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# GS103 / GS203 SUPERCAPACITOR

Datasheet Rev 4.3, July 2018

This Datasheet should be read in conjunction with the CAP-XX Supercapacitors Product Guide which contains information common to our product lines.

## Electrical Specifications

The GS103 is a single cell supercapacitor. The GS203 is a dual cell supercapacitor with two GS103 cells in series, so GS203 capacitance = Capacitance of GS103/2 and GS203 ESR = 2 x GS103 ESR.

**Table 1: Absolute Maximum Ratings**

| Parameter | Name | | Conditions | Min | Typical | Max | Units |
|---|---|---|---|---|---|---|---|
| **Terminal Voltage** | Vpeak | GS103 | | 0 | | 2.75 | V |
| | | GS203 | | | | 5.5 | |
| **Temperature** | Tmax | | | -40 | | +70 | °C |

**Table 2: Electrical Characteristics**

| Parameter | Name | | Conditions | Min | Typical | Max | Units |
|---|---|---|---|---|---|---|---|
| **Terminal Voltage** | Vn | GS103 | | 0 | | 2.5 | V |
| | | GS203 | | 0 | | 5.0 | |
| **Capacitance** | C | GS103 | DC, 23°C | 432 | 540 | 648 | mF |
| | | GS203 | | 216 | 270 | 324 | |
| **ESR** | ESR | GS103 | DC, 23°C | | 20 | 24 | mΩ |
| | | GS203 | | | 35 | 42 | |
| **Leakage Current** | $I_L$ | | 2.3V, 23°C 120hrs | | 1 | 2 | µA |
| **RMS Current** | $I_{RMS}$ | | 23°C | | | 8 | A |
| **Peak Current**[1] | $I_P$ | | 23°C | | | 30 | A |

[1] Non-repetitive current, single pulse to discharge fully charged supercapacitor.

**Table 3: Thickness**

| | | | | | |
|---|---|---|---|---|---|
| **GS103F** | **1.0mm** | No adhesive tape on underside of the supercapacitor | **GS103G** | **1.1mm** | Adhesive tape on underside, release tape removed |
| **GS203F** | **2.1mm** | | **GS203G** | **2.2mm** | |

# Definition of Terms

In its simplest form, the Equivalent Series Resistance (ESR) of a capacitor is the real part of the complex impedance. In the time domain, it can be found by applying a step discharge current to a charged cell as in Fig. 1. In this figure, the supercapacitor is pre-charged and then discharged with a current pulse, I =1A for duration 0.01 sec.

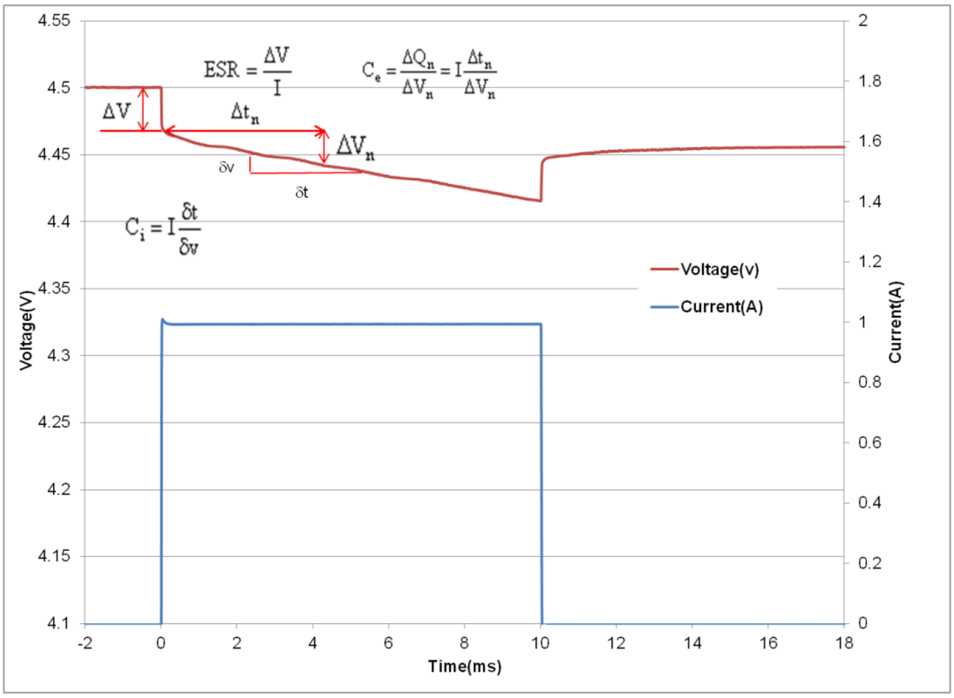

**Figure 1: Effective capacitance, instantaneous capacitance and ESR for a GS203**

The ESR is found by dividing the instantaneous voltage step (ΔV) by I. In this example = (4.5V - 4.47V)/1A = 30mΩ.

The instantaneous capacitance ($C_i$) can be found by taking the inverse of the derivative of the voltage, and multiplying it by I.

The effective capacitance for a pulse of duration $\Delta t_n$, $Ce(\Delta t_n)$ is found by dividing the total charge removed from the capacitor ($\Delta Q_n$) by the voltage lost by the capacitor ($\Delta V_n$). For constant current $Ce(\Delta t_n) = I \times \Delta t_n/\Delta V_n$. Ce increases as the pulse width increases and tends to the DC capacitance value as the pulse width becomes very long (~10 secs). After 2msecs, Fig 1 shows the voltage drop $V_{2ms}$ = (4.47 V – 4.45V) = 20mV. Therefore Ce(2ms) = 1A x 2ms/20mV = 100mF. After 10ms, the voltage drop = 4.47 V – 4.42V = 50mV. Therefore Ce(10ms) = 1 A x 10ms/50mV = 200mF. The DC capacitance of a GS203 = 0.27 F. Note that ΔV, or IR drop, is not included because very little charge is removed from the capacitor during this time. Ce shows the time response of the capacitor and it is useful for predicting circuit behavior in pulsed applications.

## Measurement of DC Capacitance

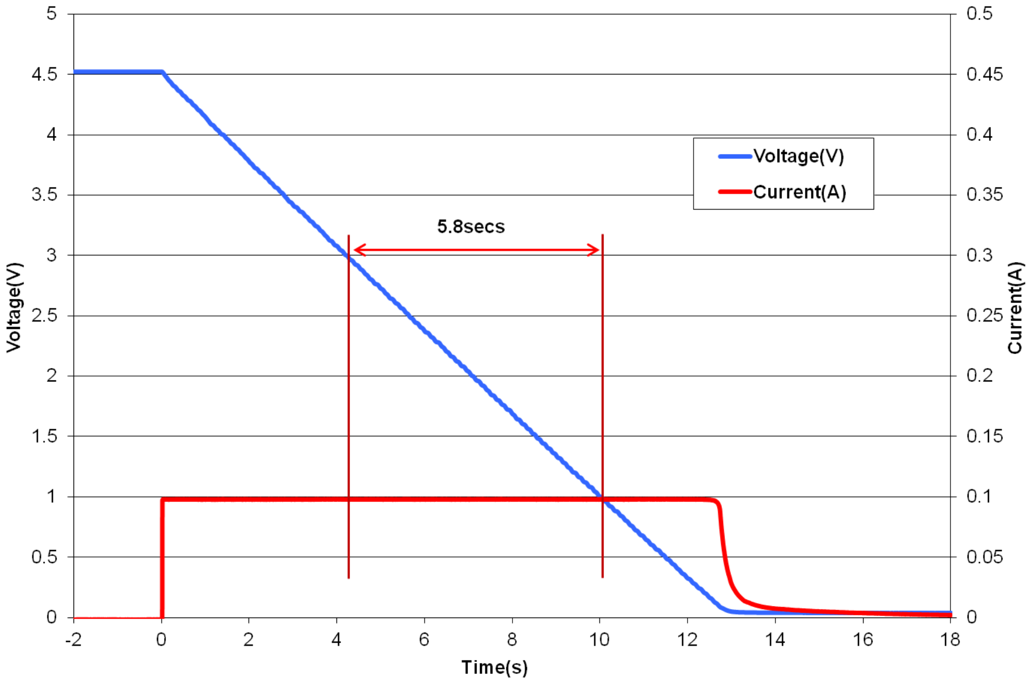

**Fig 2: Measurement of DC Capacitance for a GS203**

Fig 2 shows the measurement of DC capacitance by drawing a constant 100mA current from a fully charged supercapacitor and measuring the time taken to discharge from 1.5V to 0.5V for a single cell, or from 3V to 1V for a dual cell supercapacitor. In this case, C = 0.1A x 5.8s /2V = 290mF, which is well within the 270mF +/- 20% tolerance for a GS203 cell.

## Measurement of ESR

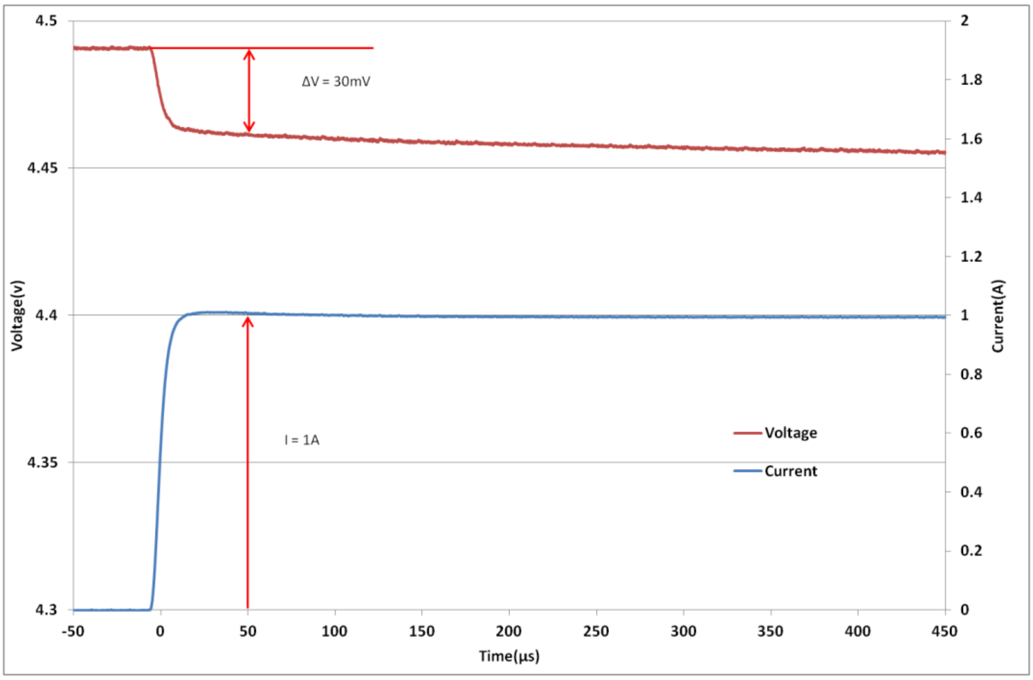

**Fig 3: Measurement of ESR for a GS203**

Fig 3 shows DC measurement of ESR by applying a step load current to the supercapacitor and measuring the resulting voltage drop. CAP-XX waits for a delay of 50µs after the step current is applied to ensure the voltage and current have settled. In this case the ESR is measured as 30mV/1A = 30mΩ.

## Effective Capacitance

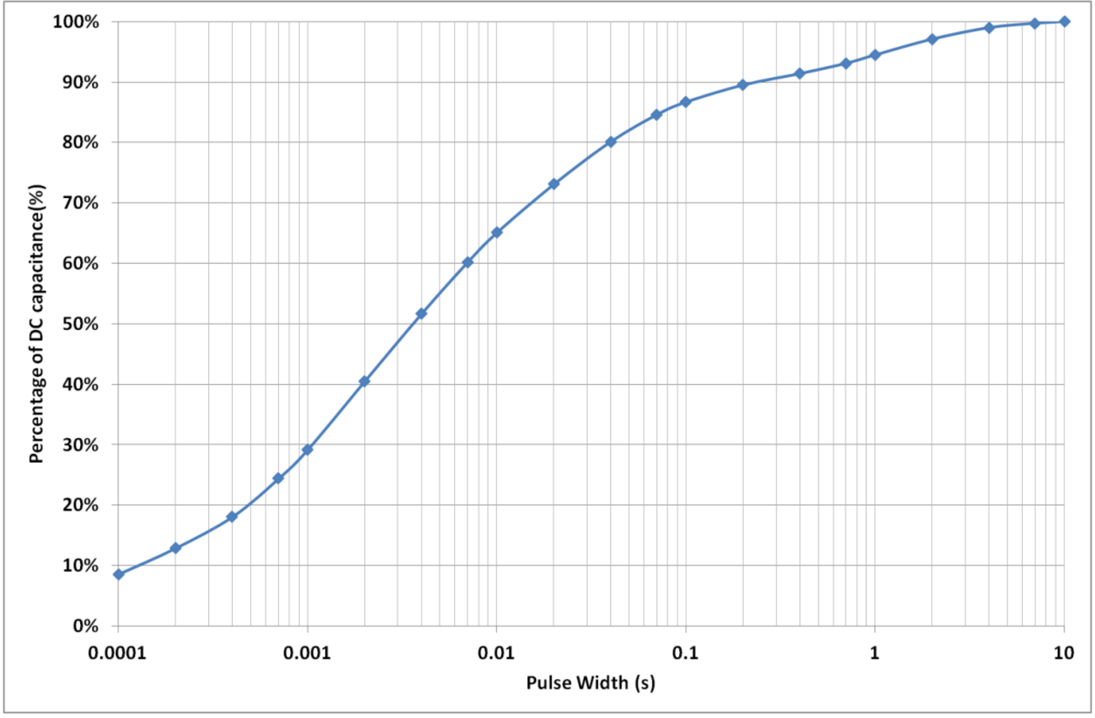

**Figure 4: Effective Capacitance**

Fig 4 shows the effective capacitance for the GS103, GS203 @ 23°C. This shows that for a 1msec PW, you will measure 29% of DC capacitance or 156.6mF for a GS103 or 78.3mF for a GS203. At 10msecs you will measure 65% of the DC capacitance, and at 100msecs you will measure 87% of DC capacitance. Ceffective is a time domain representation of the supercapacitor's frequency response. If, for example, you were calculating the voltage drop if the supercapacitor was supporting 1A for 10msecs, then you would use the Ceff(10msecs) = 29% of DC capacitance = 78.3mF for a GS203, so Vdrop = 1A x ESR + 1A x duration/C = 1A x 140mΩ + 1A x 10ms / 78.3mF = 87mV. The next section on pulse response shows how the effective capacitance is sufficient for even short pulse widths.

## Pulse Response

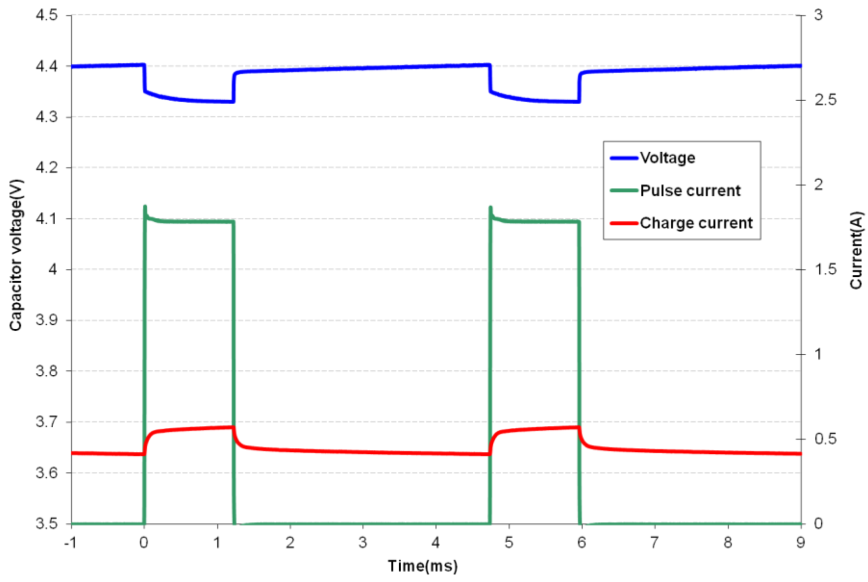

Fig 5 shows that the GS203 supercapacitor does an excellent job supporting a GPRS class 10 pulse train, drawing 1.8A for 1.1ms at 25% duty cycle. The source is current limited to 0.6A and the supercapacitor provides the 1.2A difference to achieve the peak current. At first glance the freq response of Fig 8 indicates the supercapacitor would not support a 1ms pulse, but the Ceff of 78.3mF coupled with the low ESR supports this pulse train with only ~70mV droop in the supply rail.

**Fig 5: GS203 Pulse Response with GPRS Class 10 Pulse Train**

## DC Capacitance variation with temperature

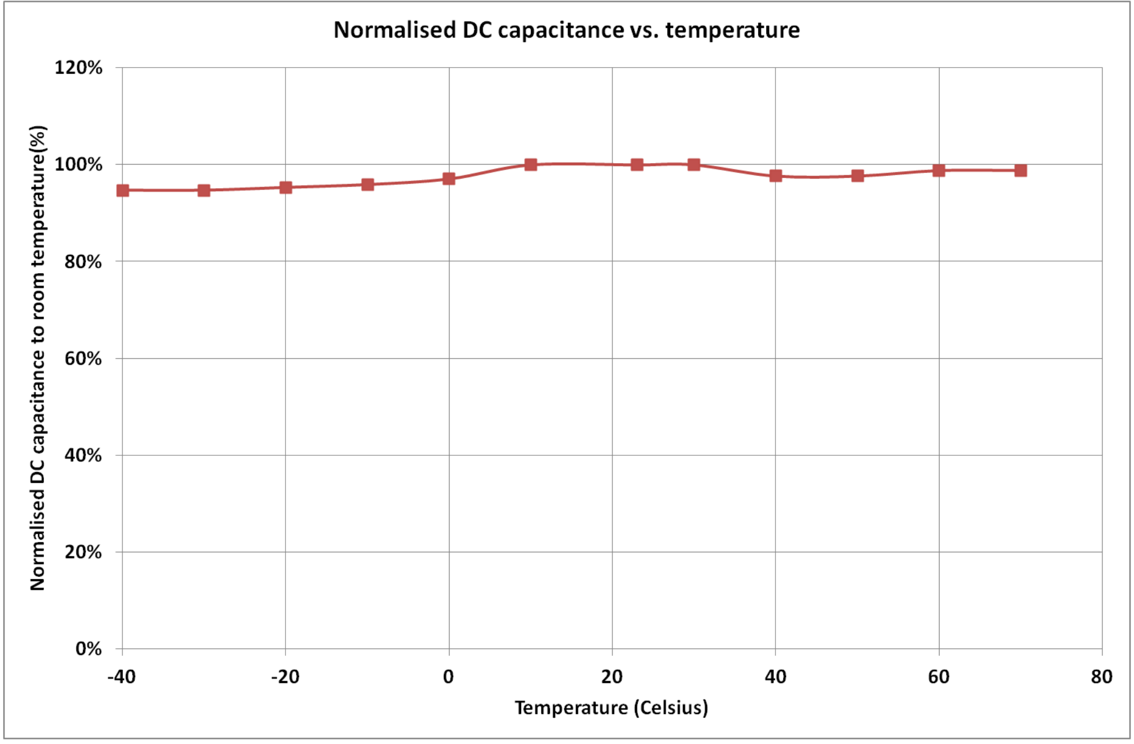

**Figure 6: Capacitance change with temperature**

Fig 6 shows that DC capacitance is approximately constant with temperature.

