

Two channel high voltage differential probe for power electronics applications

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Highlights:

- High voltage two channel differential probe for power electronics
- Bandwidth of at least 10MHz
- Follow slew rate- 7.3V/ns at the input - typical in real power converters
- The probe is tested by using high voltage source up to 8kV DC and no corona or flashover were observed between the PCB layout and the components and between the components as well.

Features

- Allows non ground referred measurements by avoiding the usage of expensive galvanic insulated oscilloscopes
- Guaranties safety measurements up to $\pm 3\text{kV}$ in differential measurement (category II)
- Two channels - cost effective per channel

Probe overview

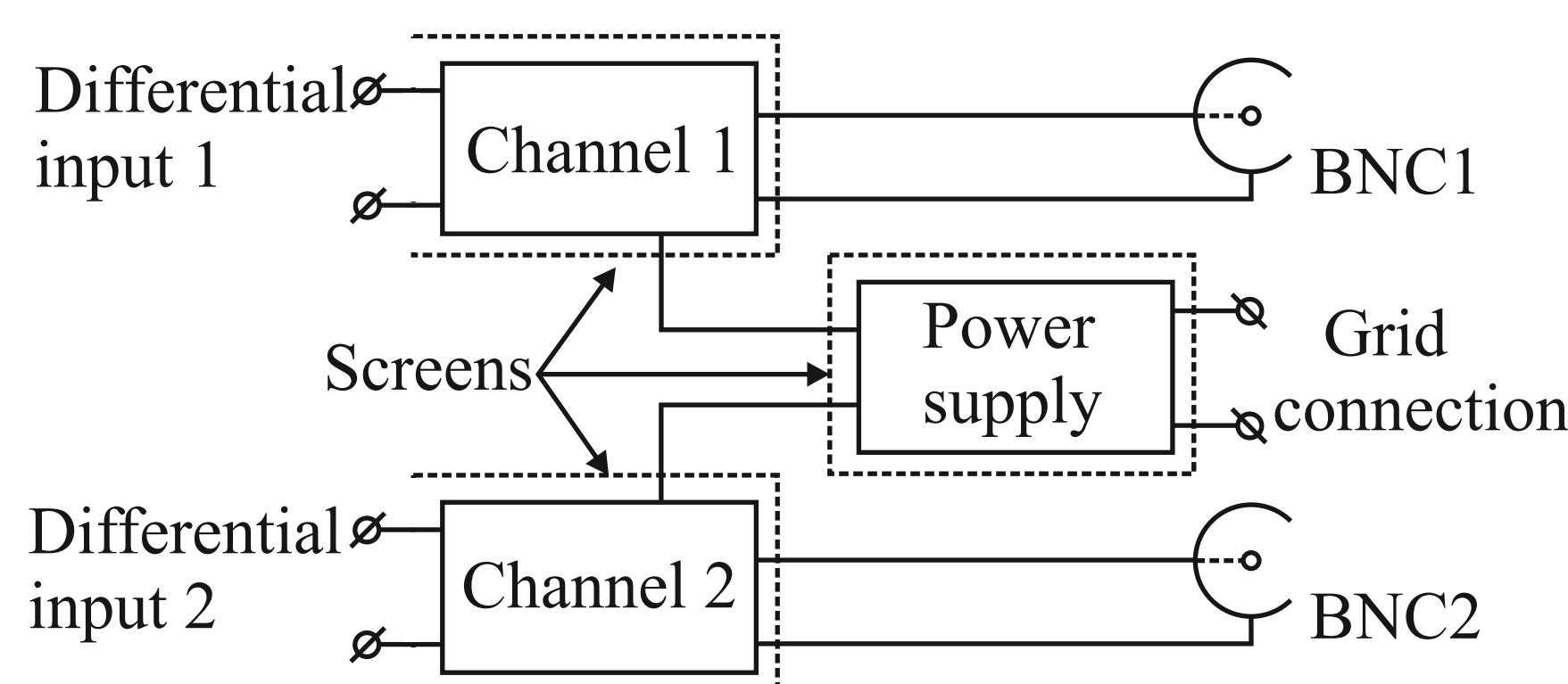


Fig. 1: Simplified block diagram of the probe

The accuracy of the high voltage resistors is 1% but they are checked for higher accuracy and 5% for capacitors which are tuned by variable capacitor.

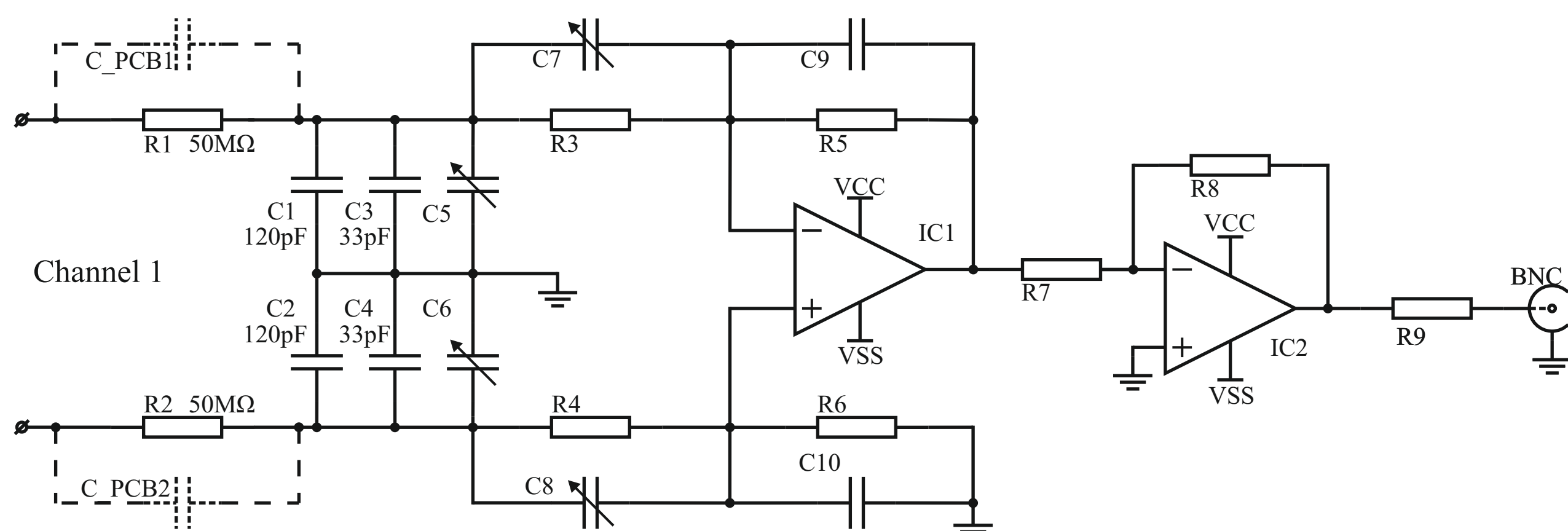
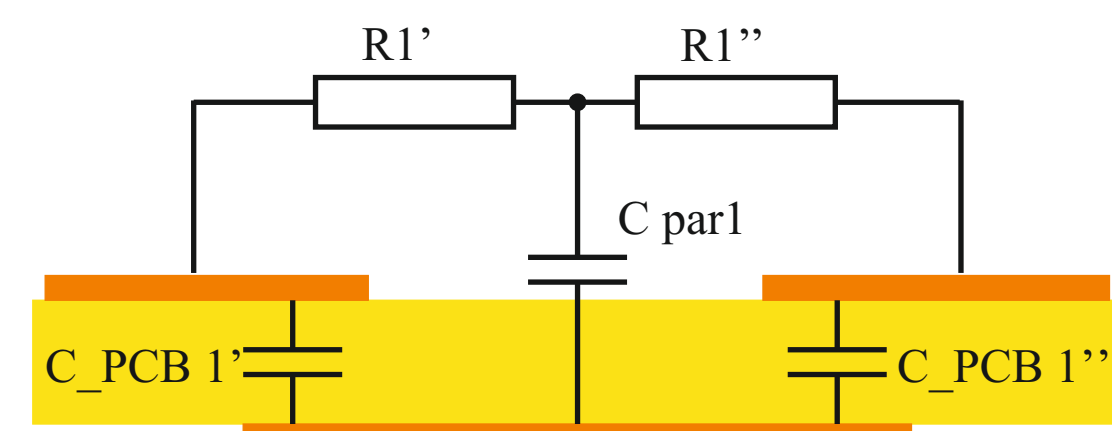


