



Basics of Ceramic Chip Capacitors



Introduction

- Purpose:
 - Provide an introduction to ceramic chip capacitors
- Objectives:
 - Describe the manufacturing process and basic structure of ceramic capacitors
 - Explain the material systems and basic specifications of ceramic capacitors
 - Describe some of the characteristics of ceramic chip capacitors
- Content
 - 13 pages
- Learning Time

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This presentation is a quick overview of ceramic chip capacitors. Subjects covered are: basic structure, manufacturing process, specifications, and basic characteristics.



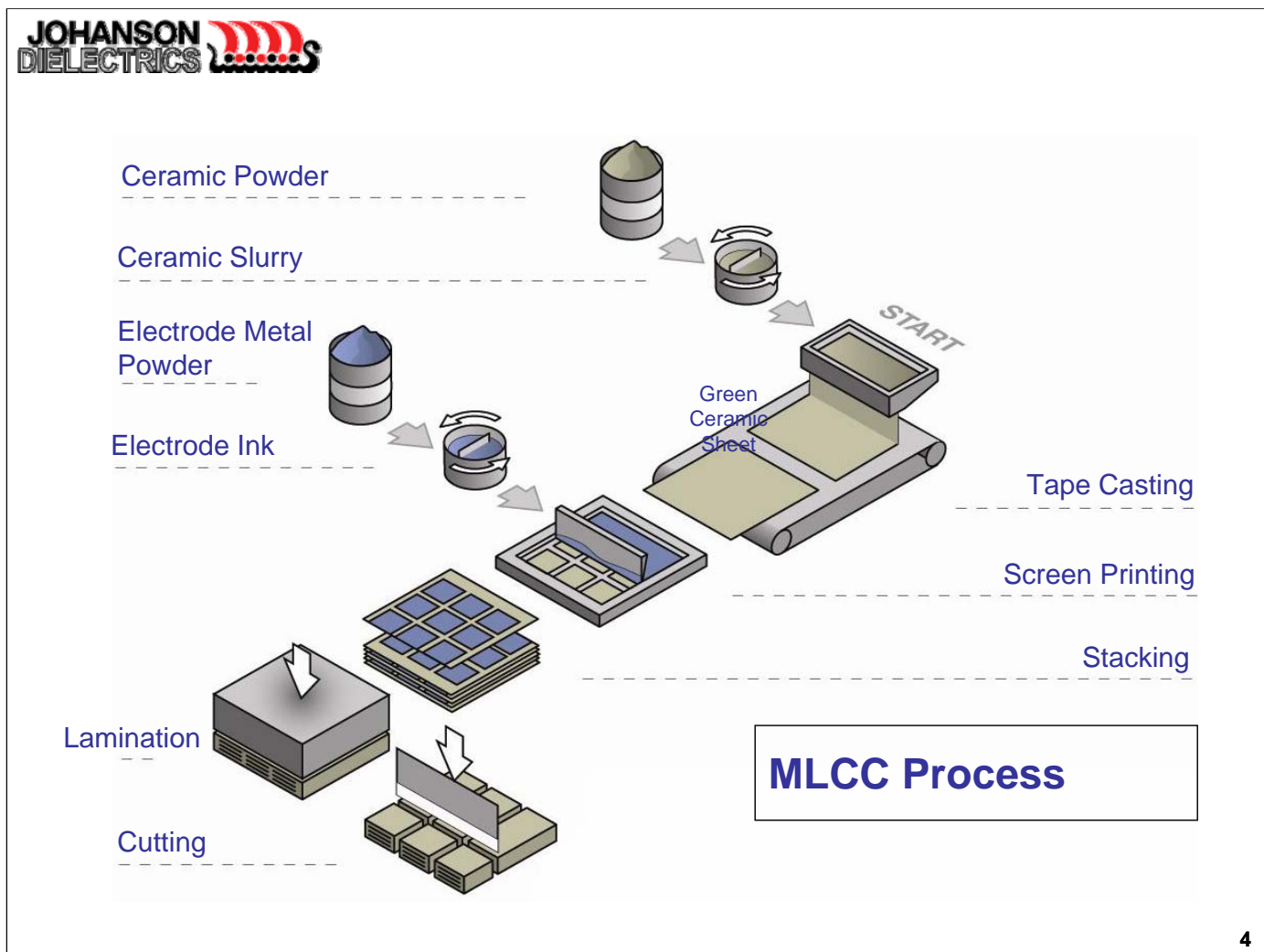
Ceramic Capacitor Basics

- A capacitor is an electrical device that stores energy in the electric field between a pair of closely spaced plates
- Capacitors are used as energy-storage devices, and can also be used to differentiate between high-frequency and low-frequency signals. This makes them useful in electronic filters