## ESR variation with temperature

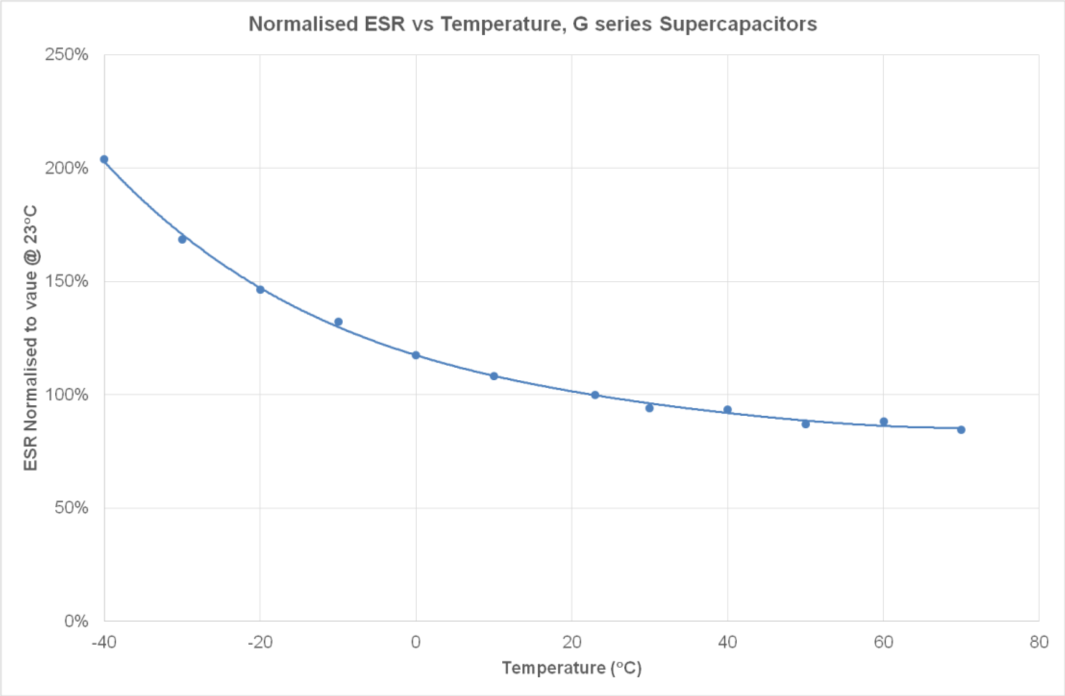

**Figure 7: ESR change with temperature**

Fig 7 shows that ESR at -40°C is ~2 x ESR at room temp, and that ESR at 70ºC is ~0.8 x ESR at room temperature.

## Frequency Response

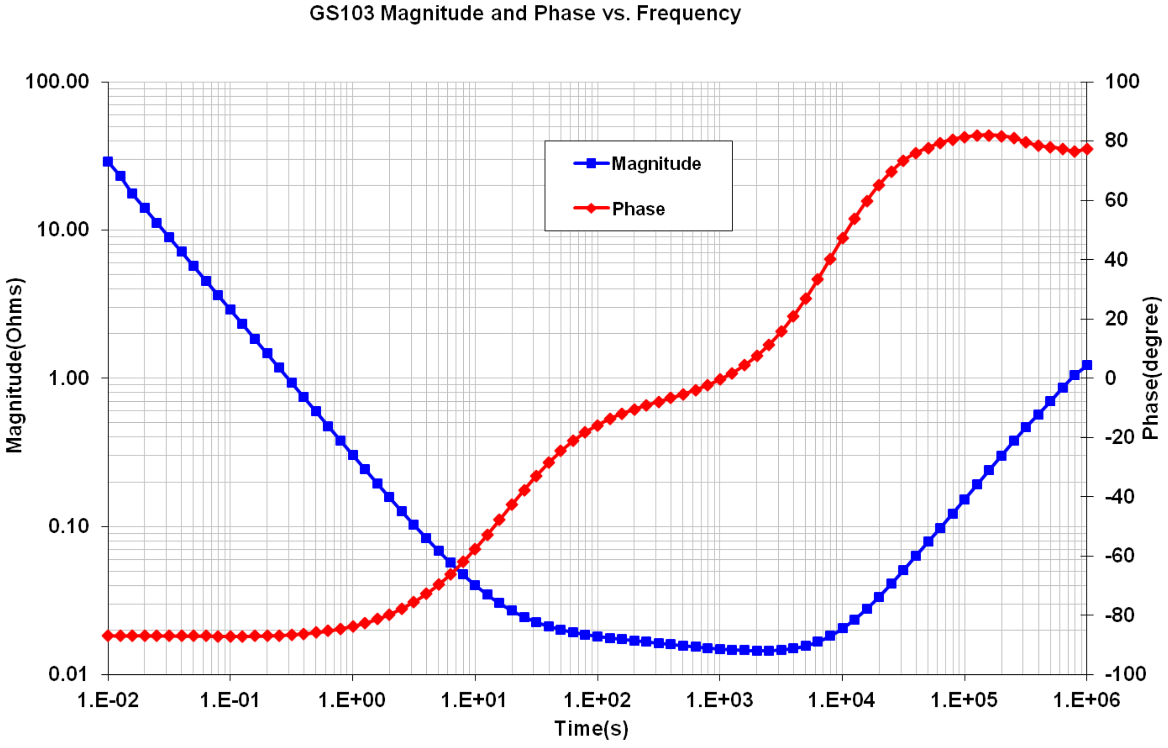

Fig 8: Frequency Response of Impedance (biased at 2.3V with a 50mV test signal)

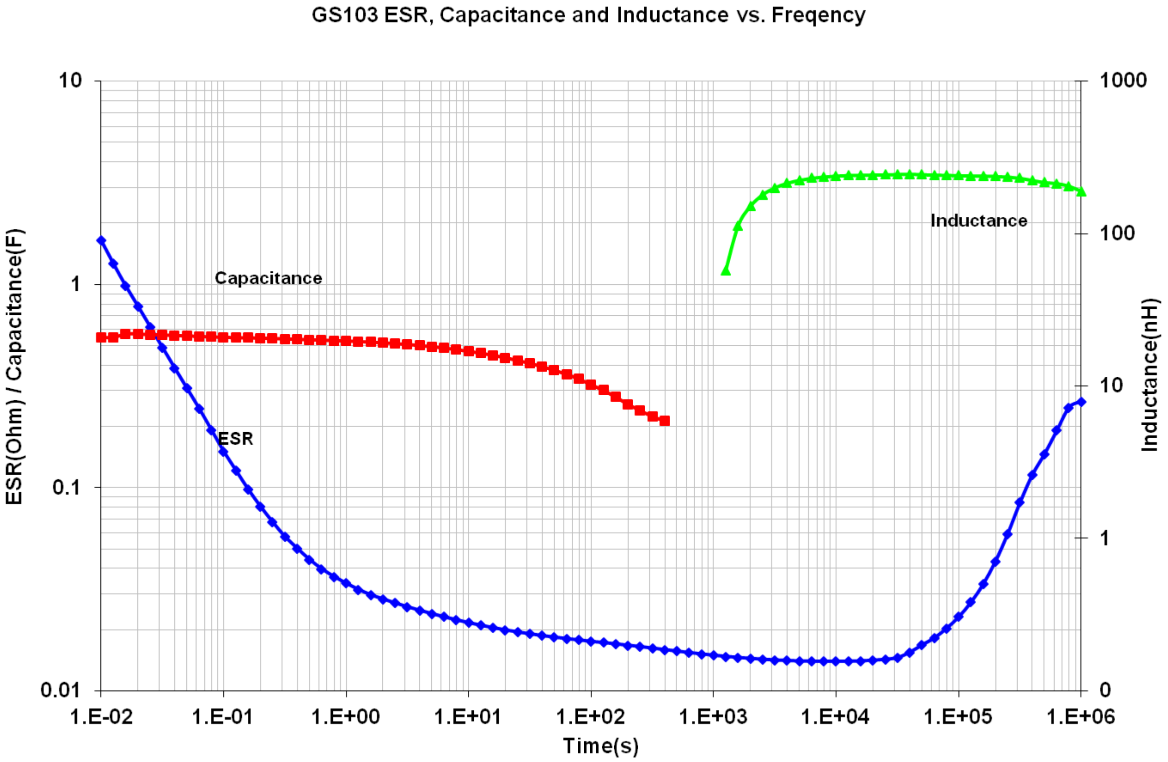

Fig 9: Frequency Response of ESR, Capacitance & Inductance

Fig 8 shows the supercapacitor behaves as an ideal capacitor until approx 10 Hz when the magnitude no longer rolls off proportionally to 1/freq and the phase crosses -45°. Performance of supercapacitors with frequency is complex and the best predictor of performance is Fig 4 showing effective capacitance as a function of pulsewidth.

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## Leakage Current

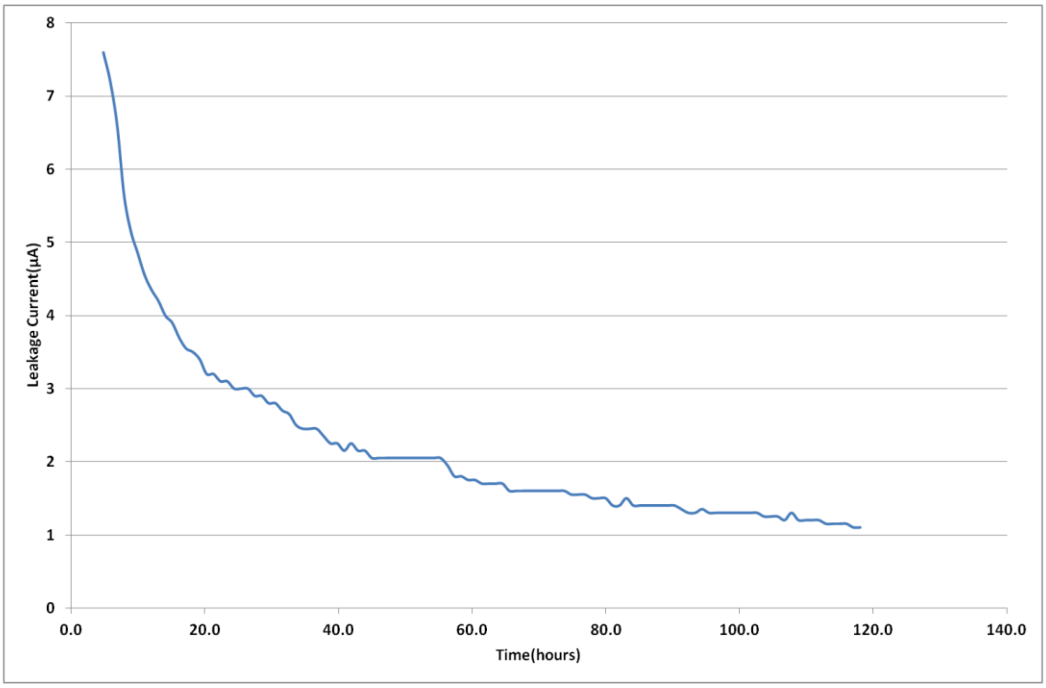

**Fig 10: Leakage Current**

Fig 10 shows the leakage current for GS103 at room temperature. The leakage current decays over time, and the equilibrium value leakage current will be reached after ~120hrs at room temperature. The typical equilibrium leakage current is 1µA at room temperature. At 70°C leakage current will be ~10µA.

## Charge Current

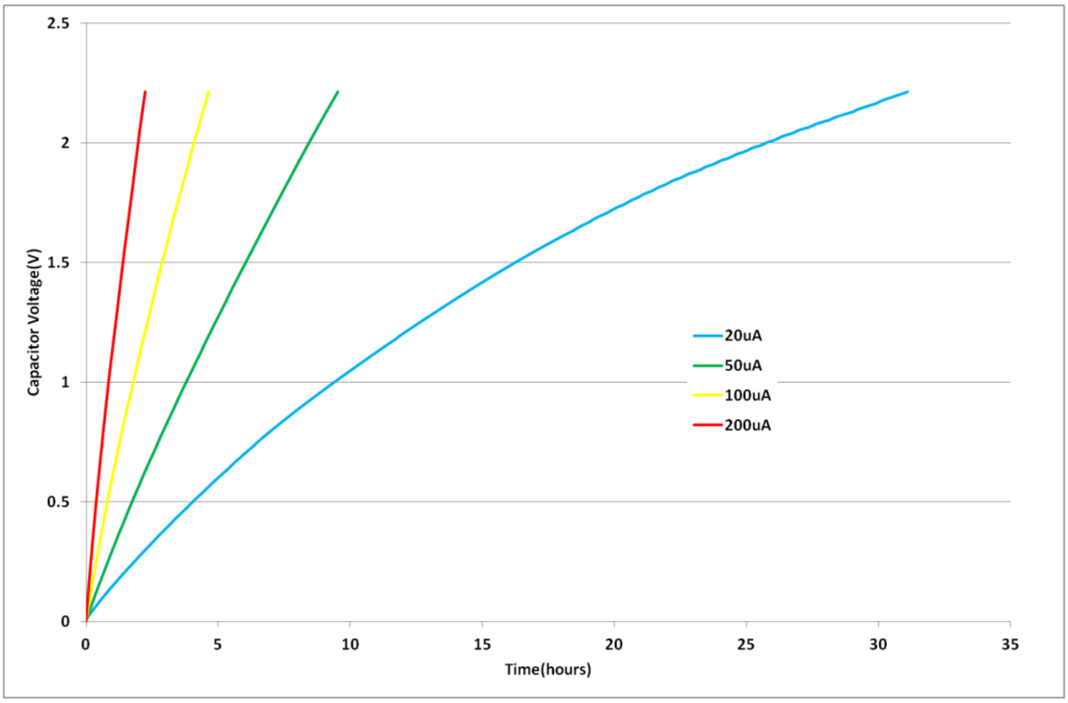

**Fig 11: Charging a GS103 with low current**

The corollary to the slow decay in leakage currents shown in Fig 10 is that charging a supercapacitor at very low currents takes longer than theory predicts. At higher charge currents, the charge rate is as theory predicts. For example, it should take 0.54F x 2.2V / 0.00002A = 18hrs to charge a 0.54 F supercapacitor to 2.2V at 20µA, but Fig 11 shows it took 32hrs. At 100µA charging occurs at a rate close to the theoretical rate.

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# RMS Current

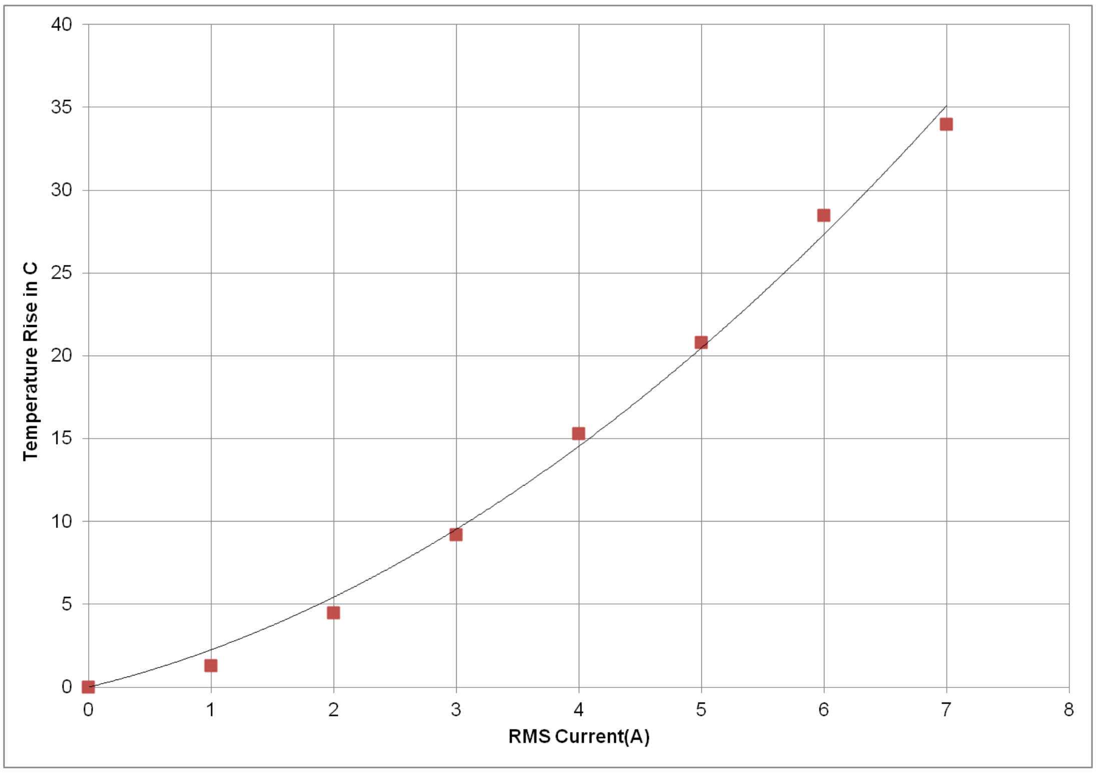

**Fig 12: Temperature rise in GS203 with RMS current**

Continuous current flow into/out of the supercap will cause self heating, which limits the maximum continuous current the supercapacitor can handle. This is measured by a current square wave with 50% duty cycle, charging the supercapacitor to rated voltage at a constant current, then discharging the supercapacitor to half rated voltage at the same constant current value. For a square wave with 50% duty cycle, the RMS current is the same as the current amplitude. Fig 12 shows the increase in temperature as a function of RMS current. From this, the maximum RMS current in an application can be calculated, for example, if the ambient temperature is 40°C, and the maximum desired temperature for the supercapacitor is 70°C, then the maximum RMS current should be limited to 6A, which causes a 30°C temperature increase.

# CAP-XX Supercapacitors Product Guide

Refer to the package drawings in the CAP-XX Supercapacitors Product Guide for detailed information of the product’s dimensions, PCB landing placements, active areas and electrical connections.

Refer to the CAP-XX Supercapacitors Product Guide for information on endurance and shelf life, transportation and storage, assembly and soldering, safety and RoHS/EREACH certification.

