DC-biased dielectric measurements using an existing frequency-domain spectroscopy (FDS) instrument and series battery

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Abstract

We present a simple method for adding DC bias to frequency-domain spectroscopy (FDS) measurements by inserting a battery in series in the 'high' lead to the specimen. An instrument designed for FDS measurements with pure AC can be used in this way without modification, even for DC voltages above the instrument's AC range. Issues and limitations of the method are discussed, along with some alternative methods. Experimental results from FDS measurements on well defined linear specimens are compared with/without the DC bias, to check that the measurement is not disturbed by the DC source. The only detected difference was the expected effect of including the battery impedance in series with the specimen in the measurement. This effect was negligible for typical lab-specimen capacitances, around and below power frequency. The nature of battery impedance is further described, as multiple small batteries in series can strongly affect the results for large specimens and at high frequencies.

1. Introduction

Various purposes exist for making dielectric measurements with a stimulus composed of multiple classic simple waveforms. Examples include:

- Application of sinusoids at two or more frequencies simultaneously, to obtain an FDS sweep in a shorter time [1] [2] on the assumption of linearity.
- Study of subsequent partial discharge phenomena stimulated by an impulse superimposed on AC or DC (or both) voltage [3] [4].
- Synthesis of a realistic situation for insulation in converters where DC is combined with AC and/or higher-frequency switching [5] [6].
- Measurement of differential capacitance or conductance from small-signal AC behaviour of a nonlinear specimen at different DC bias levels [7].
- Restriction of ionic motion by strong DC bias, in order to avoid its contribution to FDS results [8].

The last two items in the above list are examples of FDS with a DC bias. That is the focus of this work, which is also relevant to DC-bias in measurements with other waveforms than sinusoids. The method that we explain and test here was used for results presented in [9]. Its brief description there attracted comments about the method's potential and limitations, thus stimulating the present work.

2. Circuit options for DC-biased FDS

Figure 1 gives a simple view of a guarded measurement made on a dielectric specimen in a three-electrode test cell. The voltage source is shown as AC ($\sim$), to fit with traditional FDS. Measurements V and A are the voltage across the specimen and the current collected in the *measure* electrode. Signals corresponding to these quantities would typically be sampled and digitized; numerical processing can then determine their phasor values, from which are obtained the complex capacitance of the measured part of the cell, and thence the sample's complex permittivity. The *guard* electrode is optional: it is shown in the diagram as parts on both sides of the *measure* electrode, representing a single 'guard-ring'.

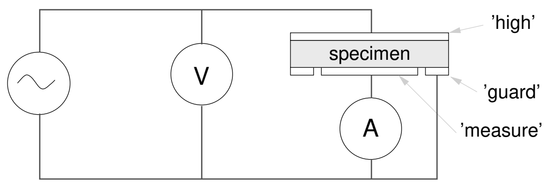

Fig. 1 – Abstract circuit-model of guarded measurement.

Figure 2 shows in principle the same circuit, but rearranged in a practical way whereby the source and measurement are contained within a single instrument. The instrument is shown in grey as a conductive box with shielded cables to the cell.

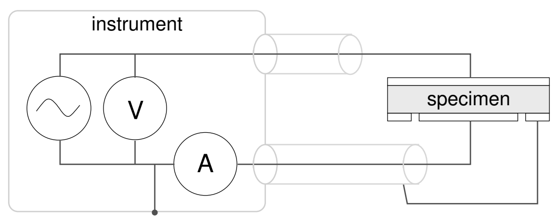

Fig. 2 – Practical arrangement of Fig. 1, as a single FDS instrument connecting to the test cell.

Our purpose is to adapt the system of Figure 2 so that the specimen is subjected to combined DC and AC voltage while FDS measurements are obtained based on the AC voltage. It is desirable to achieve this *without modification* of the FDS instrument. Several different directions could be taken.

2.1. Parallel sources

One possibility is a parallel method, in which a branch containing a DC voltage source is added in parallel with the specimen and AC source. This requires some form of blocking-impedance (filtering) to prevent the sources interfering with each other 'too much'.