- Capacitance Value: Measure of how much charge a capacitor can store at a certain voltage
- MLCC: Multilayer Ceramic Chip Capacitor
 - Layers of ceramic and metal are alternated to make a multilayer chip

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Capacitors are devices that store energy in the form of an electric field. They can also be used to filter signals of different frequencies. The capacitance value is an indicator of how much electrical charge the capacitor can hold.

Multilayer ceramic capacitors consist of alternating layers of ceramic and metal.



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The process of making ceramic capacitors involves many steps.

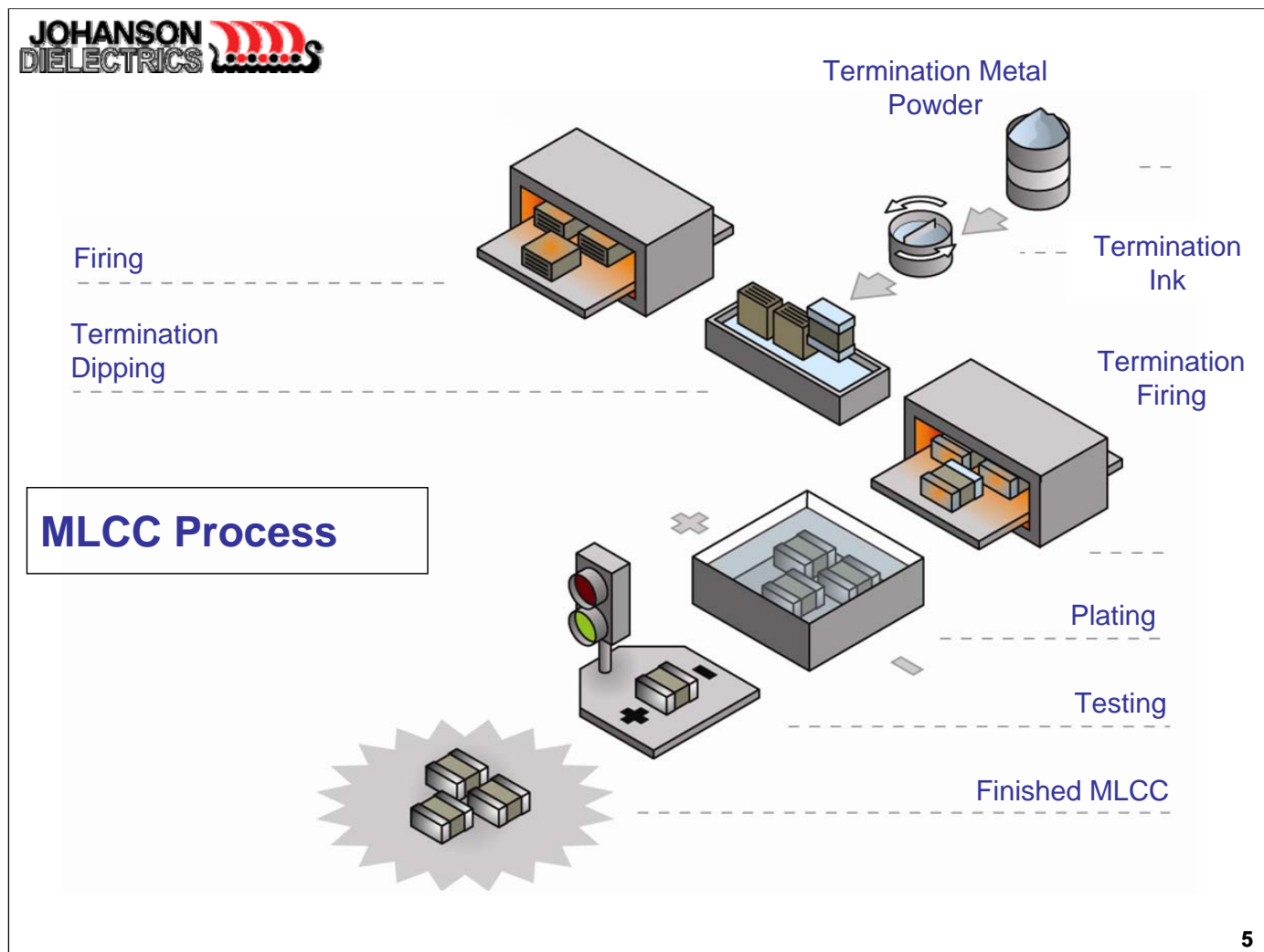
Mixing: Ceramic powder is mixed with binder and solvents to create the slurry, this makes it easy to process the material.

