

NASA Electronic Parts and Packaging (NEPP) Program

Evaluation of Ferrite Chip Beads as Surge Current Limiters in Circuits with Tantalum Capacitors

Alexander Teverovsky

ASRC Federal Space and Defense

Work performed for NASA, GSFC, Code 562

Parts, Packaging, and Assembly Technologies Office

Alexander.A.Teverovsky@nasa.gov

List of Acronyms and Symbols

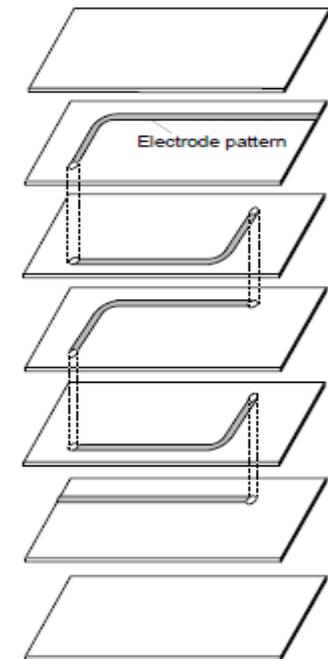
AC	Alternating current	RDC	Direct current resistance
3SCT	Step stress surge current testing	R_{eff}	Effective resistance
C A	Construction analysis	RF	Radio frequency
DC	Direct current	S&Q	Screening and qualification
DLA	Defense logistic agency	SCT	Surge current test
DPA	Destructive physical analysis	SMD	Surface mount device
DWG	Drawing	STD	Standard deviation
EMI	Electromagnetic interference	T_c	Curie temperature
ESR	Equivalent series resistance	TSD	Terminal solder dip
FB	Ferrite bead	VBR	Breakdown voltage
IWT	Ice water test	Z	Impedance
MLCC	Multilayer ceramic capacitor		

Abstract

Limiting resistors are currently required to be connected in series with tantalum capacitors to reduce the risk of surge current failures. However, application of limiting resistors decreases substantially the efficiency of the power supply systems. An ideal surge current limiting device should have a negligible resistance for DC currents and high resistance at frequencies corresponding to transients in tantalum capacitors. This work evaluates the possibility of using chip ferrite beads (FB) as such devices. Twelve types of small size FBs from three manufacturers were used to evaluate their robustness under soldering stresses and at high surge current spikes associated with transients in tantalum capacitors. Results show that FBs are capable to withstand current pulses that are substantially greater than the specified current limits. However, due to a sharp decrease of impedance with current, FBs do not reduce surge currents to the required level that can be achieved with regular resistors.

Outline

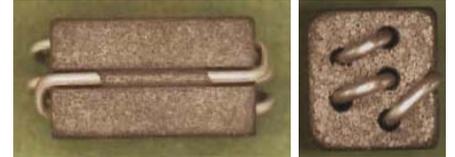
- ❑ Introduction.
 - Specific features of ferrite beads.
 - Design.
 - Specifications.
- ❑ Test plan.
 - Parts used and results of DPA.
 - Test techniques.
- ❑ Test results.
 - Initial characterization of the lots.
 - Ice water testing.
 - Effect of terminal solder dip testing.
 - Effective resistance at high current spikes.
 - Effect of ferrite beads on surge currents.
 - Failures of ferrite beads under high surge currents.
- ❑ Summary.



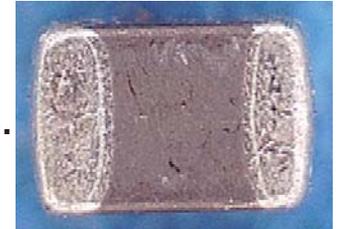
Schematic of winding electrode type of SMD FB (Murata)

Introduction

Wound chip ferrite bead



SMD chip ferrite bead



- ❑ FBs are typically used for electromagnetic interference (EMI) and noise suppression in electronic circuits.
- ❑ The parts have low resistance at DC and high resistance at high frequencies. This feature might be useful to suppress surge currents in tantalum capacitors and reduce failures.
- ❑ Replacement of limiting resistors that are currently required to limit surge currents (0.1 ohm per volt or 1 ohm, whichever is greater) with FBs might increase the efficiency of the power supply systems.
- ❑ Variety of designs are available, from through-hole beads on wires, wound beads, and SMD chip beads.
- ❑ The focus of this work was on chip ferrite beads that allow for reduction of size and weight of the circuits.

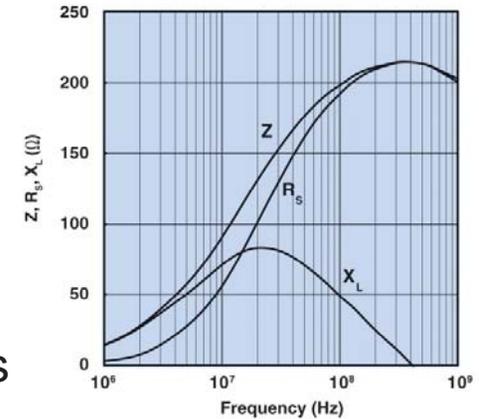
The purpose of this work was to evaluate the feasibility of using SMD chip FBs to reduce surge currents in circuits with tantalum capacitors, in particular:

- Assess the robustness of FB to soldering thermal shock stresses.
- Assess the capability of FBs to sustain current pulses exceeding rated currents.
- Estimate the effective resistance of FBs under surge current conditions and the degree of current spikes' reduction.
- Evaluate behavior of FBs under multiple high current spikes.

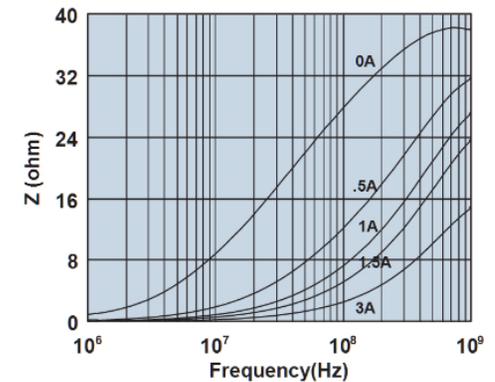
Specifics of Ferrite Beads

- ❑ Contrary to high-frequency air coils, FBs at high frequencies, work like resistors instead of inductors and dissipate RF power in the form of heat.
- ❑ FBs can be presented as frequency dependent resistors and their equivalent circuit consists of a resistor and inductor connected in series.
- ❑ Since the impedance of FBs is essentially resistive at high frequencies, the risk related to resonances experienced by other EMI filtering choices like capacitors and inductors is reduced substantially.
- ❑ Current levels even below the maximum rated DC value can cause FBs to significantly lose its effectiveness as the material of the bead becomes saturated.
- ❑ Recommended storage and operating temperature range is $-55\text{ }^{\circ}\text{C}$ to $125\text{ }^{\circ}\text{C}$.
- ❑ The rated impedance of FBs at 100 MHz is up to 1 kOhm.

✓ Considering a reduction of impedance with frequency and current, it is possible that the resistance of high-Z FBs during surge currents will remain at a level of a few ohms that might be sufficient to reduce surge current failures.



Impedance, reactance, and resistance vs. frequency for a ferrite core in 43 material (Fair-Rite)



Frequency dependence of impedance at different current levels (Fair-Rite PN 2506033007Y3)

Characteristics of Ferrite Materials (Fair-Rite)

FBs are typically manufactured using Ni/Zn ferrite compositions

44 Material Characteristics:

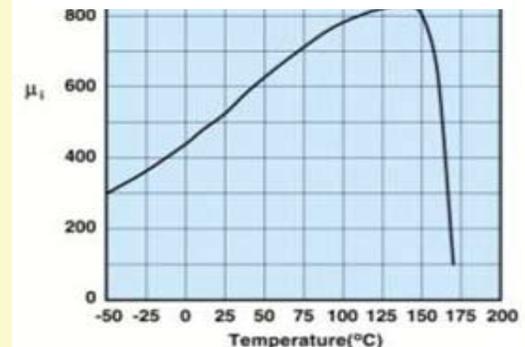
Specific Heat	0.25 cal/g/°C
Thermal Conductivity	10x10 ⁻³ cal/sec/cm/°C
Coefficient of Linear Expansion	8 - 10x10 ⁻⁶ /°C
Tensile Strength	4.9 kgf/mm ²
Compressive Strength	42 kgf/mm ²
Young's Modulus	15x10 ³ kgf/mm ²
Hardness (Knoop)	650
Specific Gravity	≈ 4.7 g/cm ³

The above quoted properties are typical for Fair-Rite MnZn and NiZn ferrites.

Property	Unit	Symbol	Value
Initial Permeability @ B < 10 gauss		μ_i	500
Flux Density @ Field Strength	gauss oersted	B H	3000 10
Residual Flux Density	gauss	B_r	1100
Coercive Force	oersted	H_c	0.45
Loss Factor @ Frequency	10 ⁻⁶ MHz	$\tan \delta/\mu_i$	125 1.0
Temperature Coefficient of Initial Permeability (20 -70°C)	%/°C		0.75
Curie Temperature	°C	T_c	>160
Resistivity	Ω cm	ρ	1x10 ⁹

- ✓ The Curie temperature (T_c) is a transition point above which the ferrite loses its magnetic properties. Typically, for materials used in FBs T_c exceeds 160 °C.
- ✓ Mechanical characteristics of ferroelectrics used for FBs are similar to ceramic materials used for MLCCs:
 - The CTE is in the range from 8 to 10 ppm/°C;
 - The tensile strength is almost an order of magnitude less than the compressive strength.
- ✓ Soldering and assembly-related cracking issues are similar for FBs and MLCCs; however, the consequences of cracking are likely less dramatic for FBs.

