15TH JUNE 2010

FREE NOTES ON ELECTRONICS

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Femto ampere current source.

Fig. 1 Keithley 610C electrometer

About 50 years ago along with nuclear science and medicine development people needed to measure doses of ionizing radiation. Ionization chamber is the simplest commonly used device to measure those doses. To extract the information from the chamber high input impedance voltmeter or picoammeter has to be used. To support those measurements the KEITHLEY company developed wide family

of so called electrometers- basically high impedance voltmeters, which additionally can measure extremely small currents and - sometimes- electric charge. One time I got one of these electrometers: Keithley type 610C (Fig.1). It utilizes MOSFET – input operational amplifier which has input impedance of $10^{14}\Omega$ and bias current of about 5fA ($1fA=10^{-15}A$). My 610C has been manufactured in the 1969. When I measured the input bias current I obtained 10fA result. Not bad, considering half century of hard work :)
The next step was to check the picoammeter function as It's most useful for me. There are two basic methods of producing small currents with accurate value. Please refer Fig.2 for details.

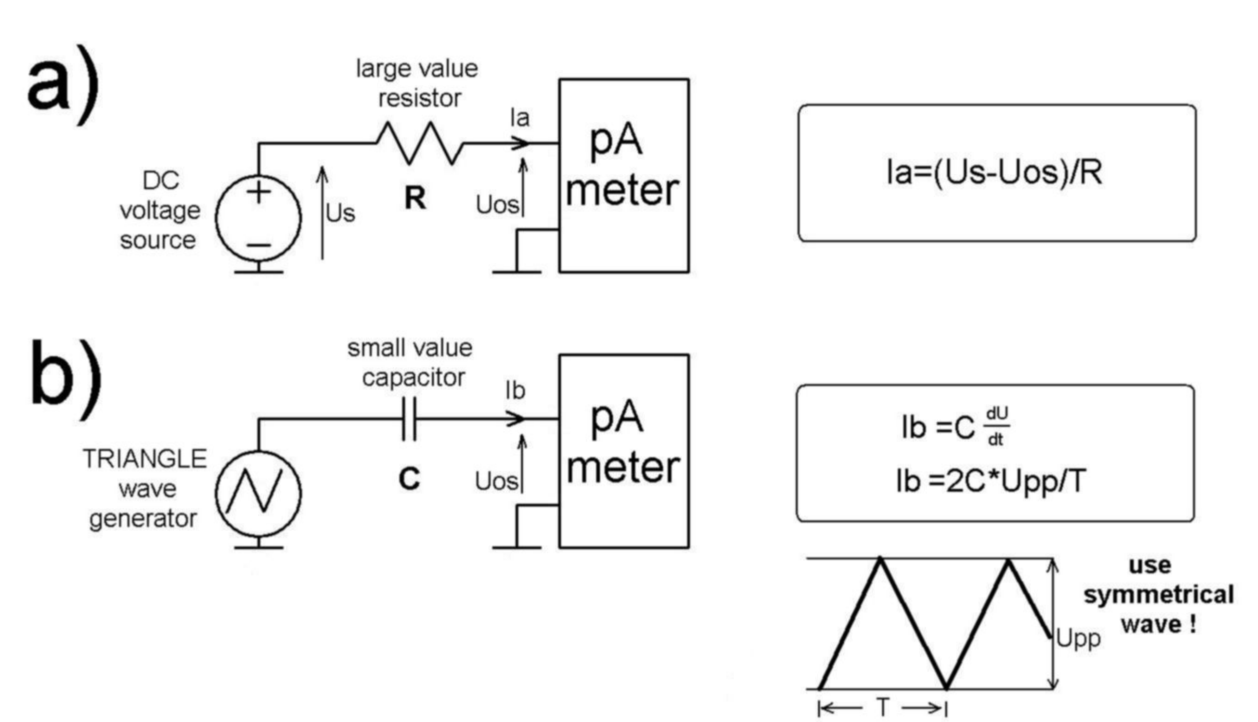

Fig. 2 Two ways of producing small value current

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Let's consider Fig.2a). The highest value resistor relatively easy to buy and with reasonable price is 1GΩ. The offset voltage of typical electrometer is 2mV. Assuming the 5% accuracy of the measurement, we should provide Us=40mV and we can obtain 40pA of current. To obtain lower current method presented on Fig.2b) should be used. This method utilizes good-linearity symmetrical triangle wave generator and a series small value capacitor C. Using the second method, currents of single femto amperes can be obtained.
A disadvantage of this method is that the current changes its polarity one time per triangle wave period.