Tape Casting: The slurry is poured onto conveyor belt inside a drying oven, resulting in the dry ceramic tape. This is then cut into square pieces called sheets. The thickness of the sheet determines the voltage rating of the capacitor.

Screen Printing and Stacking: The electrode ink is made from a metal powder that is mixed with solvents and ceramic material to make the electrode ink. The electrodes are now printed onto the ceramic sheets using a screen printing process. This is similar to a t-shirt printing process. After that the sheets are stacked to create a multilayer structure.

Lamination: Pressure is applied to the stack to fuse all the separate layers, this created a monolithic structure. This is called a bar.

Cutting: The bar is cut into all the separate capacitors. The parts are now in what is called a 'green' state. The smaller the size, the more parts there are in a bar.



Firing: The parts are fired in kilns with slow moving conveyor belts. The temperature profile is very important to the characteristics of the capacitors.

Termination: The termination provides the first layer of electrical and mechanical connection to the capacitor. Metal powder is mixed with solvents and glass frit to create the termination ink. Each terminal of the capacitor is then dipped in the ink and the parts are fired in kilns.

Plating: Using an electroplating process, the termination is plated with a layer of nickel and then a layer of tin. The nickel is a barrier layer between the termination and the tin plating. The tin is used to prevent the nickel from oxidizing.

Testing: The parts are tested and sorted to their correct capacitance tolerances.

At this point the capacitor manufacturing is complete. The parts could be packaged on tape and reel after this process or shipped as bulk.



