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Revision, preview and assignment

Revision: **7.5, 7.6, 7.13,** **self-study 7.7-7.12**

Homework: **7-8, 7-9, 7-11, 7-12, 7-13, 1 extra exercise (on the Online Learning Platform)**

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High Voltage Engineering

Measurement of High Voltage (2)

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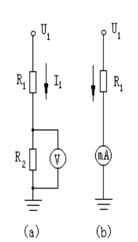
Chapter 7 Measurement of high voltage

*Note: self-study

Chapter 7 Measurement of high voltage

7.5.1 High voltage DC resistor divider

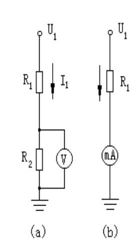
- **Concept of DC divider:**
  - **Concept:** It can be used to measure DC high voltage, consisting of resistor elements.
  - **There are 2 types** of resistor divider
  - **The resistance values** of R_1 are generally very high, and high voltage drops on it.
  - Typically, R_1 is composed of several or dozens of **resistor elements connected in series**.
- **Selection of R_1 resistance value:**
  - The choice of R_1 resistance value should not be too small
    - ✓ Heat loss is too great
    - ✓ leading to unstable resistance values and increased measurement errors.



(a) DC resistor divider
(b) High ohm resistor in series with milliammeter

7.5.1 High voltage DC resistor divider

- **Selection of R_1 resistance value:**
  - It should not be too large
    - ✓ I_1 is too small. May cause **corona discharge and leakage current** of the insulating bracket, leading to measurement errors
- **IEC specifies current I_1:**
  - I_1 should not be less than **0.5 mA**.
  - Generally, I_1 is chosen between **0.5** and **2 mA**.
  - For voltage dividers with high working voltage, a larger I_1 can be chosen.
  - In practice, I_1 is often set to **1 mA**.



(a) DC resistor divider
(b) High ohm resistor in series with milliammeter

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What are the main causes of measurement errors in resistor dividers besides corona and leakage current?

- A The resistance value is unstable
- B Instrument error
- C The output voltage of the test power supply is unstable
- D Load current is too large

提交

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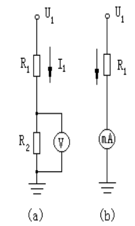
- **Main causes of measurement errors of resistor divider**
- **Main causes**
  - Unstable resistance values
  - Instrument errors
- **Causes for the actual resistance changes of R_1 and R_2**
  - Resistor itself heats up or ambient temperature changes
  - Corona discharge on or near resistor elements
  - Leakage in insulation bracket
- **Some measures taken**
- **Filling with transformer oil:**
  - Enhance heat dissipation and increase dielectric strength
  - The effect is better if the oil flow or highly insulating gas flow is circulated through an electric pump.
- **Filling with high pressure or high-insulation gas:**
  - This is effective in suppressing corona discharge and leakage current.



(a) DC resistor divider
(b) High ohm resistor in series with milliammeter

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7.5.2 High voltage AC resistor divider

- **Stray Capacitance:**
  - The high-voltage arm resistor R_1 is composed of n R' elements connected in series. Each R' has its parallel stray capacitance C', and there is a stray capacitance to ground C_e' for each R'.
  - Generally, C' is very small and can be ignored, focusing only on the impact of C_e'. The total capacitance to ground for the voltage divider is denoted as C_e, and it is equal to nC_e'.
- **Voltage across the low-voltage arm:**
  - If $u_1=U_{1m}\sin\omega t$, the voltage across the low-voltage arm is:

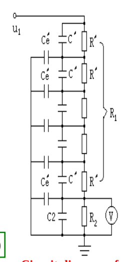
$$u_2 = AU_{1m}\sin(\omega t-\theta°)/K$$

  - The voltage ratio is

$$K=\dot{U}_1/\dot{U}_2=(R_1+R_2)/R_2\approx R_1/R_2$$

$$A\approx 1-[(\omega R_1 C_e)^2/180] \qquad \theta\approx\tan^{-1}(\omega R_1 C_e/6)$$

- **Calculation Conclusion:**
  - $A<1$, voltage divider produces amplitude error
  - $\theta\neq 0$, it produces lagging phase angle error



Circuit diagram of resistor divider

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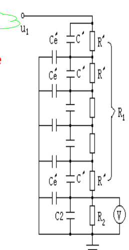
7.5.2 High voltage AC resistor divider

limitation!

