

NASA Electronic Parts and Packaging Program

EVALUATION OF ADVANCED COTS PASSIVE DEVICES FOR EXTREME TEMPERATURE OPERATION

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Background

Electronic sensors and circuits are often exposed to extreme temperatures in many of NASA deep space and planetary surface exploration missions. Electronics capable of operation in harsh environments would be beneficial as they simplify overall system design, relax thermal management constraints, and meet operational requirements. For example, cryogenic operation of electronic parts will improve reliability, increase energy density, and extend the operational lifetimes of space-based electronic systems. Similarly, electronic parts that are able to withstand and operate efficiently in high temperature environments will negate the need for thermal control elements and their associated structures, thereby reducing system size and weight, enhancing its reliability, improving its efficiency, and reducing cost.

Passive devices play a critical role in the design of almost all electronic circuitry. To address the needs of systems for extreme temperature operation, some of the advanced and most recently introduced commercial-off-the-shelf (COTS) passive devices, which included resistors and capacitors, were examined for operation under a wide temperature regime. The types of resistors investigated included high temperature precision film, general purpose metal oxide, and wirewound. Some of the specifications of these parts are given in Table 1. The capacitors comprised of NPO ceramic, stacked multi-layered NPO ceramic (MLC), and units utilizing unique relaxor ferroelectric ceramic as the dielectric. A listing of these parts is shown in Table 2.

Table 1. Manufacturer specifications for resistors tested [1-3].

| Part | Part # | Type | Company | Comments |
|-----------|--------|----------------|---------------------|--|
| Resistors | MM177 | Precision Film | Caddock Electronics | 10k Ω , -55°C to +275°C (derating), \pm 1%, 500V, 0.6W |
| | 93J10K | Wirewound | Ohmite | 10k Ω , -55°C to +350°C (derating), \pm 5%, 200V, 3.25W |
| | RS2 | Metal Oxide | SEI | 10k Ω , -55°C to +235°C (derating), \pm 5%, 350V, 2W |

Table 2. Manufacturer specifications for capacitors tested [4-7].

| Part | Part # | Type | Company | Comments |
|-------------------|------------------|---------------|---------------------|---|
| Capacitors | HRS205NPO114J4N4 | Stacked MLC | Presidio Components | 0.11 μ F, NPO Ceramic, -55°C to +25°C, \pm 5%, 200V, through-hole |
| | SM041A164KAN240 | Stacked MLC | AVX | 0.16 μ F, NPO Ceramic, -55°C to +25°C, \pm 10%, 100V, straight lead |
| | ACA69B104KGS | Ceramic | Kemet | 0.1 μ F, NPO Ceramic, -55°C to +200°C, \pm 10%, 50V, axial lead |
| | TCR09B104JWS | Ceramic | Kemet | 0.1 μ F, NPO Ceramic, -55°C to +260°C, \pm 5%, 50V, straight lead |
| | ML0455/HT300 | Ferroelectric | TRS Technologies | 0.1 μ F at 250°C, unique relaxor ferroelectric, -55°C to +300°C, \pm 30%, 500V, prototype |
| | 7570/WT2B | Ferroelectric | TRS Technologies | 0.05 μ F at 250°C, unique relaxor ferroelectric, -55°C to +500°C, 71ppm/°C, 100V, prototype |

The devices were evaluated at various frequencies from 10Hz to 500 kHz under a wide temperature range from -195°C to +200°C using a Sun Systems EC12 environmental chamber that employs liquid nitrogen as the coolant. A temperature rate of 10°C/min was used, and a soak time at a given test temperature of at least 20 minutes was allowed prior to taking measurements. A QuadTech 7400 Precision RLC meter was utilized to measure the parameters using a four-wire lead configuration for more accurate results. Three samples of each of the parts tested were evaluated in this work.

Results and Discussion

All three samples of each part tested have shown similar results and, therefore, data pertaining to only one device is reported.

Resistors

Caddock Electronics: The precision film resistor, type MM177, exhibited very good stability in its resistance in the temperature range of -120°C to $+200^{\circ}\text{C}$ regardless of the test frequency from DC to 100 kHz. As the test temperature was lowered below -120°C , the resistance underwent a gradual, slight increase with decreasing temperature. The increase in resistance at -195°C amounted to about 6% above room temperature value. Figure 1 shows the resistance of this film resistor as a function of temperature at the selected test frequencies of 1 kHz and 100 kHz.