All in all I decided to build source of small current using the Fig.2b) method. I designed the symmetrical triangle wave generator powered by two LR3 batteries to provide the "floating" power supply. The power consumption allow to use the generator for months without changing of batteries. The generator was designed to produce square wave with frequency from about 20mHz to about 20kHz. The generator's schematic diagram is presented on the Fig.3.

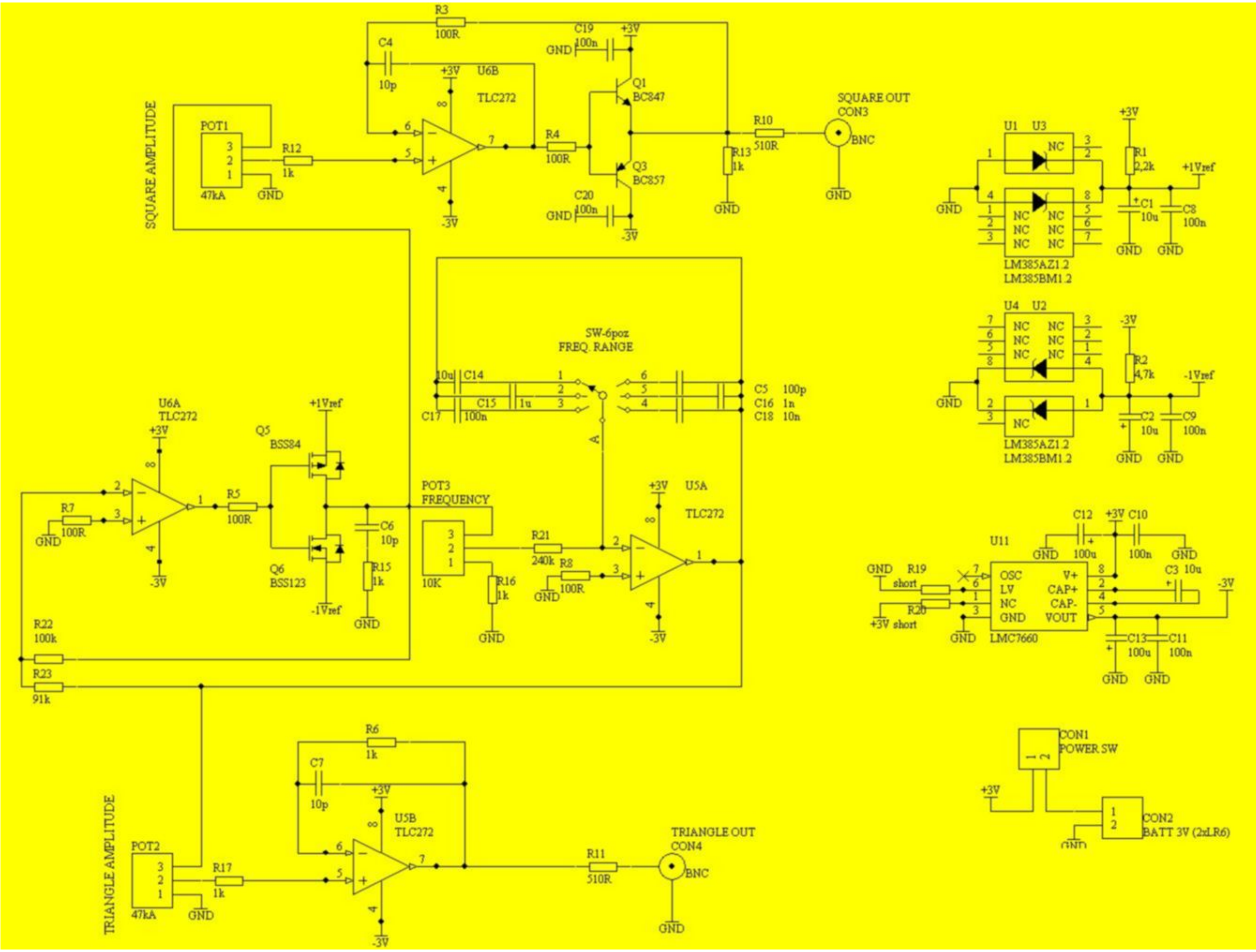