Base Metal vs. Precious Metal Systems

PME

BME

Palladium Silver

Electrodes

Nickel



Silver

Termination

Copper or Nickel

Nickel

Plating 1st Layer

Nickel

Tin

Plating 2nd Layer

Tin

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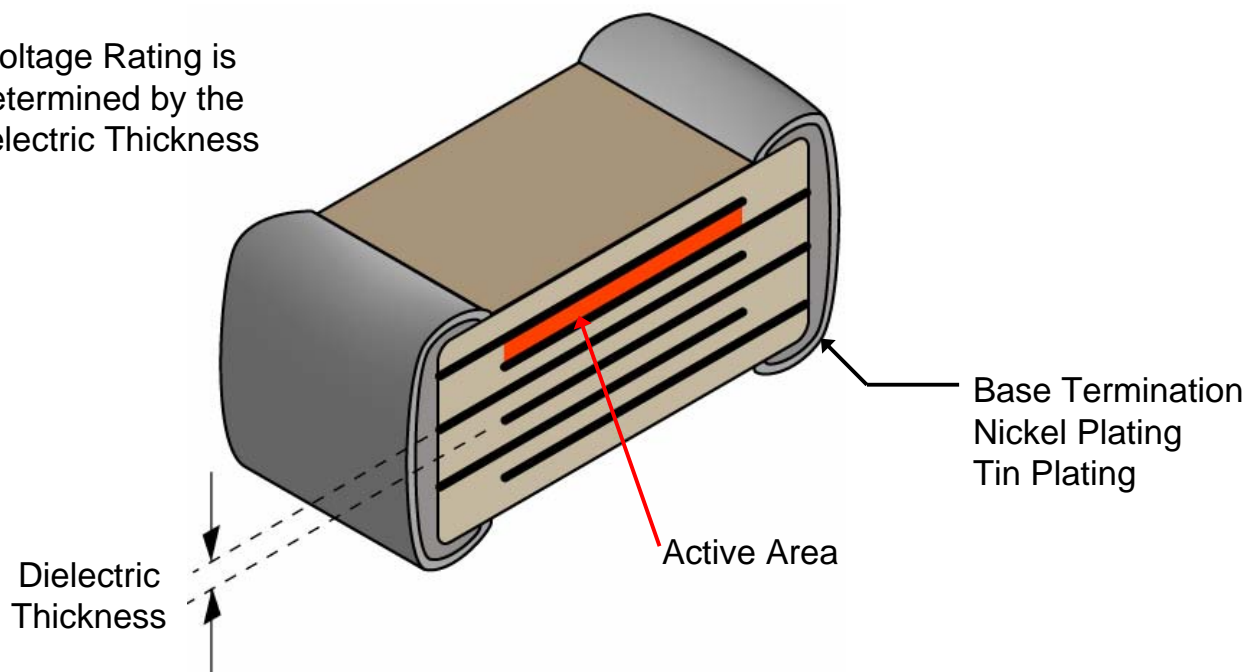
There are two material systems used today to make ceramic capacitors: Precious Metal Electrode and Base Metal Electrode. The precious metal system is the older technology and uses palladium silver electrodes, silver termination, then nickel and tin plating. Today this material system is mostly used on high voltage parts with a rating of 500V and higher. The base metal system is a newer technology and uses nickel electrodes, nickel or copper termination, and nickel and tin plating. This material system is typically used for parts with voltage ratings lower than 500VDC.



MLCC Basics

$$\text{Capacitance} = \frac{\# \text{ Layers} \times \text{Dielectric Constant} \times \text{Active Area}}{\text{Dielectric Thickness}}$$

Voltage Rating is determined by the Dielectric Thickness



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The capacitance value of a capacitor is determined by four factors. The number of layers in the part, the dielectric constant and the active area are all directly related to the capacitance value. The dielectric constant is determined by the ceramic material (NP0, X7R, X5R, or Y5V). The active area is just the overlap between two opposing electrodes.

The dielectric thickness is inversely related to the capacitance value, so the thicker the dielectric, the lower the capacitance value. This also determines the voltage rating of the part, with the thicker dielectric having a higher voltage rating than the thinner one. This is why the basic trade off in MLCCs is between voltage and capacitance.



Critical Specifications

Material	Dielectric Constant	% Capacitance Change	DF
NP0	15-100	<0.4% (-55 to 125C)	0.1%
X7R	2000-4000	+/-15% (-55 to 125C)	3.5%
Y5V	>16000	Up to 82% (-30 to 85C)	9%

- Dissipation factor: % of energy wasted as heat in the capacitor
- Dielectric Withstanding Voltage: Voltage above rating a capacitor can withstand for short periods of time
- Insulation resistance: Relates to leakage current of the part (aka DC resistance)

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The critical specifications of a capacitor are the dielectric constant, dissipation factor, dielectric withstanding voltage, and insulation resistance.