Fig. 2: Detailed schematic diagram of the probe



Orange: Copper path Yellow: FR 4 PCB material

Fig. 3: PCB capacitor implemented in the internal capacitive divider

Experimental results

Bandwidth of the probe

The parasitic capacitors make the flat bandwidth difficult, so a derivation of 2-3% is achieved. One can obtain a somewhat higher bandwidth, but at the expense of the more complexity and more tuning

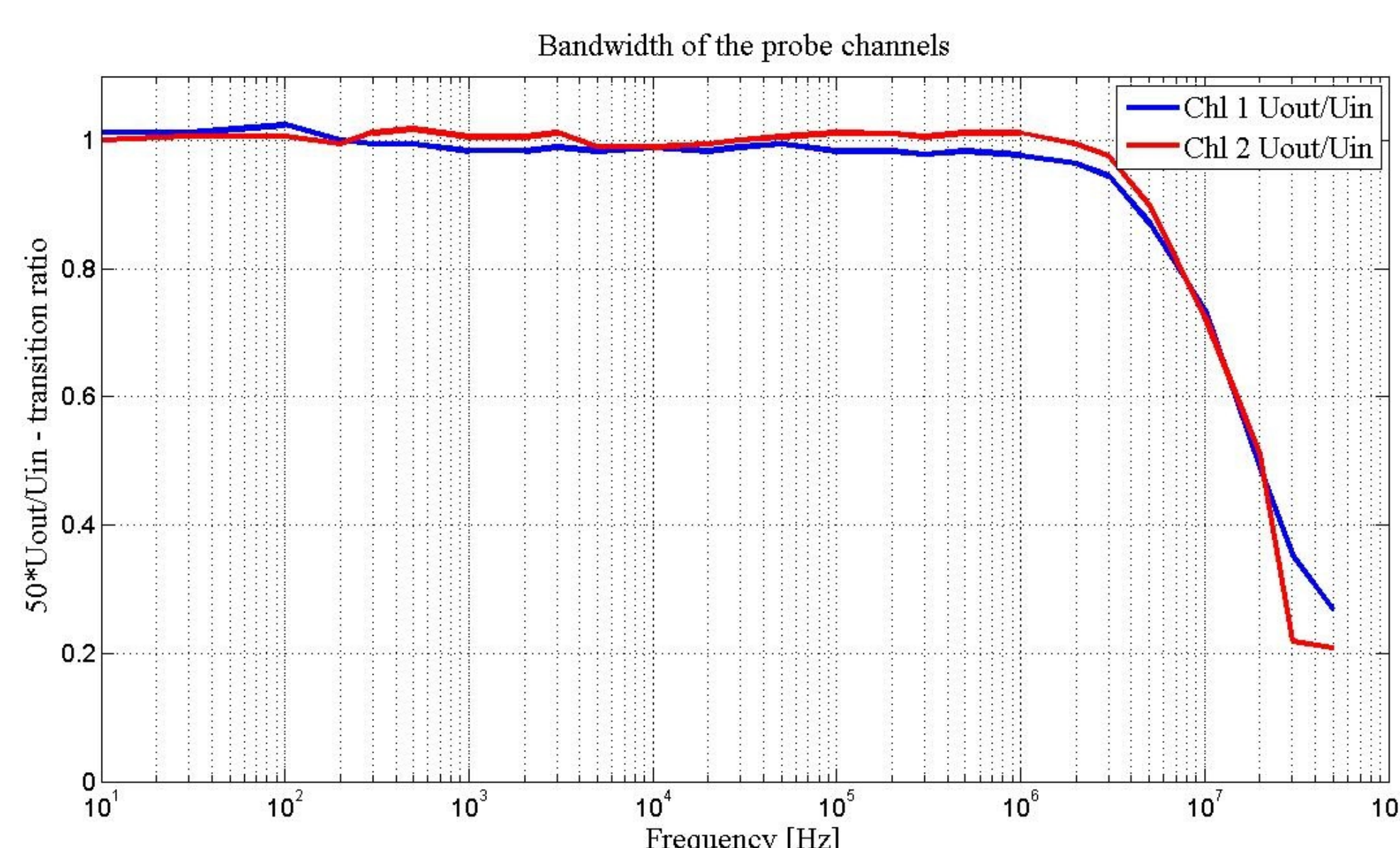
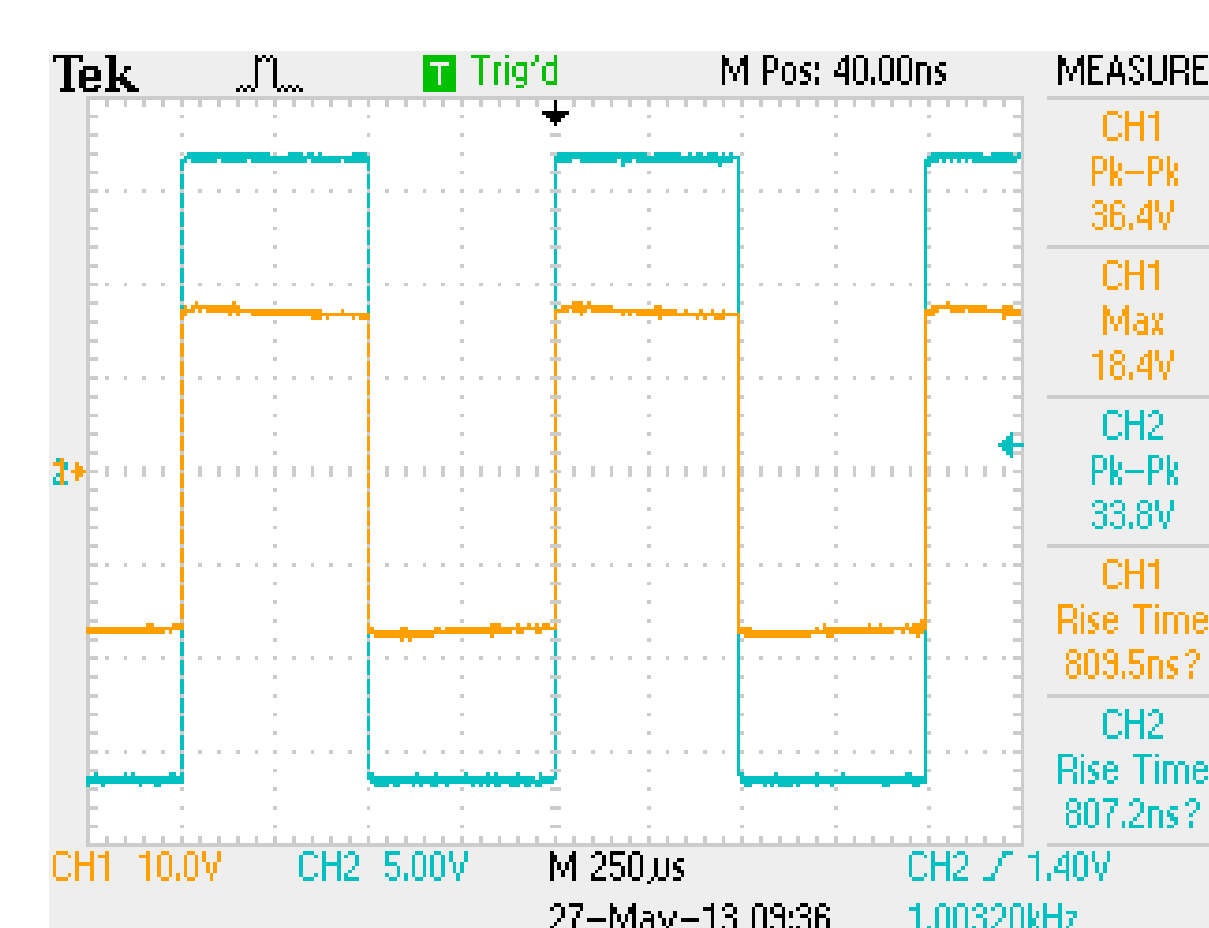