Fig.3 Schematic diagram of triangle wave generator

Fig.4 The generator in metal enclosure

The most important feature of this generator is that it produces waveforms of amplitude and frequency highly independent of temperature and battery voltage variation.

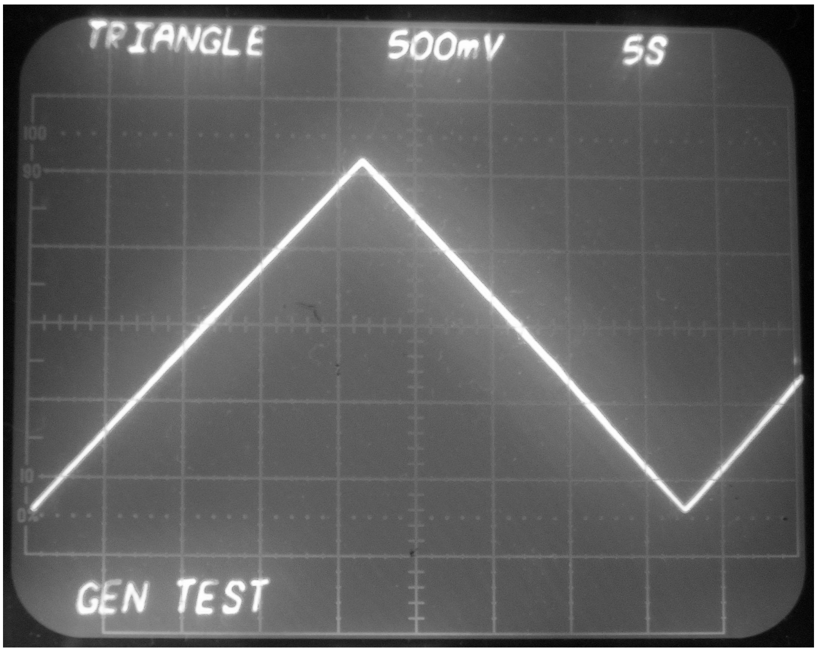

Fig.5 Performance test: lowest frequency set: 0,023Hz

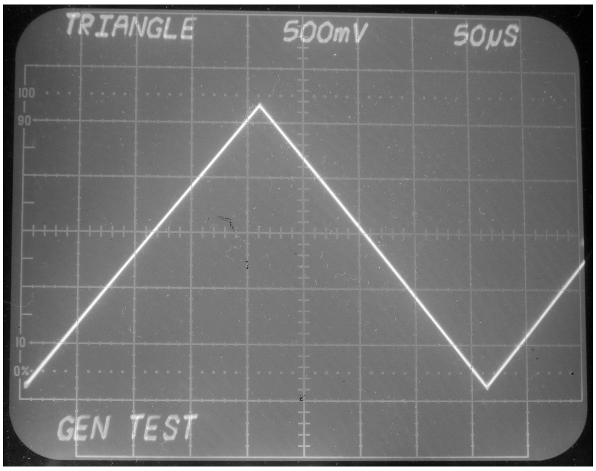

Fig.6 Performance test: 2,5kHz wave; from now on the amplitude tends to be a little too high