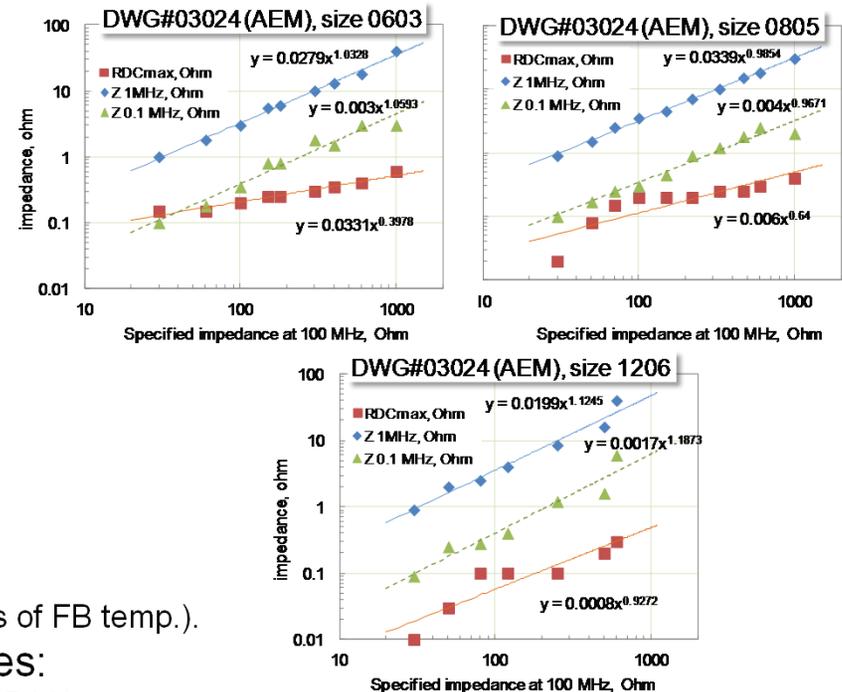
Temperature dependence of permeability at 100 kHz



DLA DWG#03024 for High-Reliability Chips

- ❑ The range of specified values:
 - Impedance at 100 MHz: from 30 ohm to 1000 ohm;
 - RDC: from 0.01 ohm to 0.6 ohm;
 - I_{max}: from 0.2 A to 4 A;
 - Size: from 0603 to 1206.
- ❑ Terminal materials and derating:
 - The terminations shall be covered with tin/lead coating.
 - The DC current should be derated linearly from the nominal value at 25°C to 50% I_{max} at 125°C.
- ❑ Screening (100%):
 - 5 TC from -65 °C to +125 °C;
 - Measurements of RDC and Z;
 - Visual examination.
- ❑ Group B inspection (4 to 8 samples) includes:
 - Resistance to solvents;
 - Solderability;
 - Resistance to Soldering Heat (solder dip);
 - Termination Strength;
 - Current Carrying Capacity (1.5hr at 3 temp with measurements of FB temp.).
- ❑ Group C inspection (by a special request) includes:
 - Low Temp. Operation (soldered chip, 4 hr at rated current at -55 °C and Life (16 samples, 125 °C, 64% of rated current for 1000 hrs);
 - Bending (similar to flex testing for MLCCs);
 - Thermal Shock (100 cycles from -65 °C to +200 °C);
 - Moisture Resistance.

Correlation between the specified impedance at 100 MHz, RDC, and impedance values estimated at 1MHz and 0.1MHz using typical data provided by AEM



✓ DWG#03024 and AEM DPA procedures have adequate requirements for space applications.

- ✓ There is no procedure to determine I_{max}, and current rating is based on “historic” data.
- ✓ Large impedance parts have greater RDC and Z at 100 kHz that is important for surge current suppression.

Part Types Used

Twelve types of SMD ferrite bead from three manufacturers were used to reveal common features in behavior of the parts at high current spikes conditions.

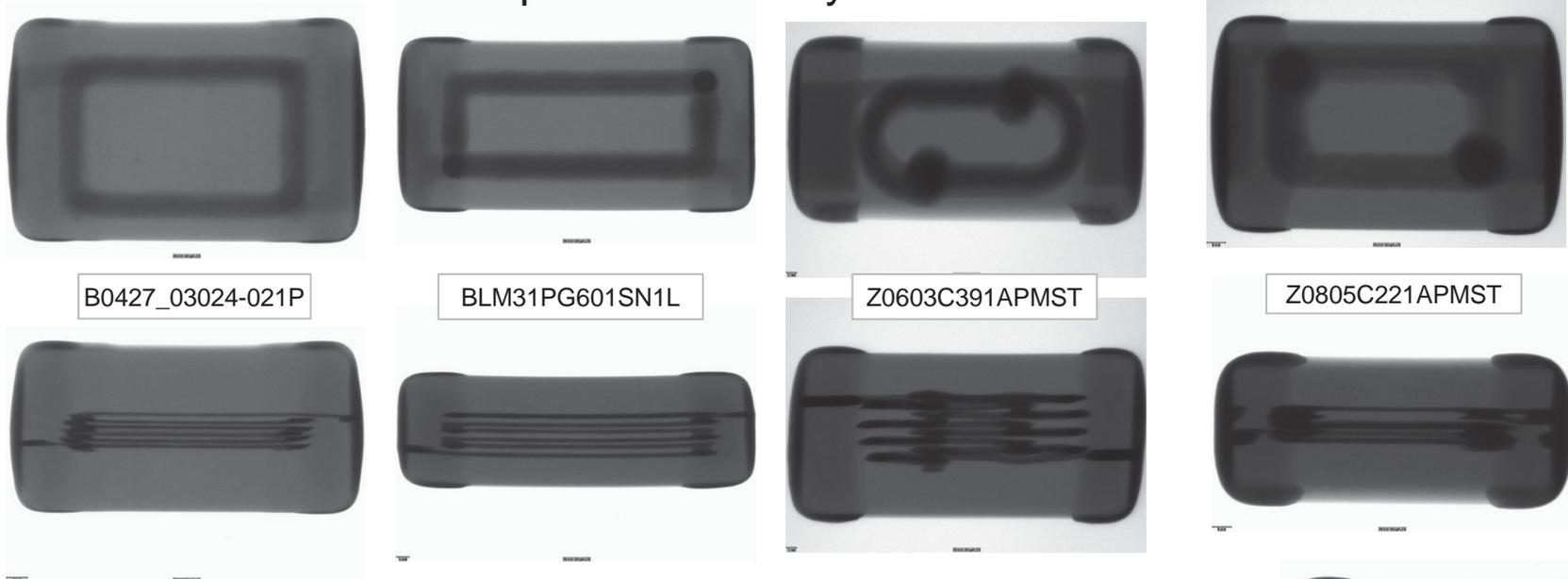
Gr.	Part	Mfr.	case size	Z, Ohm	R, mOhm	I max, A
1	BLM18PG181SN1D	Murata	0603	180	90	1.5
2	BLM31PG601SN1L	Murata	1206	600	80	1.5
3	Z0603C391APMST	KEMET	0603	390	140	1
4	Z0805C601BSMST	KEMET	0805	600	250	0.5
5	Z0805C221APMST	KEMET	0805	220	50	2
6	Z1206C800APWST	KEMET	1206	80	10	4
7	Z1806C111APWST	KEMET	1806	110	14	4
8	DWG#03024-001P	AEM	0603	30	150	0.5
9	DSCC#03024-009P	AEM	0603	1000	600	0.2
10	DSCC#03024-021P	AEM	0805	1000	400	1
11	DSCC#03024-023P	AEM	1206	50	30	3
12	DSCC#03024-028P	AEM	1206	600	300	1

Test Plan

- ❑ CA/DPA of FBs to evaluate their design, used materials, and potential reliability risks.
- ❑ Measure initial characteristics of FBs and analyze their distributions to reveal out of family parts and assess uniformity of production (5 to 30 samples in a group).
- ❑ Evaluate the robustness of FBs to soldering-related thermal shock by terminal solder dip testing and ice water tests at the range of temperatures from 175 °C to 350 °C. (5 to 10 samples in each group).
- ❑ Assess the capability of FB to suppress surge currents by comparing results of step stress surge current testing (3SCT) of tantalum capacitors with and without FBs (5 to 6 samples in a group).
- ❑ Evaluate the effect of high current pulses on characteristics of FBs by measuring RDC and impedance at different frequencies after 3SCT.
- ❑ Evaluate the capability of FBs to sustain multiple high current spikes by stressing them with 20 surge current pulses caused by charging of tantalum capacitors.

Results of DPA

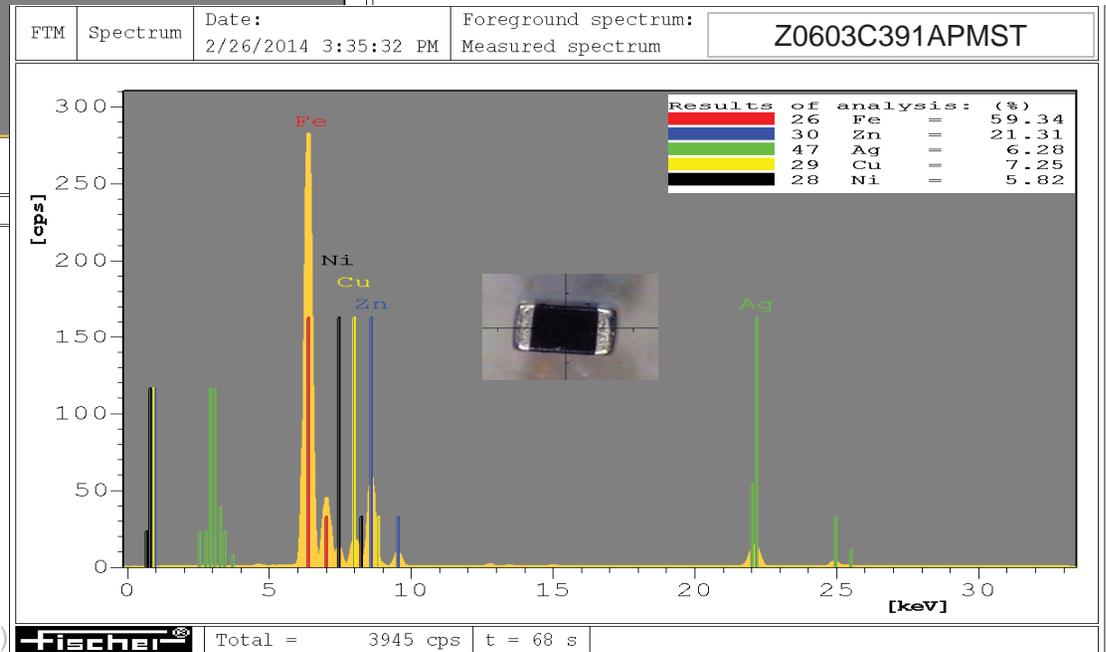
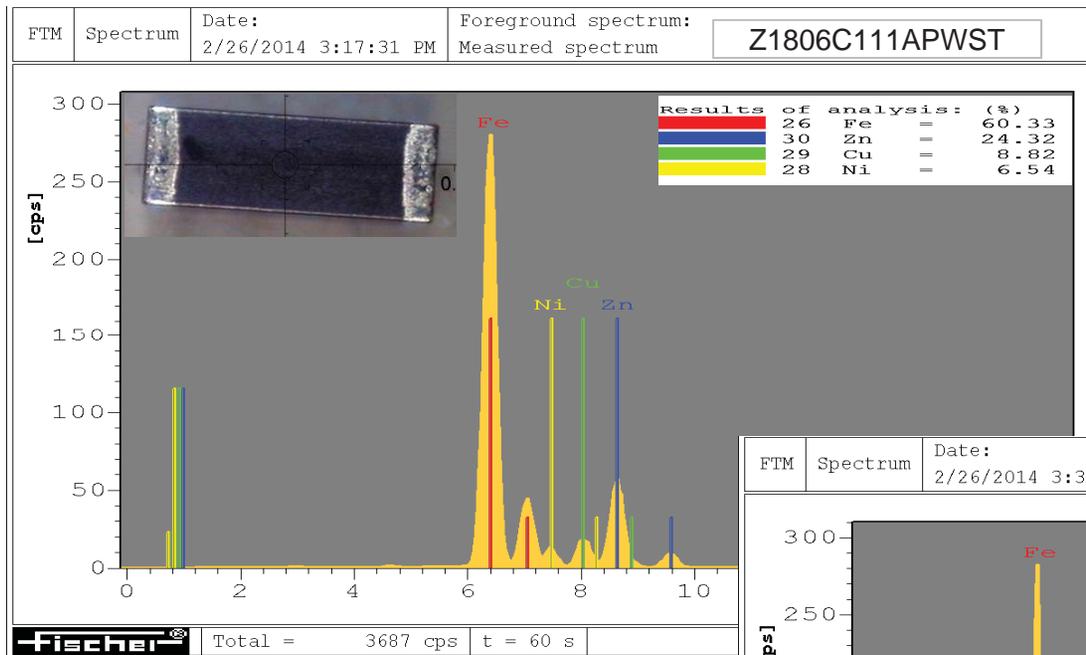
Top and side X-ray views of FBs