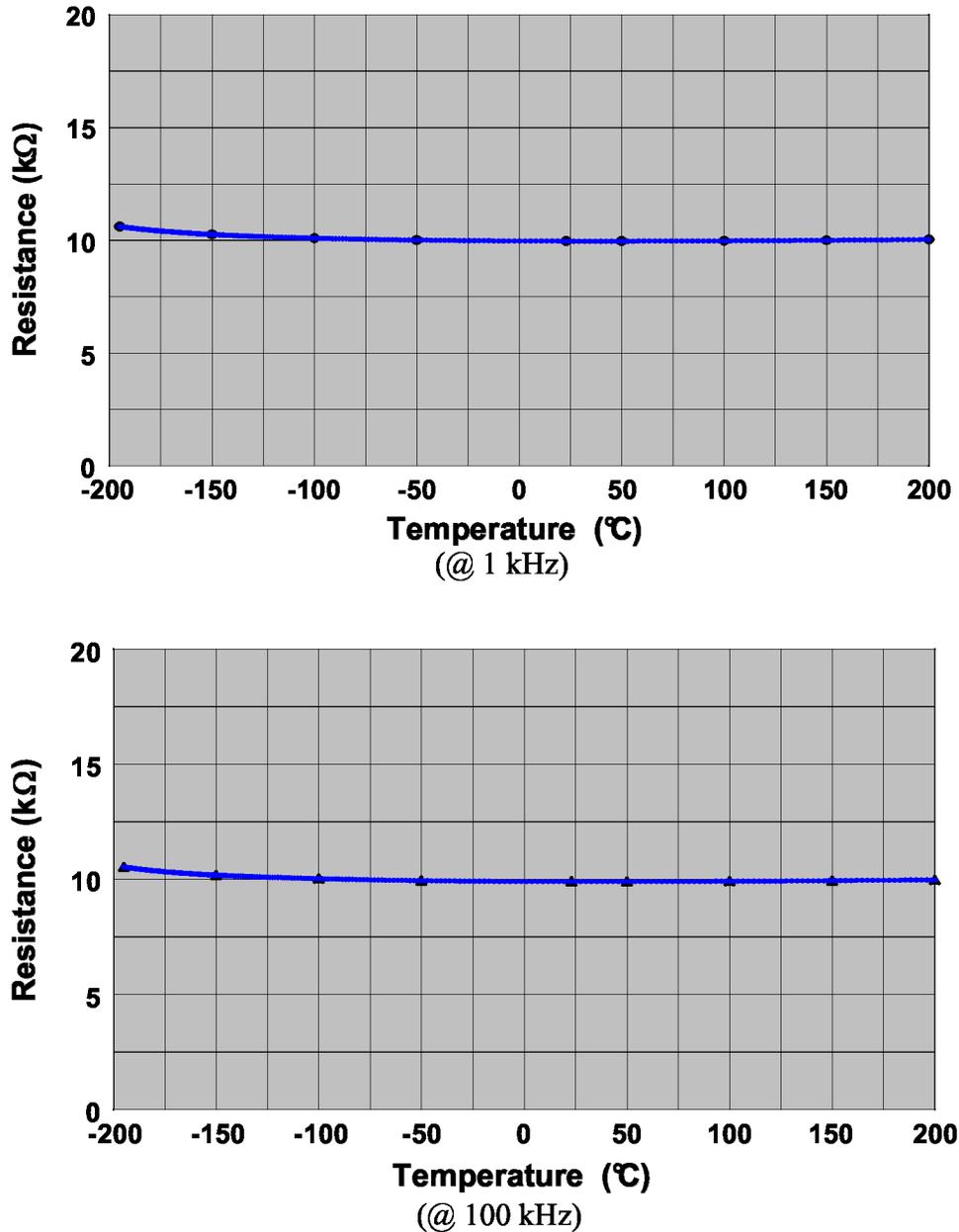


Figure 1. Resistance of the Caddock film resistor type MM177 as a function of temperature.

Resistors

Ohmite: The wirewound resistor, type 93J10K, displayed excellent stability as very minute changes in its resistance took place due to temperature variation. These insignificant changes, which mostly occurred at cryogenic test temperatures, are reflected by a small drop in resistance value that ranged from 0.5 to 1.3% as shown in Figure 2 for the test frequency of 1 kHz and 100 kHz, respectively.

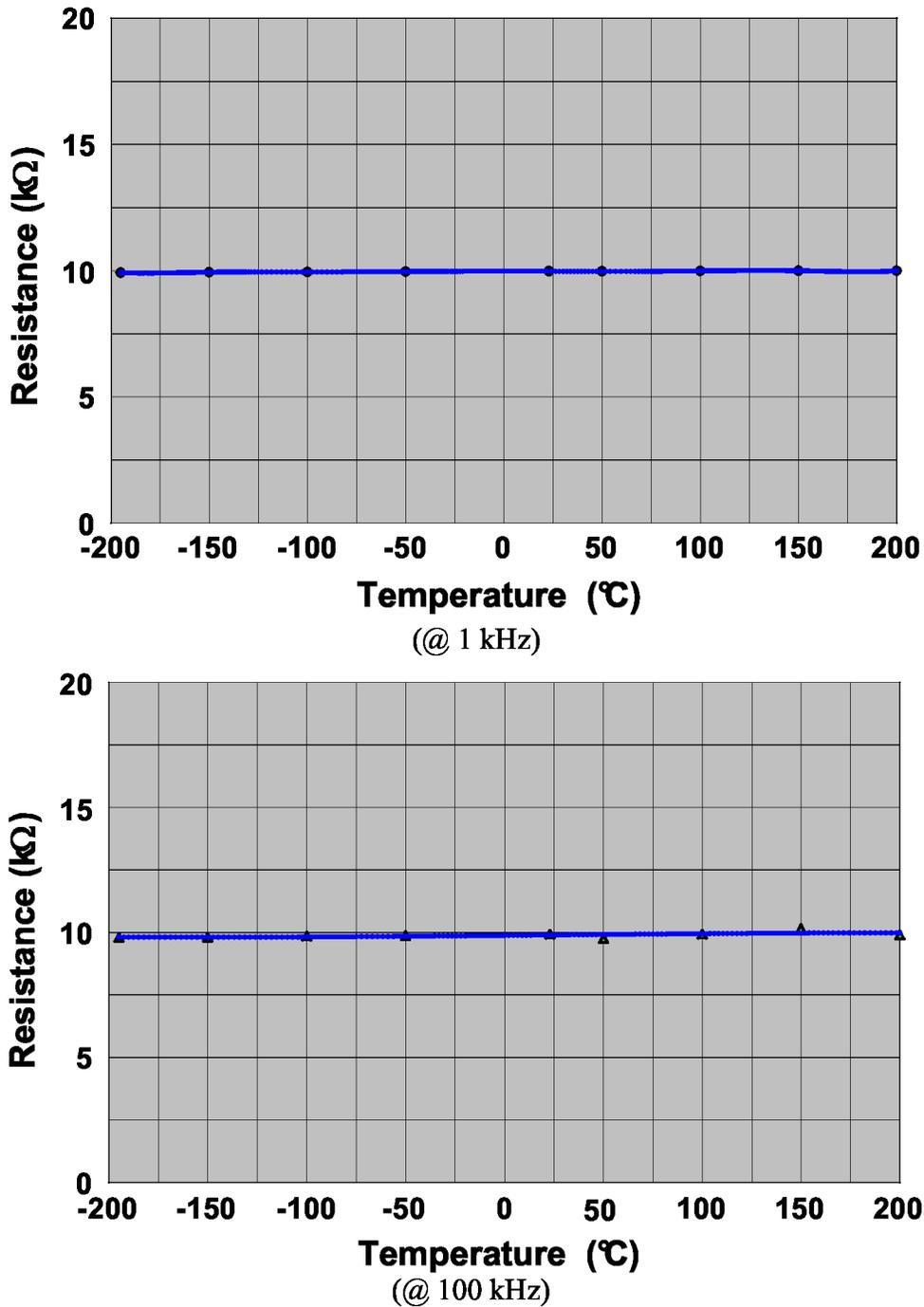


Figure 2. Resistance of the Ohmite wirewound resistor type 93J10K as a function of temperature.