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# GS106 / GS206 SUPERCAPACITOR

## Datasheet Rev 4.3, July 2018

This Datasheet should be read in conjunction with the CAP-XX Supercapacitors Product Guide which contains information common to our product lines.

## Electrical Specifications

The GS106 is a single cell supercapacitor. The GS206 is a dual cell supercapacitor with two GS106 cells in series, so GS206 capacitance = Capacitance of GS106/2 and GS206 ESR = 2 x GS106 ESR.

**Table 1: Absolute Maximum Ratings**

| Parameter | Name | | Conditions | Min | Typical | Max | Units |
|---|---|---|---|---|---|---|---|
| **Terminal Voltage** | Vpeak | GS106 | | 0 | | 2.75 | V |
| | | GS206 | | | | 5.5 | |
| **Temperature** | Tmax | | | -40 | | +70 | °C |

**Table 2: Electrical Characteristics**

| Parameter | Name | | Conditions | Min | Typical | Max | Units |
|---|---|---|---|---|---|---|---|
| **Terminal Voltage** | Vn | GS106 | | 0 | | 2.5 | V |
| | | GS206 | | 0 | | 5.0 | |
| **Capacitance** | C | GS106 | DC, 23°C | 1088 | 1360 | 1632 | mF |
| | | GS206 | | 544 | 680 | 816 | |
| **ESR** | ESR | GS106 | DC, 23°C | | 20 | 24 | mΩ |
| | | GS206 | | | 35 | 42 | |
| **Leakage Current** | $I_L$ | | 2.3V, 23°C 120hrs | | 1.5 | 3 | µA |
| **RMS Current** | $I_{RMS}$ | | 23°C | | | 7.5 | A |
| **Peak Current**[1] | $I_P$ | | 23°C | | | 30 | A |

[1] Non-repetitive current, single pulse to discharge fully charged supercapacitor.

**Table 3: Thickness**

| | | | | | |
|---|---|---|---|---|---|
| **GS106F** | **1.3mm** | No adhesive tape on underside of the supercapacitor | **GS106G** | **1.4mm** | Adhesive tape on underside, release tape removed |
| **GS206F** | **2.7mm** | | **GS206G** | **2.8mm** | |

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## Definition of Terms

In its simplest form, the Equivalent Series Resistance (ESR) of a capacitor is the real part of the complex impedance. In the time domain, it can be found by applying a step discharge current to a charged cell as in Fig. 1. In this figure, the supercapacitor is pre-charged and then discharged with a current pulse, I =1A for duration 0.01 sec.

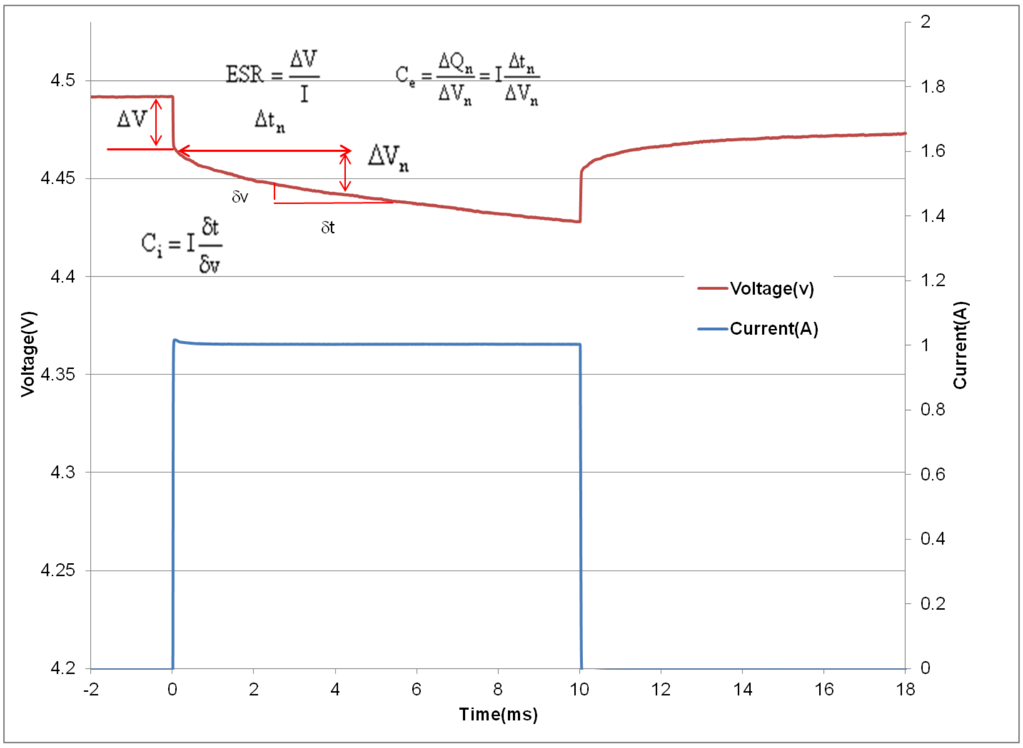

**Figure 1: Effective capacitance, instantaneous capacitance and ESR for a GS206**

The ESR is found by dividing the instantaneous voltage step (ΔV) by I. In this example = (4.49V - 4.467V)/1A = 23mΩ.

The instantaneous capacitance ($C_i$) can be found by taking the inverse of the derivative of the voltage, and multiplying it by I.

The effective capacitance for a pulse of duration $\Delta t_n$, $Ce(\Delta t_n)$ is found by dividing the total charge removed from the capacitor ($\Delta Q_n$) by the voltage lost by the capacitor ($\Delta V_n$). For constant current $Ce(\Delta t_n) = I \times \Delta t_n/\Delta V_n$. Ce increases as the pulse width increases and tends to the DC capacitance value as the pulse width becomes very long (~10 secs). After 2msecs, Fig 1 shows the voltage drop $V_{2ms}$ = (4.467 V – 4.449V) = 18mV. Therefore Ce(2ms) = 1A x 2ms/18mV = 111mF. After 10ms, the voltage drop = 4.467 V – 4.428V = 39mV. Therefore Ce(10ms) = 1 A x 10ms/39mV = 256mF. The DC capacitance of a GS206 = 0.68 F. Note that ΔV, or IR drop, is not included because very little charge is removed from the capacitor during this time. Ce shows the time response of the capacitor and it is useful for predicting circuit behavior in pulsed applications.

## Measurement of DC Capacitance

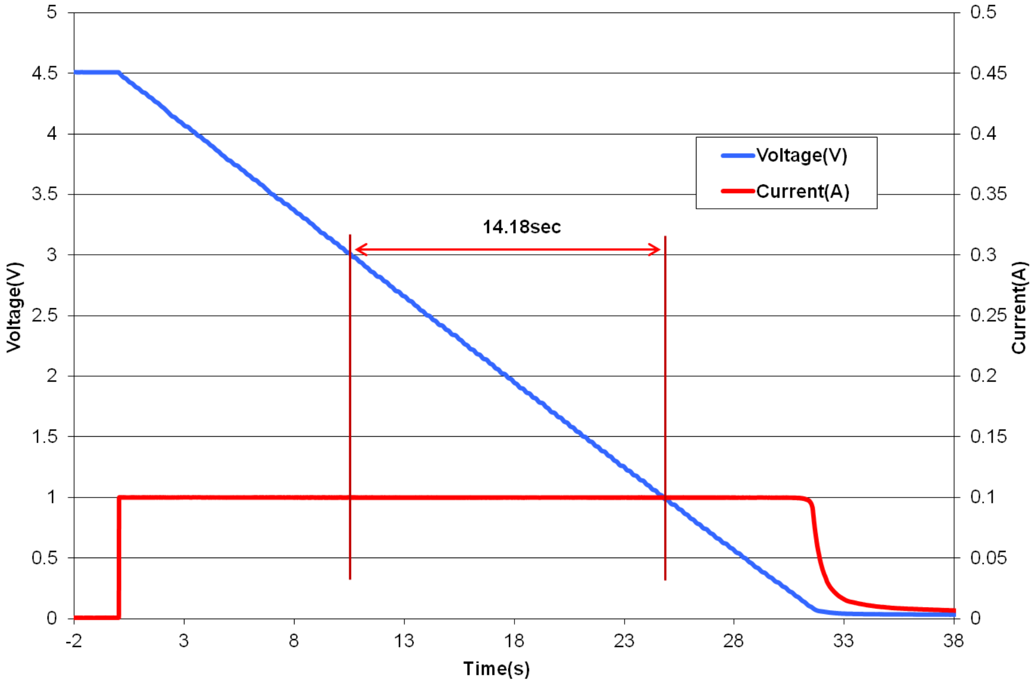

Fig 2: Measurement of DC Capacitance for a GS206

Fig 2 shows the measurement of DC capacitance by drawing a constant 100mA current from a fully charged supercapacitor and measuring the time taken to discharge from 1.5V to 0.5V for a single cell, or from 3V to 1V for a dual cell supercapacitor. In this case, C = 0.1A x 14.18s /2V = 709mF, which is well within the 680mF +/- 20% tolerance for a GS206 cell.

## Measurement of ESR

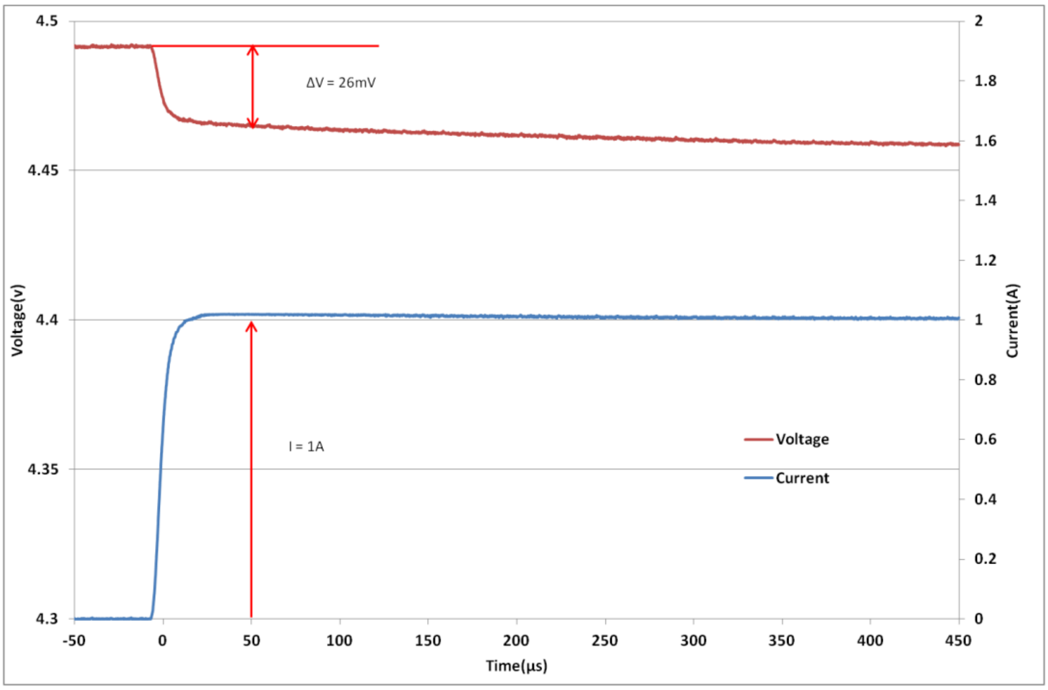

Fig 3: Measurement of ESR for a GS206

Fig 3 shows DC measurement of ESR by applying a step load current to the supercapacitor and measuring the resulting voltage drop. CAP-XX waits for a delay of 50µs after the step current is applied to ensure the voltage and current have settled. In this case the ESR is measured as 26mV/1A = 26mΩ.

## Effective Capacitance (Ceff)

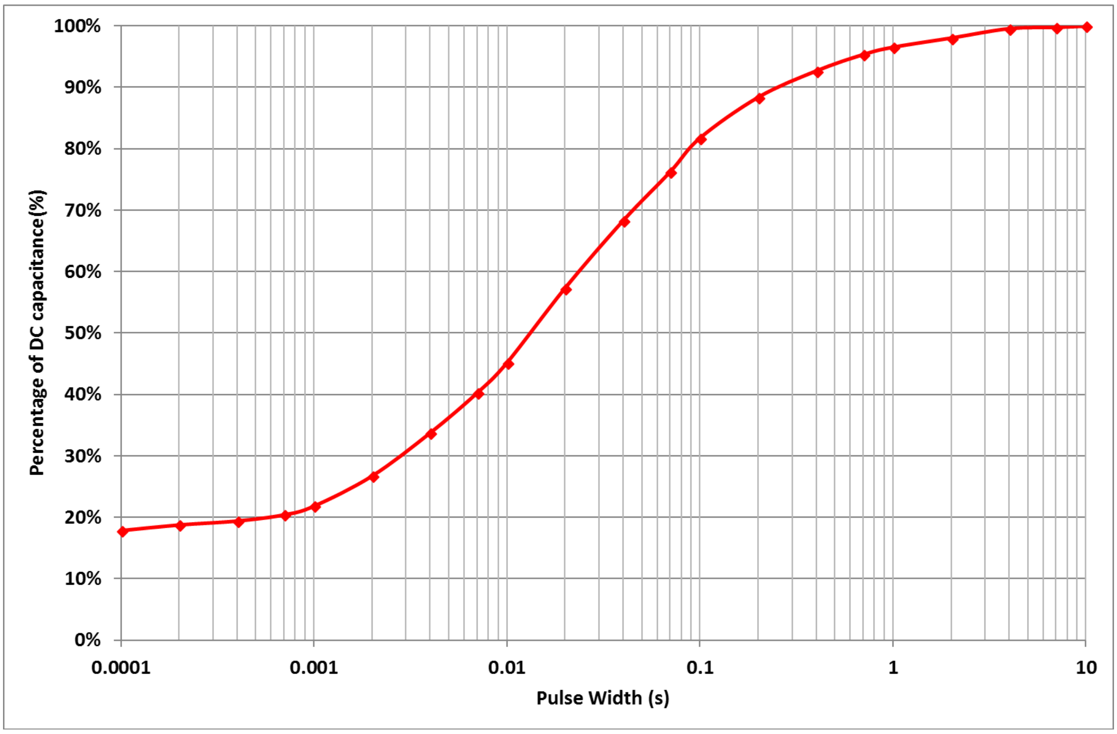

**Figure 4: Effective Capacitance**

Fig 4 shows the effective capacitance for the GS106, GS206 @ 23°C. This shows that for a 1ms PW, you will measure 22% of DC capacitance or 299mF for a GS106 or 150mF for a GS206. At 10ms you will measure 45% of the DC capacitance, and at 100ms you will measure 82% of DC capacitance. Ceffective is a time domain representation of the supercapacitor's frequency response. If, for example, you were calculating the voltage drop if the supercapacitor was supporting 1A for 10ms, then you would use the Ceff(10ms) = 45% of DC capacitance = 306mF for a GS206, so Vdrop = 1A x ESR + 1A x duration/C = 1A x 35mΩ + 1A x 10ms / 306mF = 68mV. The next section on pulse response shows how the effective capacitance is sufficient for even short pulse widths.

## Pulse Response

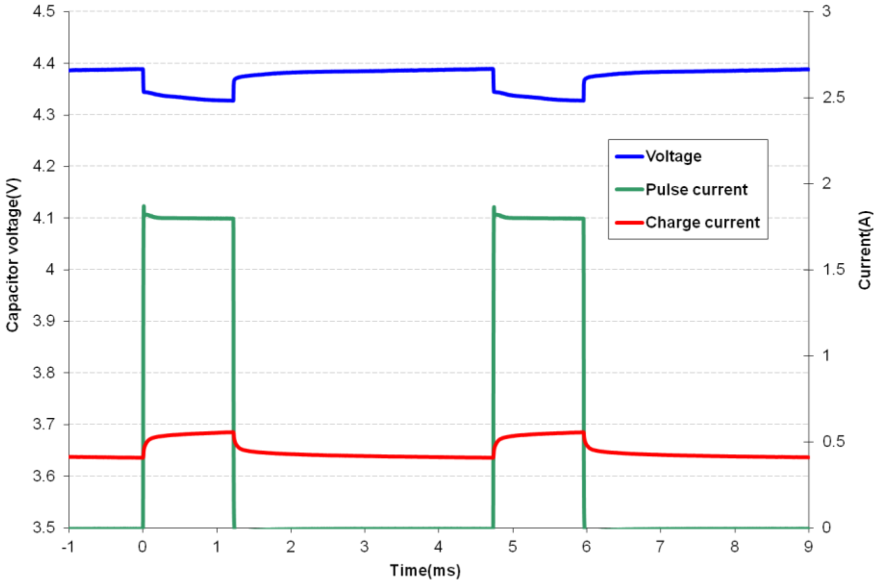

Fig 5 shows that the GS206 supercapacitor does an excellent job supporting a GPRS class 10 pulse train, drawing 1.8A for 1.1ms at 25% duty cycle. The source is current limited to 0.6A and the supercapacitor provides the 1.2A difference to achieve the peak current. At first glance the freq response of Fig 8 indicates the supercapacacitor would not support a 1.1ms pulse, but the Ceff of 122mF coupled with the low ESR supports this pulse train with only ~60mV droop in the supply rail.

**Fig 5: GS206 Pulse Response with GPRS Class 10 Pulse Train**

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## Accurate Calculation of Voltage Drop for a Pulse Using Ceff

The combination of the method used by CAP-XX to measure ESR and effective capacitance for a given pulsewidth given in Fig 4 enable the accurate calculation of voltage drop for a pulse with current *I* and pulsewidth *T* as Vdrop = *I*.[ESR + *T*/Ceff(*T*)]. Using the pulse train of Fig 5 as an example, *I* = 1.8A – 0.6A = 1.2A. *T* = 1.1ms. Nominal DC capacitance = 680mF, and from Fig 4, Ceff(1.1ms) = 18% x 680mF = 122mF. Nominal ESR = 36mΩ, so Vdrop = 1.2A[0.036Ω+0.0011s/0.122F] = 54mV. Fig 5 shows a voltage drop = 60mV verifying that the calculation is a good approximation. This avoids the need to run SPICE for a simple calculation.