Dielectric constant: this depends on the ceramic material used. The table shows different dielectrics and some of their specifications. As you can see NP0 has the lowest dielectric constant, followed by X7R which has a significantly higher constant, and Y5V which is higher still. This is why the capacitance values for X7R capacitors are much higher than NP0 capacitors, and Y5V has higher capacitance than X7R. The capacitance change vs temperature is very small for NP0 parts from -55C to 125C, and gets larger for X7R, then even larger for Y5V. So, the more capacitance a material provides, the lower the stability of capacitance over temperature.

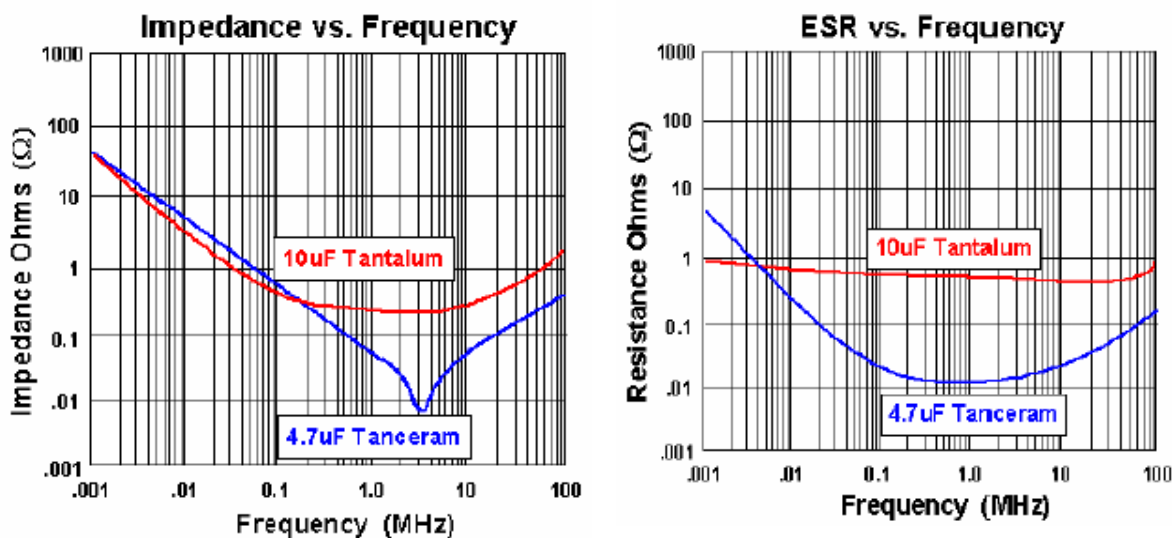
Dissipation Factor: this is the percentage of energy wasted as heat in the capacitor. As you can see, NP0 material is very efficient, followed by X7R, then Y5V which is the least efficient of the three materials.

Dielectric withstanding voltage: this refers to the momentary over voltage the capacitor is capable of withstanding with no damage.

Insulation resistance: this is the DC resistance of the capacitor, it is closely related to the leakage current.



Characteristics of Ceramic Capacitors



- Low impedance, equivalent series resistance (ESR) and equivalent Series Inductance (ESL). As frequencies increase, ceramic has bigger advantage over electrolytics

