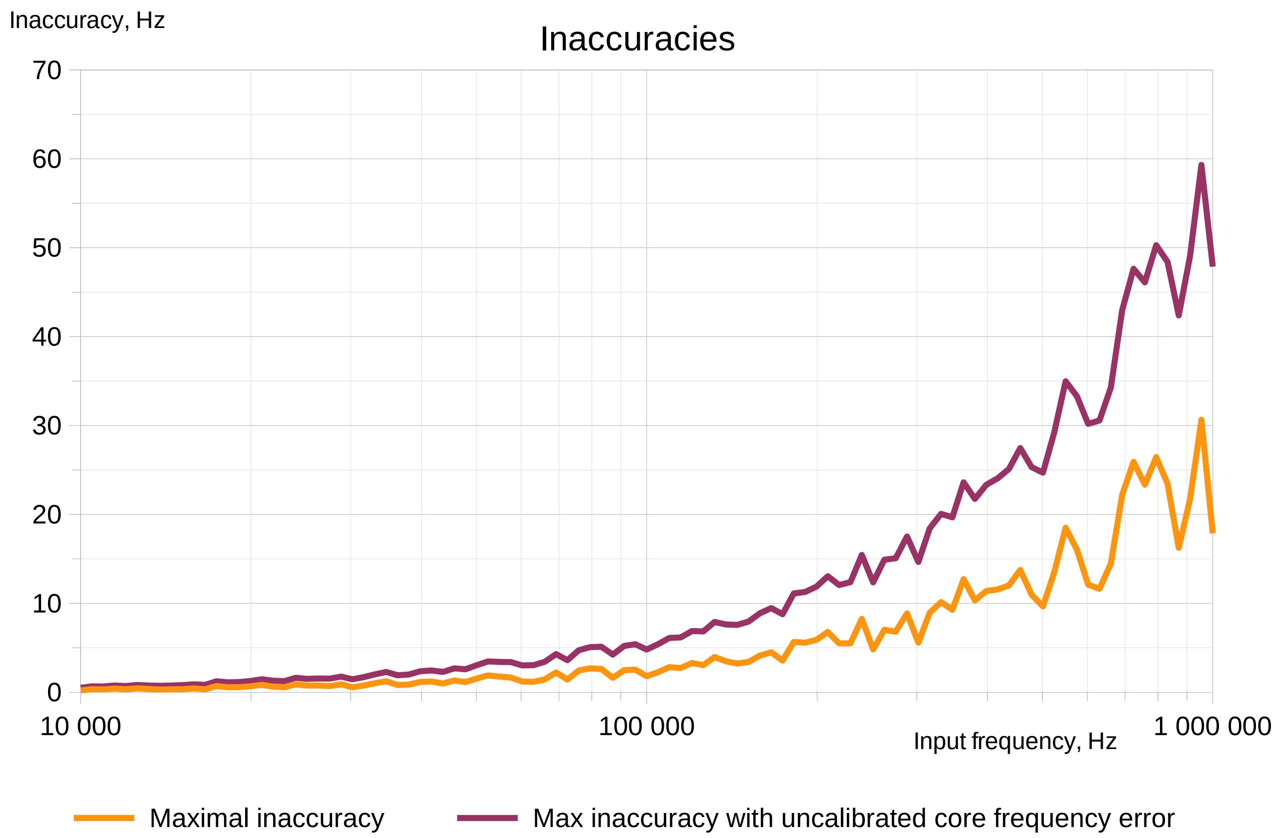
Tests

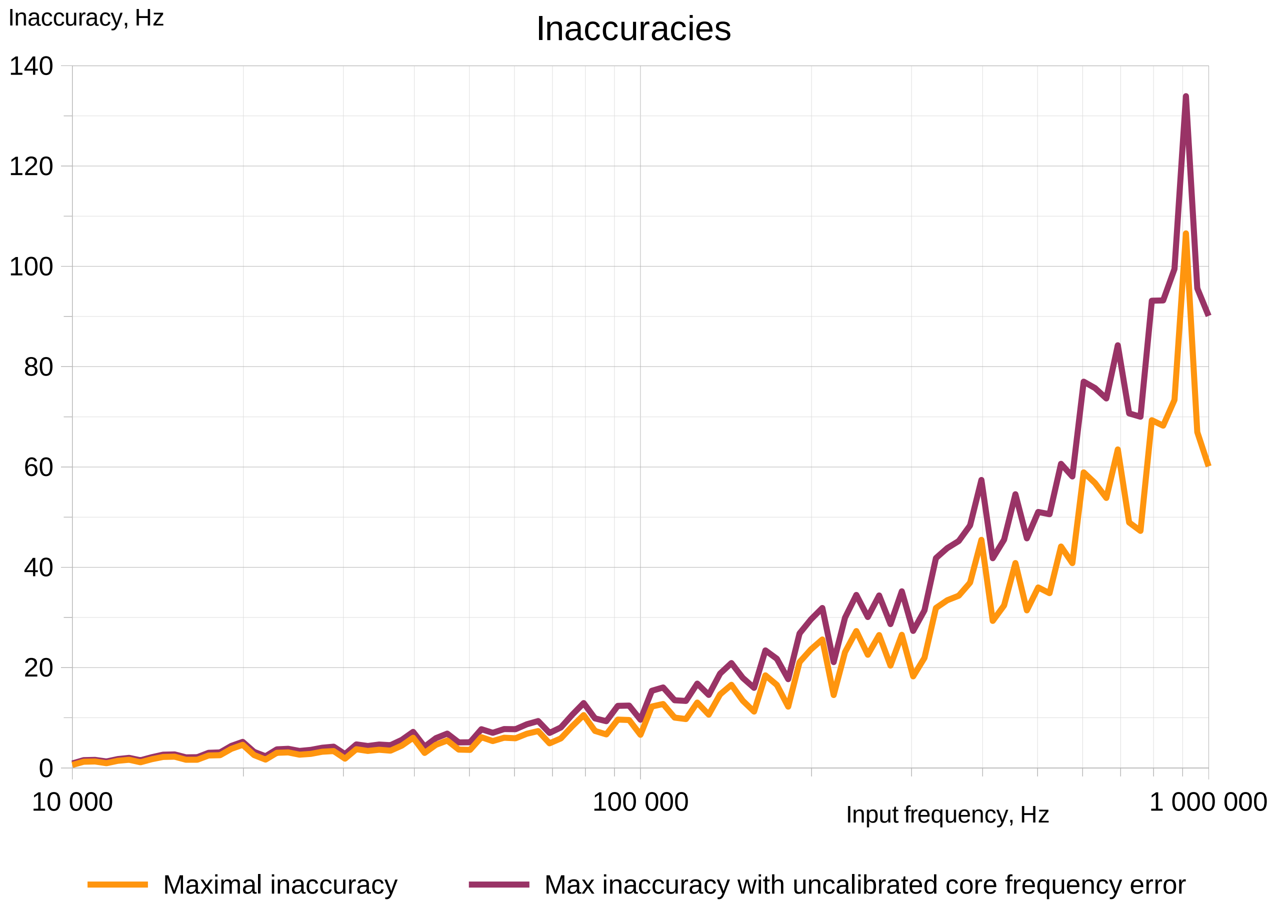
We tested measurement channel in static and dynamic operation modes – works fine. On picture 4 shown calculated and verified in practice equivalent ADC resolution of frequency meter. Base frequency of reference timer is 168 MHz. Inaccuracy ±1 LSB guaranteed by design.



Picture 4

Tests in hardware showed that real measure inaccuracies coincided with expected. Results are shown on picture 5. Uncalibrated error is caused by 30 ppm crystal resonator inaccuracy. It should be calibrated.

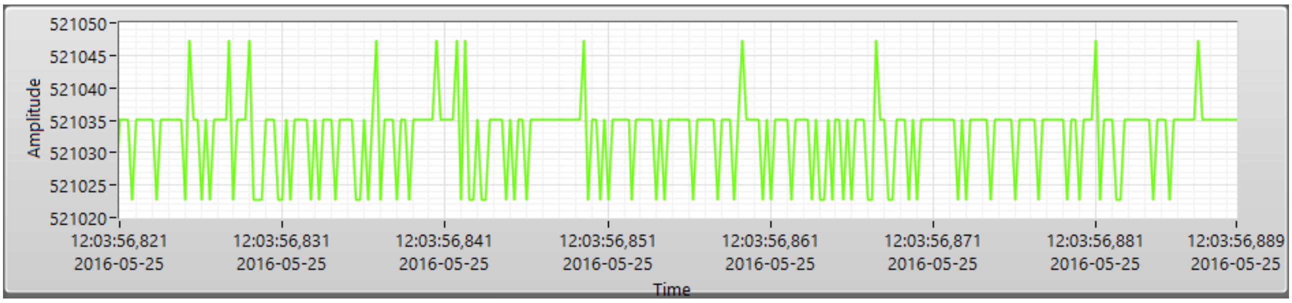




Picture 5 — Inaccuracy depends on input frequency a) sample rate 3000 Hz,
b) sample rate 10 kHz

Data visualization and processing

We also developed software for PC to monitor channels. **Secondary devices** send waveforms via multicast UDP to LAN, PC collects them, process and shows. Picture 6 shows received waveform from device. Voltage input in sensor is stable 2.500 V. Received frequency is 521035±15Hz. Theory is confirmed in practice. System works on several industrial objects.



Picture 6 – Screen shoot of measured waveform at sample rate 4000 Hz

Documents and materials we have at the time:

- Calculations and graphs in PTC Mathcad and LibreOffice Calc;
- Schematics and PCBs, developed in Altium Designer;
- C/C++ sources for STM32F4xx and STM32F7xx;
- Signal monitor for PC, which listens devices in the network. SW is written in LabVIEW development system;
- Few sketches of articles and drawings.

Lets popularize LTC699x series

We believe that with proper advertising and publications, LTC699x series will become interesting and useful for a lot of engineers. And this technical solution will find its application. We suggest and we can to:

- develop shields for STM32-Discovery and STM32-Nucleo development boards;
- make open-source well-tested release software;
- write few exhaustive articles – application notes;

We want to continue to work in this way, we need your support. Thank you for attention.

This application has been mainly used by norma-c.com