Resistors

SEI: Unlike the film and wirewound resistors, the metal oxide resistor, type RS2, demonstrated some dependency on temperature as shown in Figure 3. While the resistance underwent gradual decrease as test temperature was varied from room to +235°C, the resistor exhibited an increase in this property at a faster rate in the low temperature test region. For example, while the decrease in the resistance amounted only to 1.8% at +235°C, it increased by 14% above the room temperature value as the test temperature approached the cryogenic level of -190°C. The trend in resistance change with temperature for this type of resistor was similar at all frequencies as shown by the results depicted in Figure 3 for test frequencies of 1 kHz and 100 kHz.

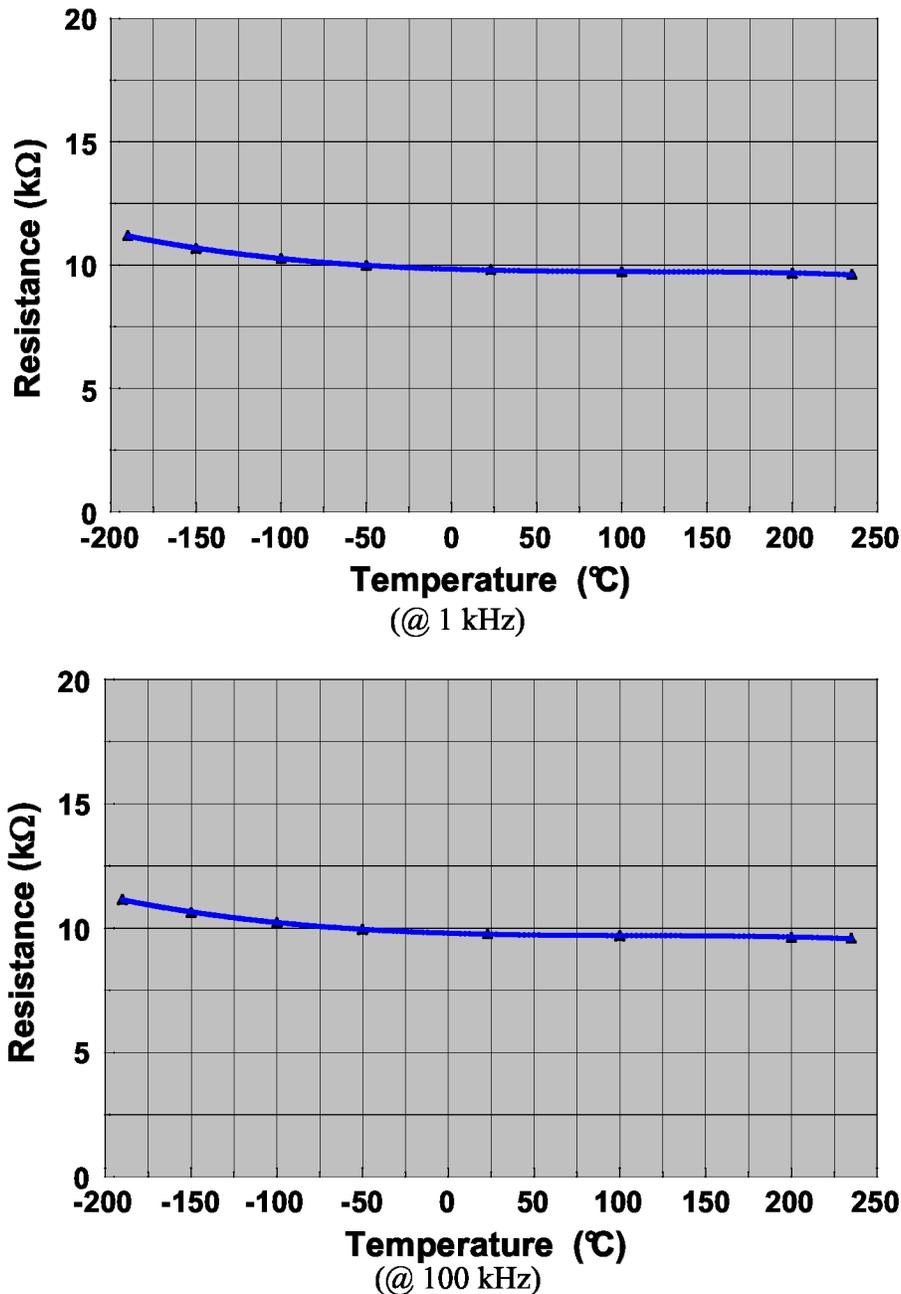


Figure 3. Resistance of the SEI metal oxide resistor type RS2 as a function of temperature.

Capacitors

Presidio: These capacitors, type HRS205NPO114J4N4, are based on NPO ceramic dielectric and are stacked to achieve desired capacitance. The dielectric properties, namely the capacitance and dissipation factor, of this 2-stack, multi-layer ceramic capacitor are shown in Figure 4 as a function of temperature at the selected test frequencies of 1 kHz, 10 kHz, 50 kHz, and 100 kHz. This type of capacitor seemed to display excellent stability in its capacitance with respect to temperature as well as frequency, which is evident from Figure 4 as the capacitance curve maintained its flatness throughout the test temperatures of -195°C to +200°C at all test frequencies. At any given frequency, the dissipation factor, in general, seemed to maintain its value except when the test temperature approached either extreme, i.e. -195°C or +200°C, whereby the dissipation factor slightly increased. As far as frequency is concerned, the dissipation factor exhibited a gradual but slight increase with an increase in frequency. This behavior in the dissipation factor is typical of most dielectrics, particularly ceramics.