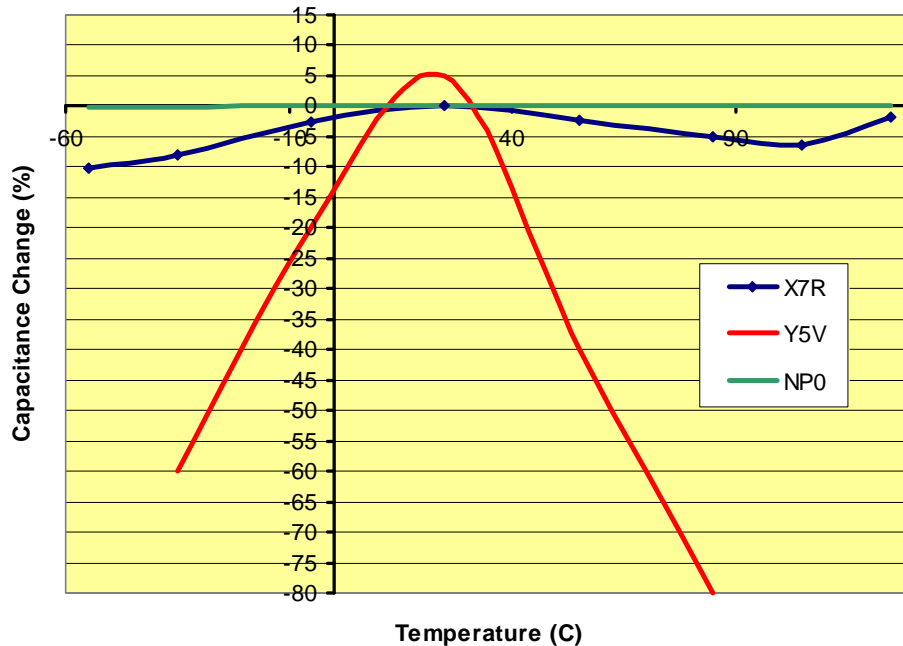
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The final part of this presentation will cover the characteristics of ceramic capacitors. MLCCs have low impedance when compared with tantalum and other electrolytic capacitors. This includes lower inductance and equivalent series resistance (ESR). This allows ceramic capacitors to be used at much higher frequencies than electrolytic capacitors.



Characteristics of Ceramic Capacitors

- **Temperature Coefficient:** Describes change of capacitance vs. temperature. Ceramic materials are defined by their temperature coefficient



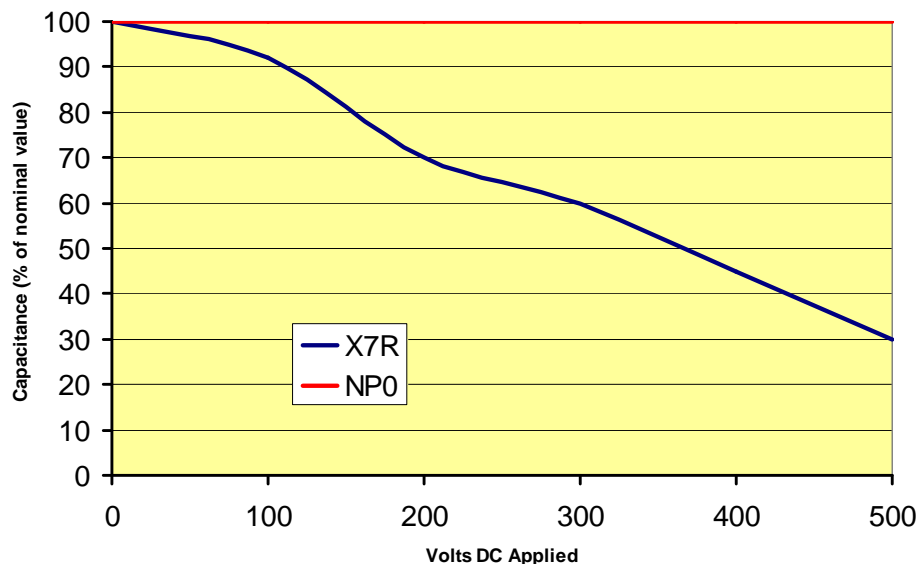
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Temperature Coefficient of Capacitance: Describes change of capacitance vs. temperature. Ceramic materials are defined by their temperature coefficient. For example, X7R means that the capacitance can change by +/-15% across a temperature range of -55C to 125C. The graph shows the temperature coefficient of NP0, X7R, and Y5V materials.