- ✓ High-Z FBs (≥ 220 Ohm) are manufactured using multilayer coil processes.
- ✓ No gross defects were observed.



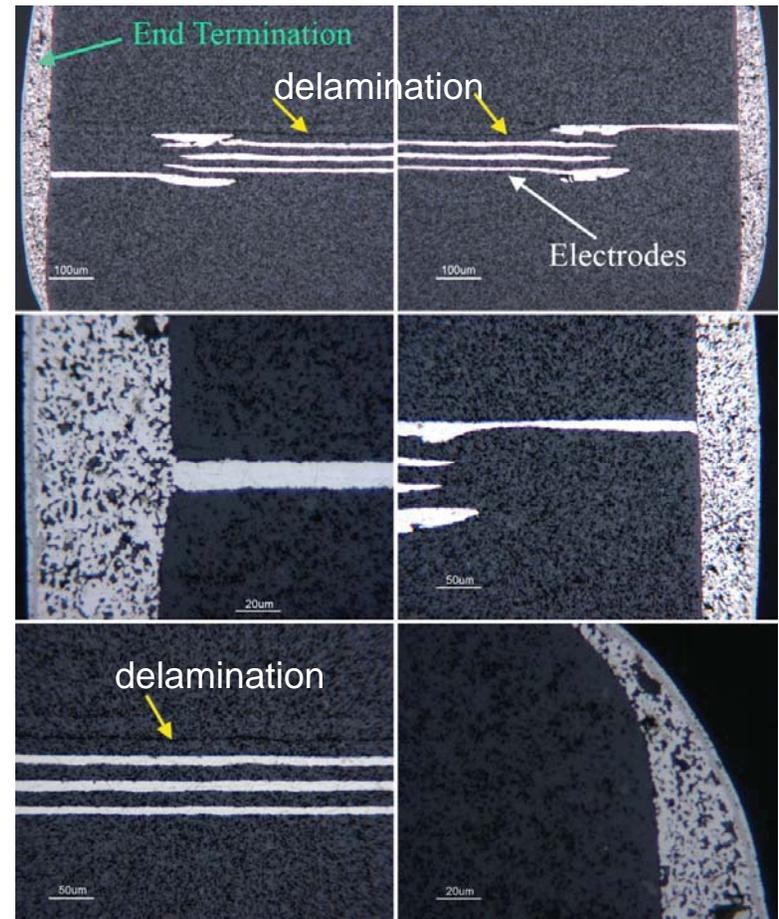
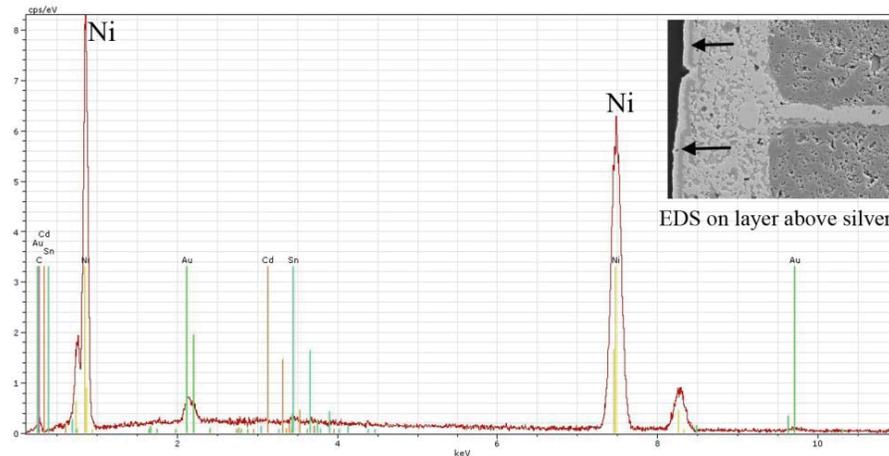
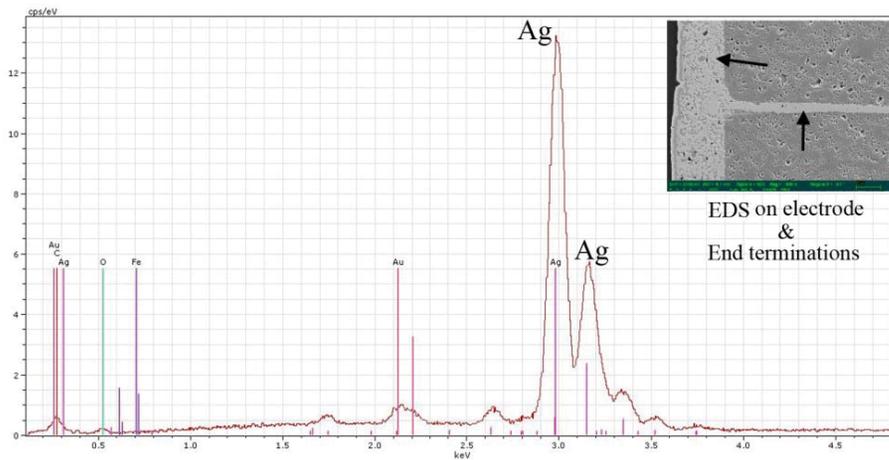
Results of XRF of FBs



✓ Typical composition of ferroelectric materials:
Fe, Ni, Cu, Zn

Deliverable to NASA Electronic Parts and Packaging (NEPP) be published on nepp.nasa.gov.

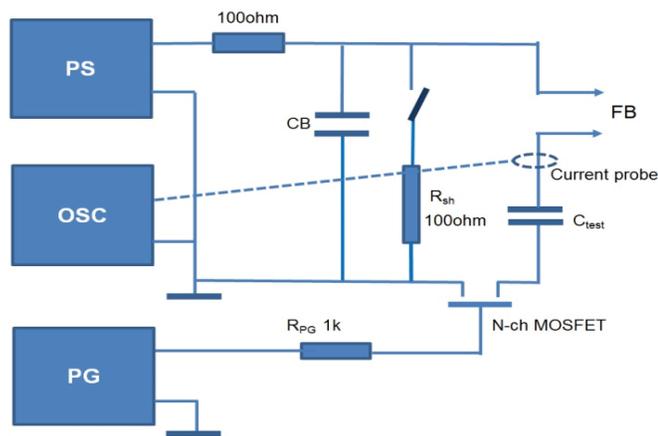
Cross-Section PN 03024-20M (0805, 600Ohm)



- ✓ Termination materials: Ag-Ni-Sn/Pb; material of coil traces: silver.
- ✓ Due to a low voltage drop along metal traces, delaminations between the layers observed during cross-sectioning are likely not a reliability concern.

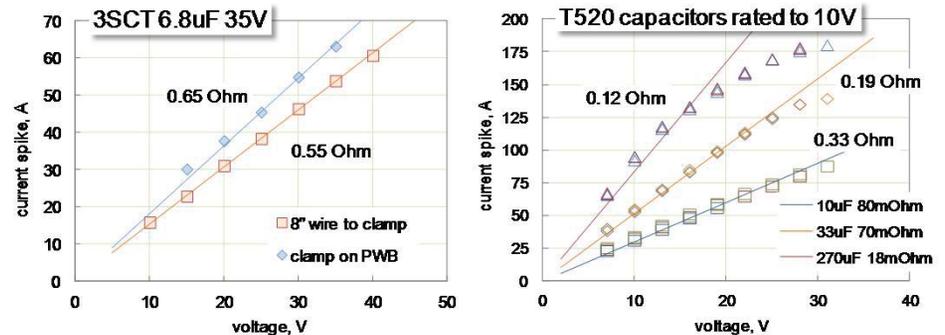
Surge Testing

- ❑ A set-up for SCT was optimized to reduce inductance and increase current spikes.
- ❑ Different types of MnO₂ and polymer (T520-series) tantalum capacitors were tested by 3SCT to select a part with minimal effective resistance and maximum current spike amplitude.

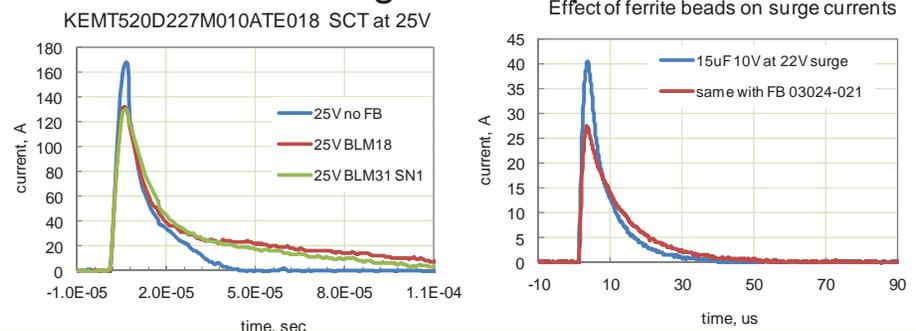


CB is the bank capacitor (4 mF) that provides energy for current spikes;
 C_{test} is a polymer tantalum capacitor 270 μ F, ESR = 18 mOhm under surge test;
 R_{sh} = 100 Ohm is a resistor that discharges C_{test} between the surge cycles.

