# Study and Evaluation of Performances of the Digital Multimeter

## 1. Introduction

Multimeters allow measuring the most common electrical quantities: voltage, current, resistance. They evolved from simple ones based on electromechanical indicators to electronic multimeters (high impedance input, larger input range) and nowadays to digital multimeters (high accuracy, microprocessor based, communication interfaces). The main instrument is a DC voltmeter with the basic scale 0.1V, 0.2V, 1V, 2V or 4V. The other scales or other quantities must be transformed, using proper converters, into voltage, corresponding to the basic scale.

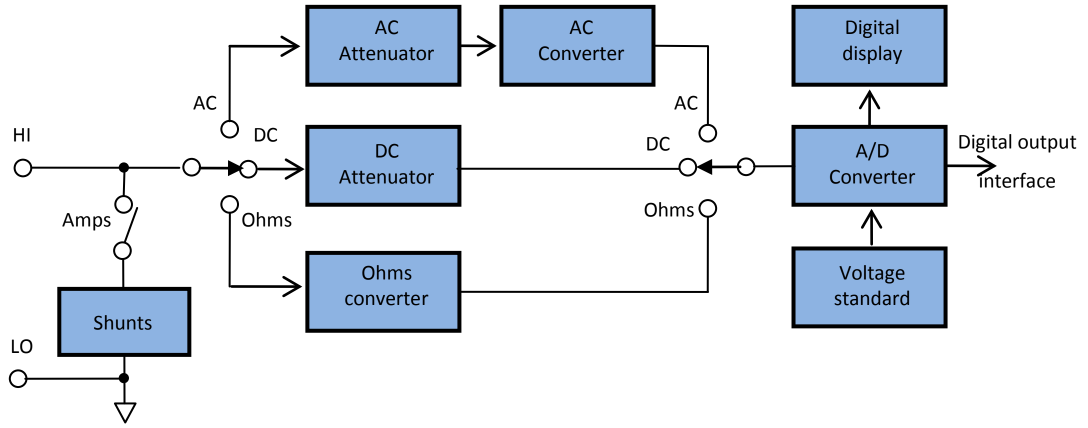



Fig. 1

## 2. The Basic Voltmeter Used in Multimeters

The main part of a digital voltmeter, that determines its properties, is the analog to digital converter. This is a device that converts a continuous physical quantity (usually a voltage) to a digital number (bits) that represents the quantity's amplitude. There are few common ways of implementing an electronic ADC, grouped into integrating and non-integrating ADCs.

Digital non-integrating voltmeters use non-integrating ADCs. The input voltage to be converted is sampled and its instantaneous value is measured. Due to this, the conversion speed is high, but, if the input voltage is affected by noises and disturbances, it has to be filtered, resulting a significant drop of the measurement speed. The main non-integrating ADC used in digital voltmeters is the successive approximation ADC.

Digital integrating voltmeters use integrating ADCs. They measure the input voltage by integrating it over a well defined time interval. The measurement time is larger than the integration time which is established by the period of the disturbing signal (usually 50Hz). The maximum measuring rate is 10 measurements/second. Thus, the disturbing signal does not affect the indication, these type of converters being preferred to be used in such applications. The main types of integrating AD converters are time to frequency, simple slope, dual-slope or multi-slope. Because of the easiness for measuring frequency or time all these integrating converters use an intermediary voltage to time or voltage to frequency conversion.

### 3. Dual slope digital voltmeter

The most used digital voltmeters are based on the intermediary voltage to time conversion like in the following figure.