## DC Capacitance variation with temperature

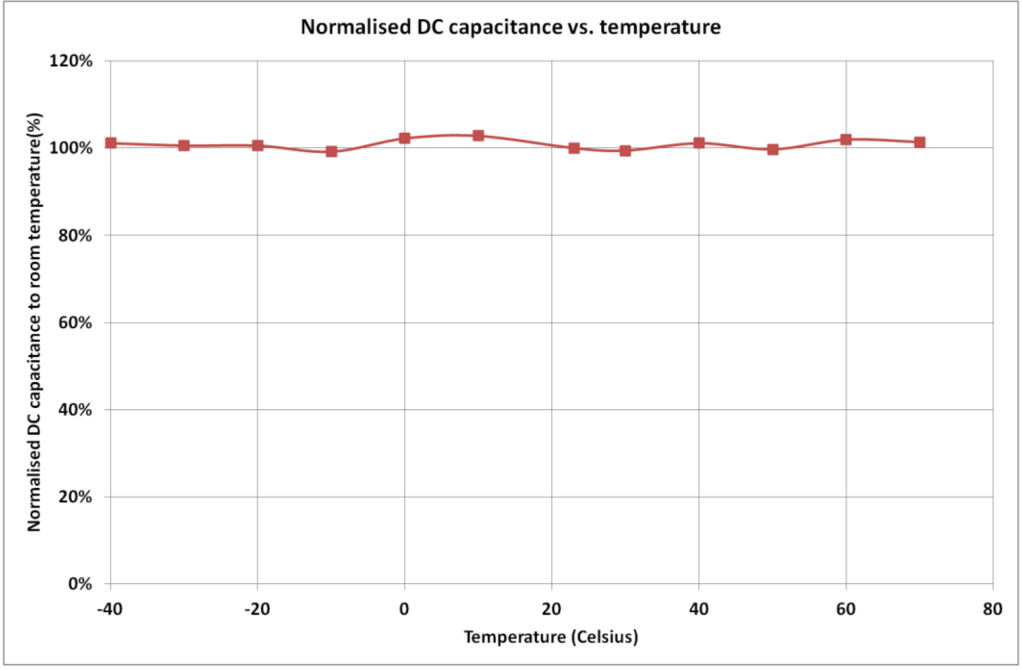

**Figure 6: Capacitance change with temperature**

Fig 6 shows that DC capacitance is approximately constant with temperature.

## ESR variation with temperature

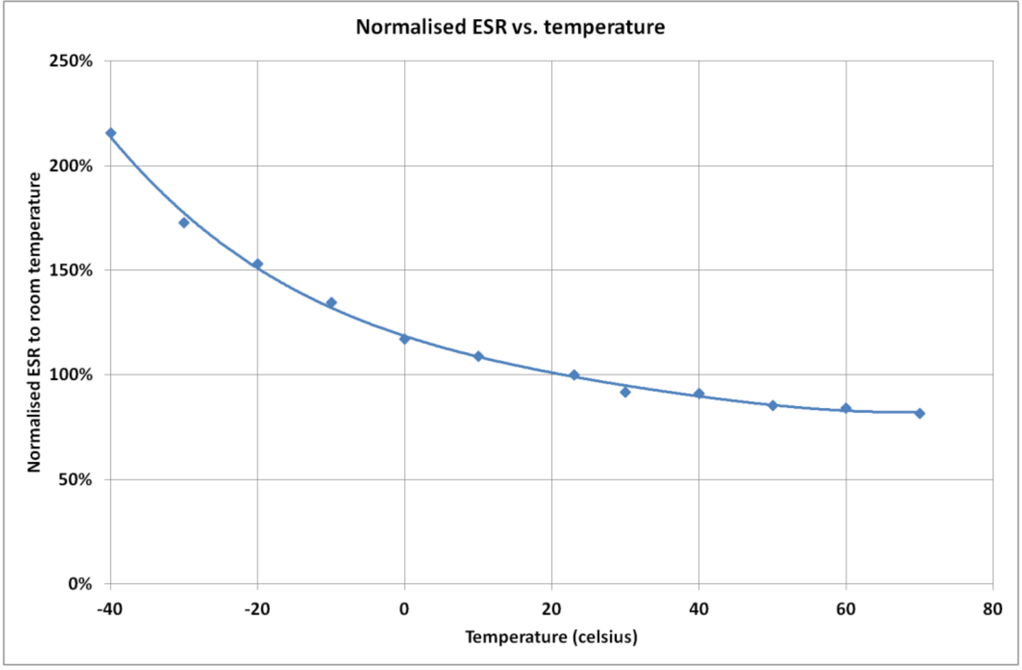

**Figure 7: ESR change with temperature**

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Fig 7 shows that ESR at -40°C is ~2.2 x ESR at room temp, and that ESR at 70ºC is ~0.8 x ESR at room temperature.

## Frequency Response

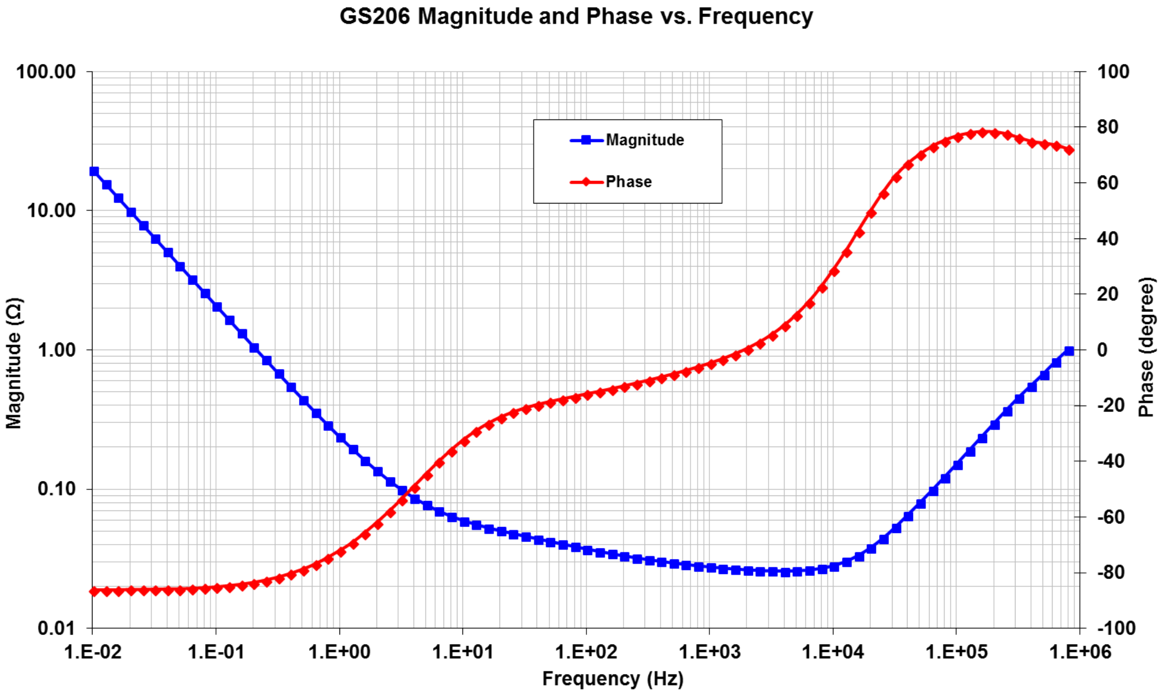

**Fig 8: Frequency Response of Impedance (biased at 5V with a 50mV test signal)**

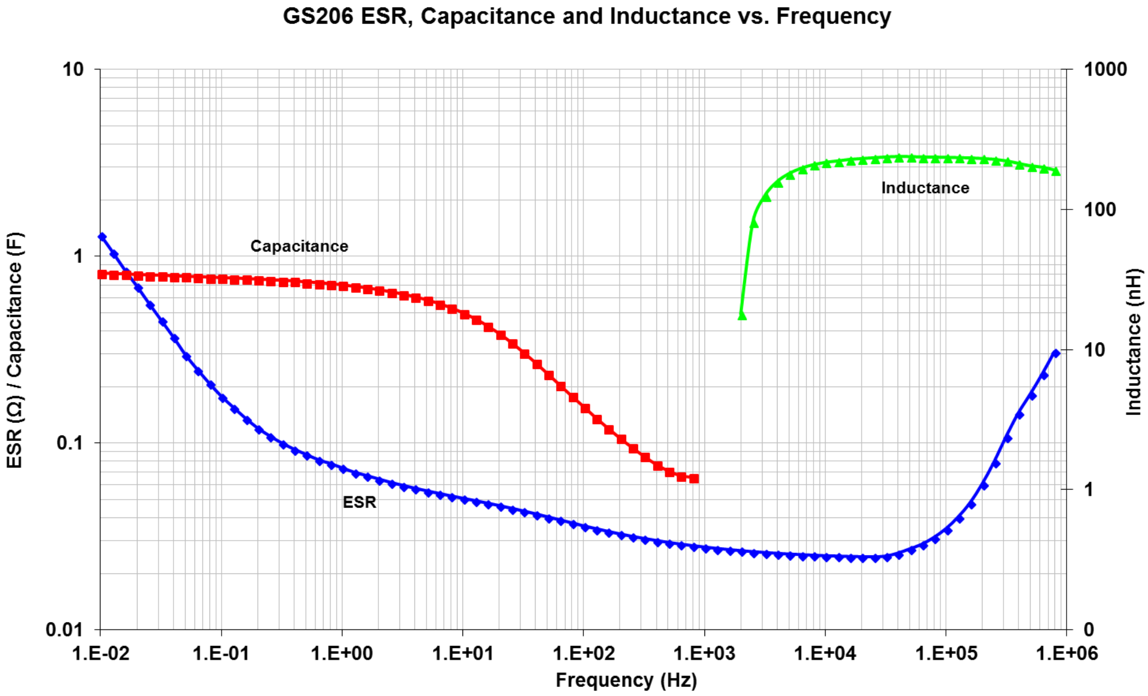

**Fig 9: Frequency Response of ESR, Capacitance & Inductance**

Fig 8 shows the supercapacitor behaves as an ideal capacitor until approx 5 Hz when the magnitude no longer rolls off proportionally to 1/freq and the phase crosses -45°. Performance of supercapacitors with frequency is complex and the best predictor of performance is Fig 4 showing effective capacitance as a function of pulsewidth.

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## Leakage Current

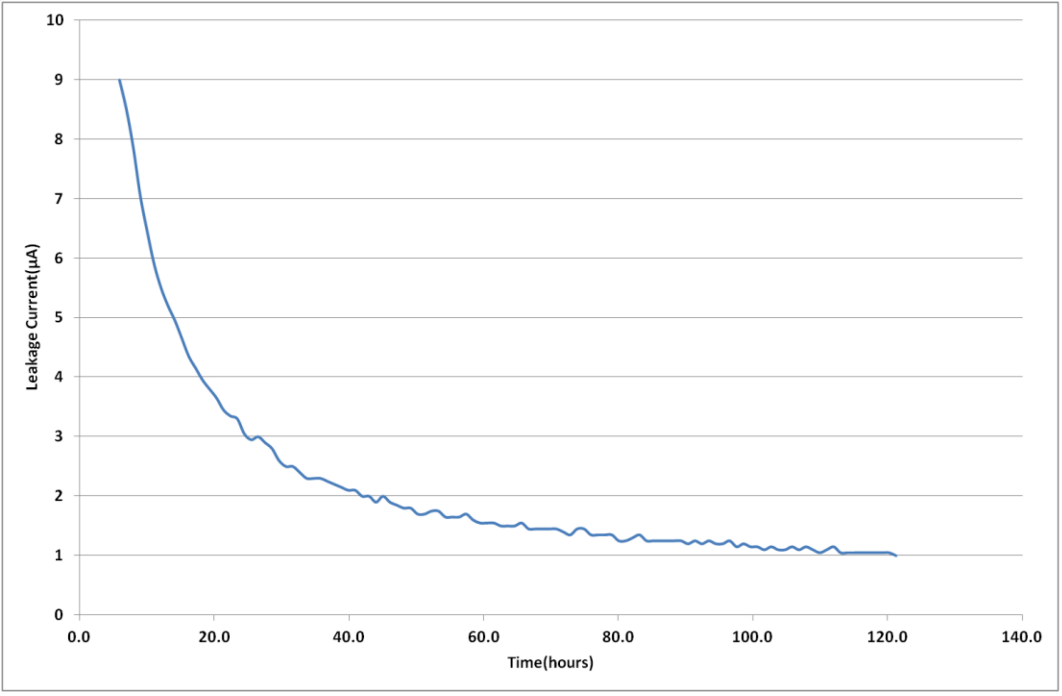

**Fig 10: Leakage Current**

Fig 10 shows the leakage current for GS106 at room temperature. The leakage current decays over time, and the equilibrium value leakage current will be reached after ~120hrs at room temperature. The typical equilibrium leakage current is 1µA at room temperature. At 70°C leakage current will be ~10µA.

## Charge Current

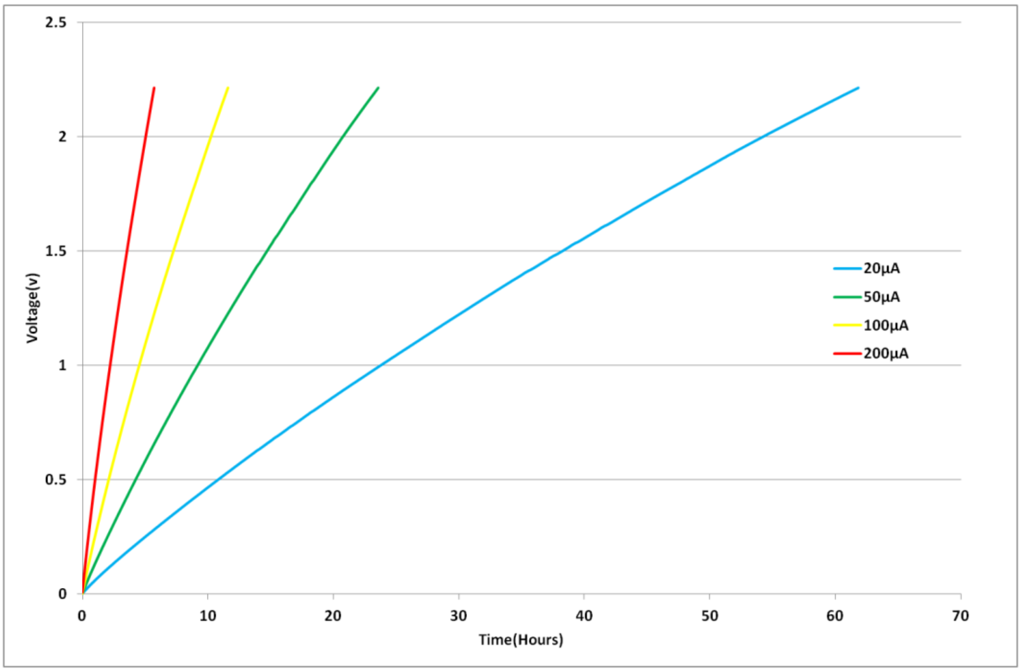

**Fig 11: Charging a GS106 with low current**

The corollary to the slow decay in leakage currents shown in Fig 10 is that charging a supercapacitor at very low currents takes longer than theory predicts. At higher charge currents, the charge rate is as theory predicts. For example, it should take 1.36 F x 2.2V / 0.00002A = 41.6hrs to charge a 1.36F supercapacitor to 2.2V at 20µA, but Fig 11 shows it took 64hrs. At 100µA charging occurs at a rate close to the theoretical rate.

## RMS Current

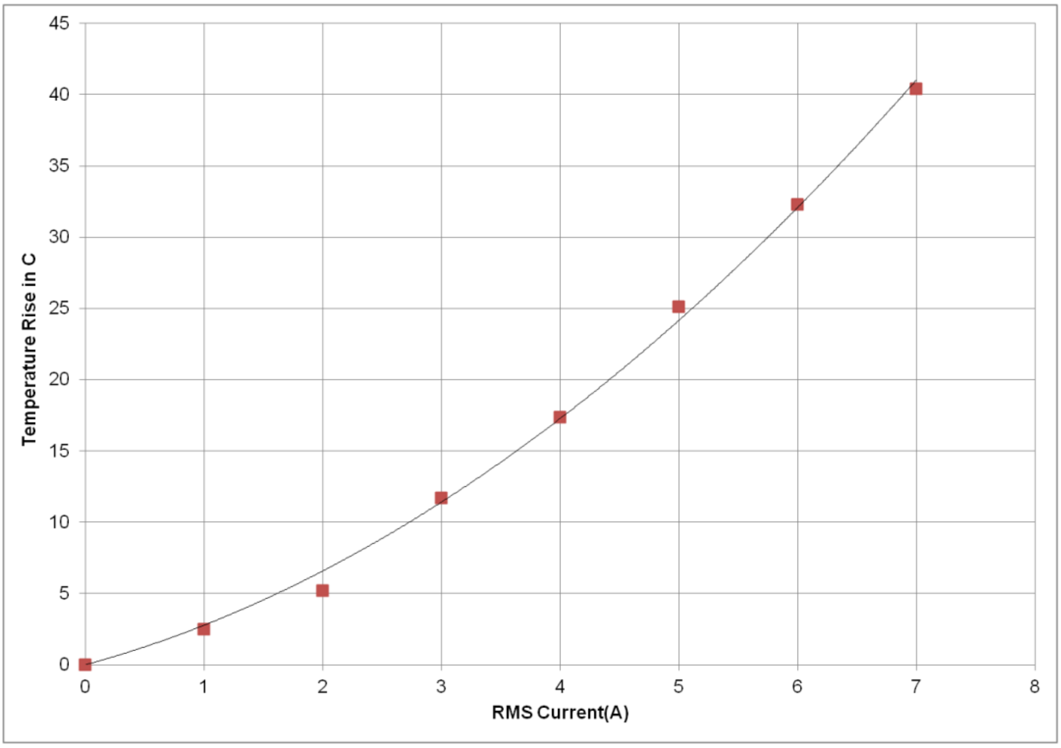

**Fig 12: Temperature rise in GS206 with RMS current**

Continuous current flow into/out of the supercap will cause self heating, which limits the maximum continuous current the supercapacitor can handle. This is measured by a current square wave with 50% duty cycle, charging the supercapacitor to rated voltage at a constant current, then discharging the supercapacitor to half rated voltage at the same constant current value. For a square wave with 50% duty cycle, the RMS current is the same as the current amplitude. Fig 12 shows the increase in temperature as a function of RMS current. From this, the maximum RMS current in an application can be calculated, for example, if the ambient temperature is 40°C, and the maximum desired temperature for the supercapacitor is 70°C, then the maximum RMS current should be limited to 5.5A, which causes a 30°C temperature increase.

## CAP-XX Supercapacitors Product Guide

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# GS108 / GS208 SUPERCAPACITOR

Datasheet Rev 4.3, July 2018

This Datasheet should be read in conjunction with the CAP-XX Supercapacitors Product Guide which contains information common to our product lines.

## Electrical Specifications

The GS108 is a single cell supercapacitor. The GS208 is a dual cell supercapacitor with two GS108 cells in series, so GS208 capacitance = Capacitance of GS108/2 and GS208 ESR = 2 x GS108 ESR.