Variations of current spike amplitude with voltage

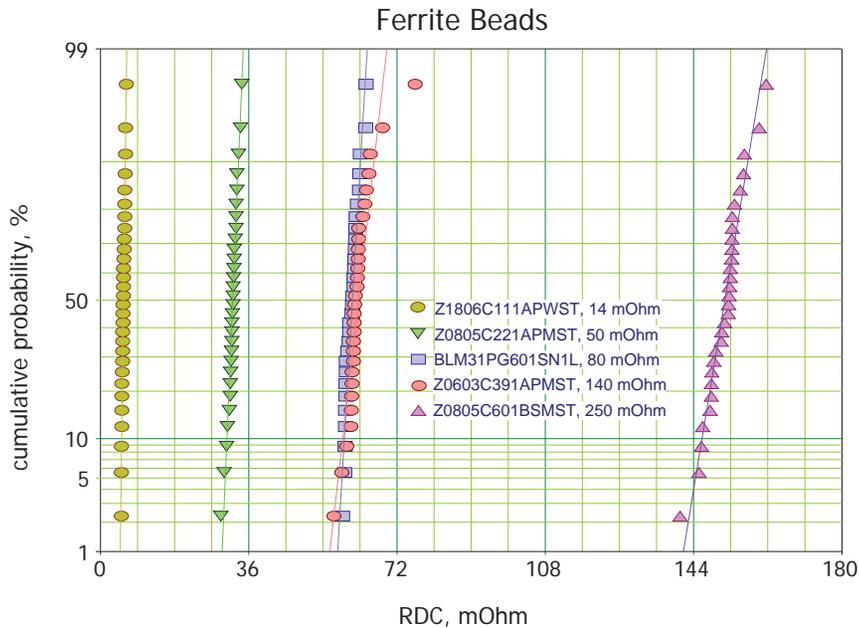


Oscillograms of spikes



- ✓ Using on-board clamps instead of wired connectors reduces R_{eff} by ~ 0.1 Ohm.
- ✓ 3SCT with different types of capacitors showed that R_{eff} of the circuit is ~ 0.12 Ohm.
- ✓ FBs reduce the amplitude of current spikes and increase their width.

Initial Characteristics, RDC

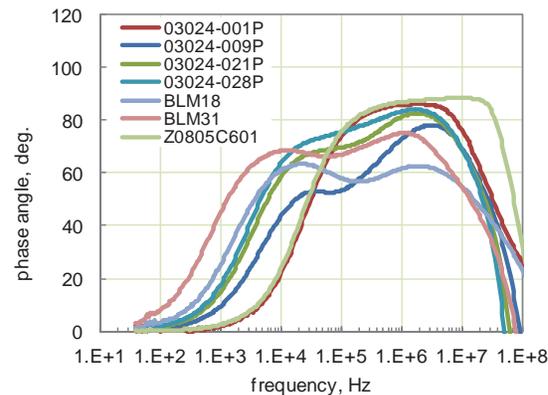
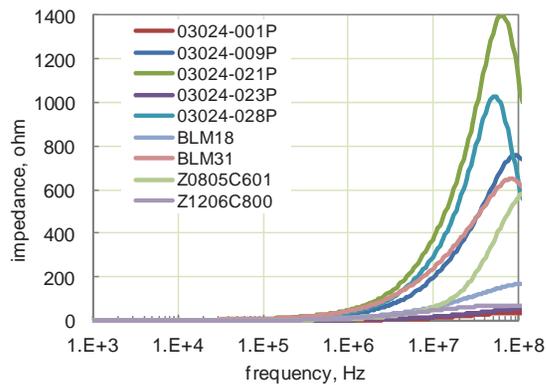


- ✓ No out of specification or out of family parts.
- ✓ Tight distributions of RDC.
- ✓ Actual RDC values are 25% to 75% less than the nominal values.

Gr.	Part	R_spec mOhm	R_avr., mOhm	R_STD, mOhm	R_avr/ R_spec ,%
1	BLM18PG181SN1D	90	65.6	13.2	72.9
2	BLM31PG601SN1L	80	61.2	1.5	76.5
3	Z0603C391APMST	140	62.6	3.0	44.7
4	Z0805C601BSMST	250	151.6	4.3	60.6
5	Z0805C221APMST	50	32.1	1.1	64.2
6	Z1206C800APWST	10	5.24	0.77	52.4
7	Z1806C111APWST	14	5.6	0.3	39.9
8	DWG#03024-001P	150	36.9	4.2	24.6
9	DSCC#03024-009P	600	310.6	11.2	51.8
10	DSCC#03024-021P	400	249.8	16.7	62.4
11	DSCC#03024-023P	30	8.5	0.2	28.3
12	DSCC#03024-028P	300	135.0	7.2	45.0

Inductance and Resistance of FBs

- Impedance amplitude (Z) and phase angle (θ) were measured in the range from 40 Hz to 110 MHz using an impedance analyzer 4294A.
- Inductance (L) and series resistance (R) were calculated using equations:

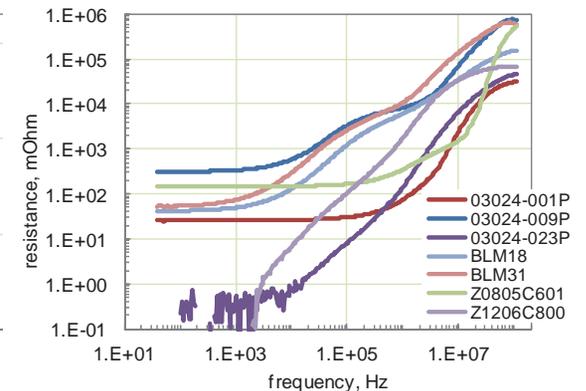
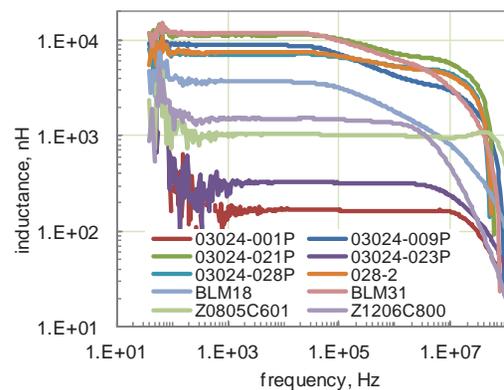


$$L = \frac{|Z| \times \sin(\theta)}{2 \times \pi \times f}$$

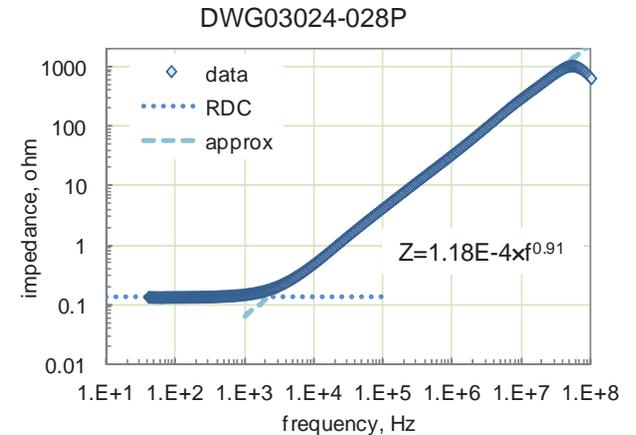
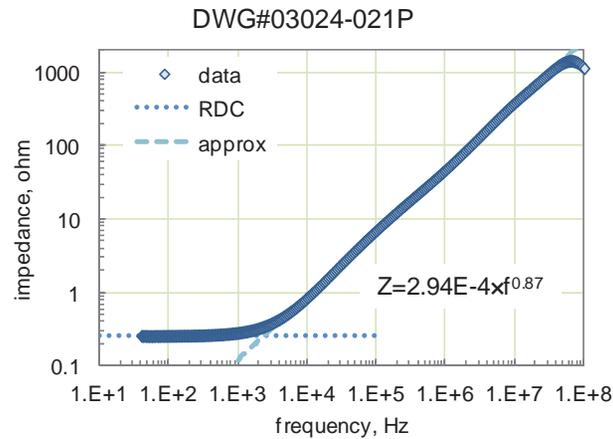
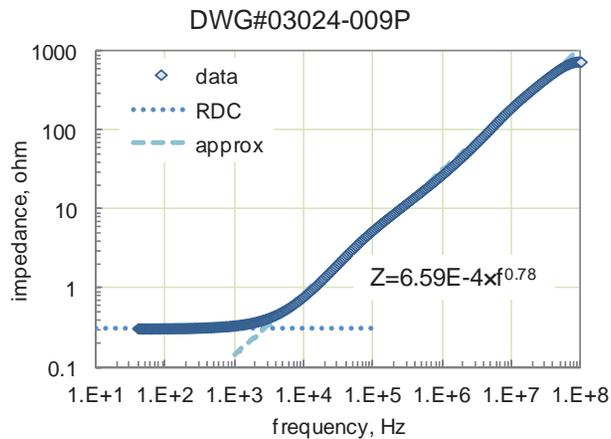
$$R = |Z| \cos \theta$$

- ✓ FBs can be presented as inductors at relatively narrow frequency range, from ~1 kHz to ~1 MHz.
- ✓ At high frequencies (>10 MHz) impedance is due to resistance.

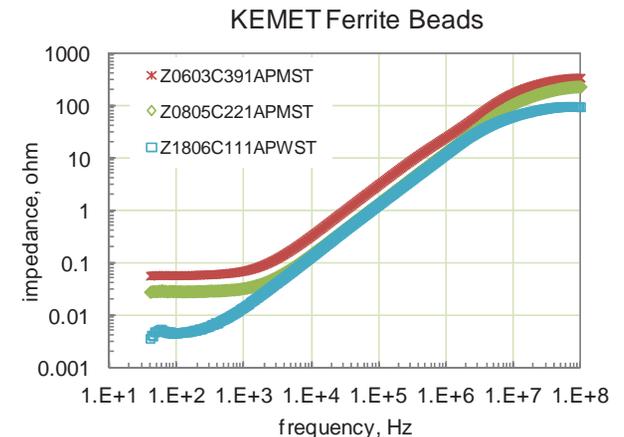
Calculated inductance and resistance



Frequency Dependence of Impedance



- ✓ Impedance reaches maximum at frequency close to the specified, 100 MHz.
- ✓ In the range of frequencies from 1 kHz to ~10 MHz impedance is a power function of frequency with the exponent varying from 0.8 to 0.9.
- ✓ At low frequencies (< 1 kHz) the impedance is close to the measured values of RDC.