- **Applicable of resistor dividers to AC voltage**
  - Only AC voltage that is not too high in frequency and amplitude
  - Generally, under power frequency voltage, it is only applied to voltage levels below several tens of kV
- **Error analysis** $A\approx 1-[(\omega R_1 C_e)^2/180]$ $\theta\approx\tan^{-1}(\omega R_1 C_e/6)$
  - ✓ The higher the frequency, the greater the resistance, the larger the stray capacitance, and the greater the measurement error
  - ✓ Higher voltage dividers will have larger dimensions, and the stray capacitance to ground will also increase accordingly.
  - ✓ When measuring higher voltages,
    - the resistance must also be increased, otherwise the current will be too large, which will affect the power supply,
    - and also will cause the temperature rise of the voltage divider, which will also cause errors.



Circuit diagram of resistor divider

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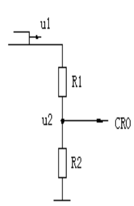
7.5.3 Resistor divider for measuring impulse voltage

- **High-voltage arm (R_1) and Low voltage arm (R_2)**
- **Materials for resistor**
- ✓ **Resistive wire:** A resistor divider for measuring impulse voltage, usually made of resistive wire.
- ✓ **Small inductance:**
  - The wire is required to be as short as possible while resistance value and temperature rise are not too high.
  - The material used is required to be non-magnetic and have a large resistivity.
- ✓ **Small temperature coefficient of resistance:**
  - to prevent the resistance value changing with temperature, it is usually made of Karma and constantin wire according to the **non-inductive winding method**.



Schematic diagram of resistor divider

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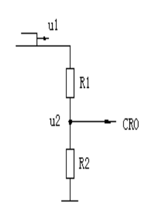
7.5.3 Resistor divider for measuring impulse voltage

✓ **Resistance value:**

- The resistance value of the resistor divider for measuring lightning impulse voltage is generally about **10,000 Ω**, and should not exceed **20,000 Ω**, and the minimum should not be less than **2000 Ω**.
- Generally the maximum measuring voltage is **2000 kV**

✓ **Limitation**

- Resistor voltage dividers are rarely used to measure switching impulse voltages, and capacitive voltage dividers are more suitable.



Schematic diagram of resistor divider

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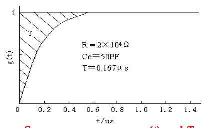
1. Error analysis and damped step response

Like the power frequency voltage divider, due to the stray capacitance to the ground, the resistor divider has **measurement errors of peak value and waveform lag** when measuring the impulse voltage (ignoring the impact of circuit inductance).

Step (square wave) response:

- When studying the errors of impulse voltage dividers, it is common to input a step waveform at their high-voltage terminal.
- Then calculate or measure the output waveform at the low-voltage arm.
- This waveform is referred to as the step response or square wave response in HV measurements.



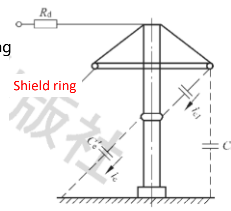
Square wave response $g(t)$ and T of the resistor divider

✓ **Response time:** The profile is step response time $T = RC_e/6$

✓ **Response time requirements:** Theoretical calculations prove that in damped step response, $T \le 0.2\mu s$ can meet the requirements for measuring **1.2μs/50μs** full wave or wave chopped at tail.

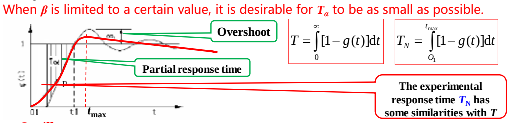
2. Measures to suppress stray capacitance

- **Shielding compensation:** However, it increases the capacitance between the high-voltage terminal and ground, leading to oscillations.
- **Volume reduction:** Immersion in oil to reduce the volume of the divider.
- **Increased distance from ground:** The support of the lower part of the voltage divider is off the ground to increase the distance between the divider and the ground.