**Table 1: Absolute Maximum Ratings**

| Parameter | Name | | Conditions | Min | Typical | Max | Units |
|---|---|---|---|---|---|---|---|
| **Terminal Voltage** | Vpeak | GS108 | | 0 | | 2.75 | V |
| | | GS208 | | | | 5.5 | |
| **Temperature** | Tmax | | | -40 | | +70 | °C |

**Table 2: Electrical Characteristics**

| Parameter | Name | | Conditions | Min | Typical | Max | Units |
|---|---|---|---|---|---|---|---|
| **Terminal Voltage** | Vn | GS108 | | 0 | | 2.5 | V |
| | | GS208 | | 0 | | 5.0 | |
| **Capacitance** | C | GS108 | DC, 23°C | 1440 | 1800 | 2160 | mF |
| | | GS208 | | 720 | 900 | 1080 | |
| **ESR** | ESR | GS108 | DC, 23°C | | 15 | 18 | mΩ |
| | | GS208 | | | 25 | 30 | |
| **Leakage Current** | $I_L$ | | 2.3V, 23°C 120hrs | | 2 | 4 | µA |
| **RMS Current** | $I_{RMS}$ | | 23°C | | | 8 | A |
| **Peak Current**[1] | $I_P$ | | 23°C | | | 30 | A |

[1] Non-repetitive current, single pulse to discharge fully charged supercapacitor.

**Table 3: Thickness**

| | | | | | |
|---|---|---|---|---|---|
| **GS108F** | **1.7mm** | No adhesive tape on underside of the supercapacitor | **GS108G** | **1.8mm** | Adhesive tape on underside, release tape removed |
| **GS208F** | **3.4mm** | | **GS208G** | **3.5mm** | |

# Definition of Terms

In its simplest form, the Equivalent Series Resistance (ESR) of a capacitor is the real part of the complex impedance. In the time domain, it can be found by applying a step discharge current to a charged cell as in Fig. 1. In this figure, the supercapacitor is pre-charged and then discharged with a current pulse, I =1A for duration 0.01 sec.

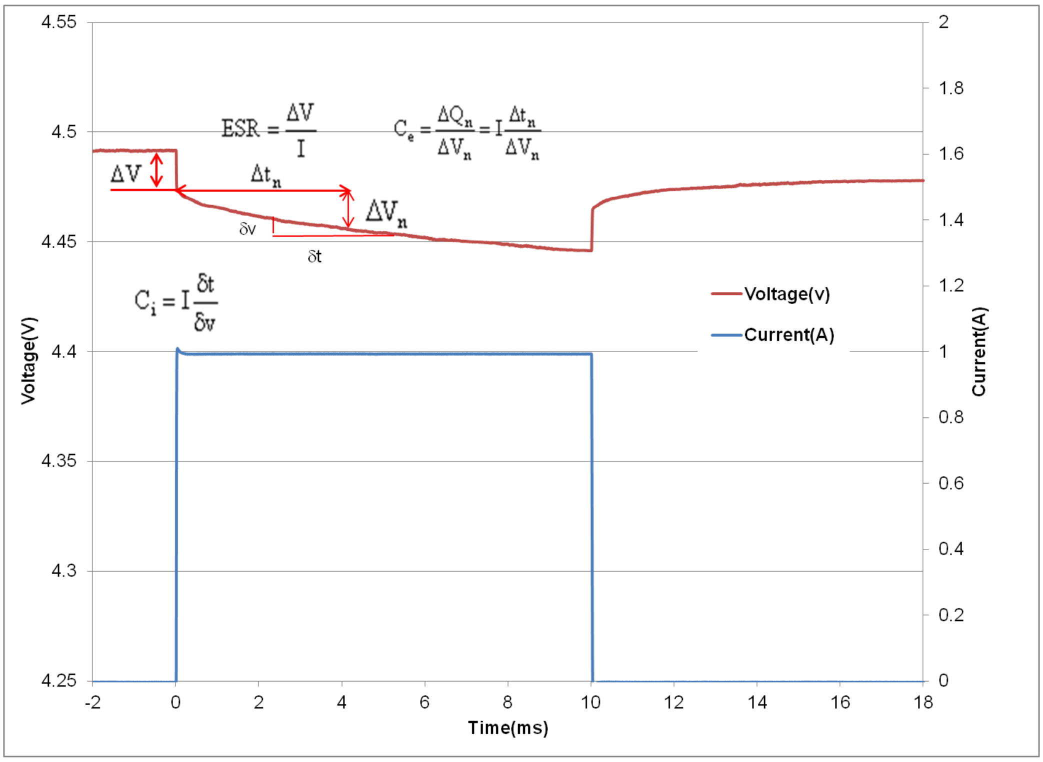

**Figure 1: Effective capacitance, instantaneous capacitance and ESR for a GS208**

The ESR is found by dividing the instantaneous voltage step (ΔV) by I. In this example = (4.49V – 4.476V)/1A = 14mΩ.

The instantaneous capacitance ($C_i$) can be found by taking the inverse of the derivative of the voltage, and multiplying it by I.

The effective capacitance for a pulse of duration $\Delta t_n$, Ce($\Delta t_n$) is found by dividing the total charge removed from the capacitor ($\Delta Q_n$) by the voltage lost by the capacitor ($\Delta V_n$). For constant current Ce($\Delta t_n$) = I x $\Delta t_n/\Delta V_n$. Ce increases as the pulse width increases and tends to the DC capacitance value as the pulse width becomes very long (~10 secs). After 2msecs, Fig 1 shows the voltage drop $V_{2ms}$ = (4.476 V – 4.461V) = 15mV. Therefore Ce(2ms) = 1A x 2ms/15mV = 133mF. After 10ms, the voltage drop = 4.476 V – 4.446V = 30mV. Therefore Ce(10ms) = 1 A x 10ms/30mV = 333mF. The DC capacitance of a GS208 = 0.9 F. Note that ΔV, or IR drop, is not included because very little charge is removed from the capacitor during this time. Ce shows the time response of the capacitor and it is useful for predicting circuit behavior in pulsed applications.

## Measurement of DC Capacitance

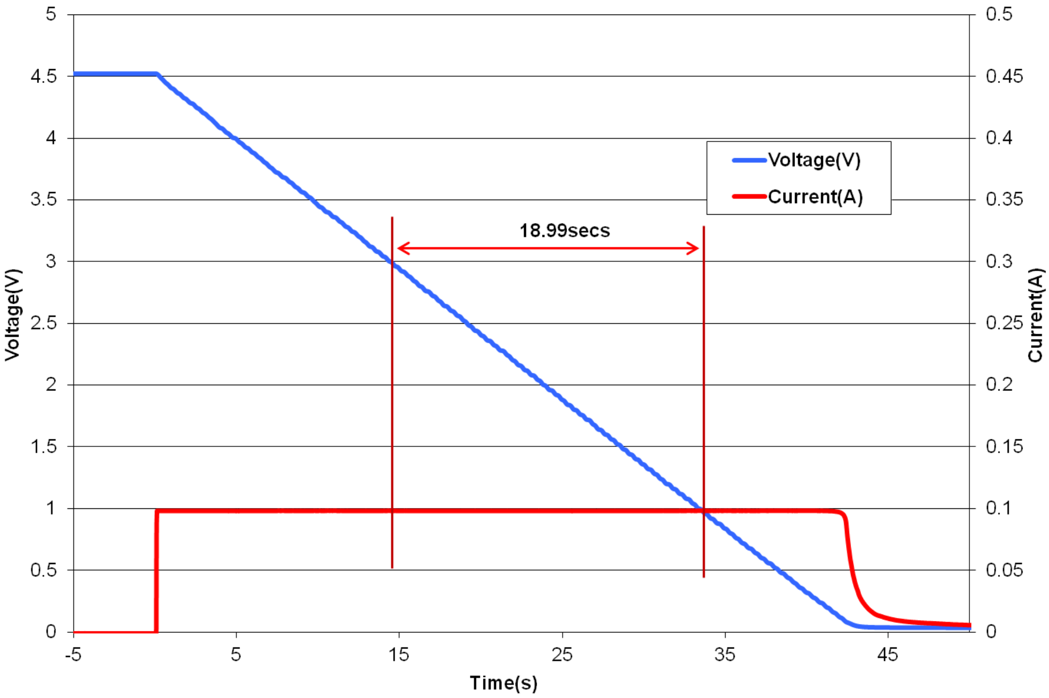

**Fig 2: Measurement of DC Capacitance for a GS208**

Fig 2 shows the measurement of DC capacitance by drawing a constant 100mA current from a fully charged supercapacitor and measuring the time taken to discharge from 1.5V to 0.5V for a single cell, or from 3V to 1V for a dual cell supercapacitor. In this case, C = 0.1A x 18.99s /2V = 949mF, which is well within the 900mF +/- 20% tolerance for a GS208 cell.

## Measurement of ESR

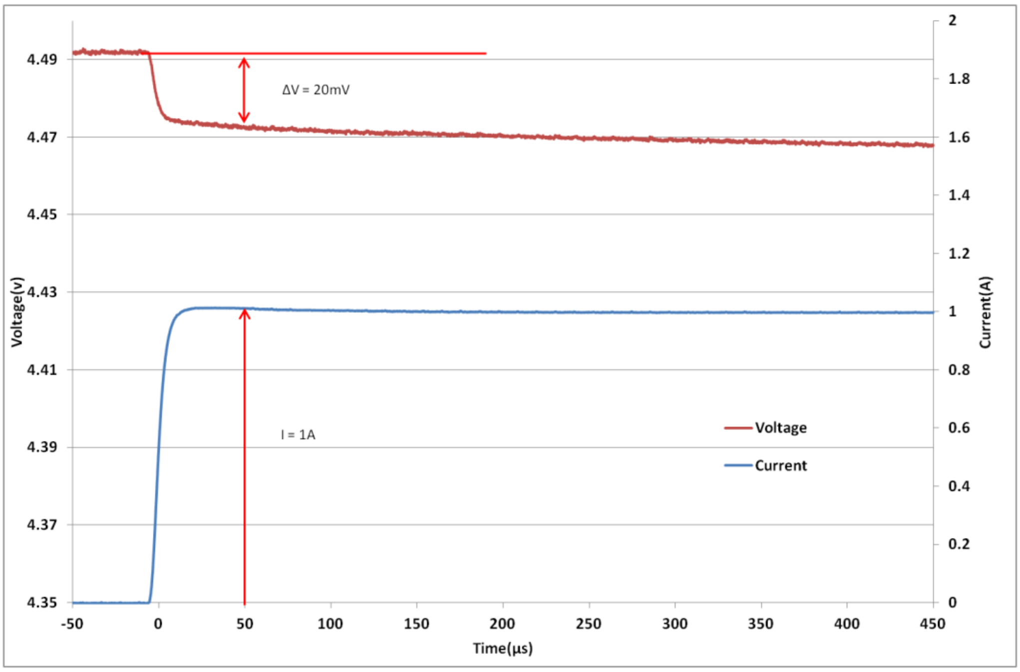

**Fig 3: Measurement of ESR for a GS208**

Fig 3 shows DC measurement of ESR by applying a step load current to the supercapacitor and measuring the resulting voltage drop. CAP-XX waits for a delay of 50µs after the step current is applied to ensure the voltage and current have settled. In this case the ESR is measured as 20mV/1A = 20mΩ.

## Effective Capacitance

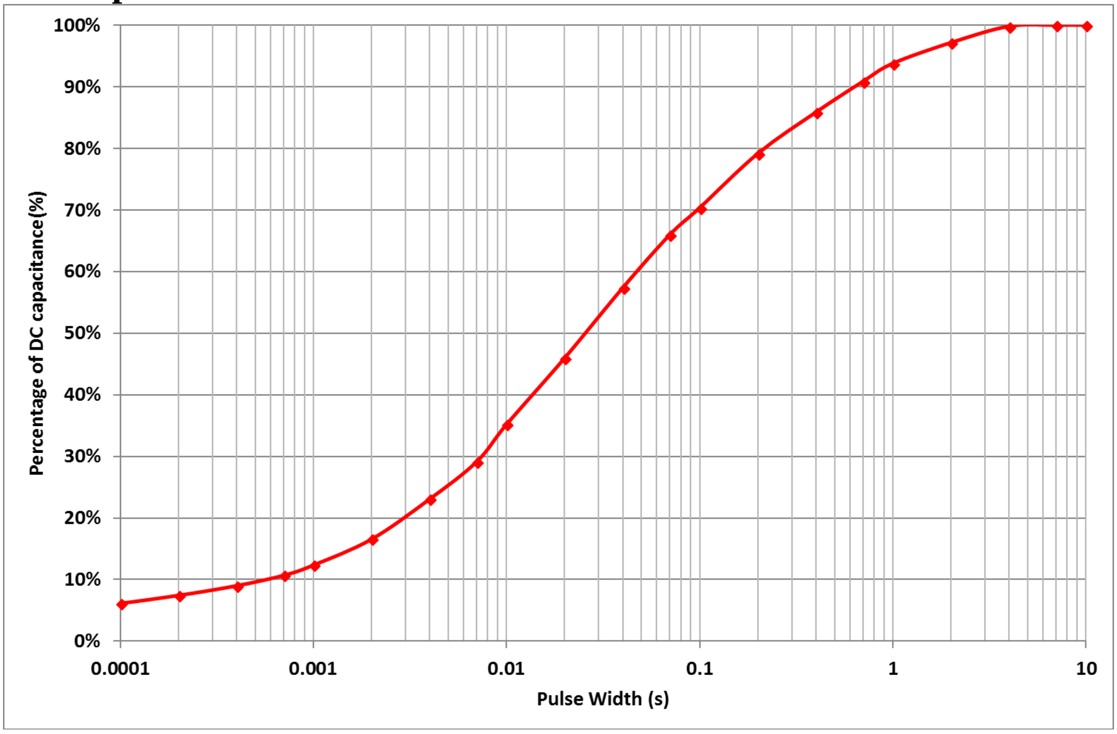

**Figure 4: Effective Capacitance**

Fig 4 shows the effective capacitance for the GS108, GS208 @ 23°C. This shows that for a 1ms PW, you will measure 12% of DC capacitance or 216mF for a GS108 or 108mF for a GS208. At 10ms you will measure 35% of the DC capacitance, and at 100ms you will measure 70% of DC capacitance. Ceffective is a time domain representation of the supercapacitor's frequency response. If, for example, you were calculating the voltage drop if the supercapacitor was supporting 1A for 10ms, then you would use the Ceff(10ms) = 35% of DC capacitance = 315mF for a GS208, so Vdrop = 1A x ESR + 1A x duration/C = 1A x 25mΩ + 1A x 10ms / 315mF = 56.7mV. The next section on pulse response shows how the effective capacitance is sufficient for even short pulse widths.

## Pulse Response

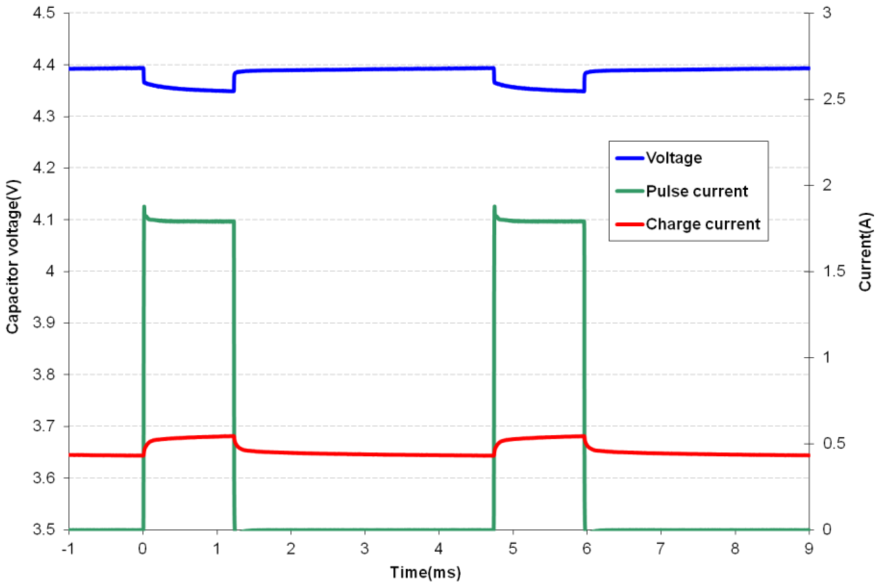

Fig 5 shows that the GS208 supercapacitor does an excellent job supporting a GPRS class 10 pulse train, drawing 1.8A for 1.1ms at 25% duty cycle. The source is current limited to 0.6A and the supercapacitor provides the 1.2A difference to achieve the peak current. At first glance the freq response of Fig 8 indicates the supercapacacitor would not support a 1ms pulse, but the Ceff of 58.5mF coupled with the low ESR supports this pulse train with only ~45mV droop in the supply rail.

**Fig 5: GS208 Pulse Response with GPRS Class 10 Pulse Train**

## DC Capacitance variation with temperature

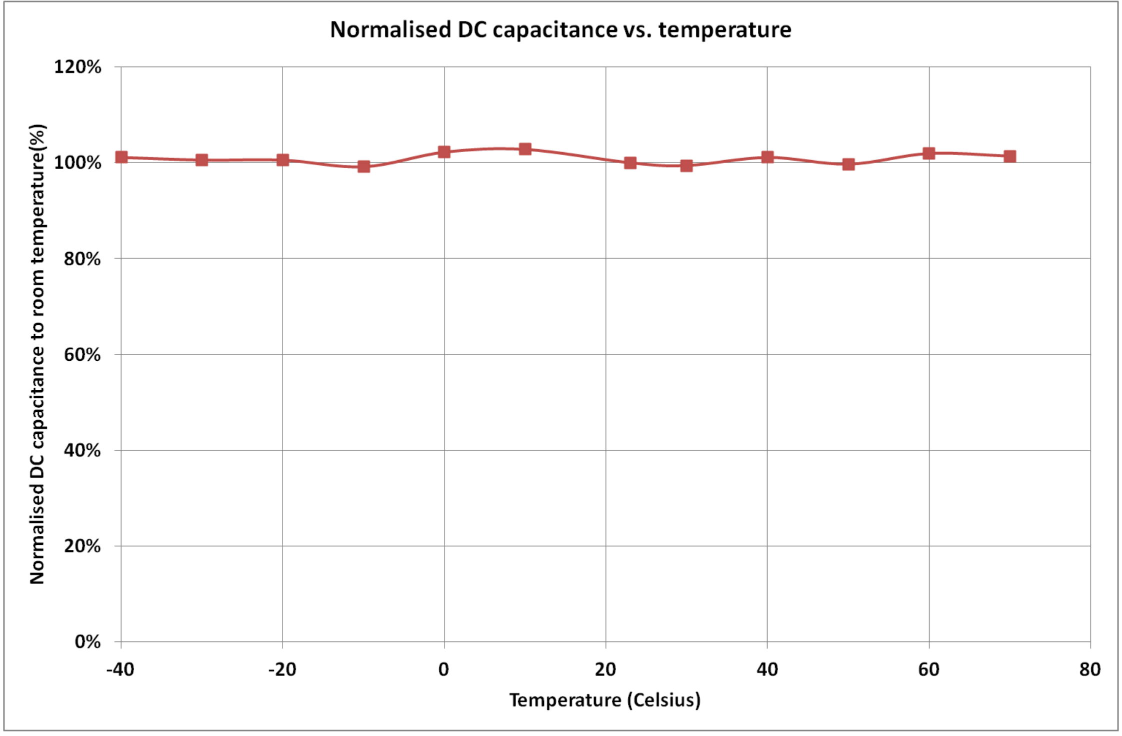

**Figure 6: Capacitance change with temperature**

Fig 6 shows that DC capacitance is approximately constant with temperature.