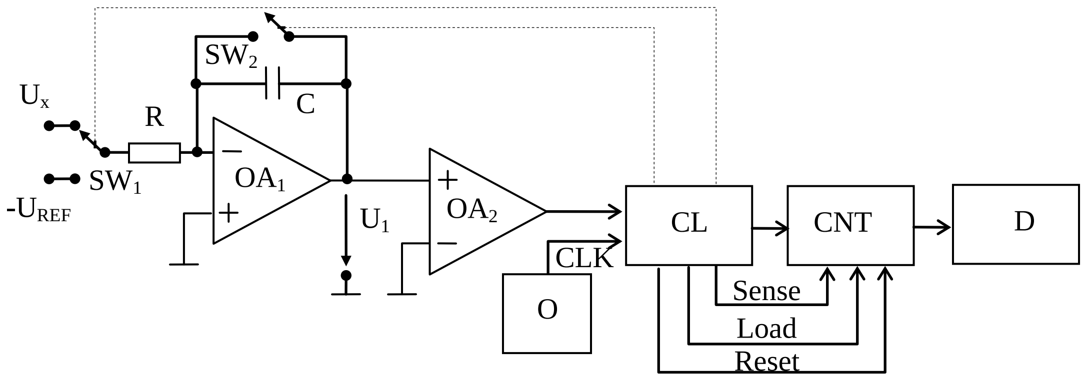



Fig. 2

The main building blocks are the integrator ($OA_1$, R and C), the comparator ($OA_2$), the oscillator (O), the control logic bloc (CL), the counter (CNT) and the display (D). The measurement consists of 2 phases:

a) The first phase is the run-up phase where the input to the integrator is the voltage to be measured. The control logic CL drive the switch $SW_1$ toward the input voltage (unknown) $U_x$. The integrator starts with no charge stored in the capacitor C and this phase take a well established period of time ($T_1$). This is set-up by the counter CNT which is loaded with its maximum capacity and will count down to zero being driven by the oscillator clock. The voltage $U_1$ decreases with constant slope:

$$U_1 = -\frac{1}{RC}\int_0^t U_x dt = -U_x \cdot \frac{t}{RC}$$

At the end of this interval the total voltage at the integrator's output will be:

$$U_1(T_1) = -U_x \cdot \frac{T_1}{R \cdot C}$$

where $T_1 = N_{max} \cdot T_0$.

b) The second phase starts when CNT reaches the value 0 when CL switch $SW_1$ to $-U_{REF}$ and the standard voltage will be integrated. It has the opposite polarity and the voltage at the integrator output will increase (run-down phase) until it reaches the value 0. Because $U_{REF}$ is constant, the slope of $U_1$ is constant:

$$U_1 = U_1(T_1) - \frac{1}{RC}\int_{T_1}^{T_1+t}(-U_{REF})dt = -U_x\frac{T_1}{RC} + U_R\frac{t}{RC}$$

The process ends at $T_2$ when $U_1$ is 0:

$$U_1(T_2 + T_1) = 0 \quad \Rightarrow \quad U_x \cdot \frac{T_1}{RC} = U_R \cdot \frac{T_2}{RC}$$

when the counter CNT counted N pulses of period $T_0$: $T_2 = N \cdot T_0$. Replacing $T_1$ and $T_2$ in the last equation, the number of pulses counted in the second phase is proportional with the unknown voltage:

$$N = \frac{N_{max}}{U_{REF}} \cdot U_x$$

After this phase ends, CL stores the result and displays the value on D, resets the counter for the next measurement and closes $SW_2$ to discharge the capacitor $C_2$. The waveforms associated with the measurement phases are presented in next figure.