Fig. 4: Bandwidth of both channels of the probe

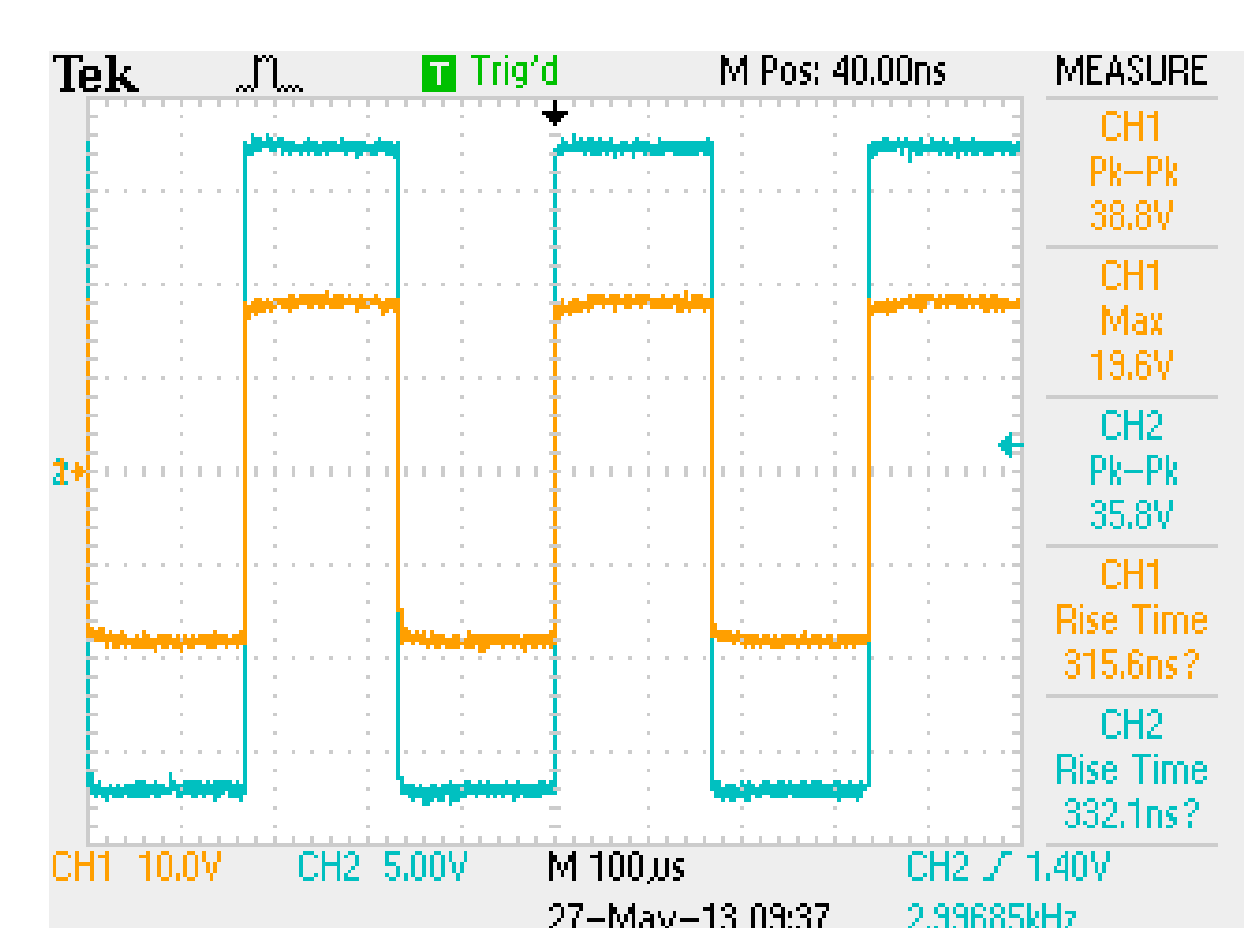
Test under rectangular pulses

Fig .5 to Fig. 8 show rectangular input pulses (blue channel) and output pulses (yellow) from the probe. The input signal is about 33V peak to peak and the tested frequencies are - 1 kHz, 3 kHz, 10 kHz, 30 kHz, 100 kHz and 300 kHz.

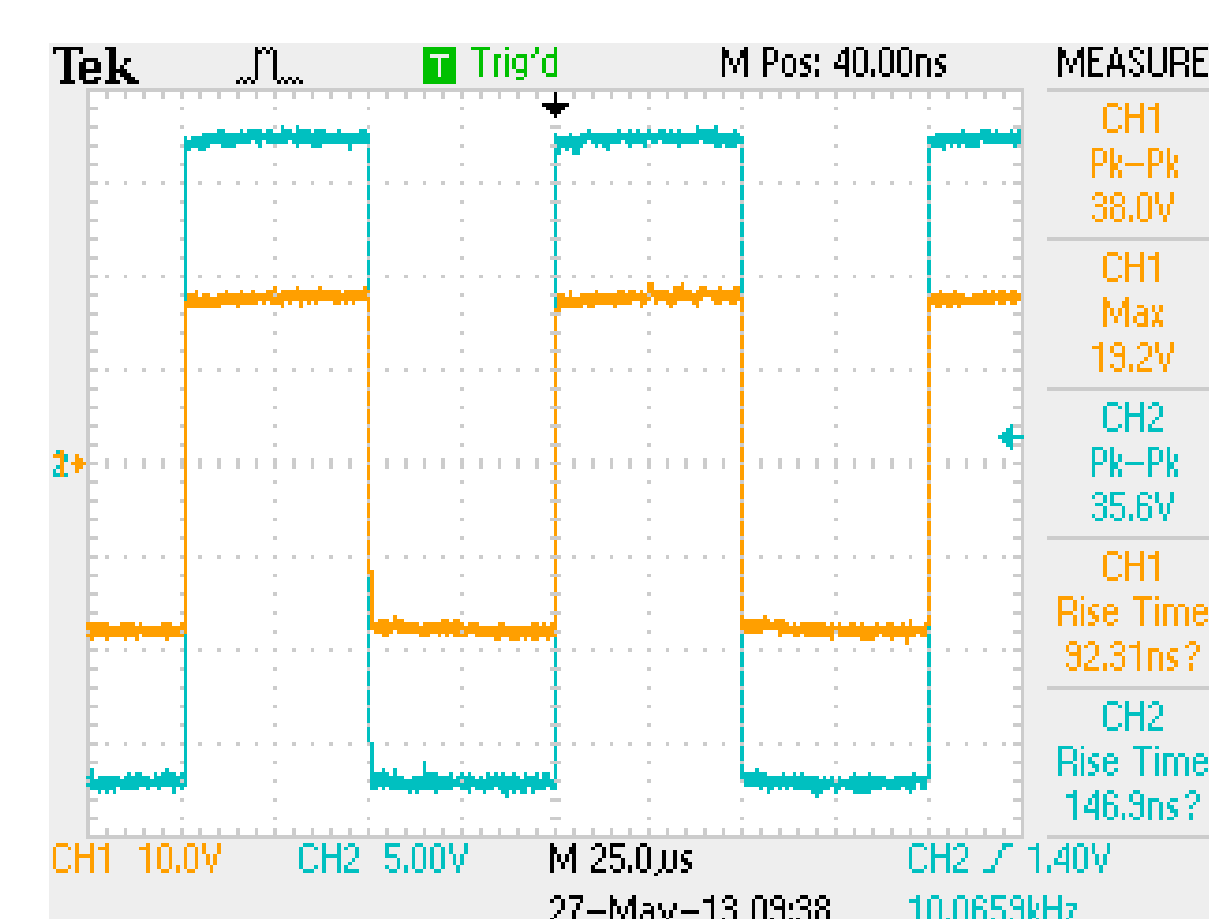
The active output of the generator is connected to the inverting input of the probe