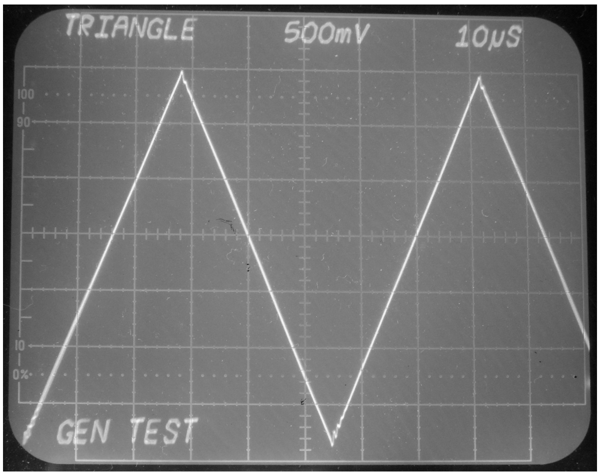

Fig.7 Performance test: 18kHz waveform ; last freq. range - amplitude too high

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But how to get low leakage vacuum or gas filled capacitor ? Why not to use the glass reed switch used to build reed relays?

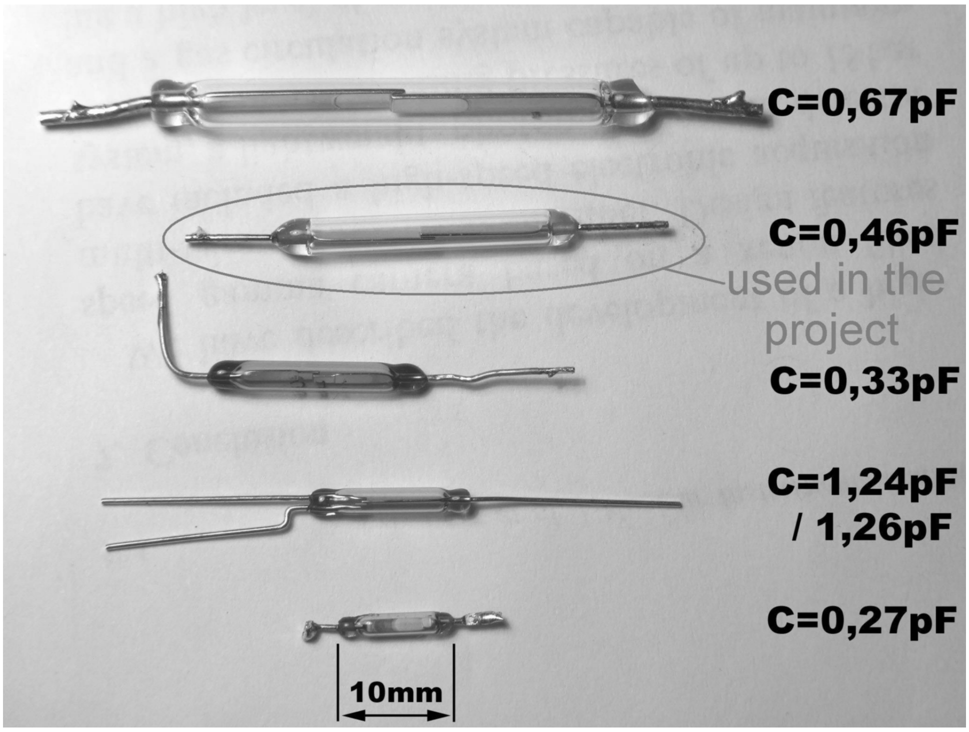

Fig. 8Reed switches and capacitances between their contacts

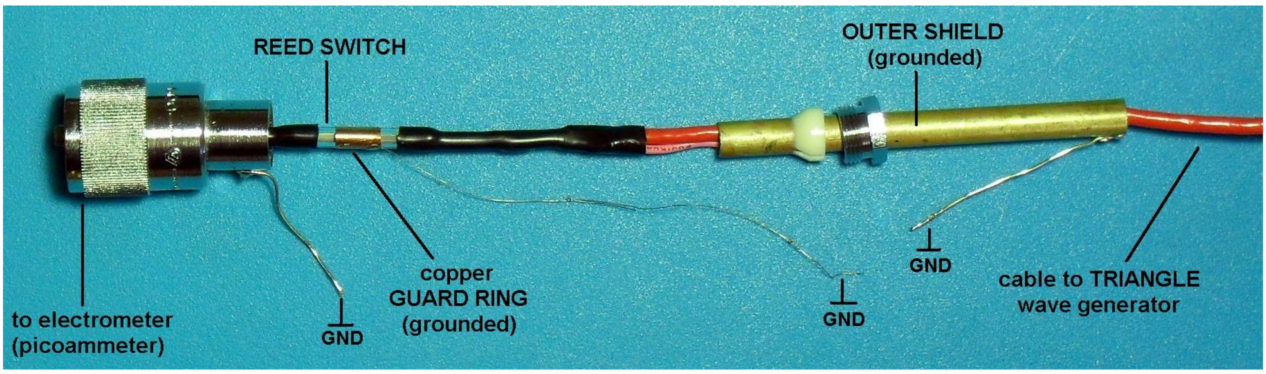

Fig. 9 Reed switch – based converter

Achtung: the outer shield significantly lowers the capacitance of the reed switch !!!