3. Oscillatory step response

- **Concept of oscillatory step response**
- ✓ The capacitance C_e'' between the high-voltage terminal of the divider and ground, forms an oscillation with the inductance of the high voltage lead. Even if a damping resistor is added to the first end of the lead, the oscillation is still unavoidable.
- ✓ The step response $g(t)$ of the measuring system is depicted in the figure, and so called oscillatory step response.
- The step responses of actual voltage divider are mostly oscillatory step responses.
- **IEC60060-2** specifies that the overshoot β and the partial response time T_a formed by the oscillation of the step response as important indicators to judge the performance of the voltage divider.
- When β is limited to a certain value, it is desirable for T_a to be as small as possible.

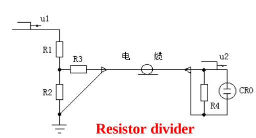


Oscillatory step response

4. Impedance matching at the head and end of the cable to eliminate high-frequency oscillation

(Not to be confused with another type of oscillations of test transformer)

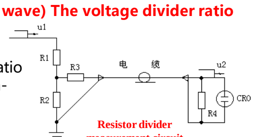
- **Connection and shielding:**
- ✓ The waveform recorder or oscilloscope is often located several meters to tens of meters away from the divider and is connected by RF coaxial cables.
- ✓ The cables use low-loss polyethylene as insulation.
- ✓ The outer metal sheath of the cable is grounded to prevent electromagnetic field interference.
- **Concept of impedance matching:**
- ✓ High/low-voltage arm resistor R_1/R_2
- ✓ End terminal matching resistor R_4, equal to the cable surge impedance Z
- ✓ Head terminal matching resistor R_3, i.e., $R_2+R_3=Z$
- ✓ The surge impedance Z of the cable is mostly **50Ω** or **75Ω**.



Resistor divider measurement circuit

4. Impedance matching at the head and end of the cable to eliminate high-frequency oscillation

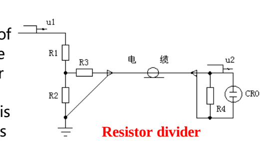
- **The reason for impedance matching:**
- ✓ Due to the steep wavefront of the measured impulse wave, the wave chopped changes rapidly.
- ✓ Therefore, one or both ends of the cable require impedance matching to prevent continuous wave reflections at the cable ends.
- ✓ Otherwise, high-frequency oscillations may appear in the recorded waveform.
- **(Considering the reflection of impulse wave) The voltage divider ratio**
- ✓ At $t=0$, the initial voltage divider ratio
- ✓ At $t=\infty$, the steady voltage divider ratio
- ✓ The total voltage divider ratio K, is the ratio between the input voltage u_1 at the high-voltage terminal and the voltage u_2 obtained at the oscilloscope (CRO).



Resistor divider measurement circuit

- **(Considering the reflection of impulse wave) The voltage divider ratio (continue)**
- ✓ It can be demonstrated that when measuring a step wave, the initial voltage divider ratio and the steady voltage divider ratio are equal (because there are no reflections).
- **Voltage divider ratio:**

  $K = [(R_1+R_2)(R_3+R_4)+R_1R_2]/R_2R_4$
- ✓ Single-terminal matching: If the value of K is too large, it can be modified to use a resistor matching only at the input or output terminal.
- ✓ Cable core resistance: When the cable is relatively long and terminal matching is applied, the voltage dividing effect of the cable core resistance needs to be taken into account.



Resistor divider measurement circuit

- **Improvement measures for resistor divider**
- **Select a resistor with low temperature coefficient:**
  - ✓ The change in resistance value due to temperature change is mainly determined by the temperature coefficient of the resistor material.
  - ✓ To minimize resistance changes caused by heating, resistors with a small temperature coefficient can be selected.
- **Types of resistors that can be used:**
  - ✓ **Wirewound resistor:** Precision wirewound resistor is usually made of alloy such as Karma. It has large heat capacity and **small temperature coefficient**.
    - Generally **<= |10ppm (Parts per million, 10^{-6})/°C|**
    - High quality can be <=|1~5ppm/°C|
  - ✓ **Precision metal film resistors**: about **±(50~100)ppm/°C**
  - ✓ **Carbon film resistors**: Mostly replaced by metal film resistors.