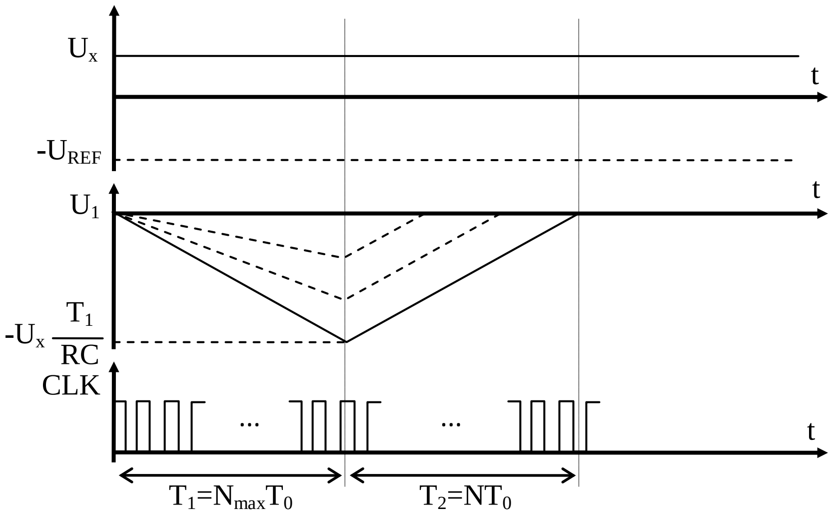



Fig. 3

From the last equation, the advantage of the method is revealed: the output N does not depend either of $T_0$ or of the components R and C. The only condition is that they are stable during the measurement phases.

## 4. Errors of the dual slope digital voltmeter

The last equation reveals that the errors that affect the measurement are generated by the standard voltage and by the counter:

$$\frac{\Delta U_x}{U_x} = \frac{\Delta U_{REF}}{U_{REF}} + \frac{\Delta N}{N} = \frac{\Delta U_{REF}}{U_{REF}} + \frac{1}{N}$$

allowing to reach an accuracy class of 0.1 to 0.01.

The measurement time is chosen as multiple of power network period (20ms) in order to minimize the influence the overlapping of such alternative voltage. This influence is characterized by the common mode rejection ratio:

$$S.M.R.R. = 20 \cdot lg\left|\frac{amplitude\ of\ \ AC\ disturbing\ voltage}{DC\ equivalent\ voltage}\right| \quad [dB]$$

This ratio is influenced by the frequency because of the fixed integration time. If over the input voltage $U_x$ it is superposed an AC disturbing voltage $U_m sin(\omega_p \cdot t+\varphi)$, at the end of the first run-up phase the voltage at the comparator's output is:

$$U_1'(T_1) = -U_x \cdot \frac{T_1}{R \cdot C} + U_m \cdot \frac{\cos(\omega_p \cdot T_1 + \varphi) - \cos\varphi}{\omega_p \cdot R \cdot C}$$

By replacing this into the SMRR equation above we get:

$$S.M.R.R. = 20 \cdot lg\left|\frac{\omega_p T_1}{\cos\varphi - \cos(\omega_p \cdot T_1 + \varphi)}\right|$$

This ratio is minimum when $\varphi = \omega_p \cdot T_1/2 + (2k+1) \cdot \pi/2$:

$$S.M.R.R. = 20 \cdot lg\left|\frac{\omega_p \cdot T_1/2}{\sin(\omega_p \cdot T_1/2)}\right| = -20 \cdot lg\left|sinc\frac{\omega_p \cdot T_1}{2}\right|$$