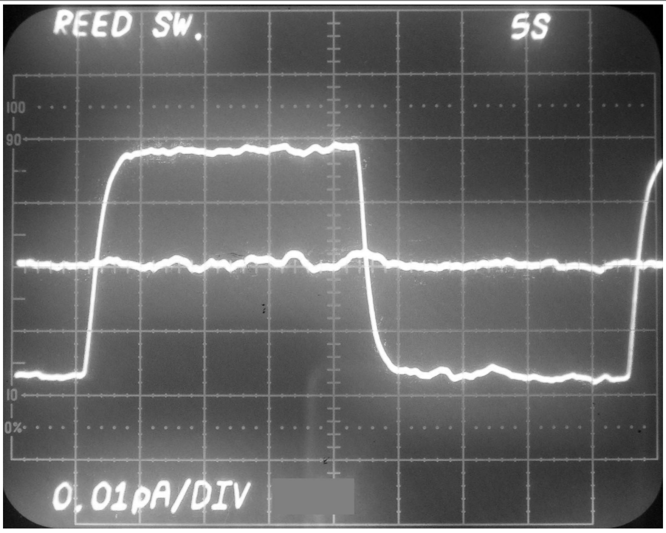

Fig. 10. Output current. Bandwidth: DC to 1Hz (filter: 3,3uF , 100kΩ);center – trace of noise about 3fA p-p

After some calculation we can obtain Cseries= 150fF.

And now let's see what happens when the 'mysterious' guard ring has been removed. The reed switch surface has been washed using acetone and isopropyl alcohol.

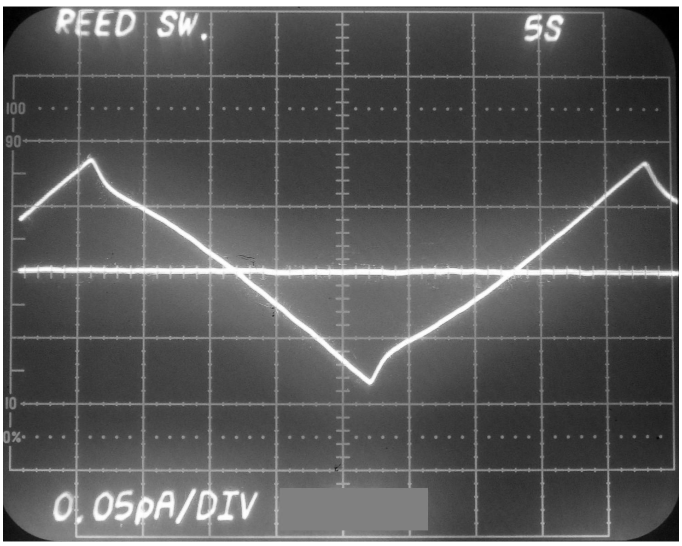

Fig. 11. Output current without guard ring. Bandwidth: DC to 1Hz (filter: 3,3uF , 100kΩ); center – trace of noise