a) comparison at 1kHz Ch1 input, Ch2 output

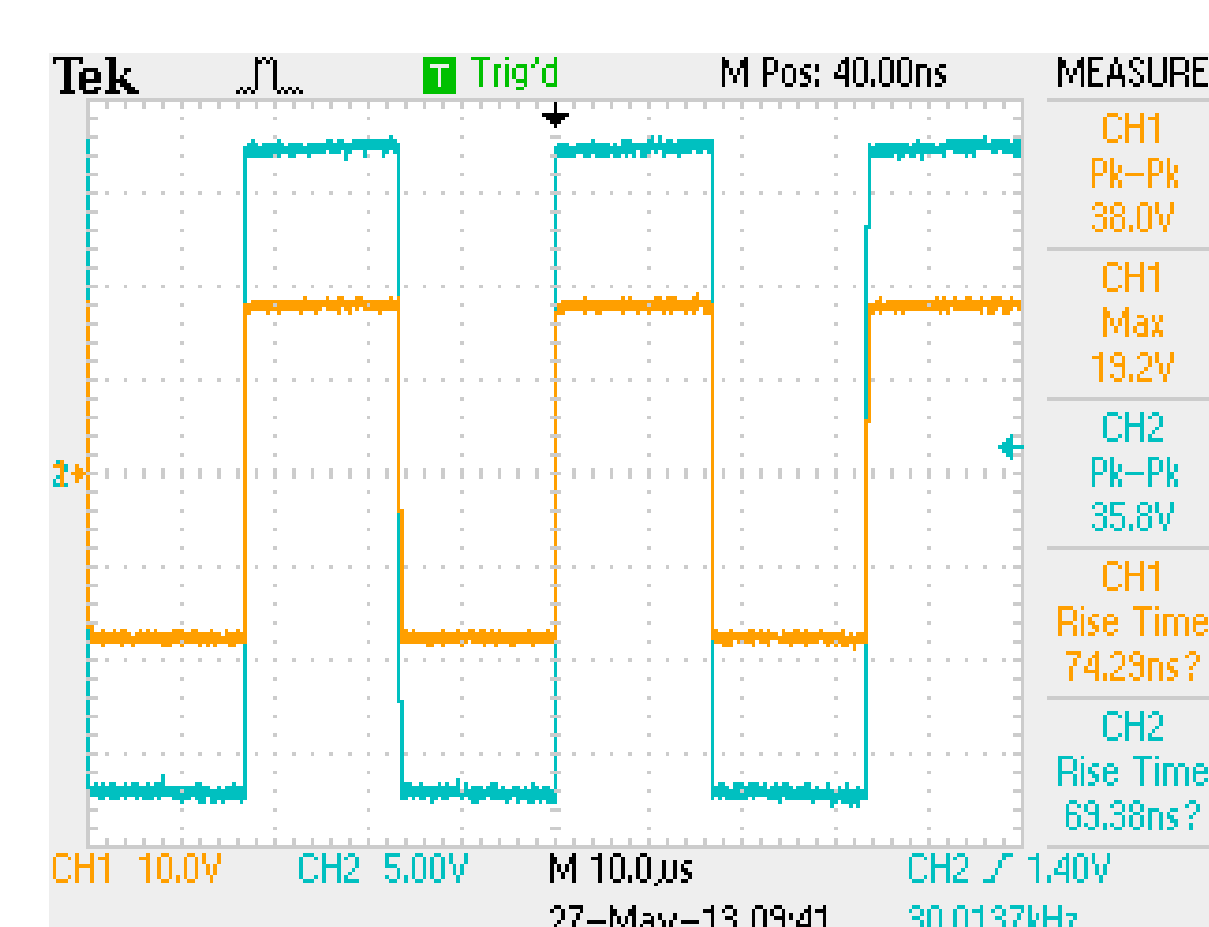


b) comparison at 3kHz Ch1 input, Ch2 output

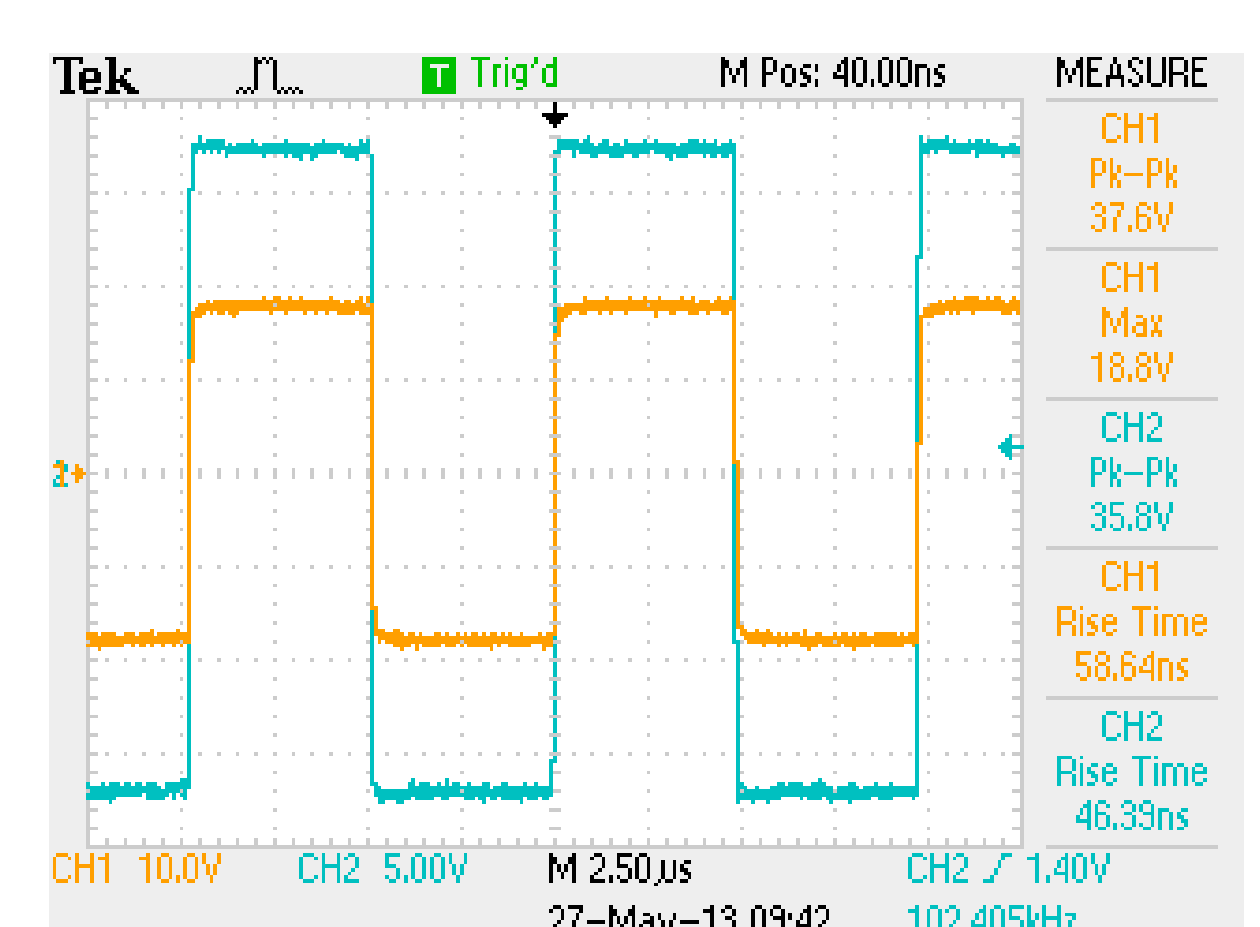


c) comparison at 10kHz Ch1 input, Ch2 output

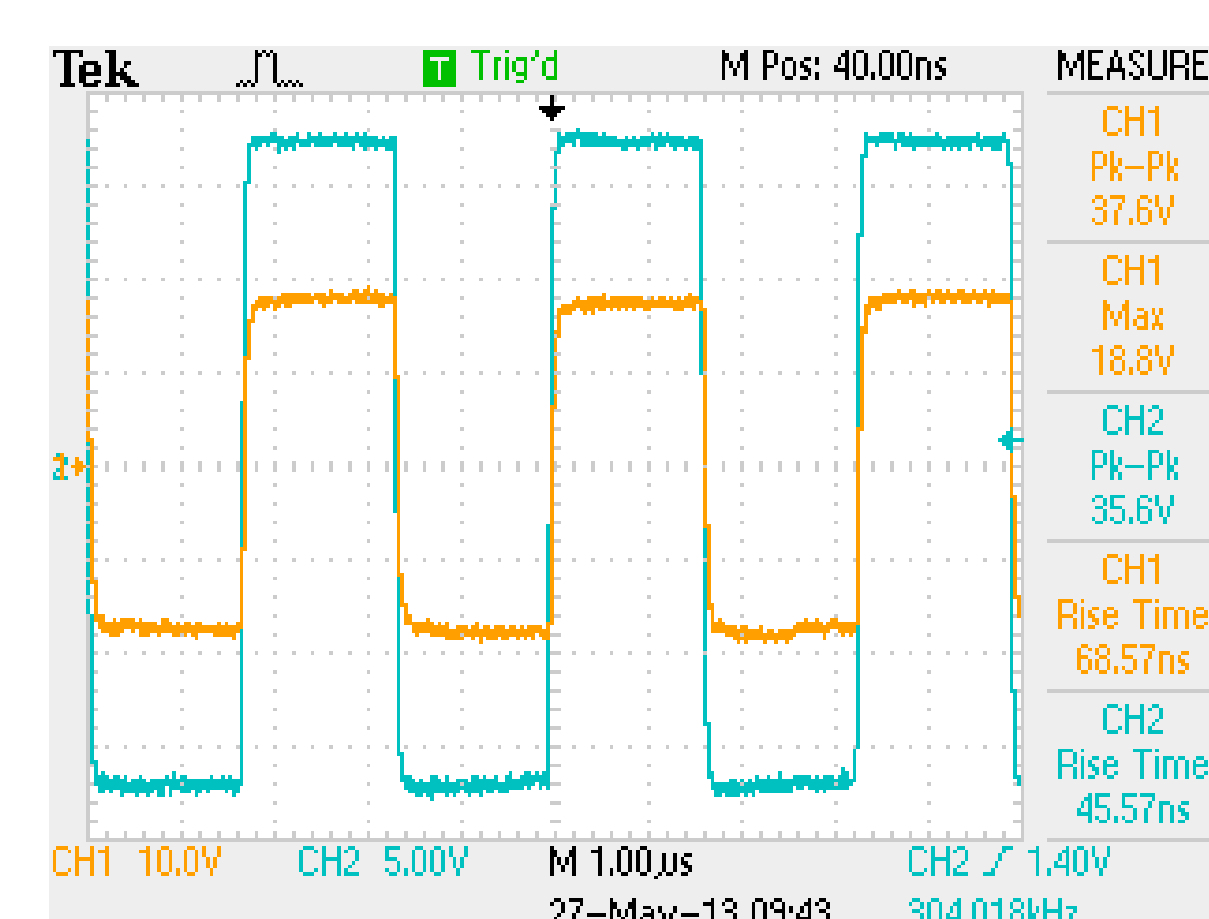
Fig.5: Wave form comparison with different frequencies 1kHz, 3kHz and 10kHz - active end of the generator is connected to the inverting input