Synthetic carbon rod resistors with a large thermal capacity (for the entire resistor size) are produced and used in Europe and the United States, while China phased them out prematurely.

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- **In addition to considering the temperature coefficient, the following measures are often taken separately or simultaneously**
  - ✓ **Choose high-power elements:**
    - Select the total power of the elements to be greater than the power required by the voltage divider to reduce the temperature rise.
  - ✓ **Use combinations of resistors with positive and negative temperature coefficients** to neutralize resistance change caused by the temperature change:
    - The temperature coefficients of metal film resistors and wirewound resistors often have positive and negative values.
    - When used in series, they can be reasonably matched to minimize the overall temperature coefficient of R_1 under certain conditions.
    - However, the magnitude and sign of the temperature coefficient are, in fact, functions of temperature, so this measure can only be implemented within a certain temperature range.

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- **Increase the voltage divider current to suppress the effects of corona**
  - ✓ **Corona aging:**
    - One of the reasons why corona can cause measurement errors is that the corona on the resistor at high potential will damage the resistor, especially the film layer of thin-film resistors, leading to degradation.
  - ✓ **Corona current shunt:**
    - The corona current to the ground will increase the equivalent resistance value of R_1, leading to measurement errors.
    - Therefore, selecting a larger value for I_1 can be appropriate to mitigate this effect.

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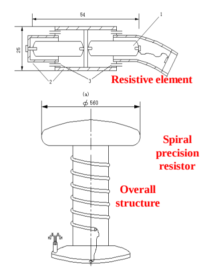
- **Shielding cover and shell:** to suppress corona
  - ✓ **Install a shielding cover:**
    - The high-voltage side should be equipped with a metal shielding cover that can make the electric field more uniform.
  - ✓ **Install a shielding shell:**
    - For voltage dividers with high accuracy requirements, the resistive components should be equipped with equipotential shielding.
    - That is, the resistive element is shielded with a metal shell with a larger radius.
    - The potential of the shell can be supplied by the resistor divider itself or by an auxiliary voltage divider.



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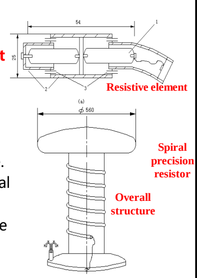
- **Reduce the leakage of the bracket or the impact of leakage**
  - ✓ **Choose high-resistance materials as brackets:**
    - Measurement errors caused by leakage of the insulating brackets can be reduced by choosing structural materials with high insulation resistance.
    - Neutral polystyrene is one such alternative material
  - ✓ **Equipotential shielding:**
    - It can also reduce leakage or the impact of leakage



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Chapter 7 Measurement of high voltage

7.6 High Voltage capacitor divider

7.6.1 Composition of capacitor voltage dividers

7.6.2 High voltage AC capacitor divider

7.6.3 Impulse voltage capacitor divider

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7.6.1 Composition of capacitor voltage dividers

- **Application range:**
  - Capacitor voltage dividers can be used over a wide AC HV range from a few kilovolts to **3 MV**
  - In some HV laboratories, capacitor voltage dividers for both power frequency and impulse voltage have been developed.
  - Example: Tsinghua University developed a ZRF-type impulse and power-frequency dual-purpose oil-paper dielectric damping capacitor voltage divider with a high-voltage arm capacitance C_1 of **300** pF.
    - The rated voltage for power frequency is **1200 kV (rms)**
    - The rated voltage for impulse **(1.2/50 μs)** is **2400 kV (peak)**.
    - It is assembled from eight resistor-capacitor elements.

7.6.1 Composition of capacitive voltage dividers

- **Two types of capacitor voltage dividers**
  - **Centralized capacitor voltage divider**
    - ✓ The high-voltage arm ueses a high-voltage standard capacitor with gas dielectric.
  - **Distributed capacitor voltage divider**
    - ✓ The high-voltage arm is assembled from multiple capacitor elements connected in series.
    - ✓ The error analysis method used previously is also available to this type of voltage divider.

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Do you agree with using a capacitive divider to measure DC voltage?