Figure 3 shows an example. A capacitor is added in series with the instrument, to block direct current. A resistor, or alternatively an inductor or combination, is in series with the DC source. Without such impedances, each of the two sources would try to drive its own voltage on the specimen, resulting in substantial AC current in the DC source and vice versa, and no useful measurement.

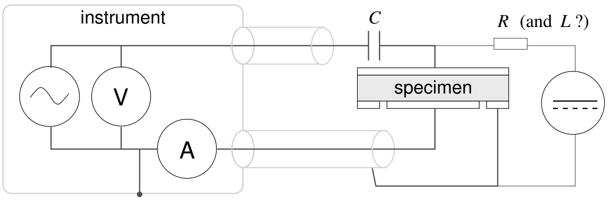

Fig. 3 – Modification of Fig. 2 to apply DC and AC voltages together, by a parallel connection.

Clearly some compensation (postprocessing) of FDS results is necessary in order to obtain the specimen's own response, as the instrument now measures a series capacitor and shunt resistor besides the specimen. The necessary modelling introduces further uncertainties in results, to an extent that may easily become unacceptable in terms of accuracy obtained and modelling effort needed, particularly if covering a wide frequency range and specimens with various capacitance and loss.

This parallel coupling of sources, through simple filtering to reduce their mutual interference, has some similarity to the combined AC and lightning-impulse circuit used in [4]. However, in that work the main requirement was to impose a particular voltage on a test object; accurate measurements within the same frequency range were not needed. Also, the separation in frequency between power-frequency AC and lightning-impulse is greater than the practically achievable separation of the DC source from very low frequency FDS.

An FDS measurement in the millihertz range is a difficult case for this circuit. The AC period is in the practical timescale for applying the DC bias. The added resistor will make a large contribution to measured dielectric loss; there is a limit to how high the resistance can be if it is to provide the required DC voltage at the specimen despite supplying any conduction current in the specimen and guarded leakage around it. The added capacitor must be large enough to provide the required AC voltage at the specimen despite conduction through the added resistor and through and around the specimen.

In contrast, for an FDS measurement in the kilohertz range this circuit has more favourable properties. Practical values of the capacitor and resistor can keep the AC source well separated from the DC source. The added resistor makes a smaller contribution to measured dielectric loss at the higher frequency.

In view of the above, the parallel method could be useful in a limited range of cases, such as above or around power frequency and without a need for very precise measurement of low losses. Its permits simultaneously: a non-floating DC source such as the 'Keithley 247' variable 3 kV source; an unmodified FDS instrument; and guarded measurement with negligible voltage between guard and measure electrodes. For the work with oil-paper insulation in [9] the measurements needed to go down to millihertz, so the parallel method was abandoned. The ability to use a non-floating source was sacrificed in order to use a series connection that permitted: an unmodified FDS instrument; guarded measurement; and no need of compensating for the influence of added components, at the studied frequencies.

2.2. Series sources

Adding a DC source in *series* in the original FDS measurement circuit is arguably the more obvious choice when the requirement is to produce an AC+DC voltage at the specimen. The series method avoids the additional components for 'blocking'. It thus avoids the need to compensate for their effect, along with the inevitable parameter uncertainties in applying this compensation.

The series DC source should be somewhere in the measurement loop around the instrument and specimen. Figure 4 shows this loop divided into regions based on the consequence of adding a series DC voltage source at different points.

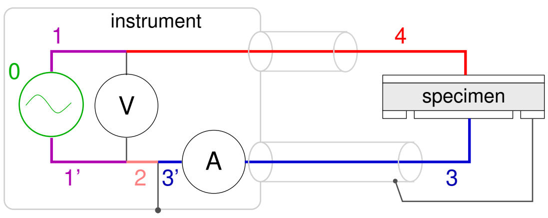

Fig. 4 – As Fig. 2, with regions marked by numbers and colours.

The following are some features of adding the DC voltage source in these different regions.

- Avoid modification of the instrument.
  This is possible for 3 and 4, in their rightmost parts. The AC source at 0 may be able to generate DC too by modification of software alone, but the total AC+DC peak is then limited by this source.