## ESR variation with temperature

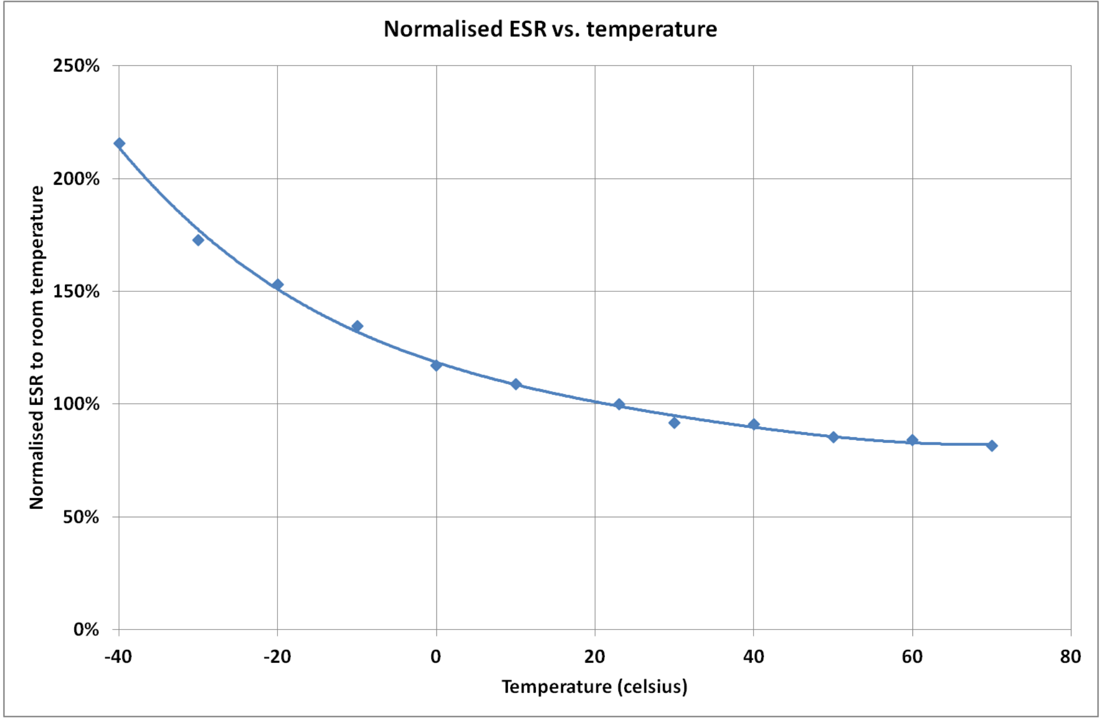

**Figure 7: ESR change with temperature**

Fig 7 shows that ESR at -40°C is ~2.1 x ESR at room temp, and that ESR at 70ºC is ~0.8 x ESR at room temperature.

# Frequency Response

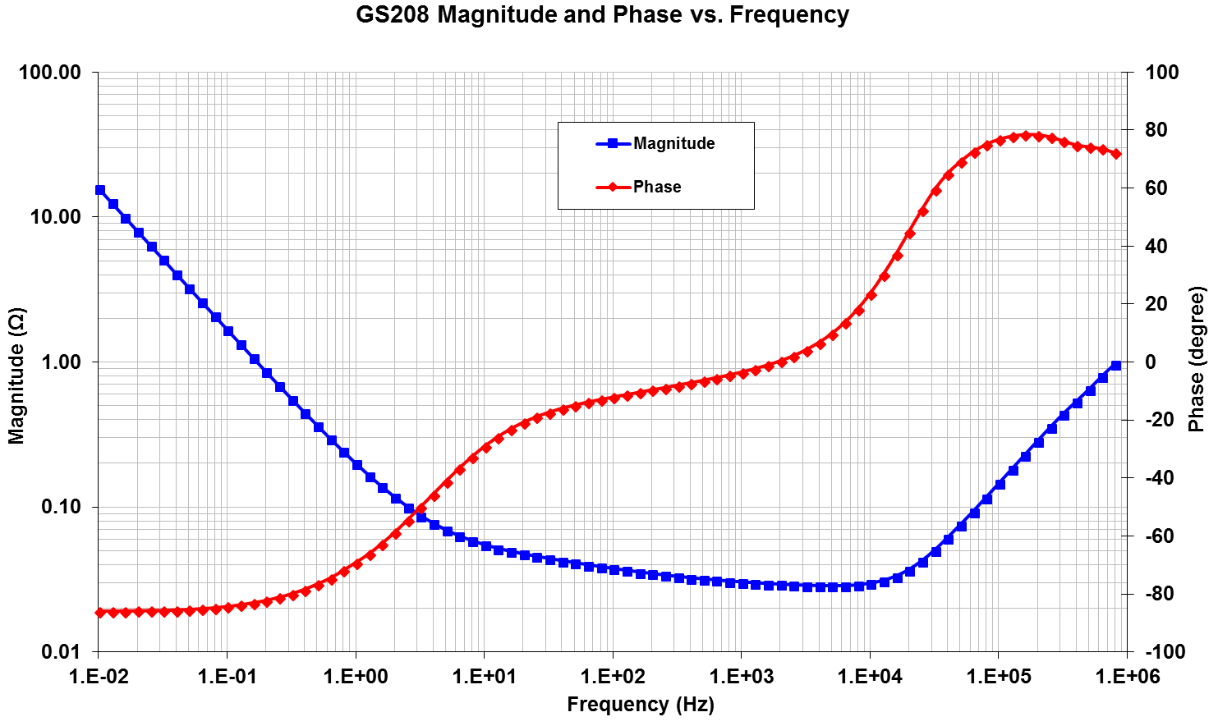

**Fig 8: Frequency Response of Impedance (biased at 5V with a 50mV test signal)**

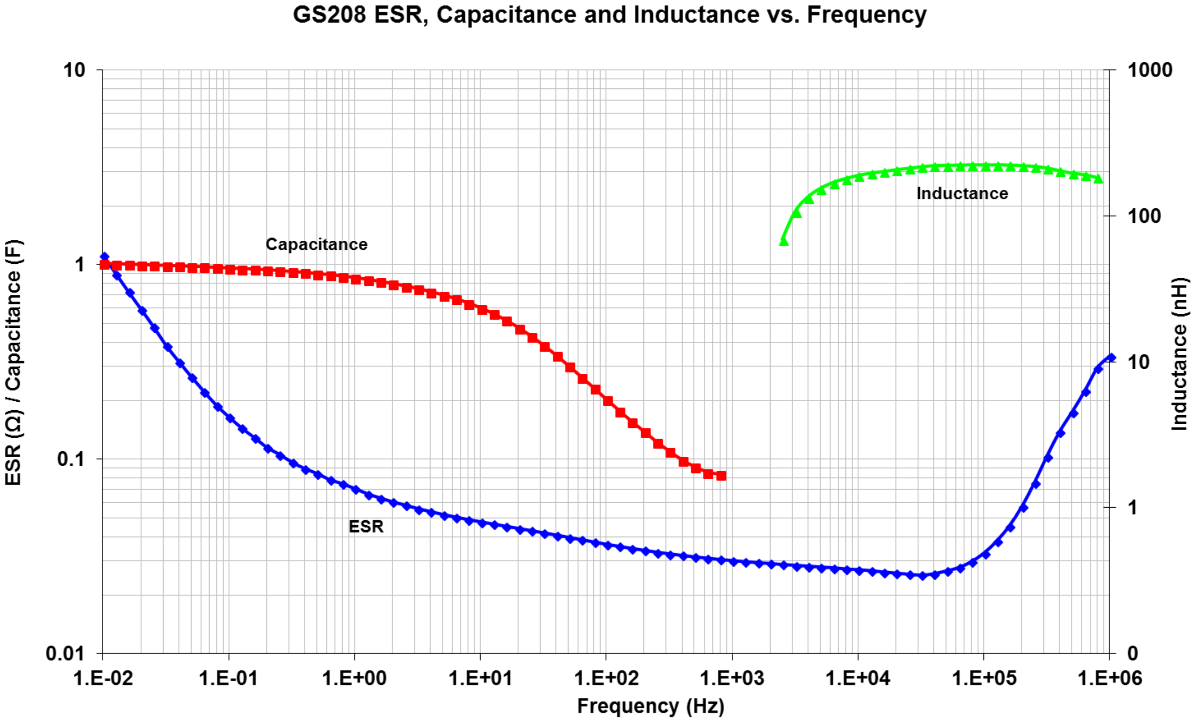

**Fig 9: Frequency Response of ESR, Capacitance & Inductance**

Fig 8 shows the supercapacitor behaves as an ideal capacitor until approx 4 Hz when the magnitude no longer rolls off proportionally to 1/freq and the phase crosses -45°. Performance of supercapacitors with frequency is complex and the best predictor of performance is Fig 4 showing effective capacitance as a function of pulsewidth.

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## Leakage Current

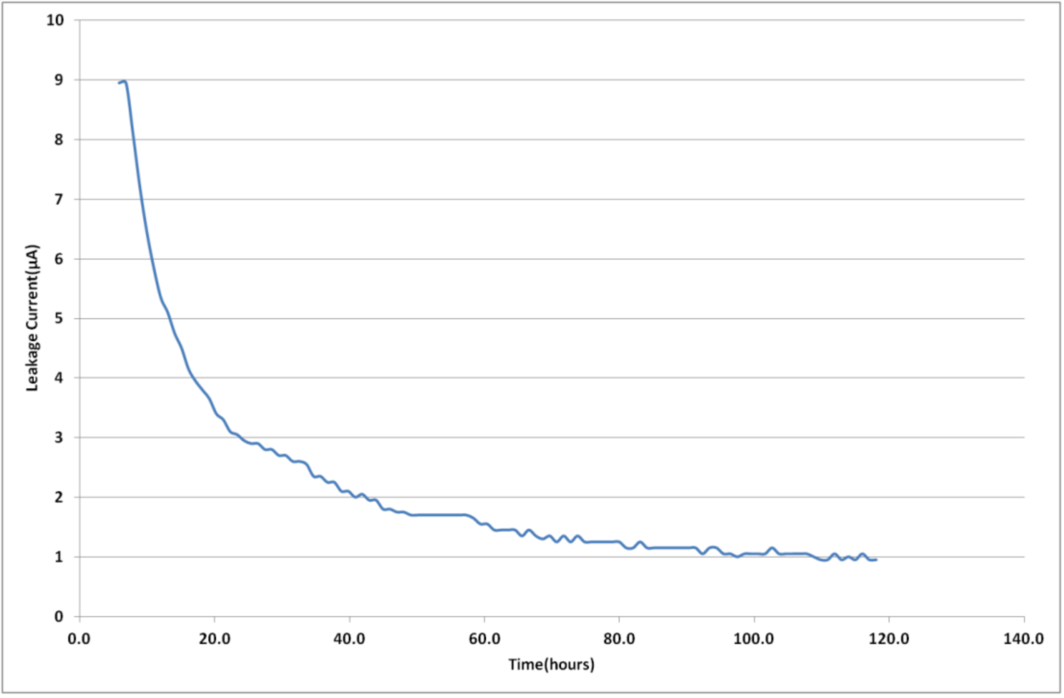

**Fig 10: Leakage Current**

Fig 10 shows the leakage current for GS108 at room temperature. The leakage current decays over time, and the equilibrium value leakage current will be reached after ~120hrs at room temperature. The typical equilibrium leakage current is 1µA at room temperature. At 70°C leakage current will be ~5µA.

## Charge Current

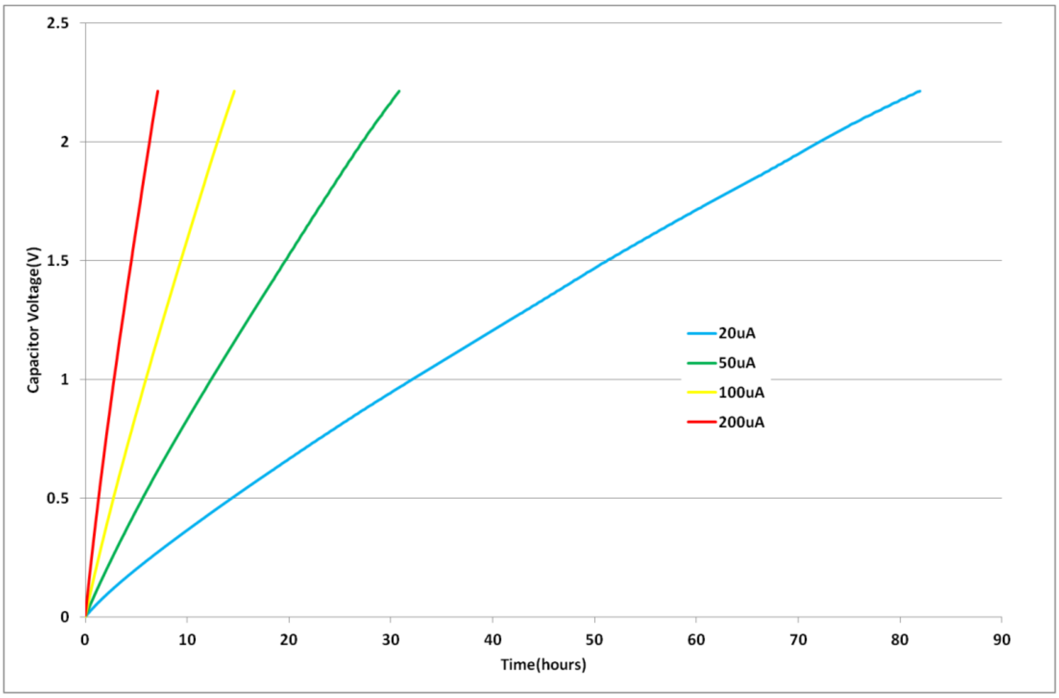

**Fig 11: Charging an GS108 with low current**

The corollary to the slow decay in leakage currents shown in Fig 10 is that charging a supercapacitor at very low currents takes longer than theory predicts. At higher charge currents, the charge rate is as theory predicts. For example, it should take 1.8 F x 2.2V / 0.00002A = 60hrs to charge a 1.8 F supercapacitor to 2.2V at 20µA, but Fig 11 shows it took 80hrs. At 100µA charging occurs at a rate close to the theoretical rate.

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## RMS Current

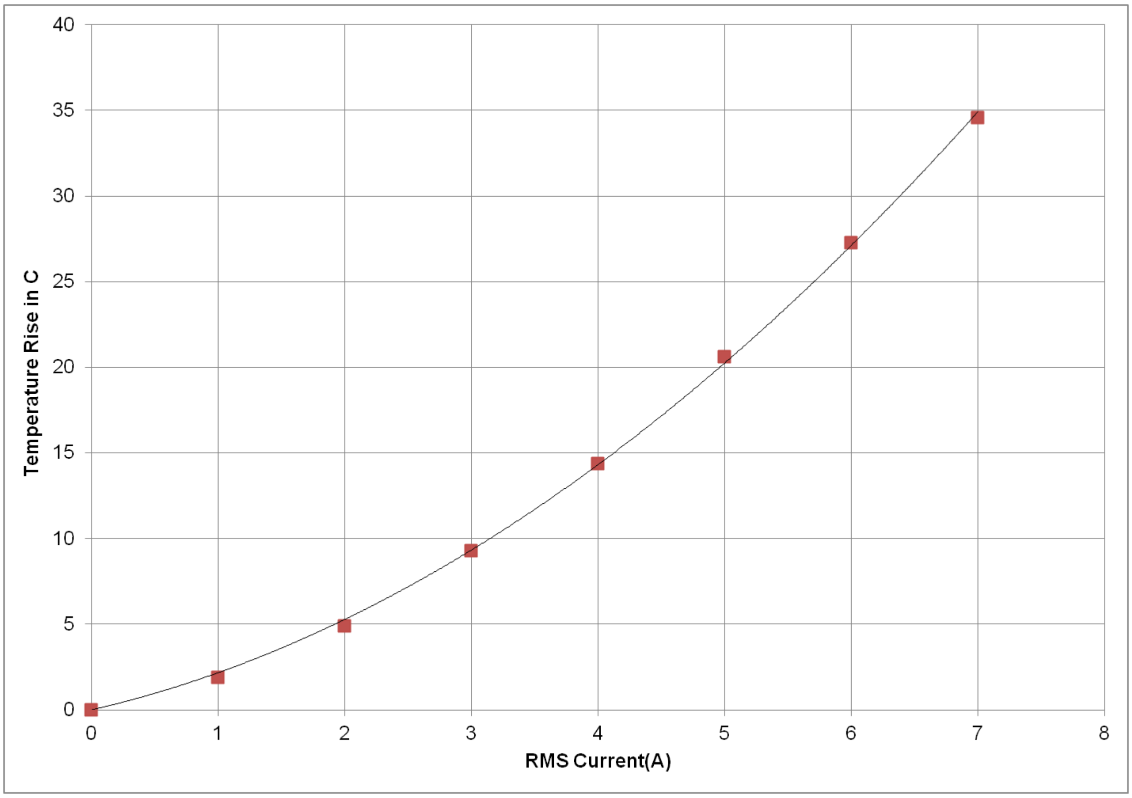

**Fig 12: Temperature rise in GS208 with RMS current**

Continuous current flow into/out of the supercap will cause self heating, which limits the maximum continuous current the supercapacitor can handle. This is measured by a current square wave with 50% duty cycle, charging the supercapacitor to rated voltage at a constant current, then discharging the supercapacitor to half rated voltage at the same constant current value. For a square wave with 50% duty cycle, the RMS current is the same as the current amplitude. Fig 12 shows the increase in temperature as a function of RMS current. From this, the maximum RMS current in an application can be calculated, for example, if the ambient temperature is 40°C, and the maximum desired temperature for the supercapacitor is 70°C, then the maximum RMS current should be limited to 6.4A, which causes a 30°C temperature increase.

## CAP-XX Supercapacitors Product Guide

Refer to the package drawings in the CAP-XX Supercapacitors Product Guide for detailed information of the product’s dimensions, PCB landing placements, active areas and electrical connections.

Refer to the CAP-XX Supercapacitors Product Guide for information on endurance and shelf life, transportation and storage, assembly and soldering, safety and RoHS/EREACH certification.