A Agree

B Disagree

提交

7.6.2 High voltage AC capacitor voltage divider

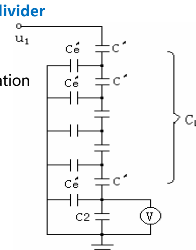
- **Low-voltage arm voltage**
  - ✓ When $u_1 = U_{1m}\sin\omega t$
  - ✓ It can be obtained by approximate calculation

$$u_2 = A(U_{1m}\sin\omega t)/K$$

$$A = 1-(C_e/6C_1)$$

$$K = \dot{U}_1/\dot{U}_2 = (C_1 + C_2)/C_1 \approx C_2/C_1$$

- **Error analysis and elimination**
  - ***A*<1, there is amplitude measurement error**
  - **No phase angle error!**



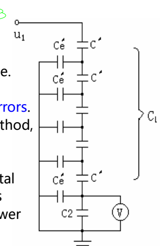
Circuit diagram of distributed capacitor voltage divider

- **Error analysis and elimination**

How to achieve?

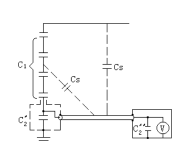
- **Stray capacitance and errors elimination**
  - ✓ The sum of stray capacitance C_e and high-voltage arm capacitance C_1 can be measured using the Schering bridge.
  - ✓ Using it as the high-voltage arm capacitance to calculate voltage divider ratio, avoiding amplitude measurement errors.
  - ✓ Calculate the stray capacitance C_e by the approximate method, and then substitute it into the low-voltage arm voltage calculation formula to calculate the measured voltage.
  - ✓ Because the stacked capacitor is cylindrical, it forms a metal cylinder perpendicular to the horizontal plane. Assume its length is l, diameter is d, and the distance between the lower end and the ground is h, then

$$C_e = 2\pi\varepsilon l / \ln\left(\frac{2l}{d}\sqrt{\frac{4h+l}{4h+3l}}\right)$$



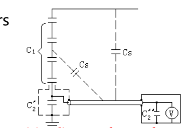
Circuit diagram of distributed capacitor voltage divider

- **Selection of capacitive elements for the high-voltage arm of a distributed divider**
  - **Principle:** Capacitive elements should be as pure as possible, with minimal dielectric loss and inductance.
  - The capacitance value should be neither too large nor too small.
  - ✓ To minimize impact of stray capacitance, the value of C_1 should not be too small.
  - ✓ **However,** increasing the value of C_1 not only increases the investment cost and size of the divider but also adds load to the power frequency test transformer.
  - ✓ C_1 should be chosen with an appropriate value. For the special AC capacitor divider without considering impulse voltage, generally C_1 is 100~200pF.



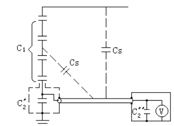
Wiring diagram of power frequency capacitor voltage dividing system

- **Actual element types used in HV arms**
  - ✓ Oil-paper capacitors or oil-impregnated plastic (such as polypropylene) film capacitors
  - ✓ polystyrene capacitor
  - ✓ ceramic capacitor
- **Selection of capacitors in LV arms**
  - ✓ C_2 is made of high stability, low loss, low inductance capacitors
  - ✓ C_2 usually uses mica, air or polystyrene dielectric capacitors
  - ✓ When accuracy requirements are not high, oil-paper capacitors or metallized paper and metallized film capacitors can be used



Wiring diagram of power frequency capacitor voltage dividing system

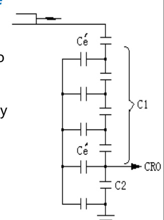
- **System Wiring and Shielding**
  - To prevent the impact of capacitance C_s caused by stray electric fields in space, the low-voltage arm capacitor and the wires connecting the high-voltage arm and the voltmeter should be shielded.
  - In practice, shielded cables are used for connections.
  - All shields should be well grounded.
  - The low-voltage arm capacitor can be placed entirely or partially at either end of the shielded cable.