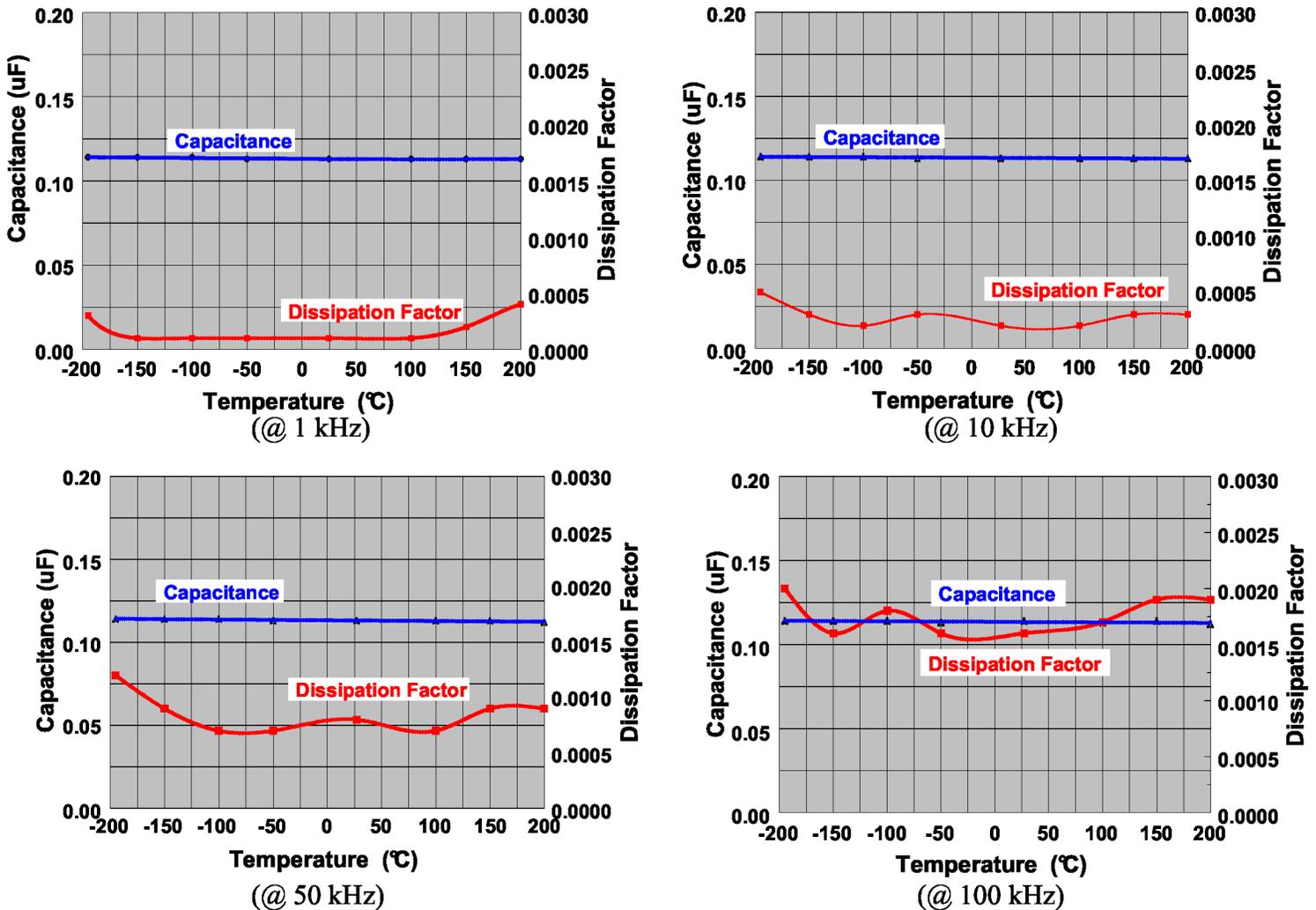


Figure 4. Capacitance & dissipation factor of Presidio capacitor HRS205NPO114J4N4 vs temperature.

Capacitors

AVX: These through-hole capacitors, type SM041A164KAN240 which are also based on NPO ceramic dielectric, are stackable and designed for switch mode power supply (SMPS) applications. The behavior in the dielectric properties of this multi-layer ceramic capacitor mimics very closely that of the Presidio part. For example, the capacitance retained its value throughout the test temperature range of -195°C to $+200^{\circ}\text{C}$, irrespective of the test frequency between 10 Hz and 100 kHz. Similarly, the dissipation factor did not, at a given frequency, undergo any noticeable change except in the vicinity of the extreme temperature points, both hot and cold. Even at these extreme temperatures, the changes in the dissipation factor were very miniscule. The dissipation factor of this capacitor also exhibited weak dependency on frequency as it increased very modestly. The behavior in the dielectric properties is shown in Figure 5 at the selected test frequencies of 1 kHz, 10 kHz, 50 kHz, and 100 kHz.