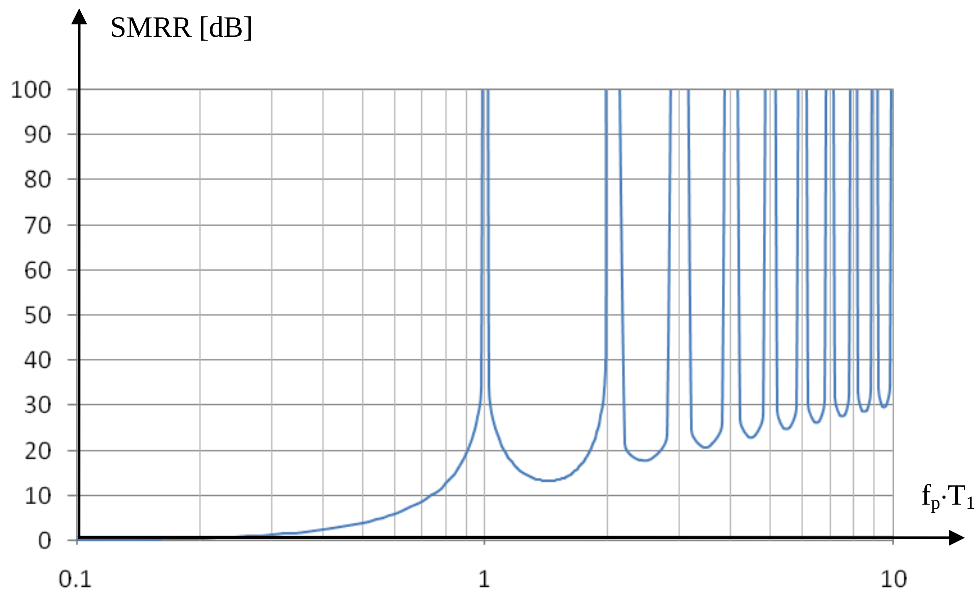



Fig. 4

SMRR becomes infinity when $T_1 \cdot f_p = k,\ k \in N$, suggesting that the influence of the disturbing signal is null when this condition is fulfilled.

Besides the series disturbing voltages, digital voltmeters are influenced by the common mode voltages (AC or DC). The effect produced by these voltages is appreciated by the Common Mode Rejection Ratio (CMRR):

$$C.M.R.R. = 20 \cdot lg \left| \frac{amplitude\ of\ common\ mode\ disturbing\ voltage}{DC\ equivalent\ voltage} \right| \quad [dB]$$

In order to achieve a good CMRR, digital voltmeters are designed with floating inputs. Next figure shows the floating input connection with 3 terminals.

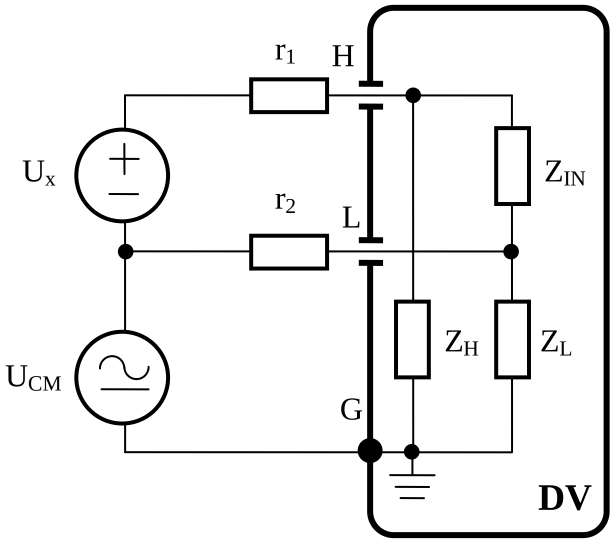



Fig. 5

In the figure $r_1$ and $r_2$ represents the equivalent resistances of the connection wires and $Z_1$ and $Z_2$ are the equivalent insulation impedances (resistance in parallel with capacitance) of H and L inputs. The disturbing voltage appearing between H and L terminals due to $U_{CM}$ is:

$$U_e = \left( \frac{r_2}{Z_2} - \frac{r_1}{Z_1} \right) \cdot U_{CM}$$

Because $Z_1 \neq Z_2$ and $r_1 \neq r_2$ this voltage cannot be completely annealed, but while $r_1$ and $r_2$ becomes as small as possible and $Z_1$ and $Z_2$ as big as possible (big resistance, small capacitance), the voltage $U_e$ can be made as small as possible. Thus, the CMRR can be estimated with the following formulas:

$$R.R.M.C._{DC} = -20 \cdot lg \left( \left| \frac{r_1}{R_1} - \frac{r_2}{R_2} \right| \right) \ [dB]$$

$$R.R.M.C._{AC} = -20 \cdot lg \left( \omega_p \cdot \left| r_2 \cdot C_2 - r_1 \cdot C_1 \right| \right) \ [dB]$$

In the following figure it is presented the CMRR and the total RR ($RR_{total}$=SMRR+CMRR [dB]) dependence versus the disturbing frequency.