Initial Characteristics, Impedance

- ❑ The Table shows specified (Z_{spec}) values of impedance and characteristics of distributions (average, Z_{avr} , and standard deviation, Z_{STD}).
- ❑ Inductance (L) was calculated at 10 kHz based on $Z - f$ and $\theta - f$ dependencies.

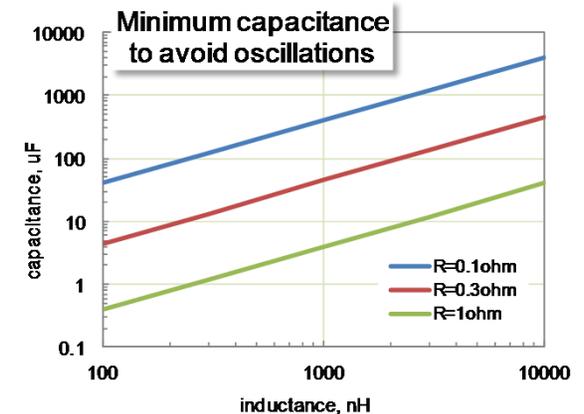
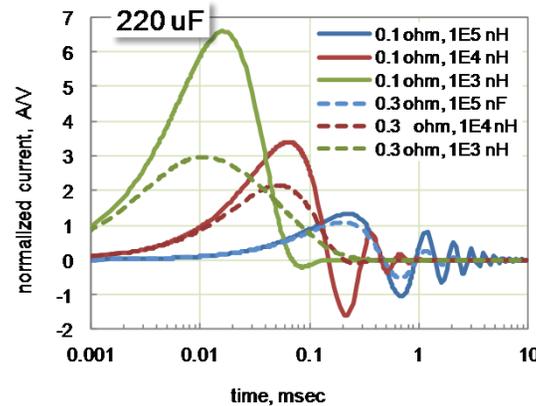
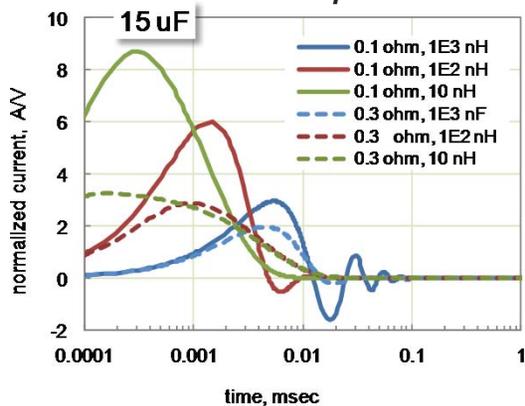
Gr.	Part	Z_{spec} , Ohm	Z_{avr} , Ohm	Z_{STD} , Ohm	$Z_{\text{avr}}/Z_{\text{spec}}$, %	L, nH
1	BLM18PG181SN1D	180	167	3	92.8	3615
2	BLM31PG601SN1L	600	609	11	101.5	11776
3	Z0603C391APMST	390	361	8	92.6	-
4	Z0805C601BSMST	600	579	17	96.5	1033
5	Z0805C221APMST	220	218	8	99.1	-
6	Z1206C800APWST	80	65	5	81.3	1513
7	Z1806C111APWST	110	91	4	82.7	-
8	DWG#03024-001P	30	34	-	113.3	167
9	DSCC#03024-009P	1000	751	-	75.1	8722
10	DSCC#03024-021P	1000	1110	-	111.0	11342
11	DSCC#03024-023P	50	51	0.4	102.0	328
12	DSCC#03024-028P	600	631	18	105.2	7143

- ✓ Distributions of Z had low STD (typically below 5%).
- ✓ No out-of family samples.
- ✓ Inductance was in the range from ~200 nH to ~10 μ H.

Surge Currents in a Circuit with Inductance

- Introduction of FBs increases inductance of the circuits.
- To avoid oscillations and assure overdamped conditions in an R-L-C circuit, the inductance should be low:
$$\left(\frac{ESR + R_{int}}{2L}\right)^2 - \frac{1}{LC} > 0$$
- Considering a typical range of inductance of FBs from 100 nH to 10 μ H and resistance of the circuit ($ESR + R_{int} \approx ESR$) from 0.1 ohm to 1 ohm, the range of capacitors that might be used with FBs without oscillations was calculated.

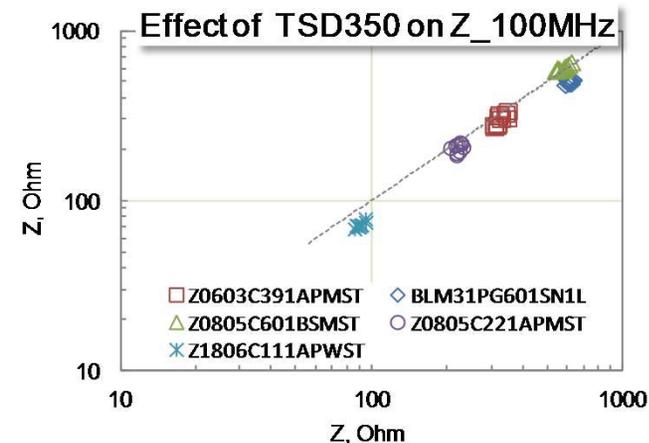
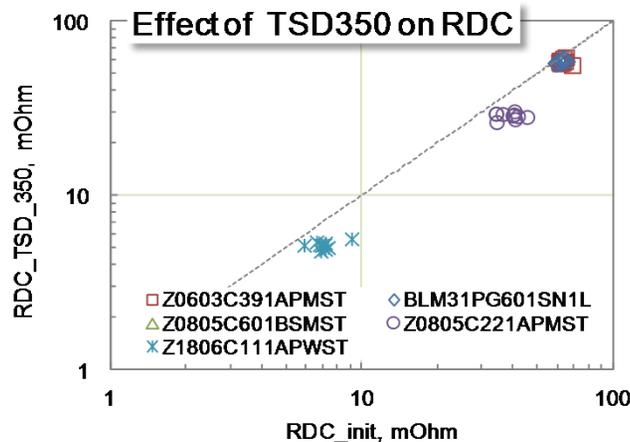
Examples of transients in R-L-C circuits



- Use of FBs with inductance up to 10 μ H for capacitors with $ESR \geq 1$ Ohm will not cause oscillations.
- For low-ESR capacitors ($ESR < 0.1$ Ohm), FBs might be used if $C > 40$ μ F.
- A resistive character of FBs at high frequencies mitigates the risk of oscillations.

Terminal Solder Dip Testing

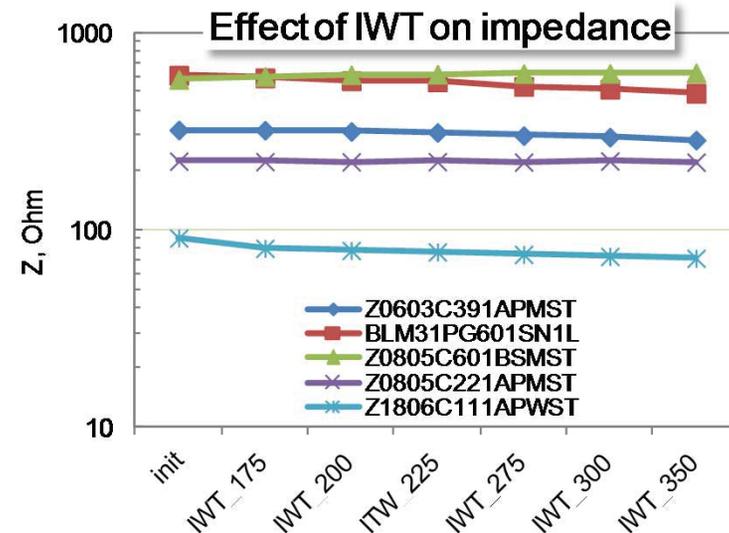
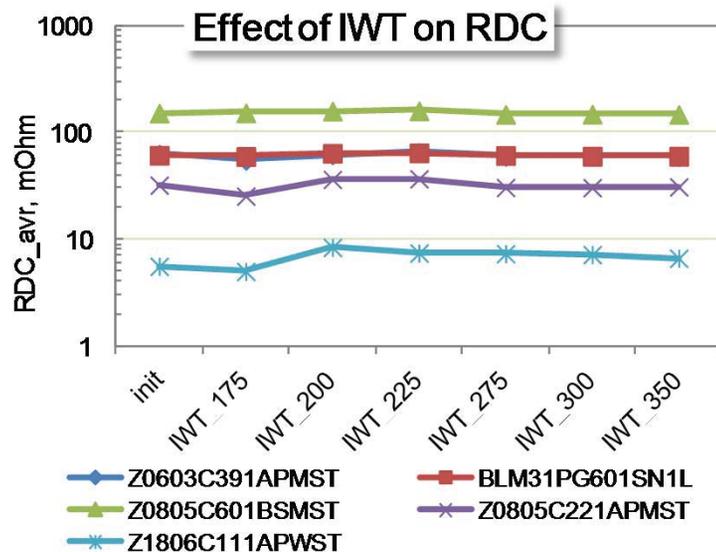
- ❑ TSD testing was carried out to assess the robustness of FB to thermal stresses associated with manual soldering.
- ❑ Five part types with 10 samples each were used for the testing
- ❑ Molten solder temperature was 350°C, and each part was stressed by 3 terminal immersion cycles.



- ✓ TSD350 did not cause any damage, degradation or failures in FBs.
- ✓ A decrease in RDC from ~5% to ~25% is likely due to the reduced contact resistance of terminals.
- ✓ Some reduction of the impedance (5% to 20%) might be due to the ageing effect in ferroelectrics.