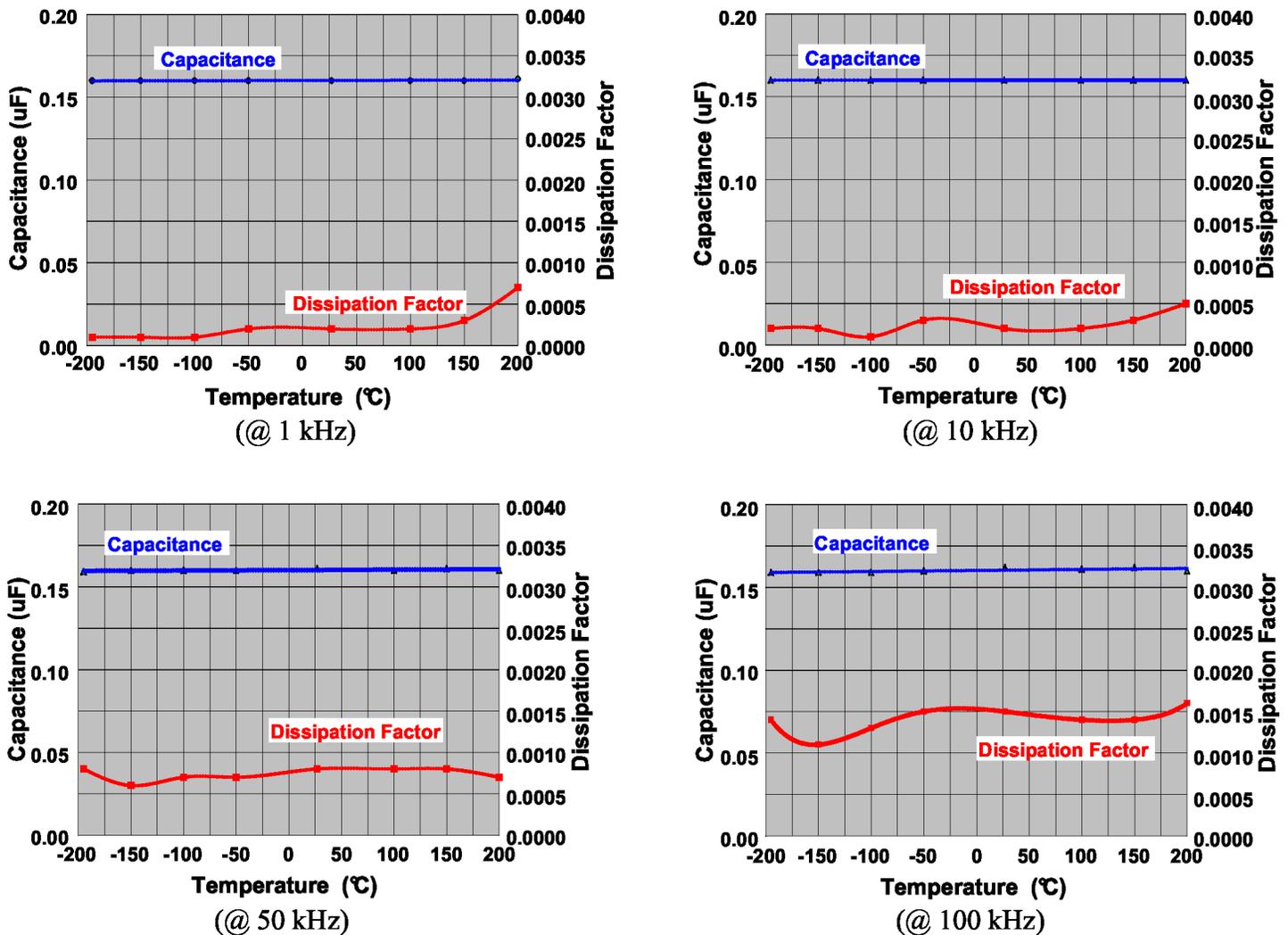


Figure 5. Capacitance & dissipation factor of AVX capacitor type SM041A164KAN240 vs temperature.

Capacitors

Kemet: The first batch of Kemet capacitors, type ACA69B104KGS, included parts that are designated as high temperature, NPO ceramic with temperature ratings up to +200°C. These axial, rectangular-molded devices had gold-plated lead wires. The capacitance and dissipation factor of this capacitor are shown in Figure 6 as a function of temperature at various frequencies. It can be seen that the capacitance displayed excellent stability with temperature but was slightly influenced by frequency since its value increased as frequency increased. For example, the capacitance rose from 0.095 μF at 1 kHz to 0.101 μF at the test frequency of 200 kHz. While the dissipation factor, which had favorable low values, remained relatively constant with temperature up to about 110°C in the low frequency range of 1 to 10 kHz, it exhibited appreciable increase as temperature was increased further. At higher frequencies, however, the dissipation factor showed gradual increase with rising temperature. The escalation in the dissipation factor became more significant the higher the frequency was, as shown in Figure 6.