- Voltage measurement 'V' across specimen only.
  With a DC source added at $1'$, 0 or 1, the voltage measurement is directly across the specimen. AC voltage drop across the DC source impedance should then not affect the FDS results.
- Voltage measurement 'V' avoids DC.
  This is the complement of the above. A DC source at 2, 3', 3 or 4 comes between the measurement and specimen, so its impedance can affect the FDS results. However, since the measurement is exposed only to the AC source's voltage, the instrument's full AC range plus unrestricted DC bias can be used without exceeding the measurement limits.
- DC voltage between 'guard' and 'measure'.
  This is special to 3, which is therefore only suitable for measurements without guard, or with guarding of capacitive rather than conductive current.
- Sensitivity to disturbance from injected current.
  Current injected at 3 has a low-impedance path through current measurement 'A'. An example of injected current is capacitive coupling from supply to output of a mains-powered DC source. Even if a disturbance-current's frequency can be rejected from FDS results, the measurement sensitivity may need to be reduced to avoid saturation.
- Non-floating DC source possible.
  At $1'$, 2 and $3'$ a DC source could have one side connected to the chassis earth. However, the AC source and measurements are likely to be designed to have a shared node, making it impossible to insert a DC source here.

From the above we see that region 4 has the distinct advantage of permitting an external DC voltage source to bias the specimen even at much more than the instrument's own AC voltage, without limiting the instrument's available AC voltage and without interfering with the guarding. The disadvantages are the effect of DC source impedance on the measurement, and the need of a floating DC source.

3. Behaviour of the circuit with series DC

The circuit studied in the remainder of this work has a DC voltage source in series with the specimen's 'high' electrode. This corresponds to region 4 in Figure 4, and is what was used in [9]. Figure 5 shows the circuit with voltages marked on the two sources and the specimen.

With ideal sources, measurements and connections, the instrument's voltage u_{i} is pure AC, the bias u_{b} is pure DC, and $u_{\mathrm{o}} = u_{\mathrm{i}} + u_{\mathrm{b}}$. The DC voltages on the DC source and specimen are equal, in opposite directions around the circuit. The instrument measures the voltage u_{i}, which equals the AC component of voltage on the specimen. The AC component of voltage at the specimen is therefore correctly measured in this ideal case, despite the presence of the external DC source. The non-ideal

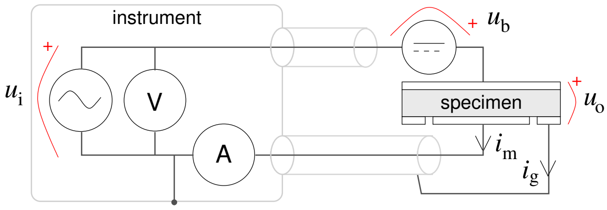

Fig. 5 – The chosen circuit with series-connected DC voltage source, showing the voltages around the loop.

case, with impedance in the DC source, is considered more in Sections 4 and 6.

The measured and guarded currents i_{m} and i_{g} could be anything from nearly pure AC to nearly pure DC. This depends on the specimen impedance and the relative magnitudes of u_{i} and u_{b}.

For good insulation specimens the loss tangent is typically $\tan\delta \lll 1$ at the frequencies of interest, so only a very small part of i_{m} can be due to conduction. Current i_{m} would in this case have a much lower DC than AC component. Exceptions could arise with a much smaller AC than DC voltage, very low AC frequency, or in the transient situation shortly after applying the DC voltage. However, for most situations with good insulation materials it is reasonable to assume that i_{m} is bidirectional in each AC period. Much the same applies to i_{g}, except that the presence of surface leakage could give it a higher DC component. Based on the above, the DC source needs to tolerate reverse current.

A specimen with strong conduction could result in a unidirectional current, due to the DC component being stronger than the AC. A constant DC component of current will not contribute to the fundamental fourier component of measured current, so will not in this way affect the FDS result. However, the current measurement needs to avoid saturation (overload), which could happen if the instrument relies mainly on capacitance as the impedance in its current measurement, or if it chooses impedances based on the expected current due to its AC source alone.

At 'short' times after applying the DC voltage, the polarization current to a dielectric specimen could be significant. A current that falls during each AC period will make some contribution to all fourier components. This effect increases with $u_{\mathrm{b}}/u_{\mathrm{i}}$ and for measured frequencies that correspond well to the rate of change of polarization current.