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ACN 077 060 872

# GS130 / GS230 SUPERCAPACITOR

Datasheet Rev 4.3, July 2018

This Datasheet should be read in conjunction with the CAP-XX Supercapacitors Product Guide which contains information common to our product lines.

## Electrical Specifications

The GS130 is a single cell supercapacitor. The GS230 is a dual cell supercapacitor with two GS130 cells in series, so GS230 capacitance = Capacitance of GS130/2 and GS230 ESR = 2 x GS130 ESR.

**Table 1: Absolute Maximum Ratings**

| **Parameter** | **Name** | | **Conditions** | **Min** | **Typical** | **Max** | **Units** |
|---|---|---|---|---|---|---|---|
| **Terminal Voltage** | Vpeak | GS130 | | 0 | | 2.75 | V |
| | | GS230 | | | | 5.5 | |
| **Temperature** | Tmax | | | -40 | | +70 | °C |

**Table 2: Electrical Characteristics**

| **Parameter** | **Name** | | **Conditions** | **Min** | **Typical** | **Max** | **Units** |
|---|---|---|---|---|---|---|---|
| **Terminal Voltage** | Vn | GS130 | | 0 | | 2.5 | V |
| | | GS230 | | 0 | | 5.0 | |
| **Capacitance** | C | GS130 | DC, 23°C | 1920 | 2400 | 2880 | mF |
| | | GS230 | | 960 | 1200 | 1440 | |
| **ESR** | ESR | GS130 | DC, 23°C | | 15 | 18 | mΩ |
| | | GS230 | | | 25 | 30 | |
| **Leakage Current** | $I_L$ | | 2.3V, 23°C 120hrs | | 2.5 | 5 | µA |
| **RMS Current** | $I_{RMS}$ | | 23°C | | | 8 | A |
| **Peak Current[1]** | $I_P$ | | 23°C | | | 30 | A |

[1] Non-repetitive current, single pulse to discharge fully charged supercapacitor.

**Table 3: Thickness**

| | | | | | |
|---|---|---|---|---|---|
| **GS130F** | **1.9mm** | No adhesive tape on underside of the supercapacitor | **GS130G** | **2.0mm** | Adhesive tape on underside, release tape removed |
| **GS230F** | **3.9mm** | | **GS230G** | **4.0mm** | |

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## Definition of Terms

In its simplest form, the Equivalent Series Resistance (ESR) of a capacitor is the real part of the complex impedance. In the time domain, it can be found by applying a step discharge current to a charged cell as in Fig. 1. In this figure, the supercapacitor is pre-charged and then discharged with a current pulse, I =1A for duration 0.01 sec.

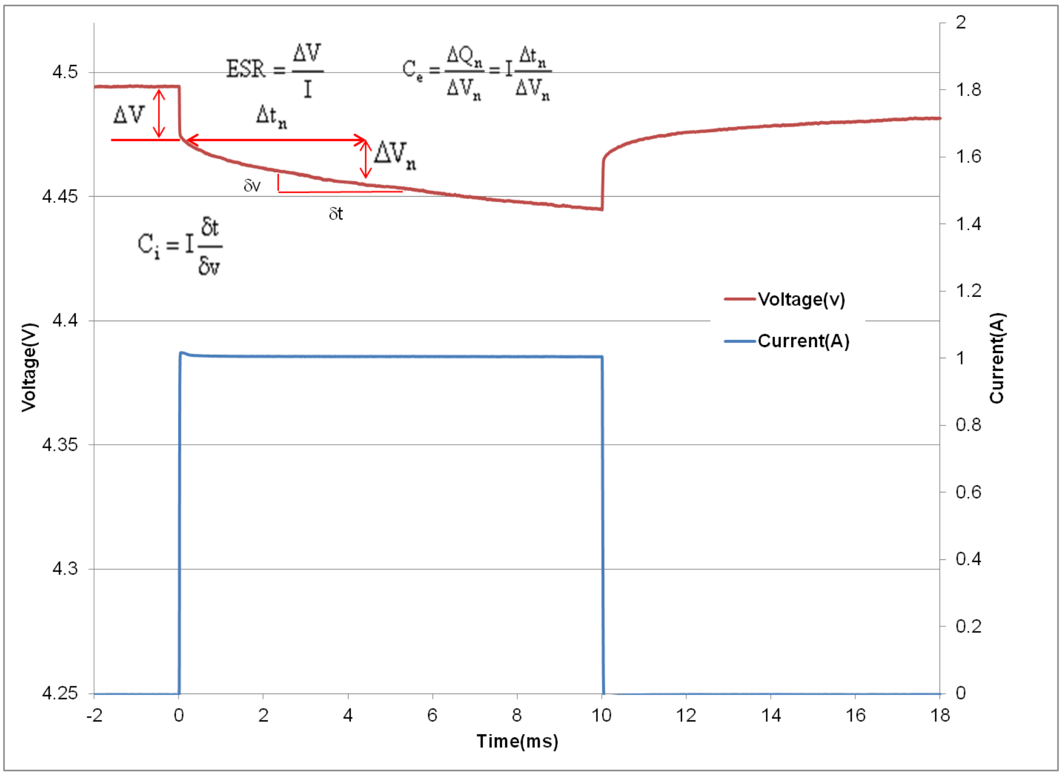

**Figure 1: Effective capacitance, instantaneous capacitance and ESR for a GS230**

The ESR is found by dividing the instantaneous voltage step (ΔV) by I. In this example = (4.49V - 4.475V)/1A = 15mΩ.

The instantaneous capacitance ($C_i$) can be found by taking the inverse of the derivative of the voltage, and multiplying it by I.

The effective capacitance for a pulse of duration $\Delta t_n$, $Ce(\Delta t_n)$ is found by dividing the total charge removed from the capacitor ($\Delta Q_n$) by the voltage lost by the capacitor ($\Delta V_n$). For constant current $Ce(\Delta t_n) = I$ x $\Delta t_n/\Delta V_n$. Ce increases as the pulse width increases and tends to the DC capacitance value as the pulse width becomes very long (~10 secs). After 2msecs, Fig 1 shows the voltage drop $V_{2ms}$ = (4.475V – 4.461V) = 14mV. Therefore Ce(2ms) = 1A x 2ms/14mV = 142mF. After 10ms, the voltage drop = 4.475 V – 4.445V = 30mV. Therefore Ce(10ms) = 1 A x 10ms/30mV = 333mF. The DC capacitance of a GS230 = 1.2 F. Note that ΔV, or IR drop, is not included because very little charge is removed from the capacitor during this time. Ce shows the time response of the capacitor and it is useful for predicting circuit behavior in pulsed applications.

## Measurement of DC Capacitance

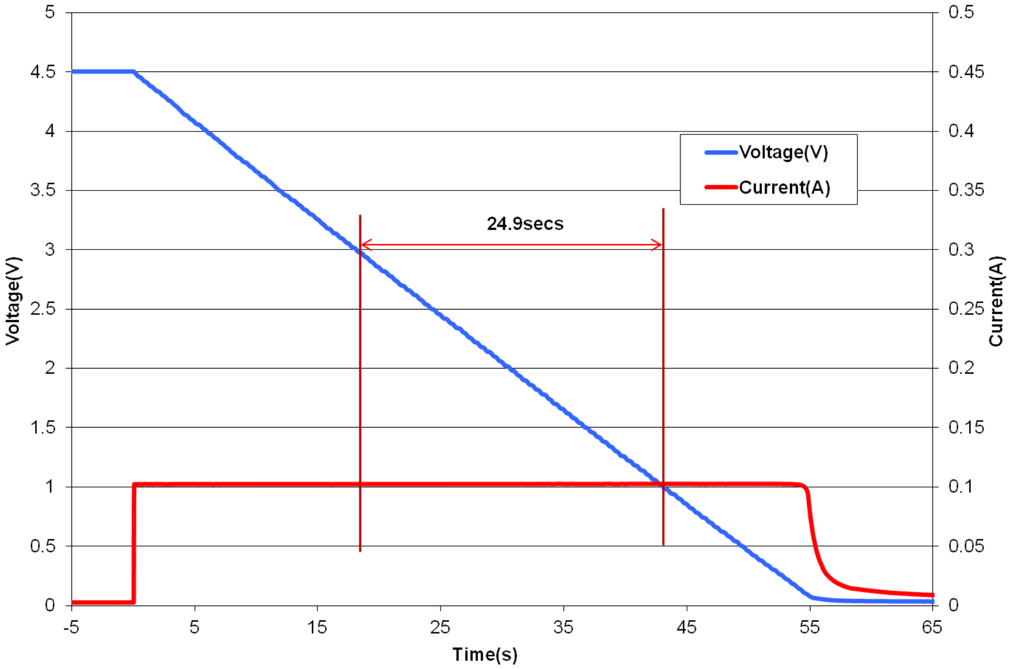

**Fig 2: Measurement of DC Capacitance for a GS230**

Fig 2 shows the measurement of DC capacitance by drawing a constant 100mA current from a fully charged supercapacitor and measuring the time taken to discharge from 1.5V to 0.5V for a single cell, or from 3V to 1V for a dual cell supercapacitor. In this case, C = 0.1A x 24.9s /2V = 1245mF, which is well within the 1200mF +/- 20% tolerance for a GS230 cell.

## Measurement of ESR

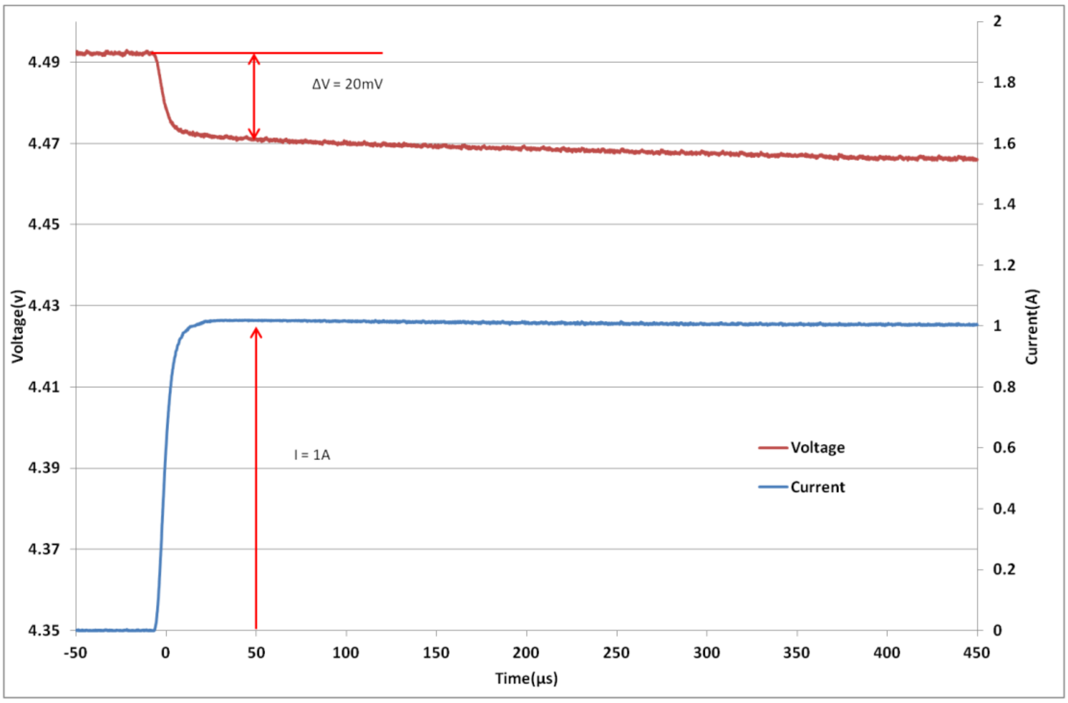

**Fig 3: Measurement of ESR for a GS230**

Fig 3 shows DC measurement of ESR by applying a step load current to the supercapacitor and measuring the resulting voltage drop. CAP-XX waits for a delay of 50µs after the step current is applied to ensure the voltage and current have settled. In this case the ESR is measured as 20mV/1A = 20mΩ.

## Effective Capacitance (Ceff)

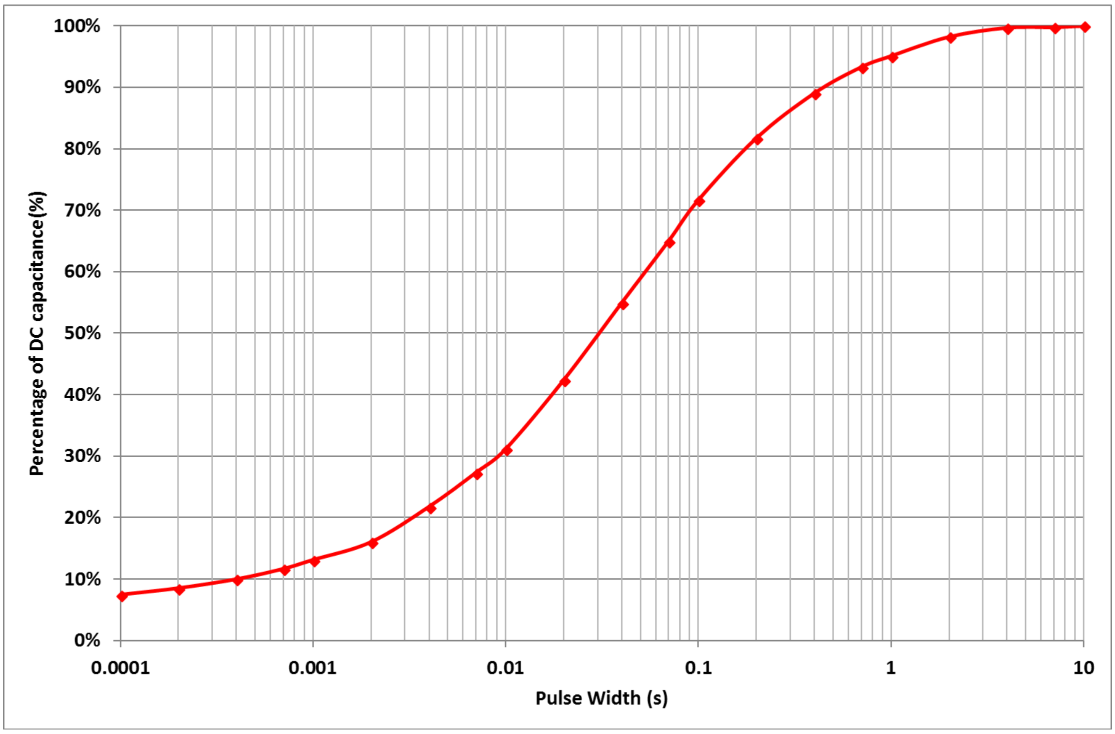

**Figure 4: Effective Capacitance**

Fig 4 shows the effective capacitance for the GS130, GS230 @ 23°C. This shows that for a 1ms PW, you will measure 13% of DC capacitance or 312mF for a GS130 or 156mF for a GS230. At 10ms, you will measure 31% of the DC capacitance, and at 100ms you will measure 72% of DC capacitance. Ceffective is a time domain representation of the supercapacitor's frequency response. If, for example, you were calculating the voltage drop if the supercapacitor was supporting 1A for 10ms, then you would use the Ceff(10msecs) = 31% of DC capacitance = 372mF for a GS230, so Vdrop = 1A x ESR + 1A x duration/C = 1A x 25mΩ + 1A x 10ms / 372mF = 52mV. The next section on pulse response shows how the effective capacitance is sufficient for even short pulse widths.

## Pulse Response

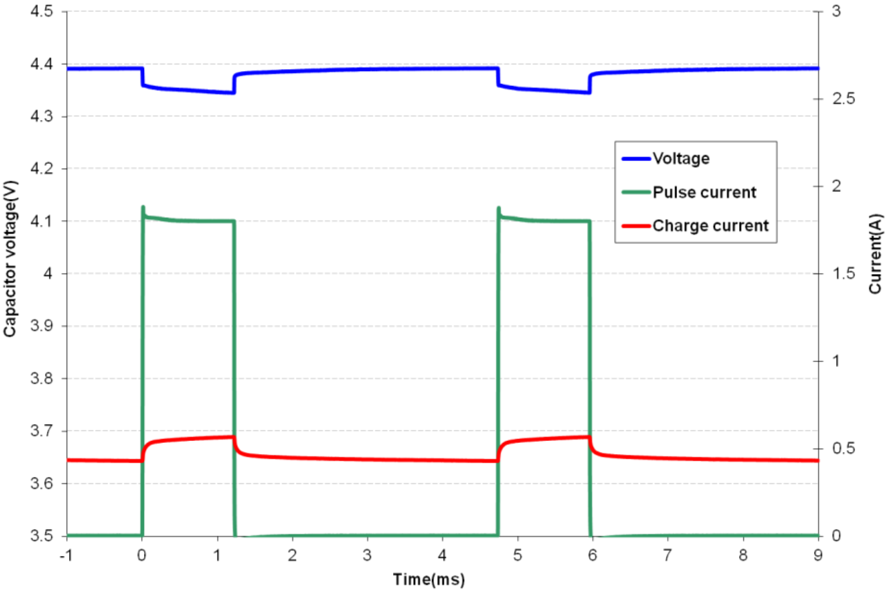

Fig 5 shows that the GS230 supercapacitor does an excellent job supporting a GPRS class 10 pulse train, drawing 1.8A for 1.1ms at 25% duty cycle. The source is current limited to 0.6A and the supercapacitor provides the 1.2A difference to achieve the peak current. At first glance the freq response of Fig 8 indicates the supercapacacitor would not support a 1.1ms pulse, but the Ceff of 132mF coupled with the low ESR supports this pulse train with only ~45mV droop in the supply rail.

**Fig 5: GS230 Pulse Response with GPRS Class 10 Pulse Train**

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## Accurate Calculation of Voltage Drop for a Pulse Using Ceff

The combination of the method used by CAP-XX to measure ESR and effective capacitance for a given pulsewidth given in Fig 4 enable the accurate calculation of voltage drop for a pulse with current *I* and pulsewidth *T* as Vdrop = *I*.[ESR + *T*/Ceff(*T*)]. Using the pulse train of Fig 5 as an example, *I* = 1.8A – 0.6A = 1.2A. *T* = 1.1ms. Nominal DC capacitance = 1200mF, and from Fig 4, Ceff(1.1ms) = 12% x 1200mF = 144mF. Nominal ESR = 24mΩ, so Vdrop = 1.2A[0.024Ω+0.0011s/0.144F] = 38mV. Fig 5 shows a voltage drop = 45mV verifying that the calculation is a good approximation. This avoids the need to run SPICE for a simple calculation.

