Ferroelectric measurement

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Direct I-V measurement

\[ i = icap + ip + icond = Cs \frac{dV_s}{dt} + As \frac{dP_s}{dt} + \frac{V_s}{R_s} \]

There are three instantaneous current components in the series circuit, polarization current \( (i_p) \), conductive current \( (I_{cond}, \text{if sample is lossy}) \) and current due to stray linear capacitances \( (I_{cap}) \).

\[ Q = \int I \, dt = \int 24I \, dV \]

\[ \frac{dV}{dt} = 15V/6\text{min} \quad dt = 24dV(\text{sec/Volt}) \]

\[ P = Q/A \quad A \sim 0.005cm^2 \]

The \( P \) is too large, cannot be real.
Ferroelectric measurement setup
Sawyer-Tower (ST) circuit measurement

The circuit consists of two capacitors, one due to sample ($C_x$) and other one is a linear-known-valued sense-capacitor ($C_{\text{sense}}$). They are in series, where $C_{\text{sense}}$ is chosen much greater than $C_x$ so that voltage drop across $C_{\text{sense}}$ is much less than that across $C_x$ (sample). So the drive voltage $V_d$ is almost equal to voltage across $C_x$. The voltage across $C_{\text{sense}}$, which gives polarization of the sample, is applied to vertical plates of the oscilloscope and the drive voltage after safe attenuation is applied to horizontal plates of the oscilloscope to measure electric field across the sample.
Lossy FE capacitor with leaky resistance and linear capacitance

Ideal linear capacitor
0.1 nF

Lossy capacitor
0.1 nF+2 MΩ

More lossy capacitor
0.1 nF+100 kΩ

Ideal resistor
2 MΩ

$C_{\text{sense}} = 10 \text{nF}$
Compensate for the linear capacitance and lossy resistance

The linear capacitance can be compensated for by subtracting from the loop a straight line with the correct slope.

The losses can be compensated for by subtracting from the loop an ellipse of proper shape and size with its major axis along the E axis.

In the general, both losses and linear capacitance are compensated by producing an ellipse whose major axis can have any desired inclination with respect to the E axis and with any desired ratio $a : b$ of the major to minor axis.
Computational compensate

\[ J = J_p + J_{cap} + J_{cond} \]

\[ E = E_m \sin(\omega t) \]

\[ J_{cap} = \varepsilon_0 \varepsilon \omega E_m \cos(\omega t) \]

\[ J_{cond} = \sigma E_m \sin(\omega t) \]

Ferroelectrics, 411:86–92, 2011
Ferroelectric loop for BTO-3
Compensate loss resistor-1965

\[ C_s R_s = C_{\text{sense}} R_{\text{sense}} \]

Figure 4 P-E plots of the PZT at the electric-field of 1.5kV/mm with variation of the magnitude of VR. (a) VR, high. (b) VR, properly adjusted. (c) VR, low.

Ferroelectrics, 230:1, 151-156
Adjusting $R_c$ to equal the sample resistivity $R_s$ removes the rounded ends of the displayed hysteresis loop. The residual capacitance $C_r$ can be compensated and measured by adjusting $C_c$ to produce a hysteresis loop ending in horizontal lines.

![Diagram of a bridge circuit](image)

**Fig. 11.** Rochelle salt with artificial conductivity ($\rho = 5.8 \times 10^9 \, \text{cm}^{-1}$); hysteresis loops as measured by hysteresis bridge. $V_o = 500 \, \text{V}$, $60 \, \text{cm}^2$; $A = 1.05 \, \text{cm}^2$, $b = 0.179 \, \text{cm}$, $Q_s = 0.22 \mu\text{F}$, $t = 0^\circ \text{C}$. (a) $R_c = \infty$, $C_c = 0$; (b) $R_c = 10 \Omega$, $C_c = 0$; (c) $R_c = 10 \Omega$, $C_c = 130 \mu\text{F}$; (d) $R_c = 5 \times 10^9 \Omega$, $C_c = 0$. 

THE REVIEW OF SCIENTIFIC INSTRUMENTS, 28, 30, 1957
Negative current compensate
Across the two secondaries of the transformers $T_1$ and $T_2$ we have two sinusoidal voltages 90° out of phase with each other. The two potentiometers $P_1$ and $P_2$ and the two switches $S$, and $S_2$ permit one to obtain any desired voltage. The connection between the two secondaries of the transformers is such that the two voltages add up so that the sum appears at point $Y_2$. With switch $S_3$ a 10 : 1 voltage divider can be inserted.

If the voltage applied to the ferroelectric sample has the same phase as $T$, then the switch $S_2$ and the potentiometer $P_2$ vary the ratio $a : b$ of the two axes of the ellipses (loss compensation); the switch $S_1$ and the potentiometer $P_1$ vary the inclination of the major axis with respect to the $E$ axis (linear capacitance compensation).

The points 0, $T$, $S$, $R$ represent the neutral point and the three phases of a three phase 50 c/s line.
Current to charge converter-1983

Basic circuit

Compensate circuit

Feedback capacitors $C_c$ are switched from 10 to 1000 nF, and feedback resistors $R$ are switched from 10 MR up to open circuit.


In our circuit $R_c$ and $C_c$ have values of 24.9 kohm and 4700 pF respectively. These values allow the compensation of the ferroelectric sample resistance and linear capacitance in the following ranges: $1245 \text{ kohm} \leq R_c \leq \infty$, and $0 \leq C_x \leq 94 \text{ pF}$. 

PUND setup