When connecting the circuit, the specimen may be uncharged or even charged oppositely to the intended bias. Thus, with $u_{\mathrm{o}} \neq u_{\mathrm{b}}$, transient voltages will appear at the instrument's output or measurement input. The output and input should be bypassed while changing connections, unless the instrument can tolerate the worst case of the DC source and a charged specimen being connected to it in directions such that their voltages sum.

4. The DC source

A DC source as shown in Figure 5 should ideally make the specimen's voltage be just the FDS instrument's AC voltage plus a constant. However, impedance in the DC source will cause an AC voltage drop due to the AC current passing through this source. This impedance will therefore be included in the FDS results. Drift of the DC source voltage will cause currents in the specimen that may affect the FDS result if they change on the timescale of the frequency being measured. Faster variation of the DC source such as from a switch-mode converter may overload the current measurement even if seemingly fast enough to avoid affecting a low-frequency measurement. Current injected by undesired coupling from an external power supply can also affect the potential of the 'high' electrode, as the FDS instrument's AC source is not an ideal voltage source.

In view of the above, sources with electronic converters and external powering need particular care, as they have the potential for switching noise, capacitive coupling from their supply source, and limited isolation between this source and their DC output. Electrochemical cells have the good feature of avoiding all external connections and switching noise. An example of this type of source used for a dielectric measurement is a 1 kV battery made from 9 V PP3-size batteries that was used for polarization current measurements in [10].

Dielectric measurements on lab samples at low frequency may involve currents lower than picoamperes. Common batteries can provide milliamperes with little change from their rated voltage, and typically several amperes of short-circuit current. This would seem to indicate that such batteries are a suitably stiff source for our purpose. However:

- FDS with higher capacitances and frequencies can reach milliamperes and more.
- Sets of batteries totalling hundreds of cells in series may be used for higher voltage, leading to more impedance.
- The current in DC-biased FDS is likely to be bidirectional, yet the batteries may be of primary ('non-rechargeable') type.
- A battery is not a simple DC Thevenin source, so dividing open-circuit voltage by short-circuit current might not give a good indication of the impedance it adds across the range of FDS frequencies.

Considering the above it is prudent to study batteries further here, before testing the whole setup in Section 6.

Electrochemical impedance spectroscopy (EIS) is widely used for studying batteries and other electrode/electrolyte systems [11]. As an impedance measurement using AC perturbation it is highly relevant to our situation where the AC voltage across a battery is of interest. A battery can give a complicated response [12] of impedance at varied frequency, depending on both electrode interfaces and the electrolyte between.

In the current work, two types of PP3-size 9 V battery were used:

- *Alkaline:* Panasonic Industrial Alkaline Powerline,
- *Lithium:* RND Power Lithium Ultra Power.

The PP3 design has the good features of a modest size, quite high voltage, and easy series connection by clipping together. For each type, eleven were used in series to give around 100 V. These two 100 V batteries were used in the EIS study below, and in the FDS tests in Section 6.

Simple EIS measurements were performed on our two types of 100 V battery to give an indication of their impedance across the frequency range of the later FDS studies.

At frequencies from 30 kHz down to tens of hertz the circuit of Figure 6 was used. The capacitor $C_\mathrm{s} = 3.52\,\mu\mathrm{F}$ blocks the battery's DC from the signal generator. The resistor $R = 10\,\Omega$ converts the current to a voltage high enough to measure easily, but without restricting the circuit's current significantly. Capacitor $C_\mathrm{m} = 66\,\mu\mathrm{F}$ blocks the battery's DC voltage from the oscilloscope input; it is large enough that when combined with the oscilloscope's $1\,\mathrm{M}\Omega$ input resistance it has negligible effect on the measured AC amplitude or phase even down to 10 Hz, which would not be true for the oscilloscope's own AC coupling. The source voltage was regulated to keep the current around 10 mA to 20 mA. The oscilloscope measured the two voltages, displaying their AC rms values v_1 and v_2, and the phase difference ϕ between them. The battery's impedance was then calculated as $Z = (v_1\angle\phi - v_2)\,/\,(v_2/R)$.