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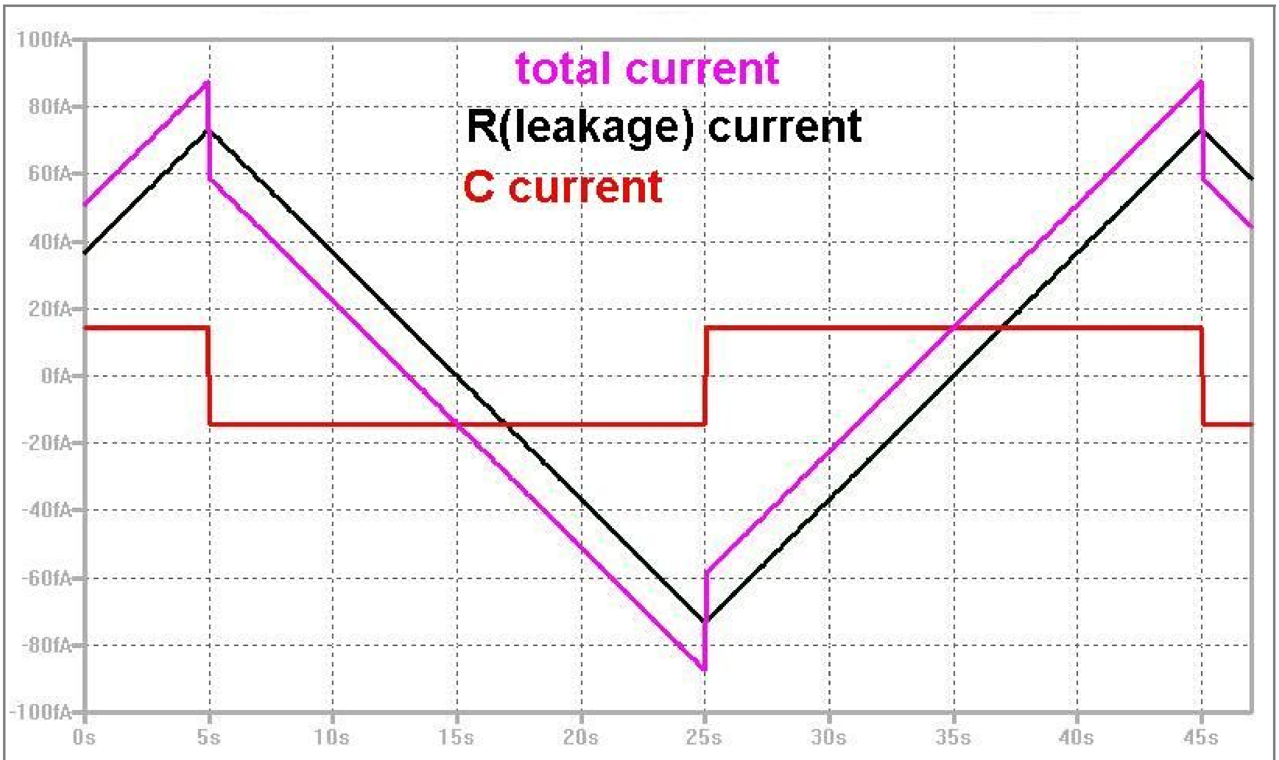

Fig. 12 Explanation of waveform from Fig.11. Bandwidth limitation (0...1Hz) is neglected here.

Such current waveform is produced by parallel connection of C=150fF and the glass enclosure leakage resistance R(leakage)=

15.000.000MΩ= 15TΩ

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Appendix 1

Measuring of small currents – three basic circuits.