Ice Water Test

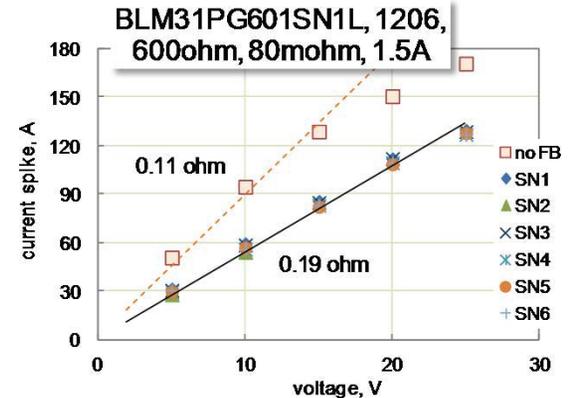
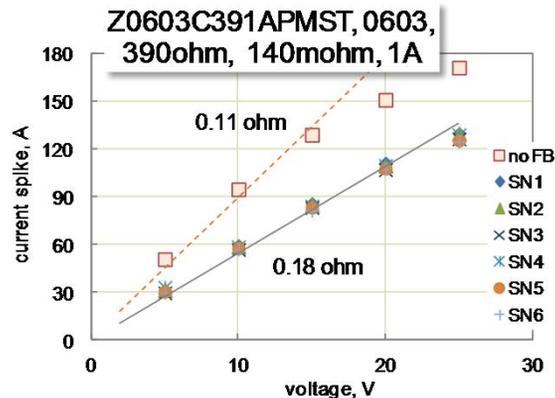
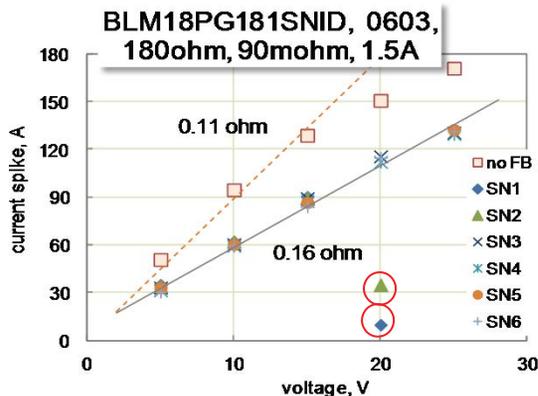
- ❑ IWT was carried out to assess the effect of thermal shock on the integrity and performance of FBs.
- ❑ Five part types with 10 samples each were used for the testing
- ❑ The parts were preheated to temperatures from 175 °C (IWT175) to 350 °C (IWT350), and immersed into ice water by sweeping from the hot plate.



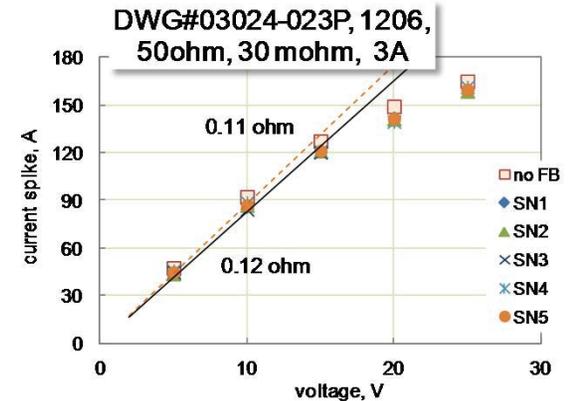
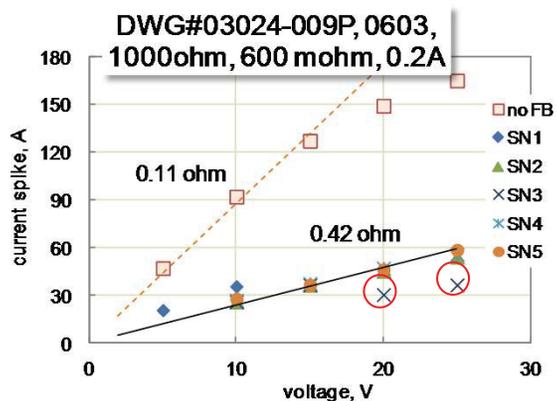
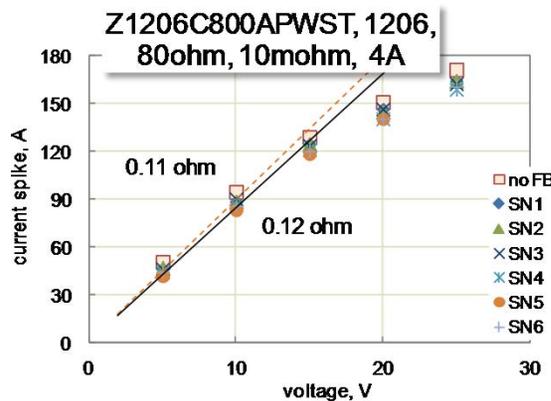
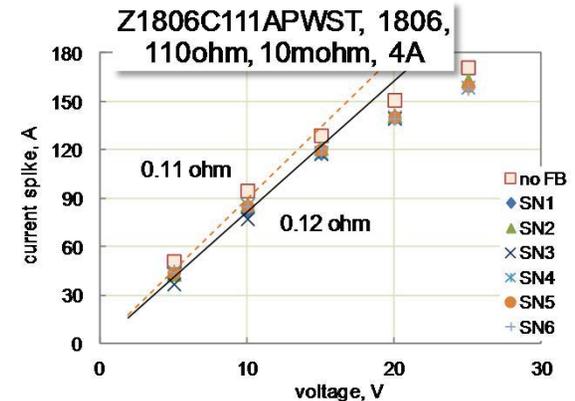
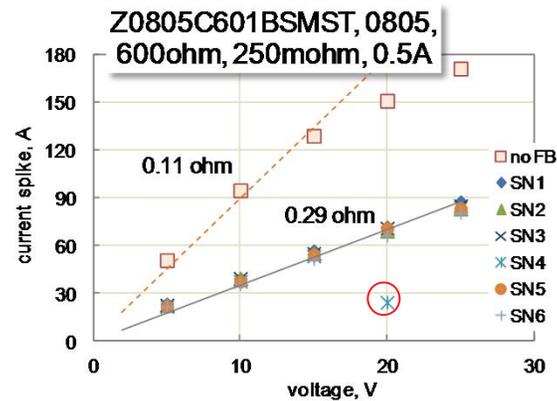
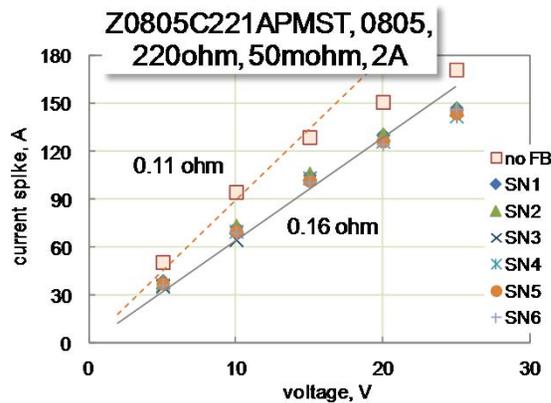
- ✓ Heating to 350 °C decreases up to 20% impedance in some parts.
- ✓ Thermal shock up to 350 °C did not cause RDC degradation or failures.

Effect of FB on Surge Currents

- 3SCT at voltages from 5V to 25V was carried out using 220 μ F, 10V, 18 mOhm polymer tantalum capacitors 520D227M010ATE018.
- The amplitude and width of current spikes were measured at each voltage, first without FBs (dashed lines), and then with different types of FBs (solid lines) Typically, 6 samples were used for each type of FBs.
- Resistances of the circuits with and without FBs were calculated as slopes of the relevant lines.
- Failures of FBs resulted in a substantial reduction of current spike amplitudes (red circles on the charts below).



Effect of FB on Surge Currents, Cont'd

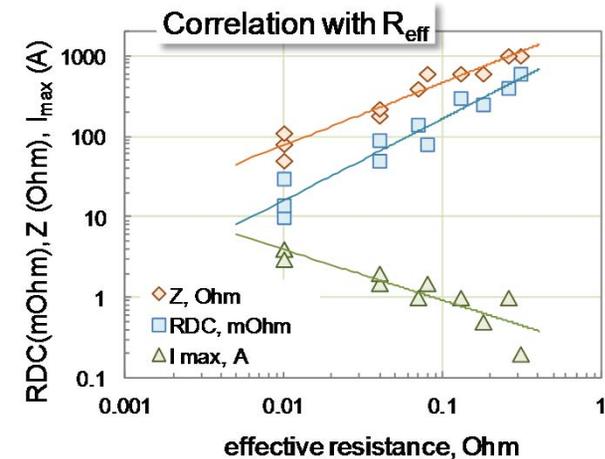


- ✓ Low-impedance FBs ($Z_{\text{spec}} < \sim 100 \text{ Ohm}$) have negligible effect on surge currents.
- ✓ A noticeable reduction of current spike amplitudes occur with FBs having $Z = 600 \text{ Ohm}$ and 1000 Ohm .
- ✓ Failures of FBs are observed at current spikes exceeding 100A .

Effective Resistance of FBs at Surge Currents

The effective resistance of FBs, R_{eff} , at high current spikes (up to 150A, $\sim 20 \mu\text{s}$) that determines the effectiveness of FBs as surge current limiters, was calculated as a difference between resistance of the circuit with and without FBs.

Gr.	Part	case size	Z, Ohm	R, mOhm	I_{max} , A	R_{eff} , ohm
1	BLM18PG181SN1D	0603	180	90	1.5	0.04
2	BLM31PG601SN1L	1206	600	80	1.5	0.08
3	Z0603C391APMST	0603	390	140	1	0.07
4	Z0805C601BSMST	0805	600	250	0.5	0.18
5	Z0805C221APMST	0805	220	50	2	0.04
6	Z1206C800APWST	1206	80	10	4	0.01
7	Z1806C111APWST	1806	110	14	4	0.01
8	DWG#03024-001P	0603	30	150	0.5	
9	DSCC#03024-009P	0603	1000	600	0.2	0.31
10	DSCC#03024-021P	0805	1000	400	1	0.26
11	DSCC#03024-023P	1206	50	30	3	0.01
12	DSCC#03024-028P	1206	600	300	1	0.13



- ✓ R_{eff} is in the range from 0.01 Ohm to 0.31 Ohm, which is ~ 3 orders of magnitude below Z.
- ✓ R_{eff} is close to RDC.
- ✓ R_{eff} increases with Z and RDC and decreases with I_{max} .

- ✓ The resistance of FBs at surge currents is several times less than the value of resistance that is required to limit surge currents (typically from 1 to 5 Ohm).