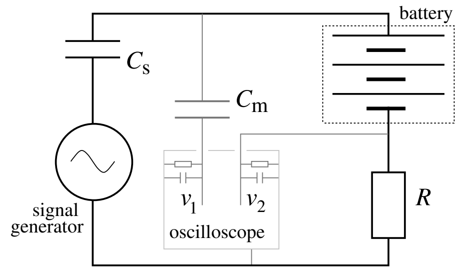

Fig. 6 – Circuit diagram for simple EIS on a battery.

For lower frequencies of 464 Hz down to 10 mHz the battery was connected to an IDAX300 FDS instrument, in series with a $66\,\mu\mathrm{F}$ capacitor to block DC. The battery's impedance was calculated as the difference between the impedance measured for the battery and capacitor together and the impedance measured for the capacitor alone. At each frequency the voltage was chosen to give 1 mA if connected to the capacitor alone; the actual current was therefore lower when a battery's impedance was added, particularly at the higher frequencies.

Figure 7 shows the results from the two measurement ranges, joined at 400 Hz.

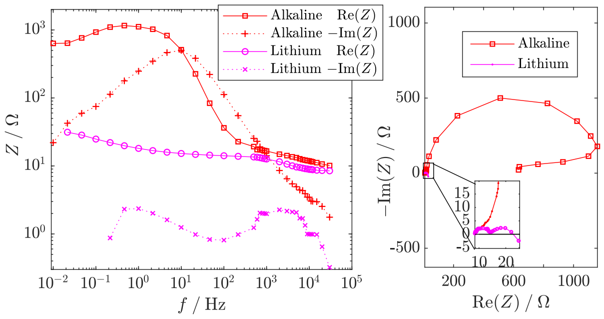

Fig. 7 – EIS results from the 100 V batteries, against frequency (left), and as a Nyquist plot (right).

The increased impedance of the alkaline battery at lower frequencies may appear worrying for FDS measurement in this range. However, it changes more slowly with frequency than the impedance of a capacitive specimen does. Its effect on FDS of good insulators remains therefore stronger at higher frequencies. See also Figure 12 which shows the effect of the battery impedance on FDS for a large capacitance.

Short-circuit tests showed a current around 6 A for the alkaline battery and 7 A for the lithium battery, in the first 1 s. This small difference gives little hint of the much larger differences seen in EIS. It is clear that the influence of a battery on FDS cannot adequately be modelled by a simple Thevenin-style method.

The above EIS results should not be seen as the general case for comparison of any alkaline or lithium PP3 battery. In [13] a study of several brands of 1.5 V AA-size alkaline cells showed widely differing EIS results between different brands at the same state of charge, despite less varied performance in typical applications.

In order to view the results from [13] in the context of what EIS results our 100 V alkaline battery could have had if we had used different brands, we should consider a suitable scaling factor for the impedance. A 9 V PP3 alkaline battery is a series connection of 6 cells, each of much less than AA size. To get an estimate of the relative impedance of AA and PP3 of similar types we compare the 'Duracell plus' alkaline range, for which detailed specifications are easily found for both sizes. For the same duration and percentage-voltage of discharge, the amp-hour capacity is about 3.5 times as much for the AA as for the PP3. If the cell impedance scaled inversely with capacity, this would suggest around $6 \times 3.5 = 21$ times as much impedance for the PP3. Impedance at 1 kHz is another common specification for batteries. This is given as 0.065 Ω for the AA, and 1.70 Ω for the PP3, a factor of 26, in fair agreement with 21. Our 100 V alkaline battery (11 PP3) can therefore be expected to have very approximately 250 times the impedance of an AA cell of similar chemistry and construction.

Differences in EIS between different battery chemistries could plausibly be even greater than the difference between different brands of alkaline batteries. Classic zinc-carbon batteries are still available. Lithium batteries are increasingly available in familiar sizes such as PP3, for long-life applications. A lithium battery may have fewer series cells than an alkaline battery of the same voltage; this also helps to reduce its impedance. In order to be confident of a battery's impedance, measurements should be made on that specific battery across the full frequency range of interest.

5. FDS instrument

The FDS instrument used for the results in Section 6 was the IDAX300 from Megger. This model and its forebears have been used in several Nordic insulation research groups, so some instrument-specific points are included for this audience. Further detail is given in [14].