a) comparison at 30kHz Ch1 input, Ch2 output



b) comparison at 100kHz Ch1 input, Ch2 output

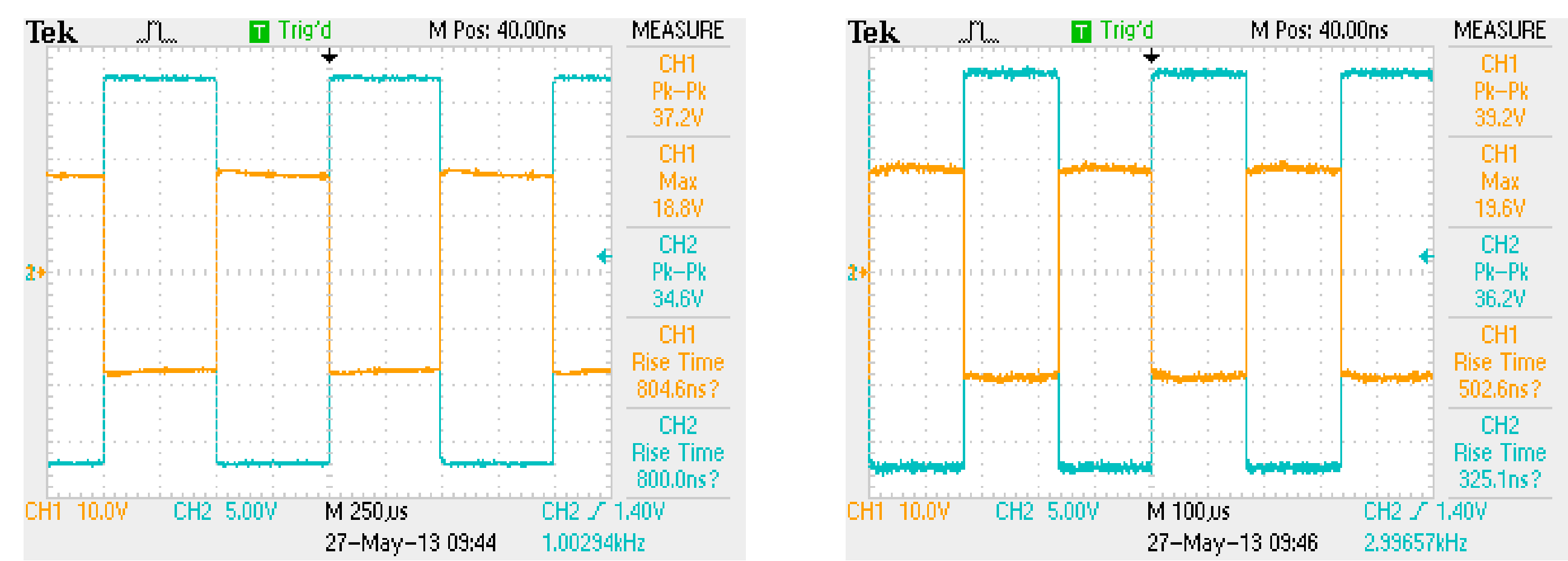


c) comparison at 10kHz Ch1 input, Ch2 output

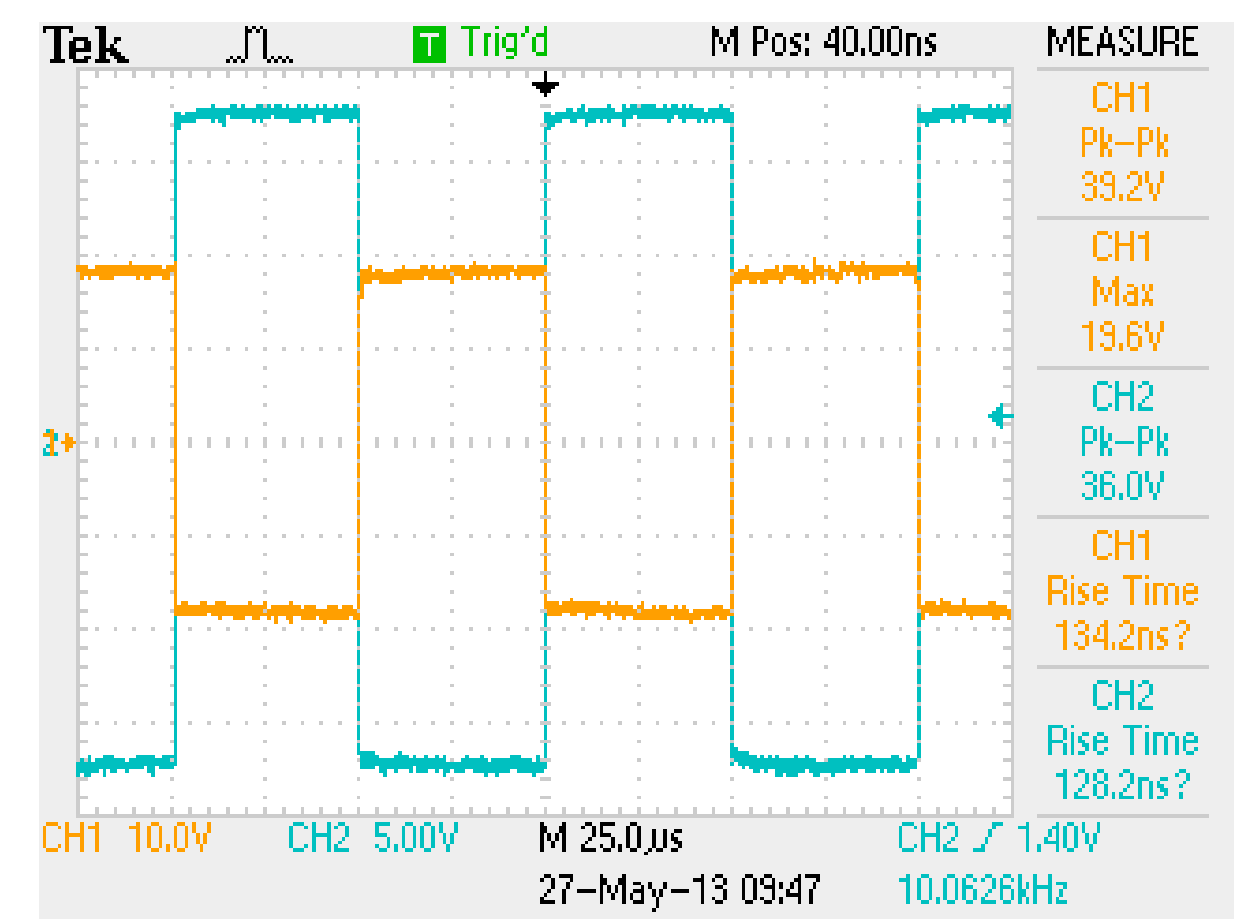
Fig.6: Wave form comparison with different frequencies 30kHz, 100kHz and 300kHz - active end of the generator is connected to the inverting input