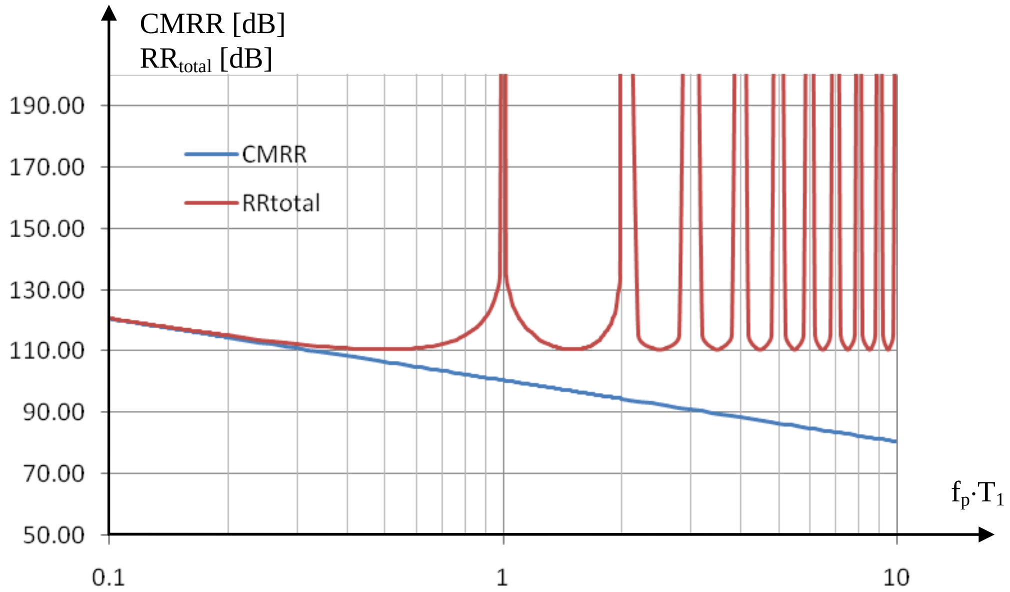



Fig. 6

## 5. Verifying the performances of a digital multimeter

*a) Verifying the accuracy class*

The digital multimeter to be tested is Fluke 179. It will be verified on the basic scale of 600mV. The voltage standard is the direct current compensator *UCFs 1.05* connected like in next figure.

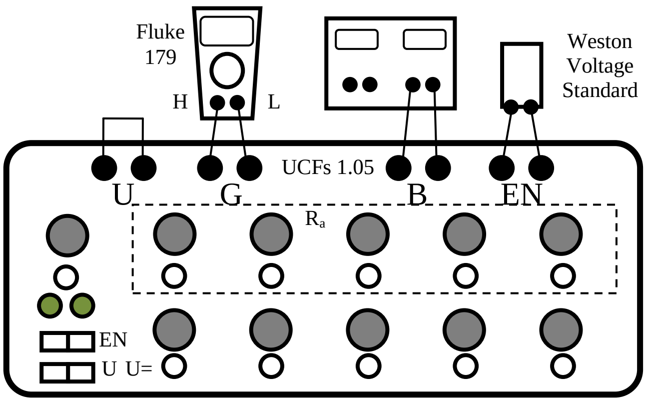



Fig. 7

Considering that the digital multimeter has very high input impedance and if terminals U are short-circuited at terminals G there will be the voltage: $U_{HL} = U_G = I_a \cdot R$

$$U_{HL} = U = Ia \cdot (A \cdot 1000 + B \cdot 100 + C \cdot 10 + D \cdot 1 + E \cdot 0{,}1) = \overline{ABCDE} \cdot Ia[V]$$