The graphical control program in its default state has no option to include DC in the voltage. With the program version 4.x 'System Control' window focused, Ctrl-Shift-F12 toggles the Tools menu between its default and advanced modes. The advanced options include 'Manual Control'. This is not intended for general use, and should be treated with caution, but it can be used to generate AC+DC voltage and measure the impedance based on the AC fundamental fourier component. The total voltage must lie within the source's peak capability. The Manual Control can even be used to log the current response to steady DC as was done for polarization current measurements in [15]. However, it does not sweep the AC to perform automated FDS with DC bias. It is therefore not a practical way to do long sweeps.

Experience of using this instrument for normal FDS sweeps with up to 300 V series DC battery has been good. The instrument is designed for field testing so it has substantial protection against transient voltages even in its idle state. No problem arose from transients when connecting the 300 V battery that was used in [9].

If guarding is not needed, the 'GST-ground' mode can be used to measure all current returning by the chassis or input. Then a non-floating DC source could potentially be used in series with the low side of the measurement.

An external HV amplifier is available to extend the 200 V range to 20 kV or 30 kV. Addition of similar levels of DC voltage from a battery on the high voltage side is rather impractical. Some amplifier models have a directly accessible BNC lead for the amplifier's ±10 V input signal, in which case a bias can be added using a DC source in series with this signal as long as the DC+AC voltage stays within the ±10 V range. Voltage measurement is done on the high-voltage side, so it measures directly across the specimen if the bias is applied on the input signal. Early versions inferred specimen voltage from the current in a reference capacitor, in which case the DC bias will not be measured. Some later versions use a resistive divider, which would make the instrument aware of the presence of DC, possibly causing a voltage-outside-limits error.

6. Experimental test of DC-biased FDS

Here we show results from FDS on a range of practically linear test objects. The purpose of the DC in real applications of DC-biased FDS is typically to stimulate a nonlinearity of the test object (specimen). The purpose here is instead to check how much the presence of a battery causes the FDS results to deviate from what we treat as the correct results measured without the battery. A linear object should have an AC current that depends on the AC voltage across it, independently of any DC bias voltage. Any difference in the FDS result when adding a battery would therefore have other causes, such as battery impedance or the effect of extra DC current on the instrument's measurement.

The simple FDS test objects were:

- a 100 pF air capacitor, with guarded frame
- a 2.2 nF polypropylene capacitor
- the 2.2 nF capacitor with a parallel 820 kΩ resistor
- a 220 nF polypropylene capacitor.

These objects cover the capacitance range from lab specimens up to large equipment, and from low loss to very high loss. Figure 8 shows the setup for the 2.2 nF capacitor with a lithium battery in series.

The same two batteries as described in Section 4 were used as the series sources to give the DC bias. They were new when used for these FDS measurements.

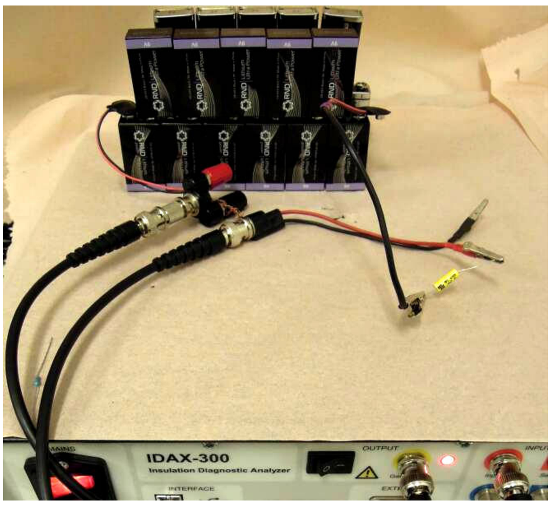

Fig. 8 – Test of DC-biased FDS on a 2.2 nF capacitor (right). The FDS instrument is below. Eleven 9 V batteries are in series with the instrument's output.

The following figures show the real and imaginary parts of complex capacitance, C' and C'', from FDS on the four test objects. The AC source's peak voltage was 10 V for the 220 nF capacitor, and 100 V for all other objects. Each figure shows five distinct cases: 'no DC' is without a battery; then each 100 V battery is used in positive and negative polarity, where positive means that u_b in Figure 5 is positive. Some repetitions were also done, showing consistent results.