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The active output of the generator is connected to the non-inverting input of the probe

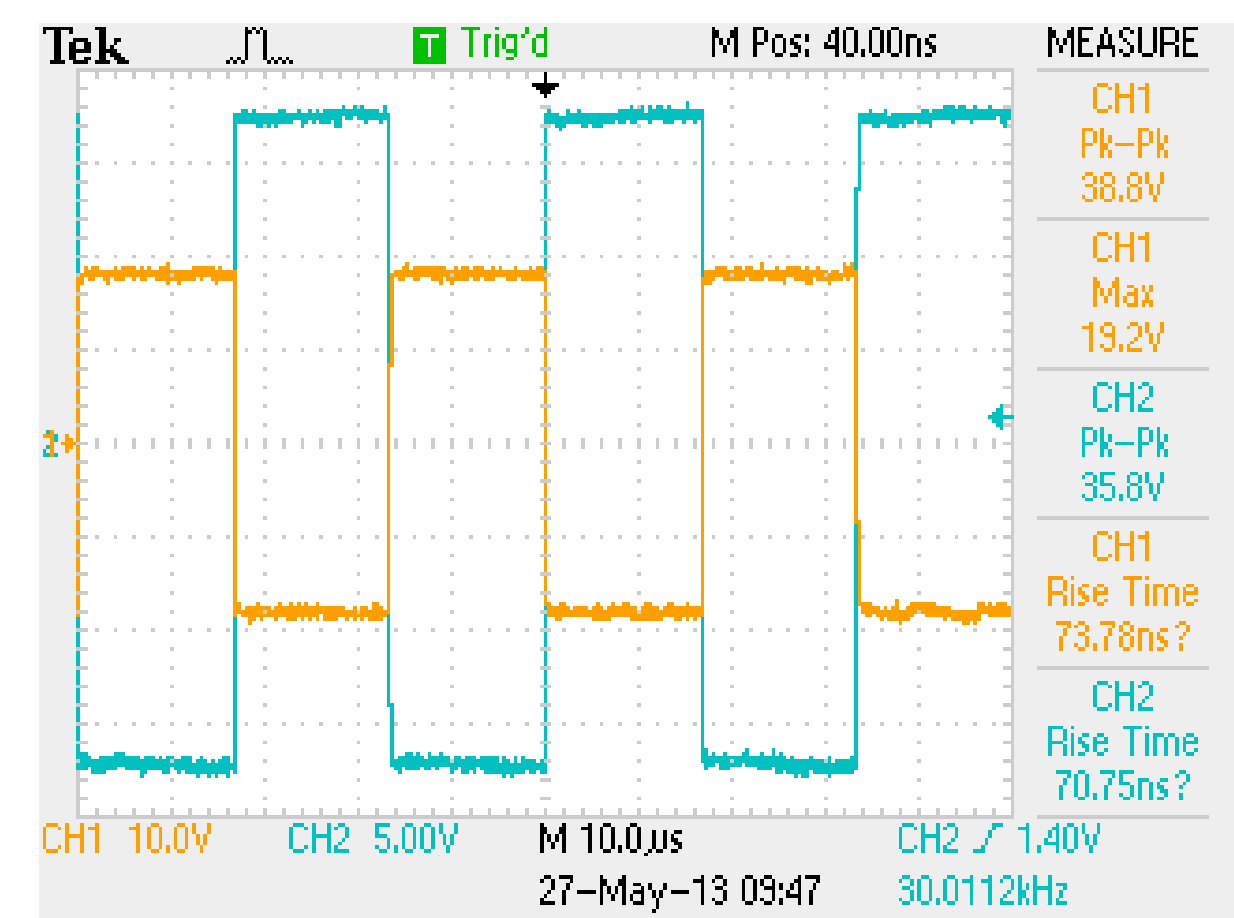


a) comparison at 1kHz Ch1 input, Ch2 output b) comparison at 3kHz Ch1 input, Ch2 output