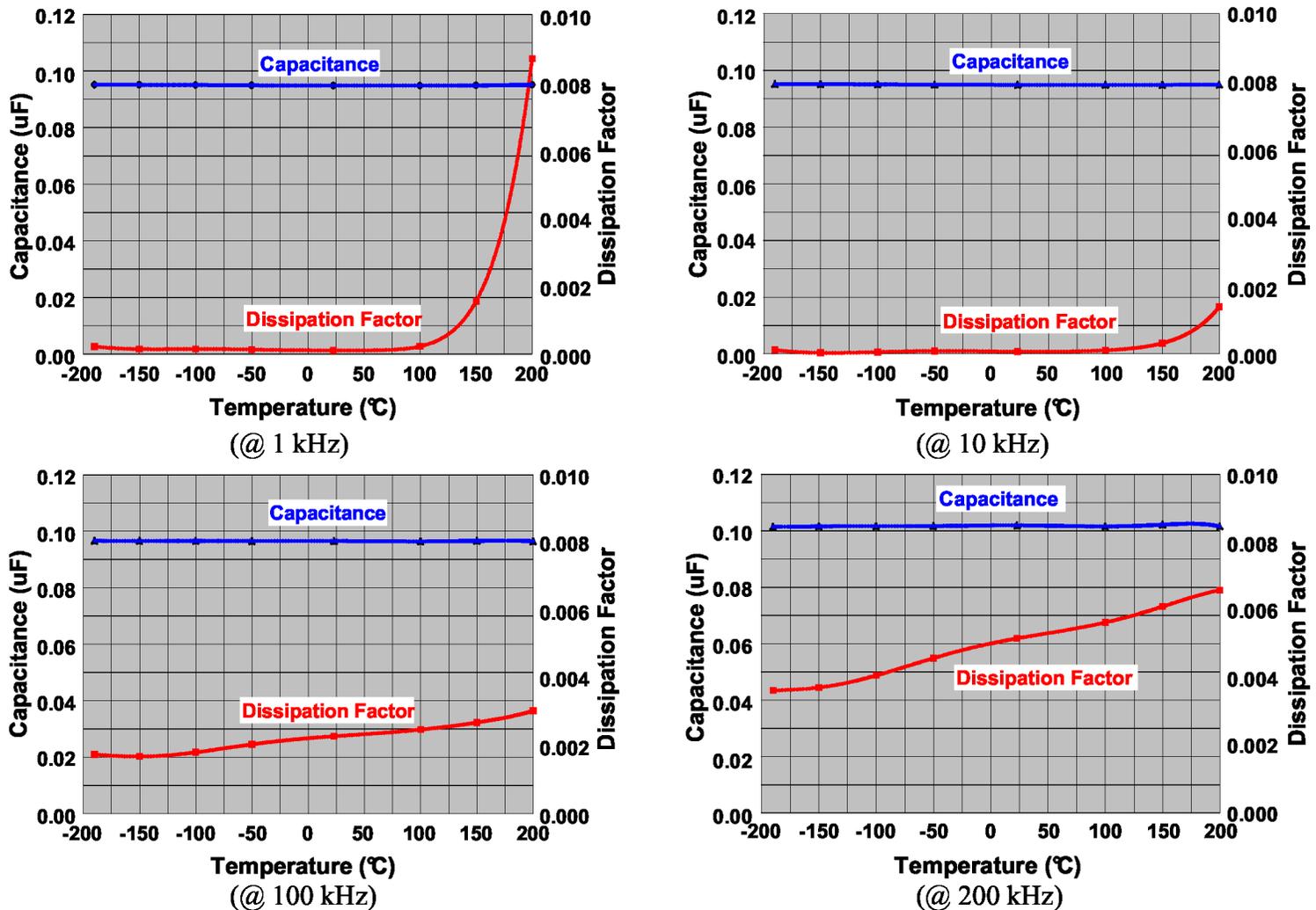


Figure 6. Capacitance & dissipation factor of Kemet capacitor type ACA69B104KGS vs temperature.

Capacitors

Kemet (Cont'd): The second batch of Kemet capacitors, type TCR09B104JWS, was comprised of NPO ceramic units rated to +260°C. Figure 7 shows the capacitance and dissipation factor of this capacitor as a function of temperature at frequencies ranging from 1 kHz to 200 kHz. It can be noted that the capacitance demonstrated excellent stability with temperature throughout the range of -190°C to +260°C, and was vaguely influenced by frequency since its value only slightly increased with frequency. For example, the capacitance went from 0.099 μF at 1 kHz to 0.107 μF at the test frequency of 200 kHz. The dissipation factor, on the other hand, displayed a less predictable trend since its behavior seemed to vary more with frequency. At low frequencies, the dissipation factor remained fairly steady between the temperatures of -190°C and +160°C, but had a prominent increase as temperatures rose to +260°C. At higher frequencies, however, the dissipation factor indicated not only an increase in value, but also a more gradual overall increase with rising temperature.

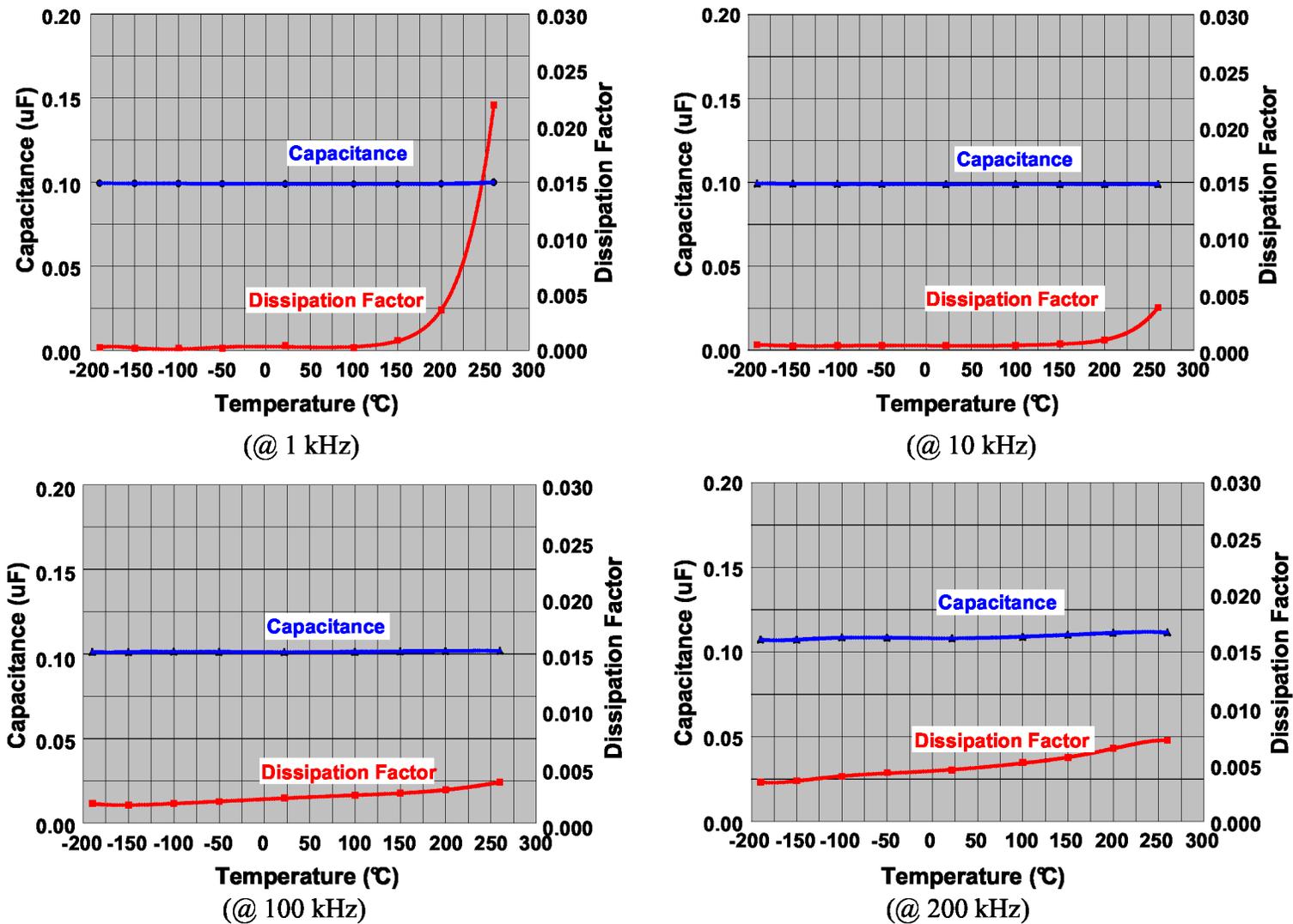


Figure 7. Capacitance & dissipation factor of Kemet capacitor type TCR09B104JWS vs temperature.