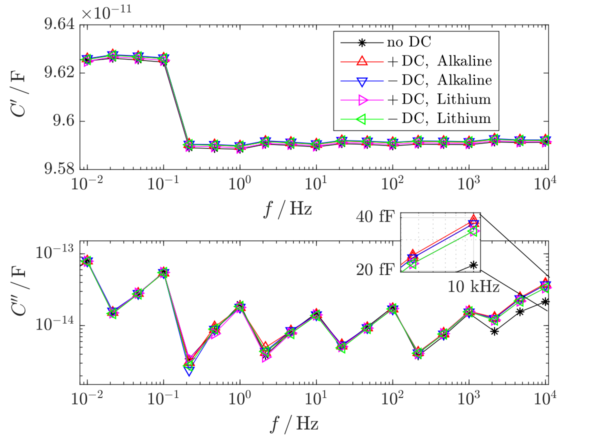

Fig. 9 – FDS results for 100 pF air capacitor, compared without and with a series battery. FDS AC voltage is 100 V peak. Battery DC voltage is 100 V. Sudden shifts in all results owe to calibration of instrument feedback components.

Figure 9 shows results for the 100 pF capacitor, which is a quite similar capacitance to the oil and paper samples studied in [9]. There is a fairly clear effect on the loss at the highest frequencies, shown as an inset. The battery that had lower resistance in Figure 7 gives less loss. The polarity shows no effect. At lower frequencies there is indiscernible effect of the battery, and most variation is due to the instrument.

Figure 10 shows results for the 2.2 nF capacitor, which is some ten times the capacitance of usual lab specimens. Now the current is more, so the AC voltage dropping across the battery is more, and the difference between the batteries and 'no DC' becomes clear for frequencies down to around 10 Hz.

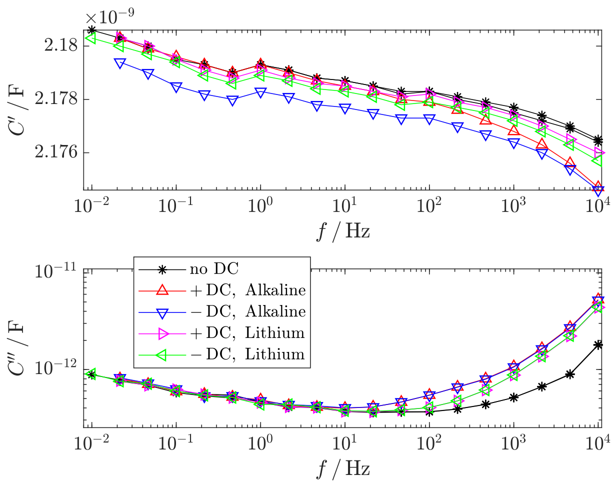

Fig. 10 – FDS results for a 2.2 nF capacitor. FDS AC voltage is 100 V peak. Battery DC voltage is 100 V.

Figure 11 keeps the same capacitor and adds a parallel resistor, to give a case with high conduction. At frequencies below about 100 Hz the conductive AC current exceeds the capacitive current.

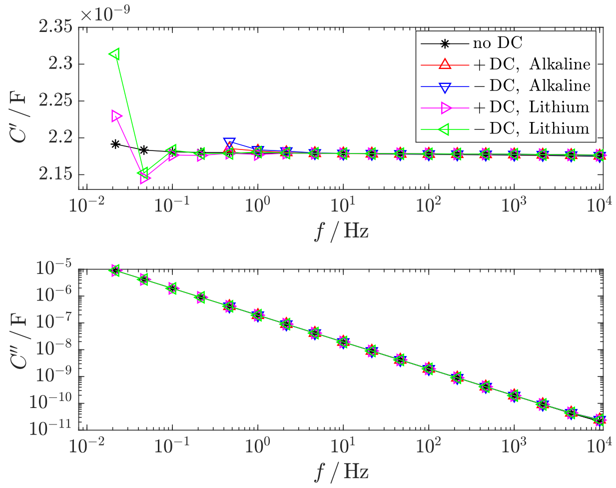

Fig. 11 – FDS results for the 2.2 nF capacitor of Fig. 10 in parallel with a 820 kΩ resistor. FDS AC voltage is 100 V peak. Battery DC voltage is 100 V.