Wiring diagram of power frequency capacitor voltage dividing system

7.6.3 Capacitor divider for measuring impulse voltage

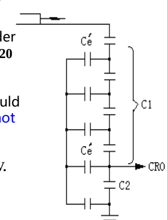
- **Types:** also two types: distributed and centralized
- **Sources of measurement error**
  - ✓ The series inductance should be minimized in the design, so its role can be ignored when the measured voltage is not high and the height of the voltage divider is not large.
  - ✓ In such cases, the measurement error of the divider is mainly caused by the stray capacitance C_e to ground.
  - ✓ Like the power frequency AC divider, the divider only has peak measurement error but no waveform error.
- **Low voltage arm voltage:** $u_2(t)=(u_1/K)(1 - C_e/6C_1)$
- **Voltage ratio:** $K=(C_1+C_2)/C_1$
- **Amplitude error:** If the divider has no inductor, the characteristics are very good in terms of measured waveforms. Its amplitude error is related to the $C_e/6C_1$



Capacitor divider and its stray capacitance to ground $C_e\,(=\Sigma C_e')$

7.6.3 Capacitor divider for measuring impulse voltage

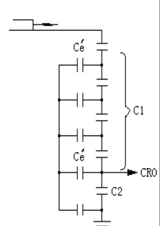
- **Estimation of stray capacitance:** The value of C_e can be estimated based on the stray capacitance of a vertical cylinder to ground. At normal diameters, the value is approximately **20 pF/m**.
- **Select capacitance of divider**
  - If the output voltage peak error of the capacitor divider should not exceed **1%**, then the capacitance of the divider should not be less than **300 pF/m**.
  - If the height of the divider is designed for **500 kV/m**, the capacitance of the divider should not be less than **600 pF/MV**.
- **Limitations on capacitance size:** For capacitive voltage dividers with higher voltages above **MV**, it is sometimes difficult to meet such requirements.
  - Capacitance value is too large, increasing cost and diameter
  - It increases the load on the impulse voltage generator, which is sometimes not allowed.



Capacitor divider and its stray capacitance to ground $C_e\,(=\Sigma C_e')$

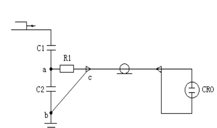
7.6.3 Capacitor divider for measuring impulse voltage

- **Capacitance used in calculations**
  - ✓ Normally, the capacitance C_1 is expressed by an effective value C_{1e} measured on-site, and C_{1e} is then used in the calculations instead of C_1 to determine the voltage divider ratio.
  - ✓ Or use a precision voltage divider to calibrate its characteristics on site.
  - ✓ When employing these methods, on-site conditions, including the position of the voltage divider, high-voltage leads, and the placement of the test specimen, should closely match the actual measurement conditions.

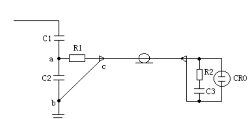


Capacitor divider and its stray capacitance to ground $C_e\,(=\Sigma C_e')$

- **There are two measurement circuits for the low voltage arm**
  - One is measurement circuit with matching resistor at the **input terminal** of the cable, $R_1=Z$
  - Another oner is measurement circuit with matching resistors at **both input and output terminals** of the cable, $R_1=R_2=Z$



Measurement circuit with only the input terminal matching of coaxial cable



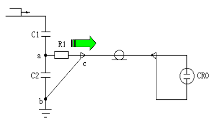
Measurement circuit with matching at both terminals of coaxial cable

●Measurement circuit with input terminal matching of the coaxial cable

➢**Entry wave amplitude:**

At the initial moment when the step voltage is applied, the amplitude of the wave entering the cable is

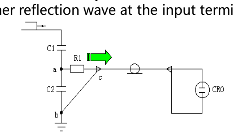
$U_1[C_1/(C_1+C_2)][Z/(Z+R_1)] = C_1U_1/[2\cdot(C_1+C_2)]$ (Due to matching, $Z=R_1$)



Measurement circuit with only the input terminal matching of coaxial cable

➢ **Wave Process**

- ✓ Wave amplitude entering the cable: $C_1U_1/[2\cdot(C_1+C_2)]$
- ✓ At the cable's end, where the oscilloscope is connected, input impedance is very high, and input capacitance is very small, approximating an open circuit.
- ✓ The voltage wave obtained by the oscilloscope at the output terminal is the superposition of the incident wave and the positive reflected wave $C_1U_1/(C_1+C_2)$.
- ✓ When the reflected wave reaches the cable 's input terminal, since C_2 is relatively large and R_1 is already matched with the cable surge impedance Z, there is no further reflection wave at the input terminal.