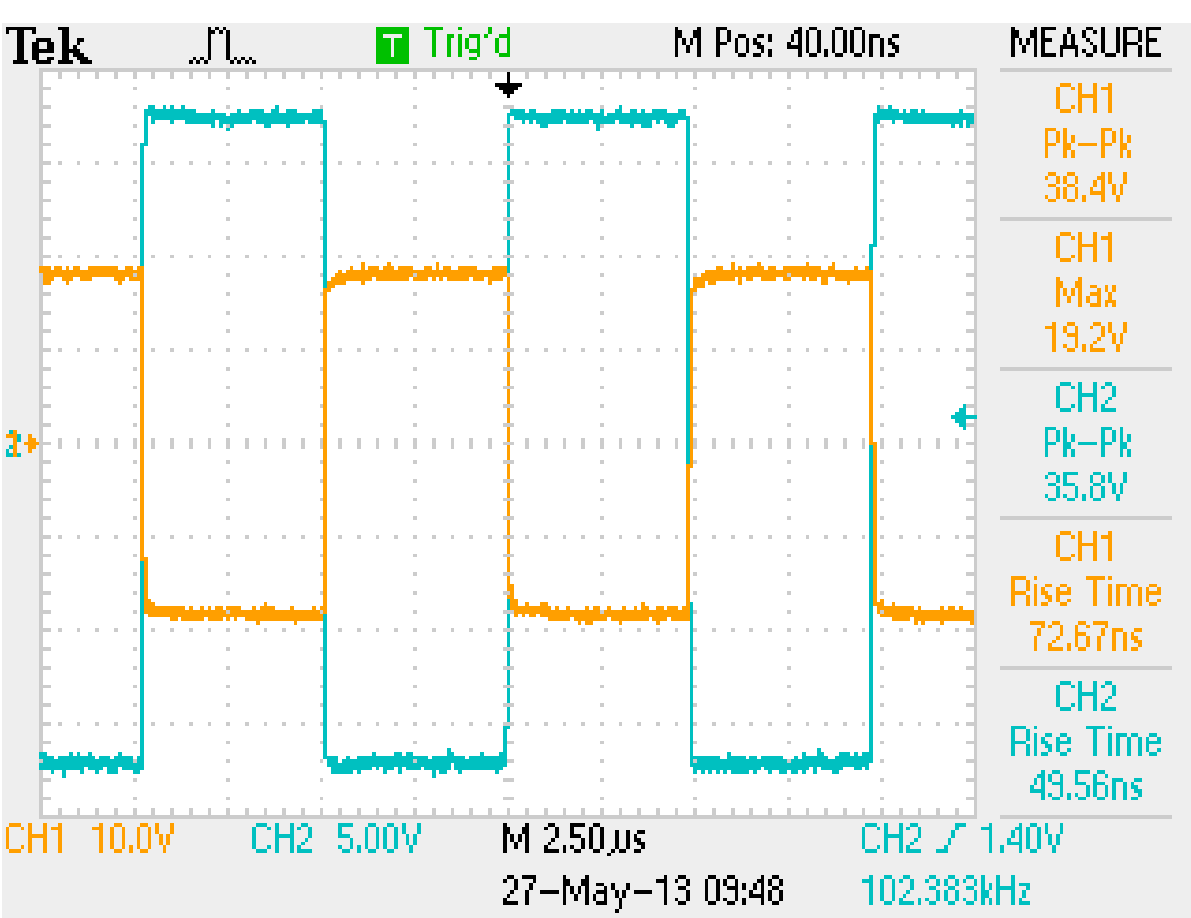


c) comparison at 10kHz Ch1 input, Ch2 output

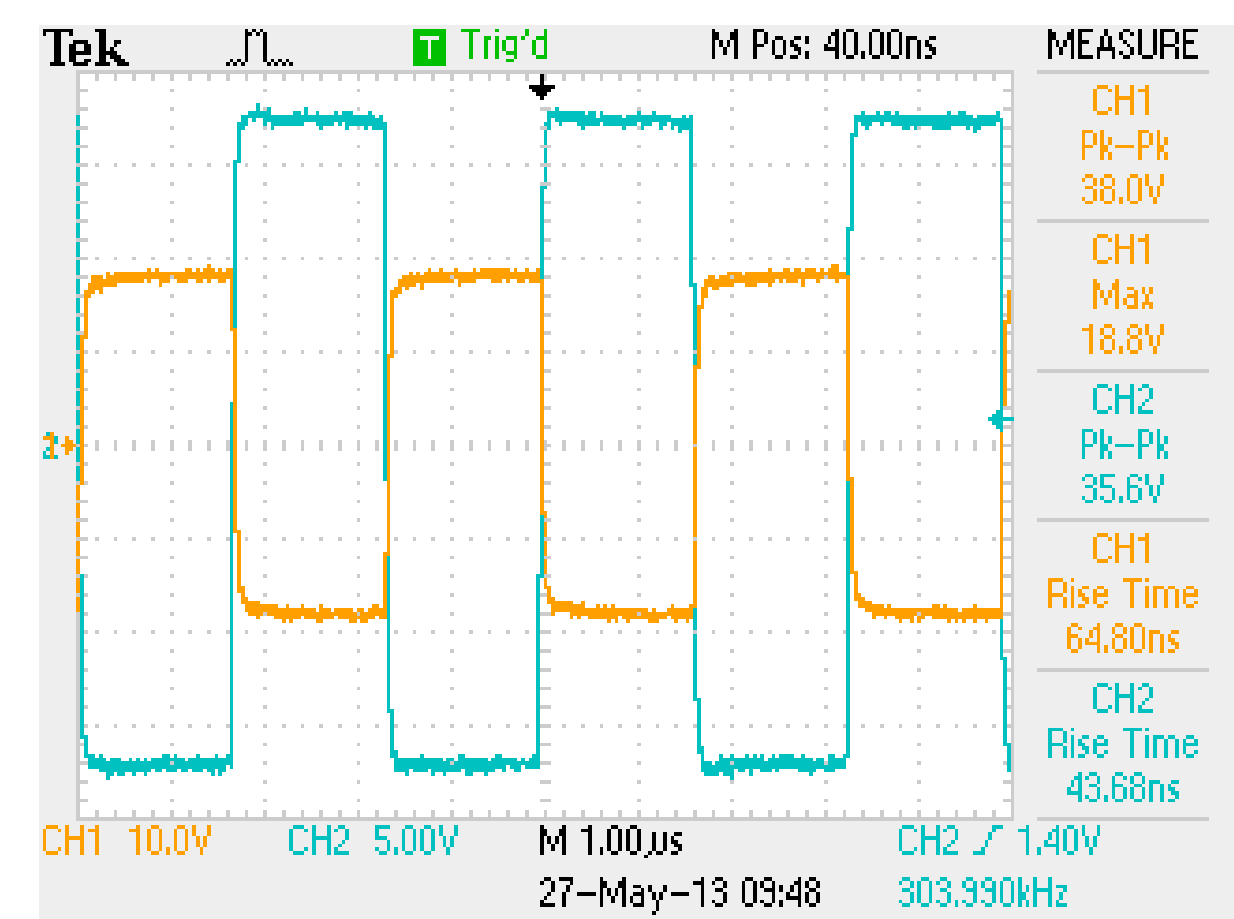
Fig.5: Wave form comparison with different frequencies 1kHz, 3kHz and 10kHz - active end of the generator is connected to the noninverting input



a) comparison at 30kHz Ch1 input, Ch2 output



b) comparison at 100kHz Ch1 input, Ch2 output



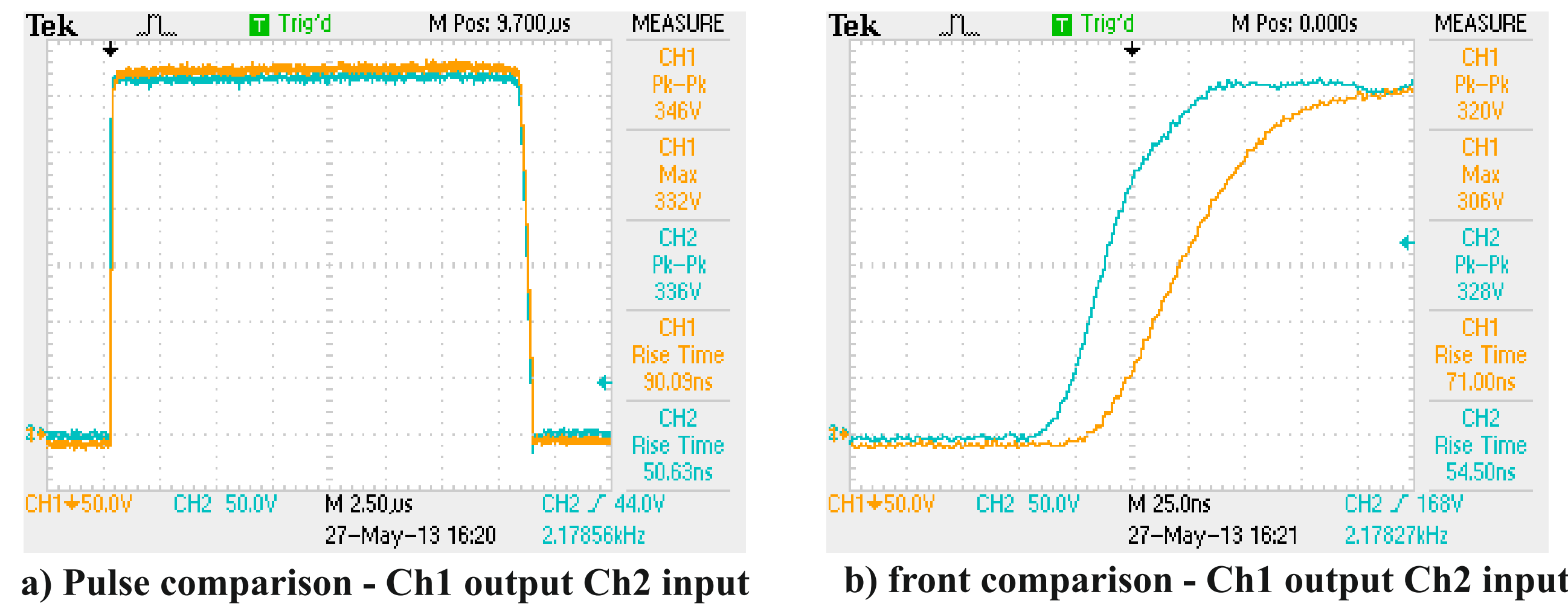
c) comparison at 10kHz Ch1 input, Ch2 output

Fig.6: Wave form comparison with different frequencies 30kHz, 100kHz and 300kHz - active end of the generator is connected to the noninverting input

We don't observe any overshoot spikes in the rising and falling edges and the pulses are very closer to the original ones. This is an important feature in converters as one wants to know the peak voltage occurring at the power components.

Pulse and edge comparison under high dV/dt source

- Pulse source - DC chopper with amplitude of 330V and slew rate of 7.3V/ns
- Used scope - Tektronix TDS2014 together with high voltage probe P5120



a) Pulse comparison - Ch1 output Ch2 input b) front comparison - Ch1 output Ch2 input

Fig.10: Wave form comparison at high dV/dt

The dV/dt of the input signal is close to 7.3V/ns or 220V/30ns (channel 2 - blue) and as we can see the output (channel 1 - yellow) voltage is capable of following such high dV/dt voltages.

CMRR test and CMRR under high dV/dt voltages

- With the current settings of the components in the probe common mode rejection is roughly 40dB. The small spikes in Fig. 11 show that some more tuning of the forcing capacitors C7 and C8 is needed but the amplitude is acceptable for at this level of design.
- Input voltage - 344V, output voltage is 1.88V multiplied by 50 from the scope, so we have about 0.55V output per 100V input. Most of the gates driving pulses are above 10V, so in case of measurements such signals on the top transistors in an inverter supplied with 300V the common mode voltage which will appear is 1.5V, so the differential probe is appropriate and for this kind of measurements as well.