Capacitors

TRS Technologies: The first type of TRS capacitors, type ML0455/HT300, was based on unique relaxor ferroelectric dielectrics that are engineered to achieve maximum capacitance at high temperatures. Their characteristics were reported to be similar to those of the Y5V and X7R ceramics except that the operating temperatures were shifted to higher levels [7]. These particular units were rated for operation between -55°C and $+300^{\circ}\text{C}$ with capacitance reaching $0.1\mu\text{F}$ at $+300^{\circ}\text{C}$. The capacitance and dissipation factor of the ferroelectric capacitor are shown in Figure 8 as a function of temperature at the selected test frequencies of 1 kHz, 10 kHz, 100 kHz, and 200 kHz. As expected, the capacitance demonstrated a continuous increase as temperature was increased. The frequency, on the other hand, seemed to have no influence on the capacitance in the measured test range of 1 kHz to 200 kHz. Similar to the aforementioned ceramic types, i.e. Y5V and X7R, this ferroelectric dielectric exhibited strong dependency in its dissipation factor on temperature. The behavior in the dissipation factor revealed the occurrence of two peaks, with varying intensity, at two different temperatures. The more prominent peak occurred at about -100°C , while the other took place at about $+125^{\circ}\text{C}$. Figure 8 also shows that an increase in test frequency not only caused the dissipation factor to slightly increase, but also resulted in a slight shifting of the temperatures at which the two peaks occurred.

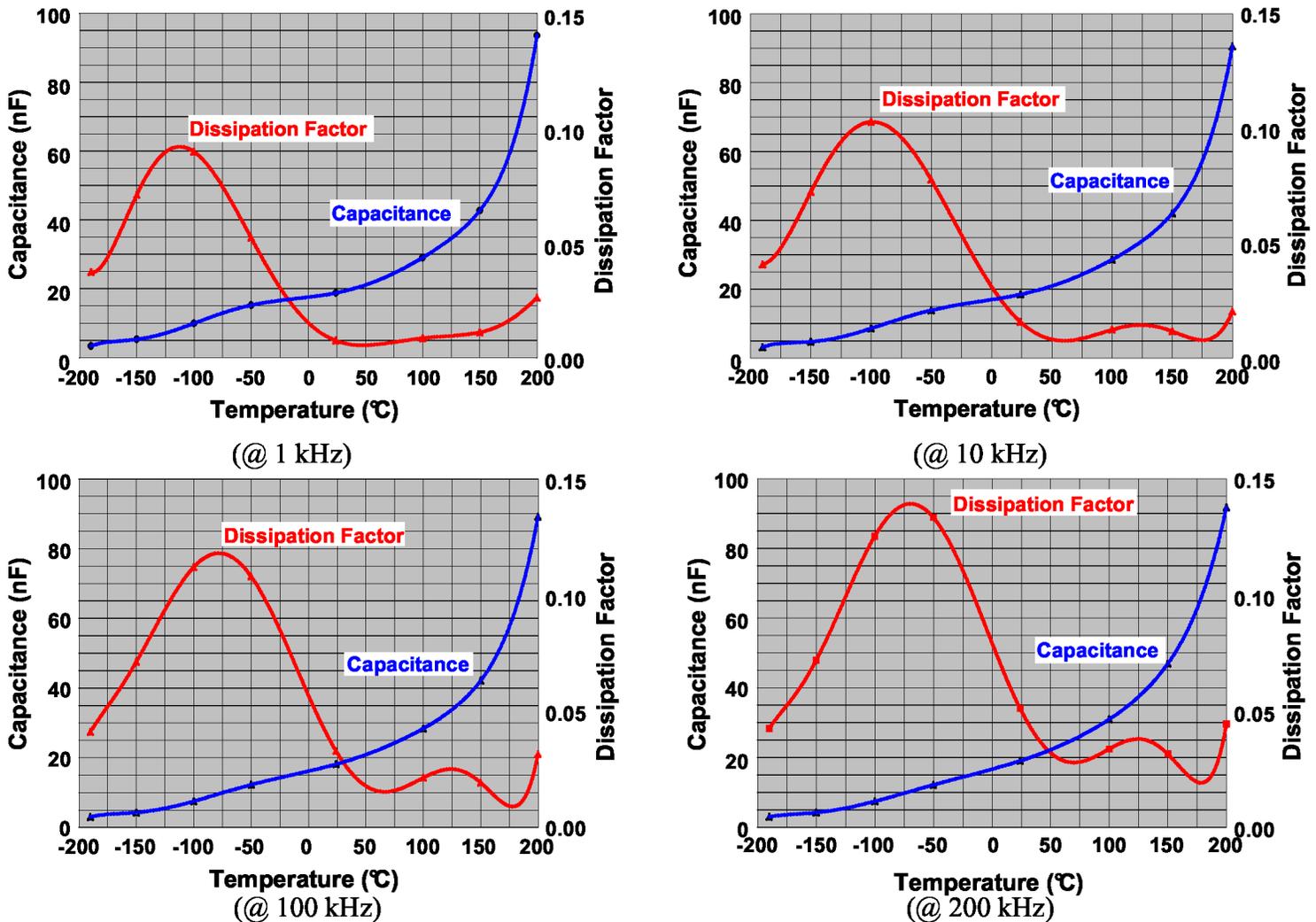


Figure 8. Capacitance & dissipation factor of TRS capacitor type ML0455/HT300 vs temperature.

Capacitors

TRS Technologies (Cont'd): The prototype capacitors, type 7570/WT2B, utilized high temperature ferroelectric materials with specified operating temperatures up to +500°C. Figure 9 shows the capacitance and dissipation factor of one of these capacitors as a function of temperature at various test frequencies. At any given frequency, the capacitance demonstrated slight but gradual increase with increasing temperature. Similarly, an increase in the test frequency resulted in a slight increase in capacitance, becoming more evident at the extreme frequency of 200 kHz. The effect of temperature on the dissipation factor of this capacitor was found to be greatly influenced by the frequency of interest as shown in Figure 9. For example, while moderate variation in the magnitude of the dissipation factor took place at low frequencies, these changes became more significant at higher frequencies. At the test frequency of 200 kHz, for instance, the dissipation factor at least tripled its value as compared to those obtained at lower frequencies. In addition, the appearance of two peaks in the dissipation factor profile with temperature is markedly more evident at high frequencies.