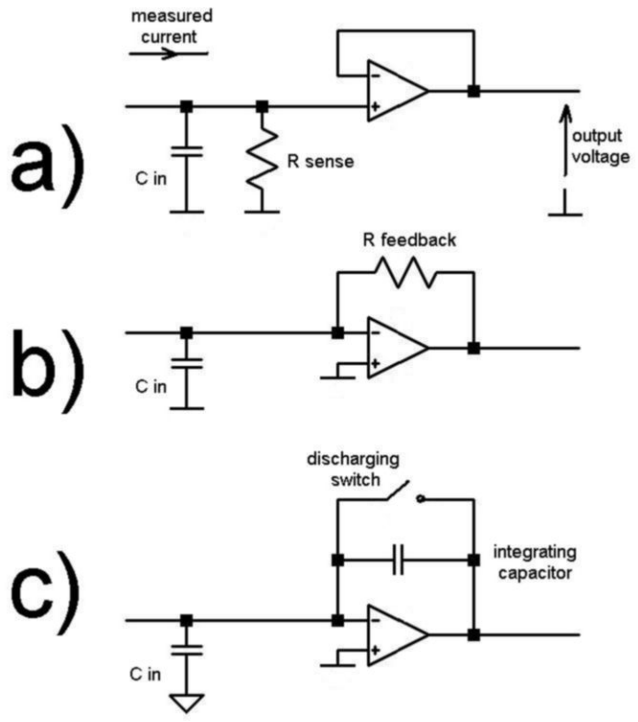

Fig. 13

a) simple but slow and noisy; Uin≠0V. It can be performed using typical multimeter with Rin=10Mohm;

b) fast but noisy (large value resistor produces thermal noise);

c) low noise but slow (capacitor don't produce noise but requires long integration time)

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Appendix 2

Keithley type 640 – vibrating capacitor electrometer

Fig.14 Keithley 640 electrometer

The Keithley 640 model is an interesting meter. The Keithley engineers used vibrating capacitor to change the DC voltage into 6kHz sinewave. This unusual modulator allows to move away from 1/f noise. When $R_{feedback}$ is not connected (R = infinity) DC current has no returning path and the device acts as a voltmeter with input resistance of $10^{16}\Omega$!!! It uses lot of saphire and teflon insulators.