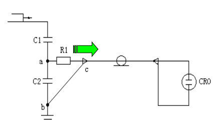
Measurement circuit with only the input terminal matching of coaxial cable

➢ **Initial voltage divider ratio:**

- ✓ At the initial moment, $K_1 = (C_1+C_2)/C_1$

➢ **Quasi-steady state:**

- ✓ After the wave travels twice the distance in the cable for a time of 2τ, it can be regarded as reaching a quasi-steady state.
- ✓ At this time, the cable is regarded as a capacitor C_0, so when $t \geq 2\tau$, $K_2 = (C_1+C_2+C_0)/C_1$



Measurement circuit with only the input terminal matching of coaxial cable

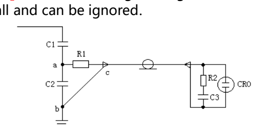
$K_1 = (C_1+C_2)/C_1$, $K_2 = (C_1+C_2+C_0)/C_1$

➢ **Voltage overshoot**

- ✓ Due to differences between K_1 and K_2, the cable will cause a voltage error.
- ✓ Its relative value is related to $C_0/(C_1+C_2)\approx C_0/C_2$

➢ **Error resolution**

- ✓ For short or medium length cables, and high C_2 values, that is, high voltage divider ratios, the effect of this overshoot is very small and can be ignored.
- ✓ When capacitor dividers are used for on-site testing of transient voltages with longer cables, a wiring diagram proposed by F· G· Burch in earlier years can be used.
- ✓ Matching both input and output terminals of the coaxial cable measurement loop, which can eliminate the voltage error.



Measurement circuit with matching at both terminals of coaxial cable

● Measurement circuit with both ends matching of the coaxial cable

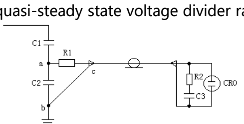
- ➢ In this circuit, choose: $C_1+C_2 = C_3 + C_0$
- ➢ Initial voltage divider ratio: at $t = 0^+$,

$$K_1 = \frac{U_1}{[C_1U_1/(C_1+C_2)]\,[Z/(R_1+Z)]} = 2(C_1+C_2)/C_1$$

- ➢ Quasi-steady state voltage divider ratio: When $t \geq 2\tau$,

$$K_2 = (C_1+C_2+C_3+C_0)/C_1 = 2(C_1+C_2)/C_1$$

- ➢ The initial and quasi-steady state voltage divider ratios are the **same**.



Measurement circuit with matching at both terminals of coaxial cable

Chapter 7 Measurement of high voltage

Self-study

7.7 Resistor-capacitor divider*

7.8 Differential and integral measurement systems*

7.9 Requirements for response characteristics of impulse voltage measurement systems*

7.10 Oscilloscopes for measuring impulse HV*

7.11 Measuring HV using photoelectric technology*

7.12 Measurement of HV electric field *

Chapter 7 Measurement of high voltage

7.13 Anti-interference measures for weak current instruments
7.13.1 Sources of electromagnetic interferences
7.13.2 Interference suppression measures

投票 最多可选1项 设置

Will residents living near power transmission lines be affected by the electromagnetic fields from the lines, leading to health problems?

A Yes

B No

提交

7.13.1 Sources of electromagnetic interferences

- **Electromagnetic compatibility (EMC):** Refers to the ability of electrical equipment (including electronic equipment) to work satisfactorily in their electromagnetic environment.
  - When functioning as a **source of interference**, the equipment should emit only permissible levels of interference.
  - When acting as a **receptor**, the equipment should be only tolerably sensitive to interference.

- **Electromagnetic compatibility issues in HV measurements**
  - **Weak current measuring instrument and working environment**
    - ✓ On site, various electrical equipment and wires with HV and large current.
    - ✓ In a laboratory, there are HV or large current generating devices
  - **consequences**
    - ✓ **more serious situation**
      - Measuring equipment or instruments are affected by interference
      - Seriously distort the recorded signal
    - ✓ **most serious situation**
      - Weak current measuring equipment or instruments, causing "ground counterattack" due to increased ground potential
      - Individual crucial components may be damaged due to strong electromagnetic interference.
      - This can result in the inability of the measurement equipment or instruments to function properly.

多选题 1分 设置

What are the sources of electromagnetic interference?