Effect of Surge Current Pulses on RDC and Failures of FBs

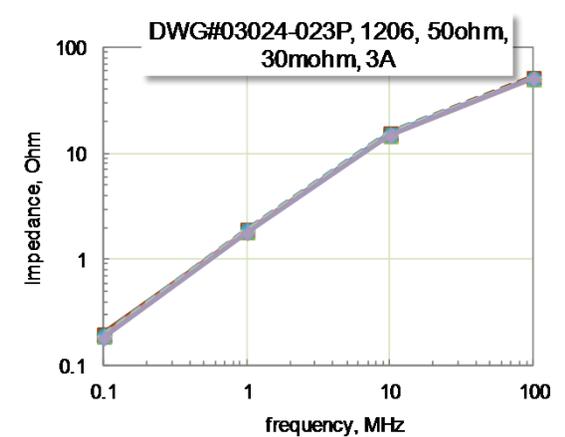
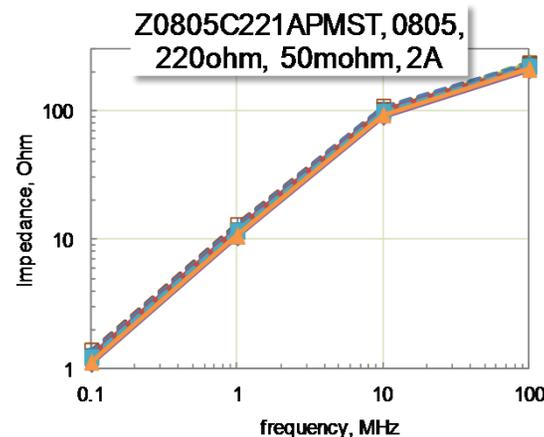
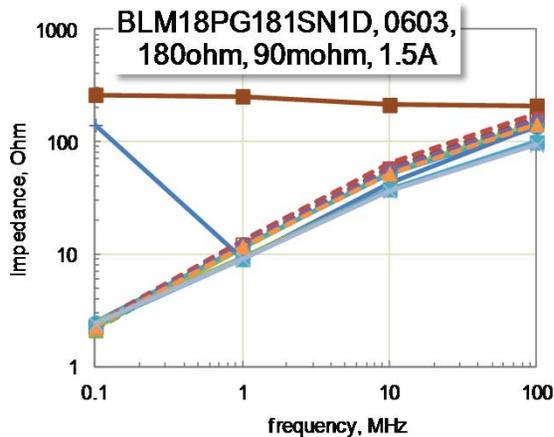
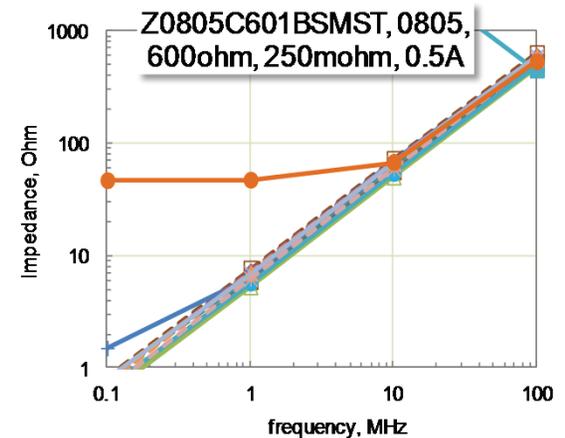
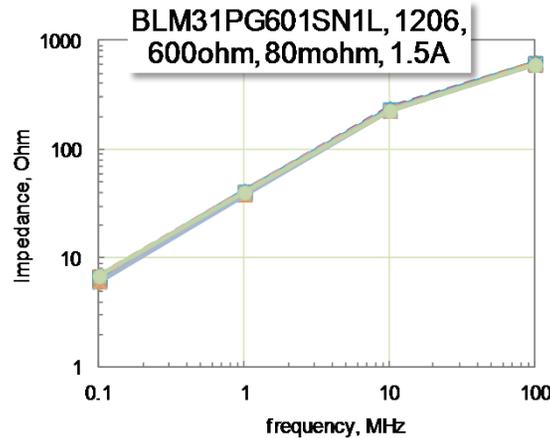
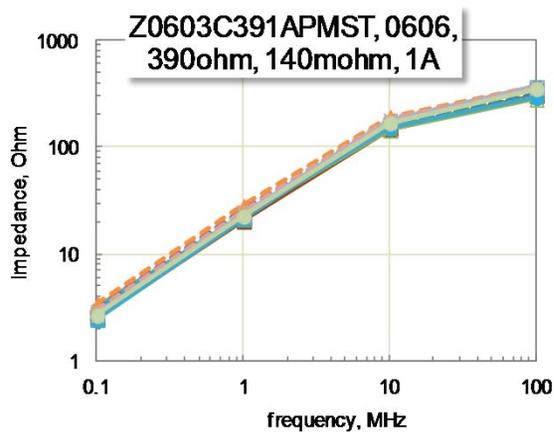
Comparison of RDC measured before and after 3SCT

Gr.	Part	case size	RDC _{spec} mOhm	RDC _{init} mean (STD), mOhm	RDC _{SCT} mean (STD), mOhm	Fail ures
1	BLM18PG181SN1D	0603	90	67.5 (11.6)	65.6 (13.2)	2
2	BLM31PG601SN1L	1206	80	62.6 (3.0)	61.5 (1.4)	0
3	Z0603C391APMST	0603	140	61.2 (1.5)	62.3 (1.2)	0
4	Z0805C601BSMST	0805	250	152 (4.3)	147 (4.5)	3
5	Z0805C221APMST	0805	50	32.1 (1.1)	30.6 (1.0)	0
6	Z1206C800APWST	1206	10	6.3 (0.9)	5.2 (0.8)	0
7	Z1806C111APWST	1806	14	5.6 (0.3)	7.8 (0.7)	0
8	DWG#03024-001P	0603	150	37.0 (4.2)	-	-
9	DSCC#03024-009P	0603	600	311 (11.2)	301 (4.5)	2
10	DSCC#03024-021P	0805	400	250 (16.7)	259.8	0
11	DSCC#03024-023P	1206	30	8.5 (0.2)	7.4 (0.4)	0
12	DSCC#03024-028P	1206	300	135 (7.2)	132 (5.8)	0

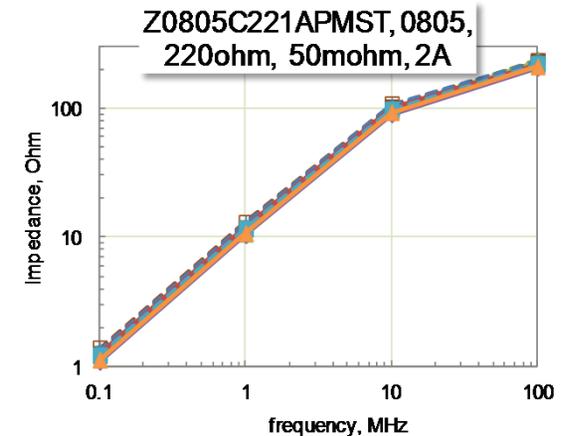
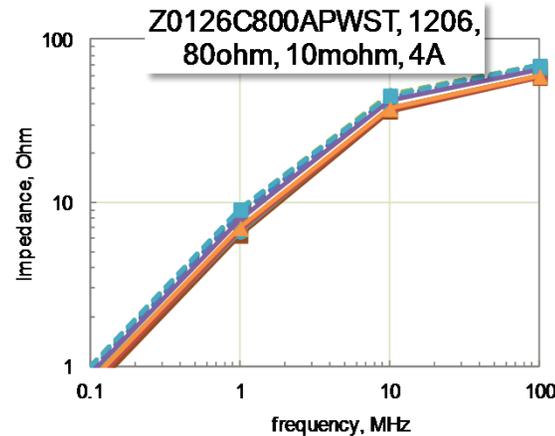
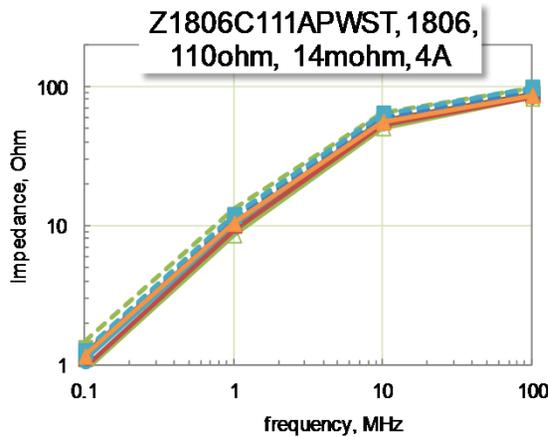
- ✓ Majority of the parts had normal characteristics after surge pulses up to 170 A that exceeded I_{max} by 50 to 300 times.
- ✓ There was no degradation of RDC, unless the part failed catastrophically.
- ✓ No correlation between the probability of failures and characteristics of the FBs was revealed.

Effect of Surge Current Pulses on Impedance

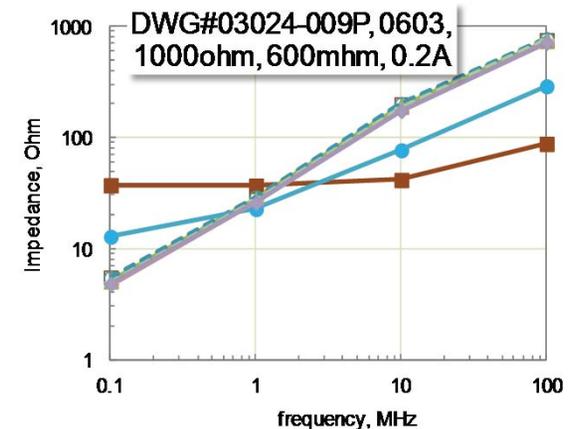
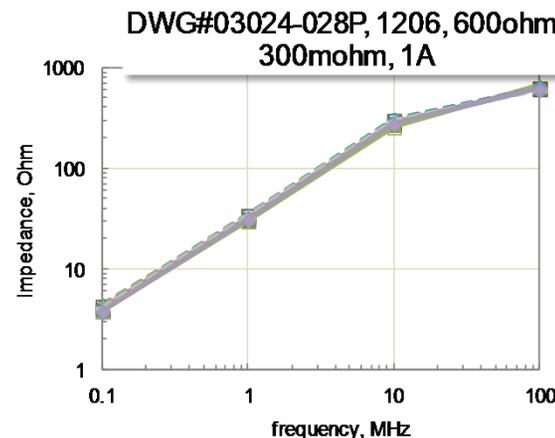
- Impedance at $f = 0.1, 1, 10,$ and 100 MHz was measured in six samples from each group before (dashed lines) and after (solid lines) step stress surge current testing.
- Substantial deviations from the initial values indicate catastrophic failures of FBs.