If $I_a=0.1mA$ (x0.1) we have $U_{HL} \leq 0.2V$ (x1) and if $Ia=1mA$ we have $U_{HL} \leq 2V$. The compensator must be balanced at the beginning using the same multimeter. The instrument will be verified on its basic scale (600mV) in 10 points uniformly distributed on the whole scale and results will be recorded in the following table:

| Nr. crt | U [V] | $U_{VN}$ [V] | $\Delta U_{VN}$ [V] | $\Delta U_{VN}/U_{VN}$ [%] | $\Delta U_{VN}/U_{VNnom}$ [%] | $(\Delta U_{VN}/U_{VN})$adm [%] | $\Delta U/U$ [%] |
|---|---|---|---|---|---|---|---|
| 1 | | | | | | | |
| 2 | | | | | | | |
| .. | | | | | | | |

The error of the generated voltage is the compensator error while neglecting the error of the Weston element:

$$\frac{\Delta U}{U} = c \cdot \left(1 + 0{,}1 \cdot \frac{U_n}{U}\right)$$

*b) Measuring the SMRR*

The following figure shows the electric setup for measuring the series mode rejection. The input voltage is DC (E) and it is added an AC voltage with the amplitude equal to the DC voltage:

$$U_{HL} = E \cdot [1 + \sin(2\pi f t)]$$

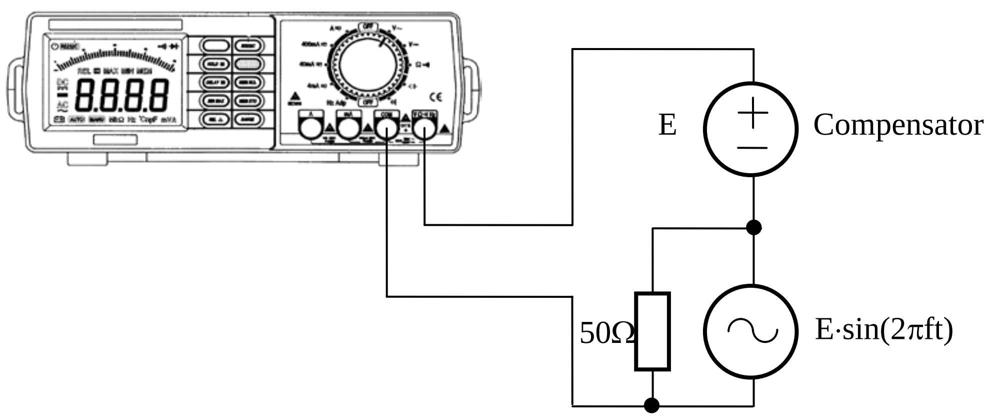



Fig. 8

The indication is dependent on the series disturbing signal frequency (f). On the display fluctuations of the indication will be noticed. The working mode for measuring SMRR is the following:

- Make the amplitude of the disturbing signal E=0. Balance the compensator by adjusting $R_a$ (with EN buttons pressed and $R_0$=1.0186V). Release EN and press U buttons and adjust R in order to have 1.000V on the multimeter display.

- Connect the AC generator, switch the multimeter on AC and adjust the amplitude of the AC signal at 0.707·E (1V amplitude) at 100Hz.
- Switch the multimeter again on DC and adjust the frequency between 10Hz and 110Hz and record the maximum and minimum indication for each frequency. Around the frequencies where SMRR has maximum take measurements at two frequencies before and after it (50Hz – 48Hz and 52 Hz). Record the data in the following table.

| f [Hz] | Umin [V] | Umax [V] | Umax-Umin [V] | RRS | RRS [dB] | Obs. |
|---|---|---|---|---|---|---|
| 10 | | | | | | |
| … | | | | | | |

- Compute SRMM with

$$R.R.S. = 20 \cdot \log \frac{E}{(U_{max} - U_{min})/2} \; [dB]$$

- Draw the SMRR graph

*c) Measuring the CMRR*

CMRR (f) needs 2 measurements: one in DC and another at a given frequency (>10Hz). The measurement must be performed only for the terminal COM because this is the most unfavorable case. The electric setup is presented in figure 9. The voltage E is generated with the compensator and $U_{CM}=400V$. The working mode is the following:

- Adjust the voltage E=0.1000V generated by the compensator and record the value indicated by the multimeter $U_1$.
- Connect the CM voltage ($U_{CM}=400V\ DC$) and read the value indicated by the multimeter after 10s.
- Calculate the DC equivalent voltage $U_e = U_1 - U_2$ and CMRR:

$$RRMC_{cc} = 20\lg \frac{U_{CM}}{U_e} \; [dB]$$

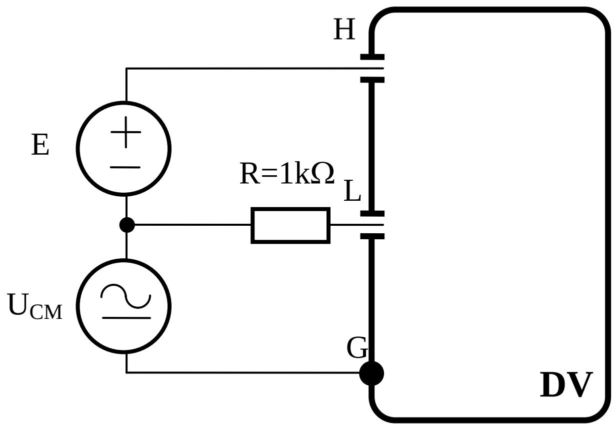



Fig. 9

- Replace the DC voltage with an AC voltage $U_{CM}$=280V (400Vpp) with adjustable frequency and record the maximum ($U_{max}$) and the minimum ($U_{min}$) indication on the display.
- Calculate the CMRR:

$$RRMC_{ca} = 20\lg\frac{U_{mc}}{(U_{\max}-U_{\min})/2}\ \ [dB]$$

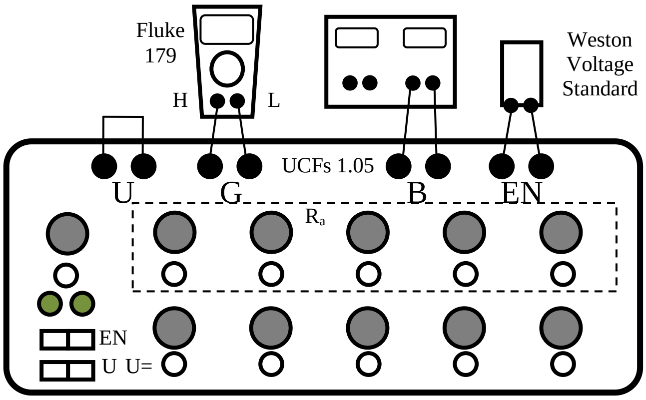
- Draw the CMRR(f) graph.
- Draw the $RR_{total}$ (f).

Group Name Date

# Study and Evaluation of Performances of the Digital Multimeter

## Labworks

1. Verify the accuracy class of the digital multimeter Fluke 179.




Record the data in the following table:

**Table 1**

| Nr. crt | U [V] | $U_{DV}$ [V] | $\Delta U_{DV}$ [V] | $\Delta U_{DV}/U_{DV}$ [%] | $(\Delta U_{DV}/U_{DV})adm$ [%] | $\Delta U/U$ [%] | $(\Delta U/U)/(\Delta U_{DV}/U_{DV})adm$ (≥3?) | $(\Delta U_{DV}/U_{DV})adm / \Delta U_{DV}/U_{DV}$ (≥1?) |
|---|---|---|---|---|---|---|---|---|
| 1 | | 0,100 | | | | | | |
| 2 | | 0,200 | | | | | | |
| 3 | | 0,300 | | | | | | |
| 4 | | 0,400 | | | | | | |
| 5 | | 0,500 | | | | | | |
| 6 | | 0,600 | | | | | | |
| 7 | | 0,700 | | | | | | |
| 8 | | 0,800 | | | | | | |
| 9 | | 0,900 | | | | | | |
| 10 | | 1,000 | | | | | | |
| 11 | | 1,100 | | | | | | |
| 12 | | 1,200 | | | | | | |
| 13 | | 1,300 | | | | | | |
| 14 | | 1,400 | | | | | | |
| 15 | | 1,500 | | | | | | |
| 16 | | 1,600 | | | | | | |
| 17 | | 1,700 | | | | | | |
| 18 | | 1,800 | | | | | | |
| 19 | | 1,900 | | | | | | |
| 20 | | 2,000 | | | | | | |