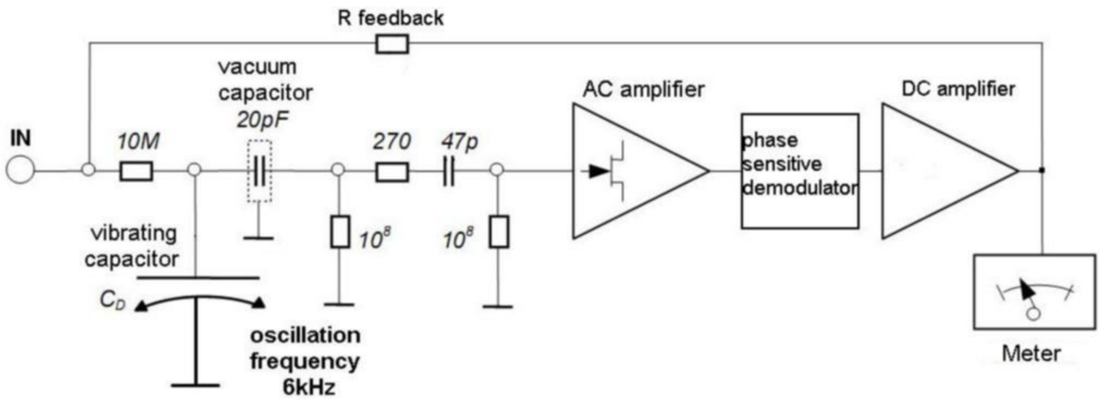

Fig. 15 Conceptional diagram of Keithley 640 electrometer

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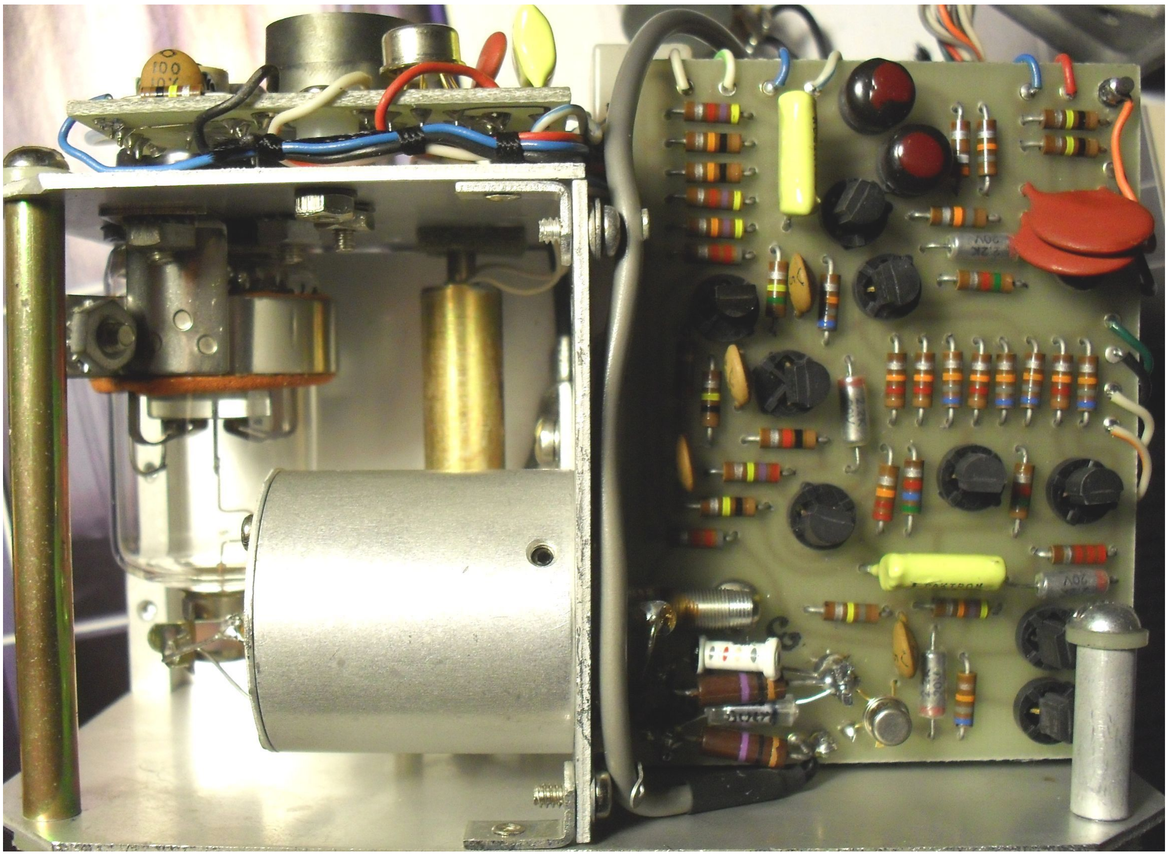

Fig. 16 Inside of the Keithley 640 Input Head.: Vibrating capacitor in glass enclosure, vacuum capacitor in metal enclosure.

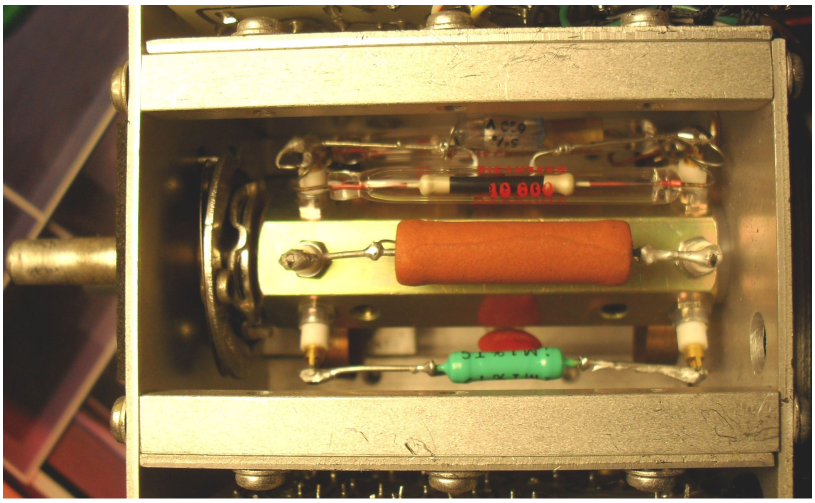

Fig. 17 High value resistors mounted on teflon distances. 10GΩ carbon film resistor in glass enclosure.

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Conclusion:
Try not to use long cables to connect the current source to the picoammeter as cables produce triboelectric effect. If it is necessary use low noise cables with conducting carbon layer between shield and inner insulator.

And remember :
when measuring picoamperes and lower currents everything must be

REALLY

WELL

SHIELDED

ANY. COMMENTS.
AND. SUGGESTIONS.
ARE. WELCOMED.