Effect of Surge Current Pulses on Impedance, Cont'd

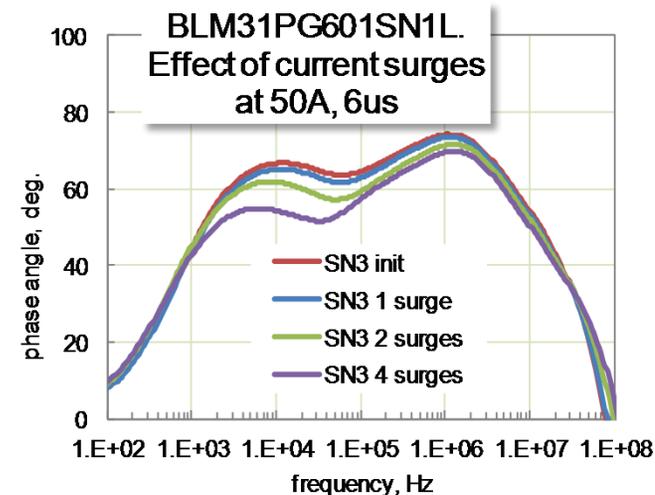
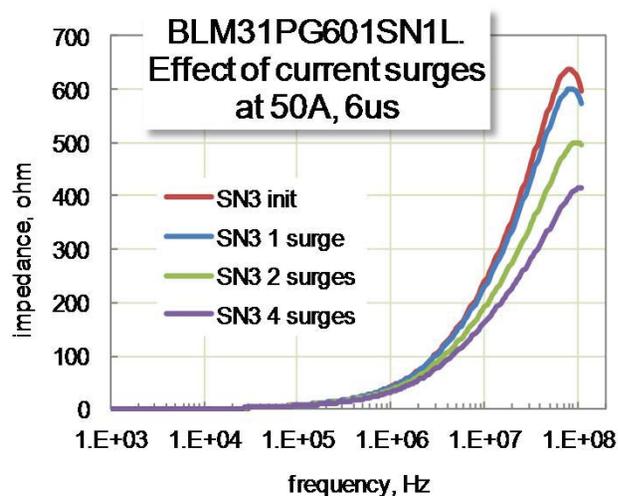


- ✓ Some decrease of impedance after SCT (1% to 12% for different part types) was observed in most samples.
- ✓ Catastrophic failures were observed only in small case size parts:
Z0805C601BMST(0805),
BML18PG18SN1D (0603),
DWG#03024-009P (0603)



Effect of Surge Current Pulses on Impedance, Cont'd

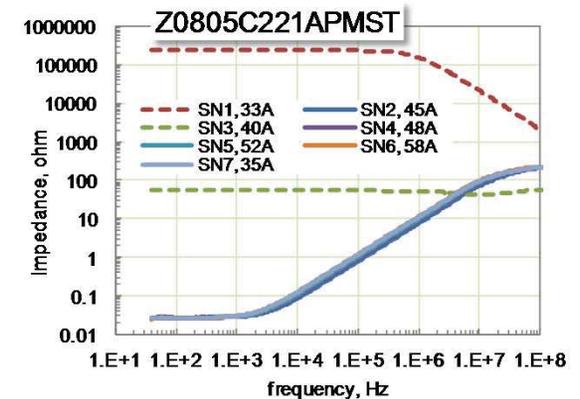
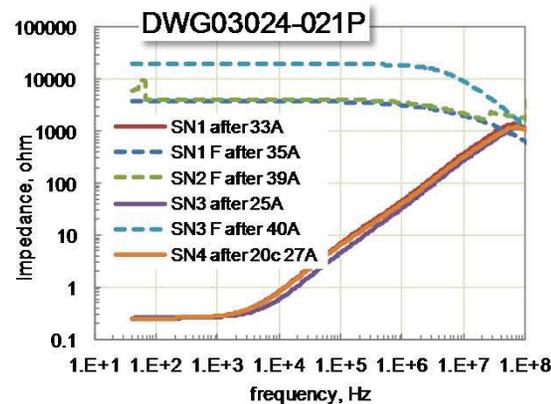
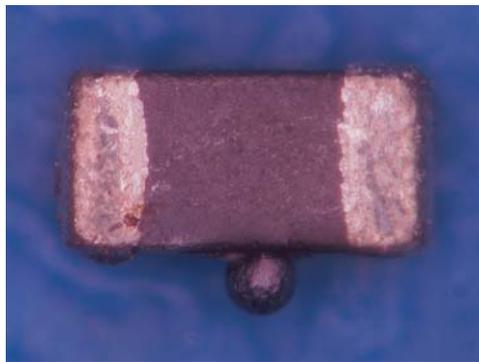
To better understand the effect of SCT on impedance, Z - f and θ - f characteristics were measured for gr.2 FBs initially, after 1, 2, and 4 surge pulses of 50A and 6 μ s.



- ✓ Post-SCT impedance decreases with the number of high current pulses.
- ✓ Considering that the magnetic permeability decreases at high currents (high magnetic fields), the result is likely due to a remnant magnetization after exposure to high magnetic fields.
- ✓ The effect is likely can be annealed with time even at $T < T_c$.

Failures of FBs after Surge Current Spikes

An external view and frequency dependencies of impedance in ferrite beads failed catastrophically after surge current testing (solid lines correspond to normal samples and dashed lines to failed samples).



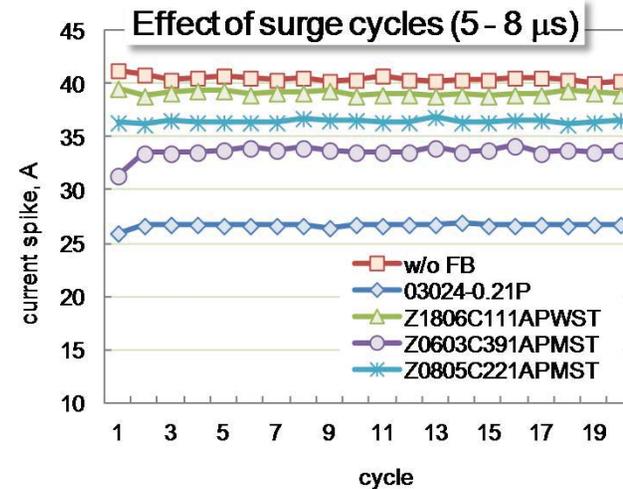
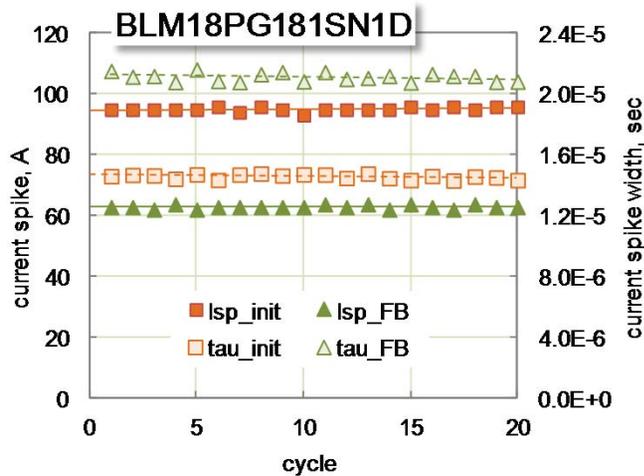
A sample of BLM18PG181SN1D, 180ohm, 90mohm, 1.5A, 0603, failed catastrophically after 130 A, 9 μ sec spike.

The ball at the bottom is silver ejected from metal trace that formed an internal coil.

- ❑ Three samples of DWG#03024-021 failed RDC (>1 kOhm) after 5 μ sec pulses 25 A and 39 A amplitude.
- ❑ Two samples of Z0805C221APMST parts failed RDC (80 Ohm and 3×10^5 Ohm) after 5 μ sec pulses 33 A and 40 A.
- ❑ Catastrophic failures are due to blown open (or high resistance) overheated coil traces.

Behavior of FB under Multiple Surge Current Spikes

Variations of current spike amplitude and width during 20 cycles of surge currents for different types of ferrite beads



- ✓ No variations in characteristics of pulses during multiple microsecond-range current spikes with amplitudes exceeding rated currents by 10 to 40 times.
- ✓ Considering that FBs can sustain pulse currents exceeding the rated level by 30 to 500 times, multiple cycling at pulses ~ 30% of the maximum pulse current are acceptable for operation under multiple surges.

Summary

❑ *Effect of soldering stresses.*

- Five types of chip FBs passed hot (TSD350) and cold (IWT350) thermal shock testing at temperatures up to 350 °C indicating high resistance to soldering-related stresses.

❑ *Operating of FBs at high current pulses.*

- Ferrite beads can tolerate pulse currents (5 to 20 μ s width) with amplitudes 50 to 300 times greater than the specified maximum current.
- FBs rated to 1A can sustain without degradation at least 20 pulses up to 40 A.
- Impedance of the parts decreases after exposure to high current pulses.
- The resistance of FBs at surge currents increases with the specified impedance, RDC, and decreases with I_{max} .
- For high-Z FBs R_{eff} is in the range from 0.01 Ohm to 0.31 Ohm, which is more than 3 orders of magnitude below the specified impedance.
- Low resistance of FBs under surge currents is due to a rapid decrease of impedance with reduction of frequency and increase of currents.

❑ *Failures of FBs*

- Three out of 11 types of FBs had failures at current spikes in the range from 33 to 40 A due to blown open (or high resistance) overheated coil traces.
- Although no correlation between the probability of failures and characteristics of the FBs was revealed, catastrophic failures were observed only in small case size parts: 0603 and 0805.

Summary

□ *Effect of FBs on surge currents.*

- Low-impedance FBs ($Z_{\text{spec}} < \sim 100 \text{ Ohm}$) have negligible effect on surge currents.
- A reduction of current spike amplitudes occur when high-Z FBs (600 Ohm and 1000 Ohm) are used.
- However, event for high-Z ferrite beads the effective resistance under high current pulses remains substantially below the value that is required to limit surge currents in tantalum capacitors (from 1 to 5 Ohm).

□ *Reliability assurance for tantalum capacitors operating under surge current conditions.*

- A proper derating [1] and baking of chip tantalum capacitors before assembly [2] should provide the necessary assurance for reliable operation of capacitors under surge current conditions.

1. "Derating of surge currents for tantalum capacitors," presented at the ESA 1st International Symposium 'Space Passive Component Days', Noordwijk, The Netherlands, 24-26 September, 2013 Available: <https://escies.org/webdocument/showArticle?id=984&groupid=6>
2. "Effect of Preconditioning and Soldering on Failures of Chip Tantalum Capacitors," NEPP report, NASA/GSFC, Greenbelt, MD 2014, Available: <https://nepp.nasa.gov/>