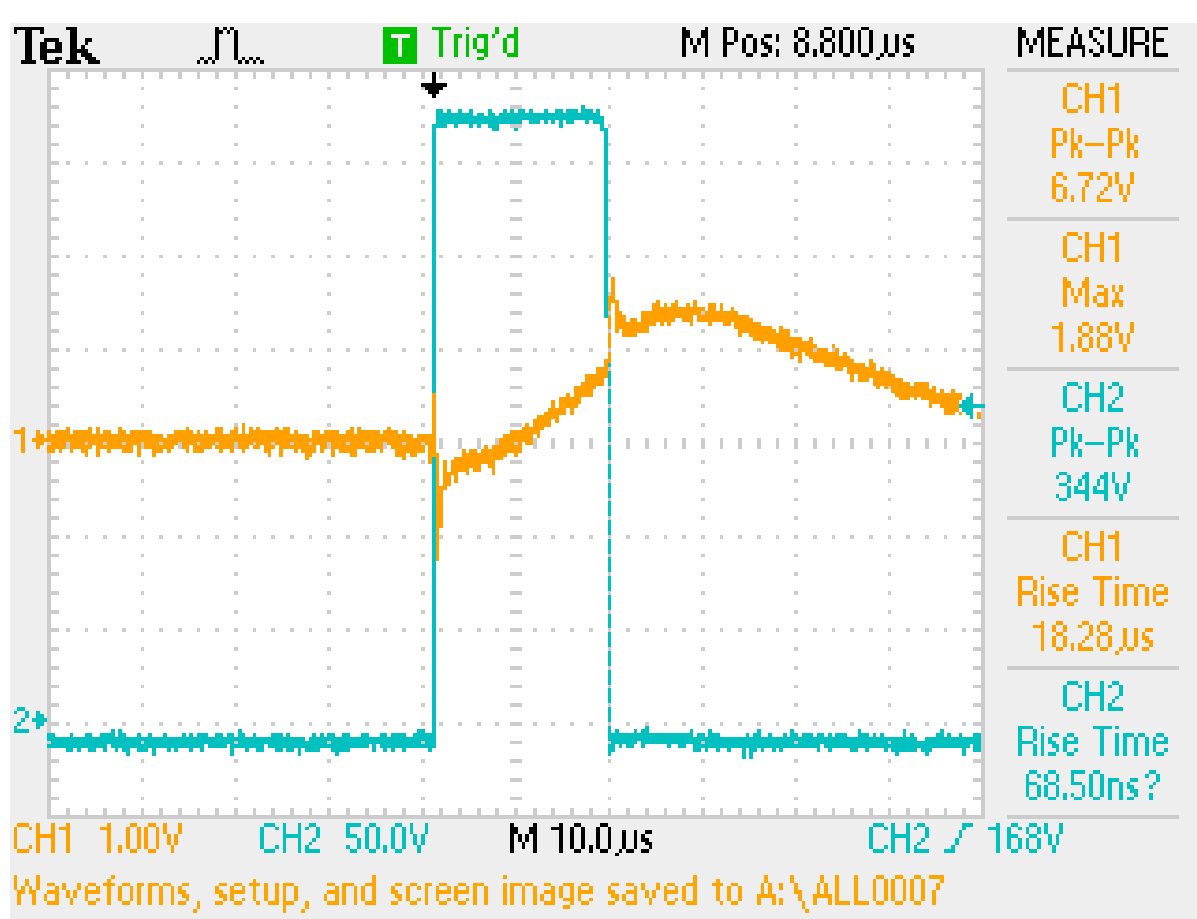
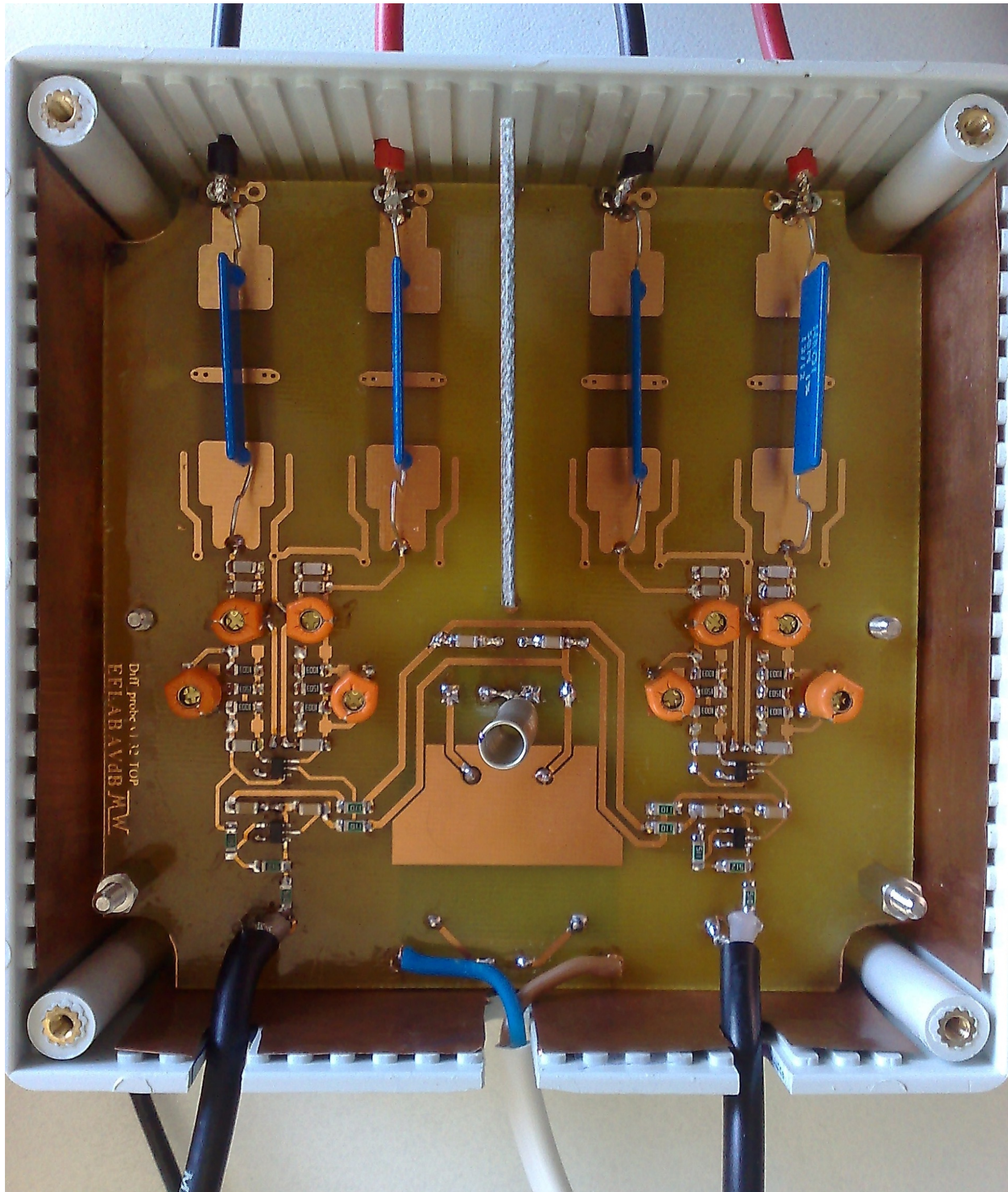


Fig.11: CM rejection at high dV/dt

Final design

- Symmetrical topology - similar performance between both channels
- Distance between the screens and the inputs - above 12mm which provides enough safety margins for operational voltages up to +/-2kV.



Conclusions

- A probe with very good performance is developed, specially adapted to the needs of didactical and development use in power electronics.
- The bandwidth is sufficient most of for power electronic applications, but special attention has been given to dV/dt aspects. It follows the slew rate of 5V/ns at /50 and V/ns at highest attenuation of /500 and it displays square waves without overshoot.
- The small input capacitance and the very good CMMR, allows MOSFET and IGBT gate measurements in real power converters.
- The stand-by power is below 0.9W.

Acknowledgments

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