A Grounding system

B Power system

C Space electromagnetic field

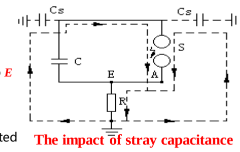
D Ultrasonic waves

提交

7.13.1 Sources of electromagnetic interferences

- **three main sources of electromagnetic interferences (EMI):**
  - ✓ Interferences caused by transient currents passing through the outer sheath of RF coaxial cables used in measurements. **(ground interferences)**
  - ✓ Electromagnetic radiation in the space generated during gap discharges **(space interferences)**
  - ✓ Interferences introduced through the power lines of instruments **(power supply interferences)**
- The first type of interference in impulse high voltage measurement requires the most attention.

- **The process of voltage drop generated by loop current and the ground potential rise caused by stray capacitance**
  - *C*: Main capacitance C_s: Stray capacitance
  - *E* point: Connected to ground through grounding resistor *R*, potential is zero.
  - *A* point: Lower end of the test sample, connected to *E* through a wire, original potential is zero.
  - The process of Increased ground potential (ground counterattack)
  - ✓ When the sample or the copper sphere gap connected in parallel with *C* suddenly discharges
    - *C* forms a discharge circuit through the discharge gap *S*
    - C_s is also discharged through *S* and ground resistor *R*
  - ✓ At the moment of discharge, the current flows through *R*, the potential of point *E* is no longer zero, and the ground potential rises, causing a back discharge
- **Voltage drop caused by loop current (loop voltage)**
  - Since the current in the main discharge circuit produces a voltage drop in the line connecting point *A* and point *E*, the potential of point *A* is not equal to the potential of point *E*, and it is not equal to zero potential.

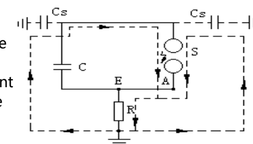


The impact of stray capacitance C_s on the potential of point *E*

When generating impulse currents, the loop voltage (E.g.)

- ✓ If the distance between point *A* and point *E* is **1m**
- ✓ The inductance of the connecting wire is approximately **1μH/m**
- ✓ Suppose the change rate of the current is **10kA/μs**, then the voltage difference between *A* and *E* at the moment of discharge is

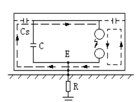
  $L \times di/dt = 1\mu H \times 10kA/\mu s = 10kV$
- ✓ Measures: It is best to connect the grounding point of the voltage divider or current shunt directly to point *E*.



The impact of stray capacitance C_s on the potential of point *E*

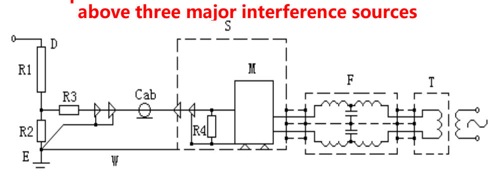
7.13.2 Interference suppression measures

- **Reduce loop voltage drop:** The ground loops in all HV tests should be made of larger aluminum (or copper) plates or wide bands to reduce the voltage drop.
- **Ground resistance** should be as small as possible.
- Measurement cables should be as compact as possible.
- **The laboratory adopts full shielding.** The high-voltage test hall can be fully shielded with metal conductors (plates or mesh) to form a large **Faraday cage, constructing a full shielding lab**.
  - ✓ It can significantly reduce loop resistance
  - ✓ It can also act as electromagnetic shielding
- **Single-point grounding should be adopted.** The Faraday cage has only one point connected to the ground, so the stray capacitance current flows back through the metal cage and the potential at point *E* will not increase.
- **Build a small shielded room** or box specifically for general-purpose digital oscilloscopes and other ancillary equipment in high-voltage testing.



The laboratory adopts fully shielded single point grounding

Comprehensive anti-interference measures for the above three major interference sources



Wiring diagram of comprehensive anti-interference measures

D - Voltage divider	Cab - Double shielded cable
E - Concentrated grounding electrode	W - Metal plate grounding
S - Shielded room	M - Measuring instrument
F-Filter	T - 1:1 isolation transformer

清華大學 Tsinghua University

High Voltage Engineering

Measurement of High Voltage (2)

THE END! THAKS!