At low frequencies the measured current will be practically unidirectional. The instrument handled it without needing forced feedback settings. The only clear deviations between batteries and ‘no DC’ is in C' at such low frequency that the capacitive current is $\sim 10^{-4}$ of the total and is therefore sensitive to small changes.

Figure 12 shows results from a 220 nF capacitor. This required a lower voltage to keep the current within the instrument’s current-limit. It is therefore an example with much higher DC than AC voltage. However, the current is largely symmetric (AC) as the test object has low conduction.

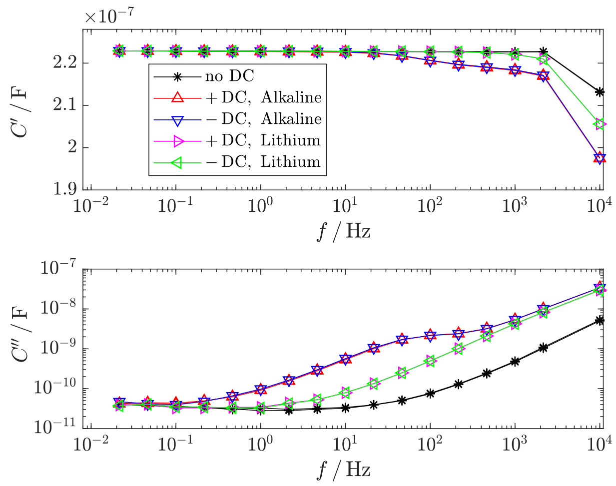

Fig. 12 – FDS results for a 220 nF capacitor. FDS AC voltage is only 10 V peak. Frequencies above about 3 kHz overload the instrument’s source. Battery DC voltage is 100 V.

This large capacitance has low impedance compared to the earlier objects. The battery’s series impedance is therefore more significant in this case, which is seen even in C' and all the way down to 0.1 Hz in C''. As expected from EIS results, the alkaline battery has a larger effect.

A further concern is whether the battery’s voltage/current behaviour is different for currents in the forward (discharge) and reverse directions. Such an effect would not be seen in the fundamental-frequency impedance measured for linear specimens. However, it could distort the results for specimens that themselves have a polarity dependence.

A polarity dependence would be visible in the current-harmonics, since a waveform that is not symmetric between positive and negative half-periods will contain some even-order harmonics. The FDS instrument used in this work records harmonics from the fundamental frequency to the 8th harmonic. These can be used to check for asymmetry in the current in the presence of a battery. The measurements with the 220 nF capacitor are a good candidate for checking, as the currents were bidirectional and relatively high, with the battery impedance clearly affecting the results. All the recorded current harmonics from 2nd to 8th had magnitude of the order of 10^{-4} of the fundamental, and with negligible difference between the cases with and without a battery present. This reassures that the batteries did not give a significant polarity-dependent restriction to the current.

7. Conclusion

For FDS measurements on typical capacitances of lab specimens (hundreds of picofarads) at frequencies of hundreds of hertz and below, the presence of a 100 V series DC source made of common 9 V batteries had negligible effect on the results for linear specimens. This connection provides an easy way to obtain potentially hundreds of volts of DC bias, even when using an unmodified FDS instrument designed to work at much lower AC voltage. Careful thought and checking is of course needed, to avoid damage to the instrument by connection transients, breakdown in the specimen, etc.

For higher frequencies the battery impedance had clear effect on the measured dielectric loss of low-loss objects, when going up to just some nanofarads of capacitance. With much larger capacitance nearer the microfarad range there was major effect even down to sub-hertz frequencies. These problems would be largely avoided by measuring the voltage directly at the specimen, which requires some modification of the instrument. Subtraction of a modelled AC voltage drop across the battery is an alternative. This requires frequency-dependent characterization of the battery’s complex impedance. It should be noted that different brands of battery can behave very differently from each other.

8. Acknowledgements

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9. Open Data

Data, notes, programs and plots from this work will be made available with this paper in the NTNU repository for the NORD-IS conference, for unrestricted use.

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