Conclusions:..........................................................................................................................
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2. Measure the SMRR(f) for the Mastech M9803R multimeter.

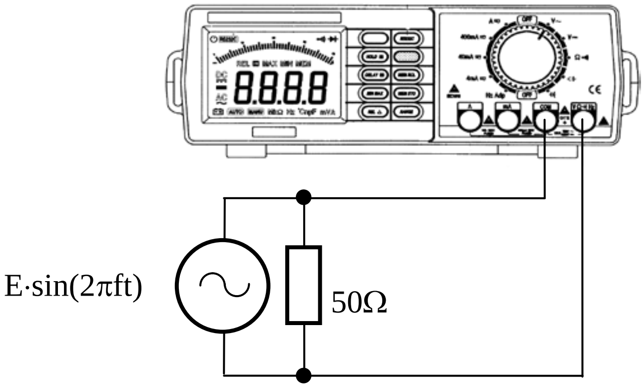
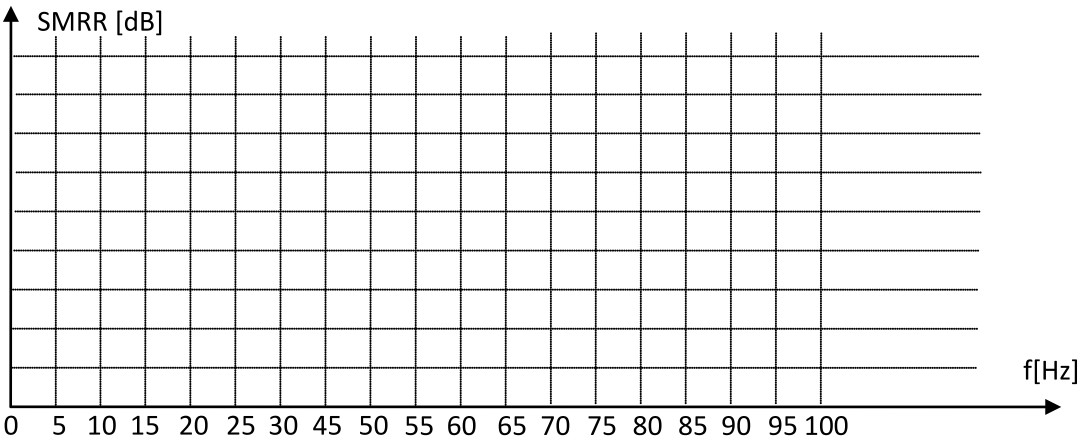



**Table 2**

| f [Hz] | Umin [V] | Umax [V] | Umax-Umin [V] | SMRR | SMRR [dB] | Obs. |
|---|---|---|---|---|---|---|
| 5 | | | | | | |
| 10 | | | | | | |
| 15 | | | | | | |
| 20 | | | | | | |
| 25 | | | | | | |
| 30 | | | | | | |
| 35 | | | | | | |
| 40 | | | | | | |
| 45 | | | | | | |
| 50 | | | | | | |
| 55 | | | | | | |
| 60 | | | | | | |
| 65 | | | | | | |
| 70 | | | | | | |
| 75 | | | | | | |
| 80 | | | | | | |
| 85 | | | | | | |
| 90 | | | | | | |
| 95 | | | | | | |
| 100 | | | | | | |




Conclusions: …………………………………………………………………………………….
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