## DC Capacitance variation with temperature

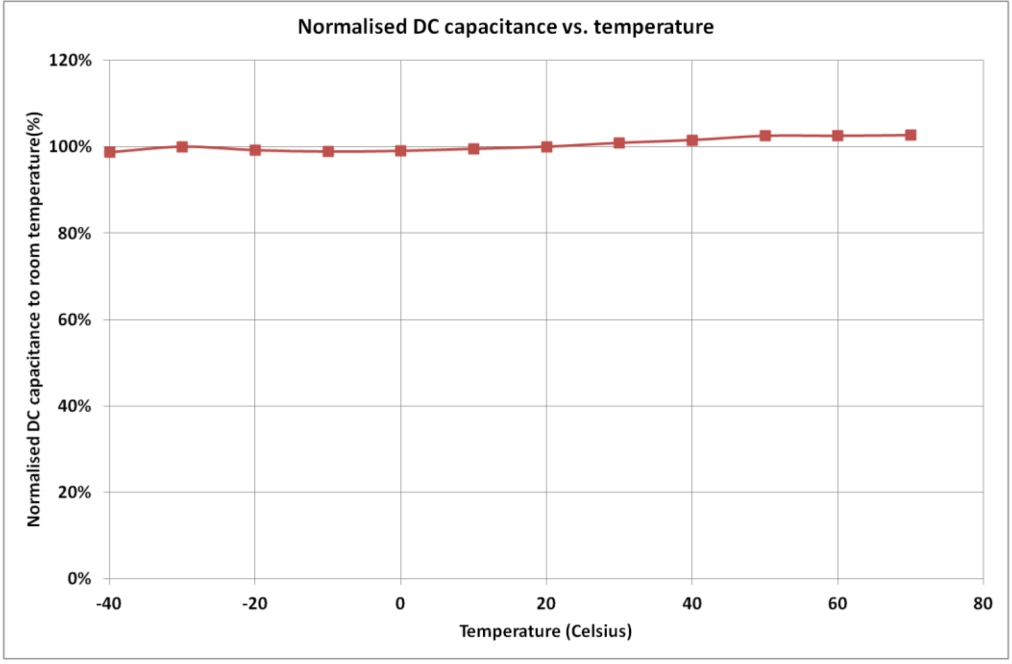

**Figure 6: Capacitance change with temperature**

Fig 6 shows that DC capacitance is approximately constant with temperature.

## ESR variation with temperature

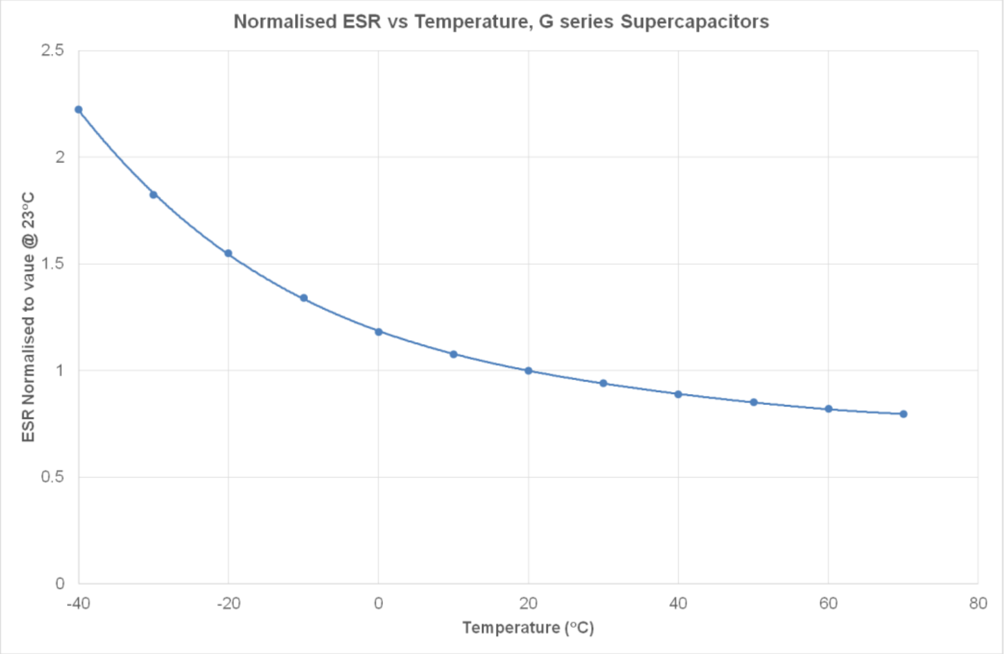

**Figure 7: ESR change with temperature**

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Fig 7 shows that ESR at -40°C is ~2.2 x ESR at room temp, and that ESR at 70ºC is ~0.8 x ESR at room temperature.

## Frequency Response

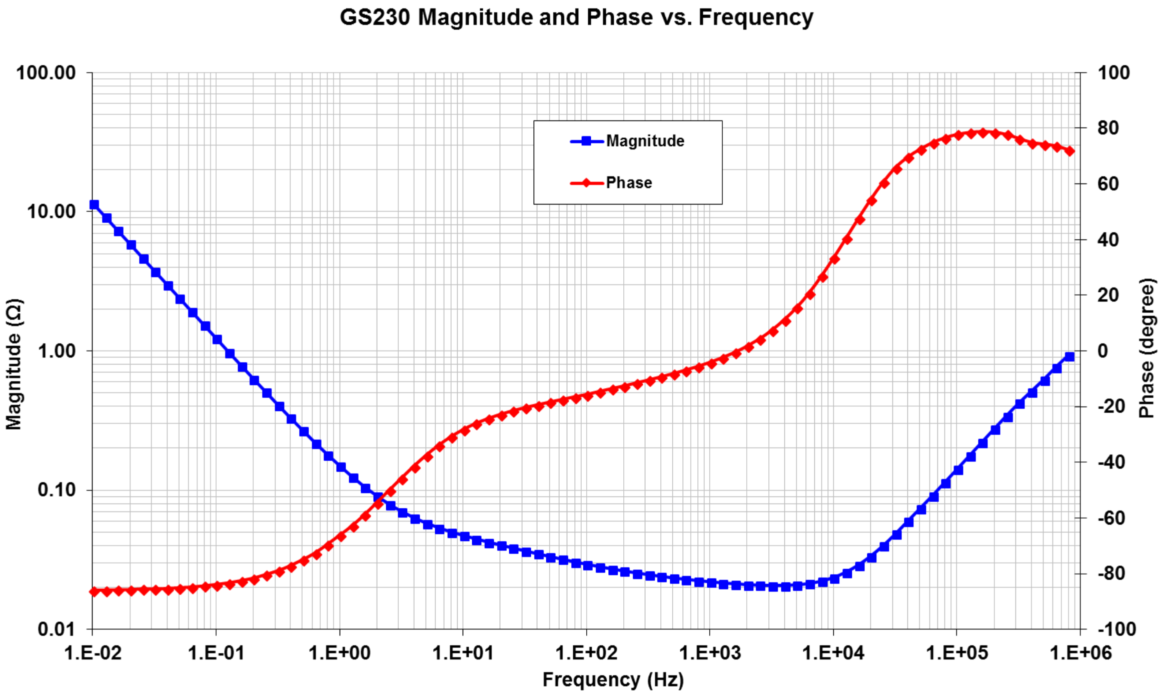

Fig 8: Frequency Response of Impedance (biased at 5V with a 50mV test signal)

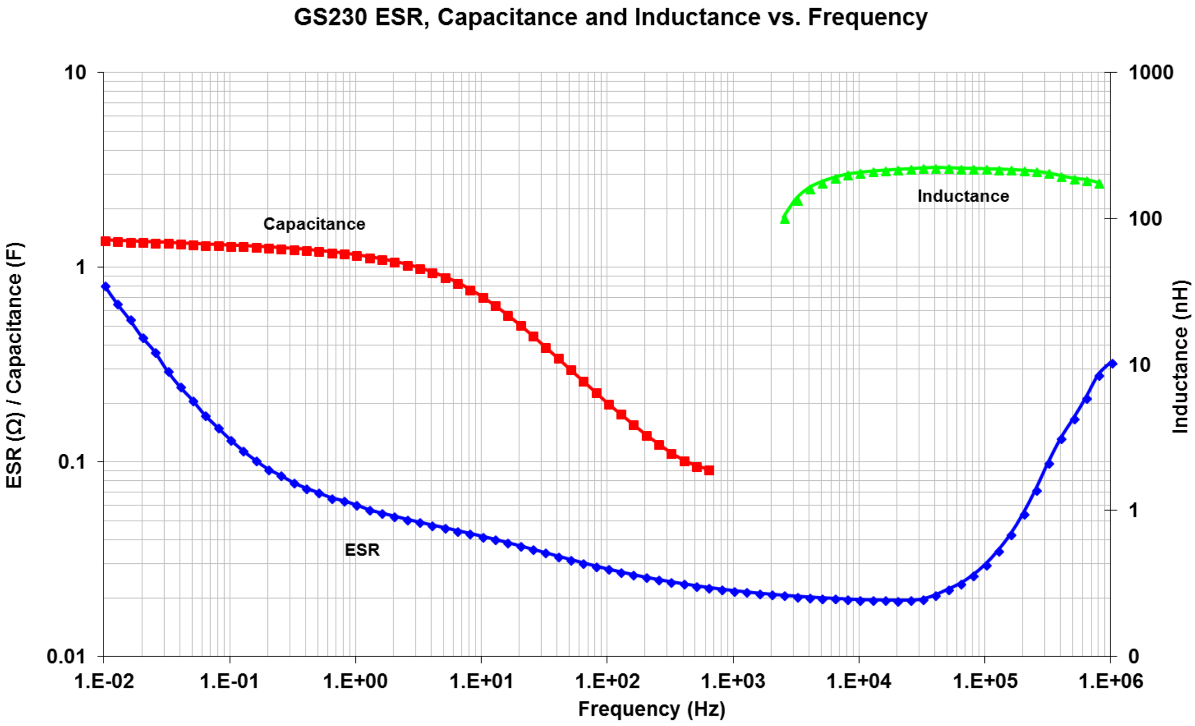

Fig 9: Frequency Response of ESR, Capacitance & Inductance

Fig 8 shows the supercapacitor behaves as an ideal capacitor until approx 3 Hz when the magnitude no longer rolls off proportionally to 1/freq and the phase crosses -45°. Performance of supercapacitors with frequency is complex and the best predictor of performance is Fig 4 showing effective capacitance as a function of pulsewidth.

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## Leakage Current

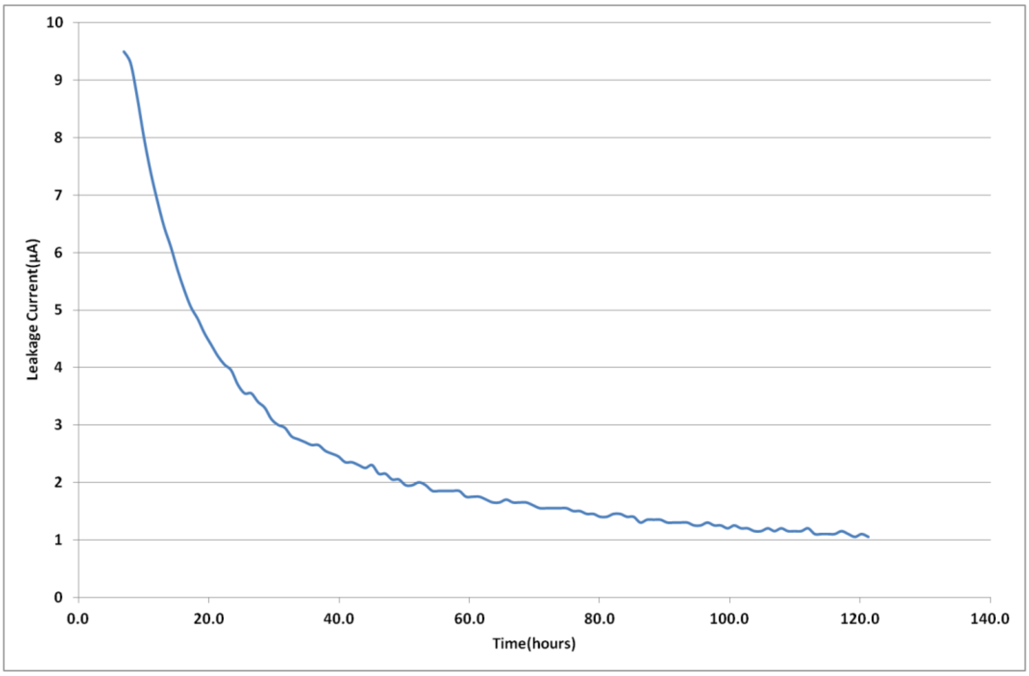

**Fig 10: Leakage Current**

Fig 10 shows the leakage current for GS130 at room temperature. The leakage current decays over time, and the equilibrium value leakage current will be reached after ~120hrs at room temperature. The typical equilibrium leakage current is 1µA at room temperature. At 70°C leakage current will be ~10µA.

## Charge Current

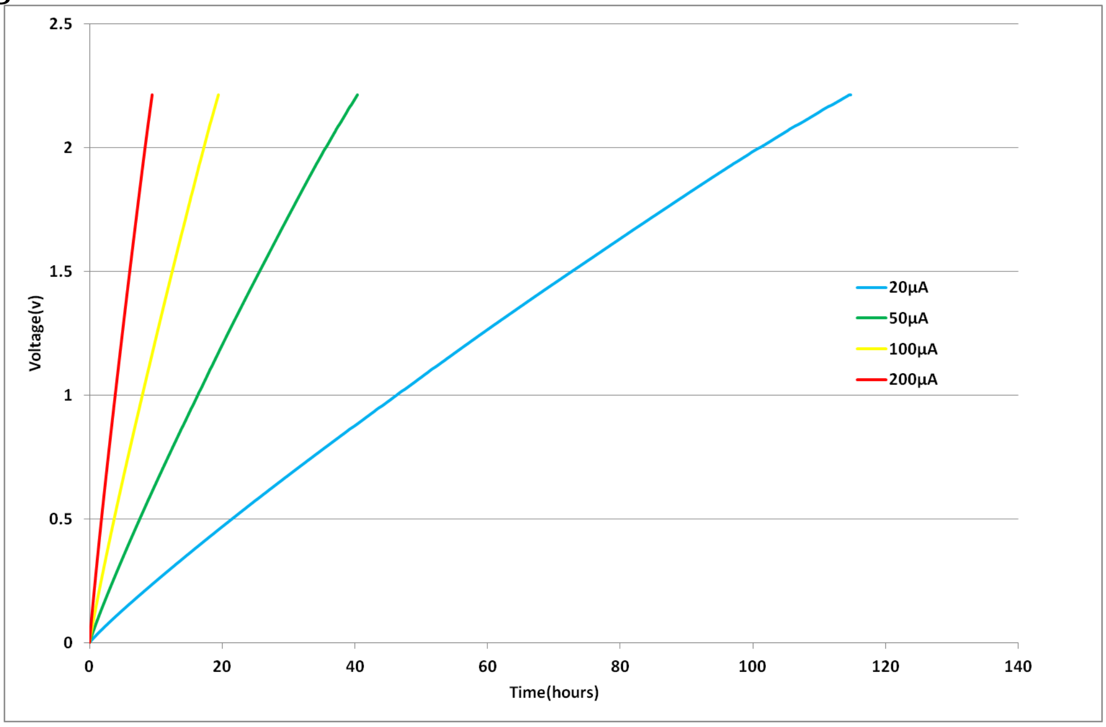

**Fig 11: Charging a GS130 with low current**

The corollary to the slow decay in leakage currents shown in Fig 10 is that charging a supercapacitor at very low currents takes longer than theory predicts. At higher charge currents, the charge rate is as theory predicts. For example, it should take 2.4F x 2.2V / 0.00002A = 80hrs to charge a 2.4 F supercapacitor to 2.2V at 20µA, but Fig 11 shows it took 120hrs. At 100µA charging occurs at a rate close to the theoretical rate.

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## RMS Current

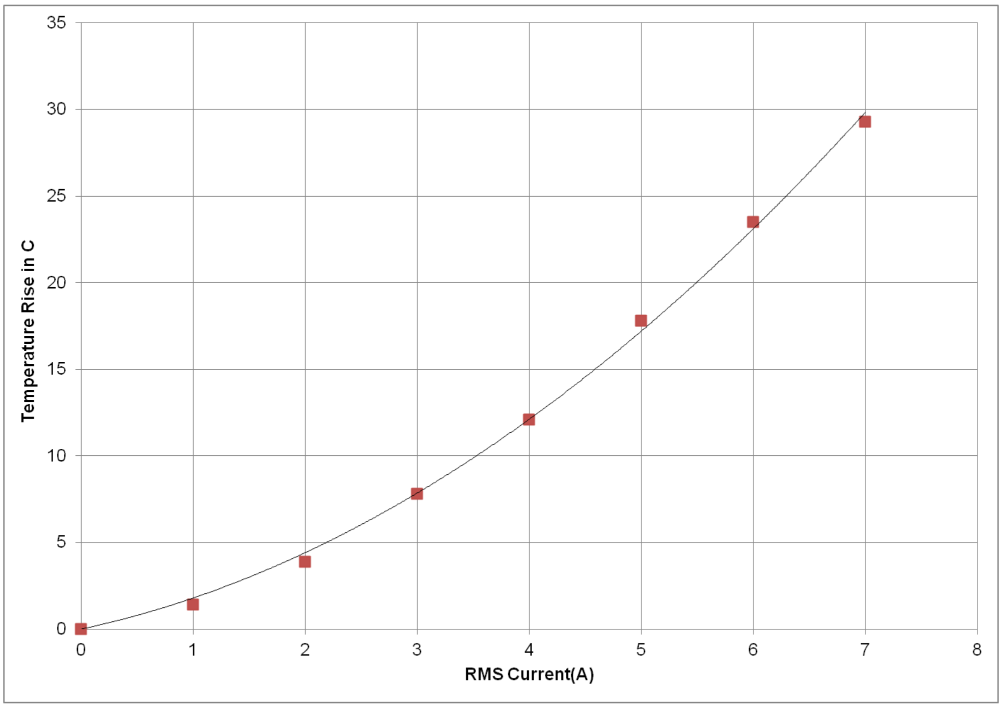

**Fig 12: Temperature rise in GS230 with RMS current**

Continuous current flow into/out of the supercap will cause self heating, which limits the maximum continuous current the supercapacitor can handle. This is measured by a current square wave with 50% duty cycle, charging the supercapacitor to rated voltage at a constant current, then discharging the supercapacitor to half rated voltage at the same constant current value. For a square wave with 50% duty cycle, the RMS current is the same as the current amplitude. Fig 12 shows the increase in temperature as a function of RMS current. From this, the maximum RMS current in an application can be calculated, for example, if the ambient temperature is 40°C, and the maximum desired temperature for the supercapacitor is 70°C, then the maximum RMS current should be limited to 7A, which causes a 30°C temperature increase.

## CAP-XX Supercapacitors Product Guide

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