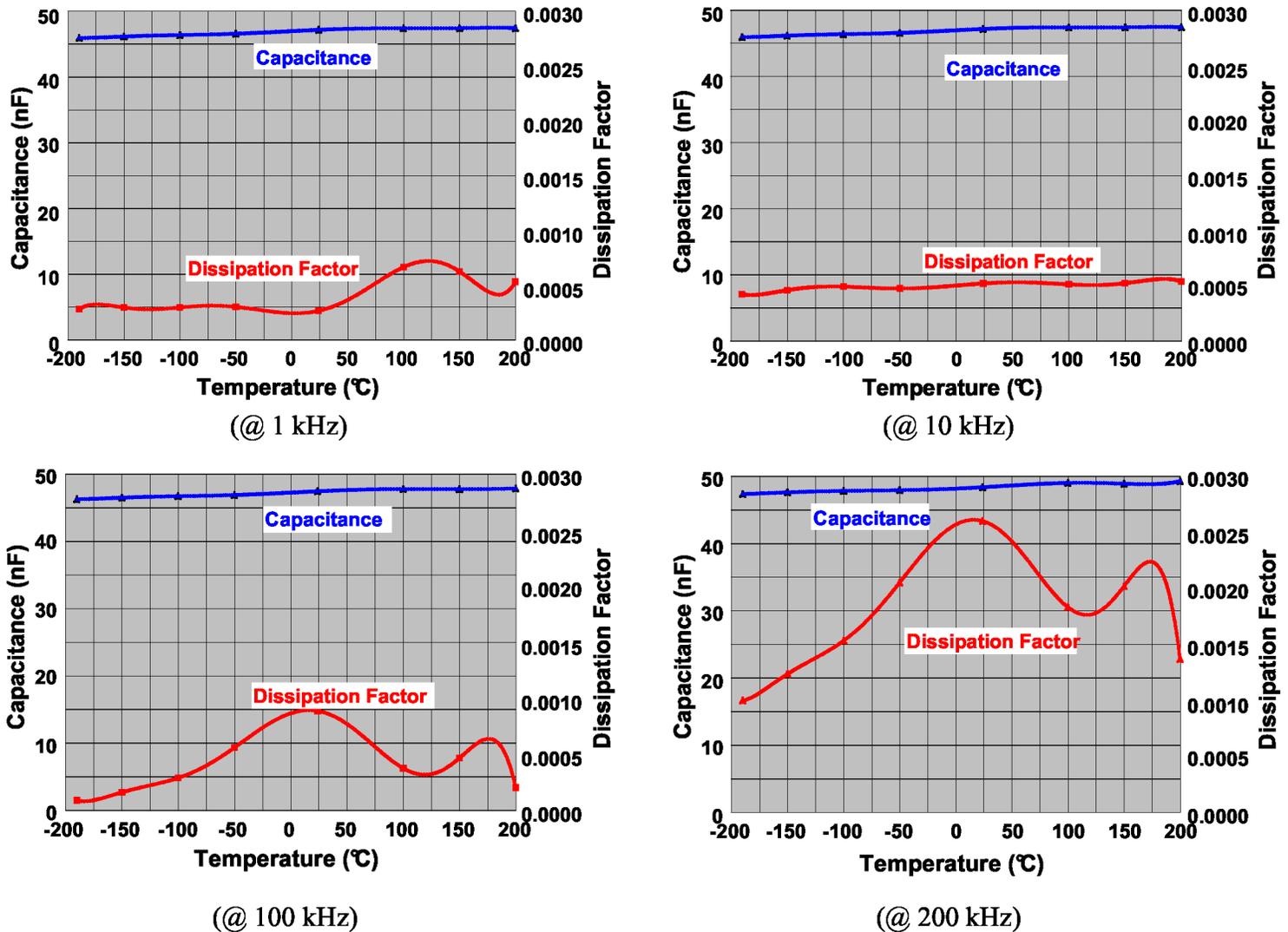


Figure 9. Capacitance & dissipation factor of TRS capacitor type 7570/WT2B vs temperature.

Conclusion

Electronic parts and circuits capable of extreme temperature operation constitute a key requirement for the development of advanced, reliable power and communication systems for use in space exploration missions. Advanced COTS (commercial-off-the-shelf) passive devices that included resistors and capacitors were investigated for their potential use under wide temperature conditions. The resistors, which included precision film, wirewound, and metal oxide types, were characterized for their resistance stability in the temperature range of -195°C to $+200^{\circ}\text{C}$ from DC to 100 kHz. The capacitors were comprised of NPO ceramic units from different manufacturers as well as prototype devices utilizing unique relaxor ferroelectric as the dielectric medium. These components were also evaluated under a wide temperature range in terms of their capacitance and dissipation factor over the frequency range of 10 Hz to 200 kHz. Among the three resistors tested, the wirewound was the most stable since little change in resistance was caused by temperature variation. The precision film resistor also exhibited excellent stability except at cryogenic temperatures (below -150°C) where its resistance underwent a slight increase in its value. The metal oxide resistor, on the other hand, experienced changes in its resistance at both extreme temperatures. These temperature-induced changes, which comprised of a decrease in the resistance value with increasing temperature, were more profound though in the cryogenic region. All of the NPO ceramic capacitors displayed excellent capacitance stability with temperature. The dissipation factor, however, seemed to slightly increase at high temperatures with the changes becoming more intense at high frequencies. The dielectric properties of the prototype ferroelectric-based capacitors displayed, as expected, a strong dependency on test temperature. In particular, changes in the dissipation factor were found to be governed by both the temperature as well as the test frequency. More comprehensive testing, such as thermal cycling and long-term temperature exposure, is required to fully characterize the behavior of these passive devices and to determine their reliability for use in space missions.

References

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Acknowledgments

This work was performed at the NASA Glenn Research Center under GESS-2 Contract # NNC06BA07B. Funding was provided from the NASA Electronic Parts and Packaging (NEPP) Program Task "Reliability of SiGe, SOI, and Advanced Mixed Signal Devices for Cryogenic Power Electronics".