Characteristics of Ceramic Capacitors

- **Voltage Coefficient:** Describes change of capacitance vs voltage applied. Capacitance loss can be as much as 80% at rated voltage. This is a property of ceramic materials and applies to all manufacturers



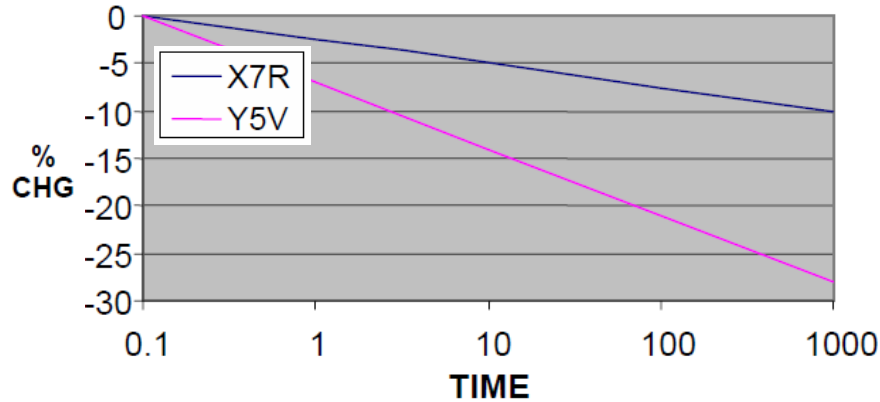
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Voltage Coefficient of Capacitance: describes change of capacitance vs DC voltage applied. This is a property of ceramic materials and applies to all manufacturers. The graph shows typical voltage coefficient curves for 500VDC rated X7R and NP0 capacitors. Note that the capacitance of the NP0 remains stable with applied voltage, while the X7R material can have a capacitance loss of 80% at rated voltage.



Characteristics of Ceramic Capacitors

- **Aging:** X7R, X5R, and Y5V experience a decrease in capacitance over time caused by the relaxation or realignment of the electrical dipoles within the capacitor.



- For X7R and X5R the loss is 2.5% per decade hour and for Y5V it is 7% per decade hour, NP0 dielectric does not exhibit this phenomenon
- De-Aging: aging is reversible by heating the capacitors over the “Curie Point” (approx 125°C), the crystalline structure of the capacitor is returned to its original state and the capacitance value observed after manufacturing.

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Aging: X7R, X5R, and Y5V experience a decrease in capacitance over time caused by the relaxation or realignment of the electrical dipoles within the capacitor. For X7R and X5R the loss is 2.5% per decade hour and for Y5V it is 7% per decade hour, NP0 dielectric does not exhibit any aging.

Aging is reversible by heating the capacitors over the “Curie Point” (approx 125°C), the crystalline structure of the capacitor is returned to its original state and the capacitance value observed after manufacturing.



Johanson Part Number Breakdown

500

Voltage

1st 2 digits are significant
3rd digit denotes # of zeros to follow

e.g 500 = 50VDC
R denotes decimal eg
6R3 = 6.3VDC

Standard Voltages
6R3 = 6.3VDC
100 = 10VDC
160 = 16VDC
250 = 25VDC
500 = 50VDC
101 = 100VDC
201 = 200VDC
251 = 250VDC
501 = 500VDC
102 = 1000VDC
202 = 2000VDC
302 = 3000VDC
402 = 4000VDC
502 = 5000VDC

S41

Size

Code EIA Size

R07 0402
R14 0603
R15 0805
R18 1206
S41 1210
S43 1812
S47 2220
S48 2225
S49 1825
X14 0603 X2Y
X15 0805 X2Y
X18 1206 X2Y
X41 1210 X2Y
X43 1812 X2Y
X44 1410 X2Y

W

Dielectric

N = NP0/COG
W = X7R
Y = Y5V
X = X5R

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Capacitance

1st 2 digits are significant
3rd digit denotes # of zeros to follow

e.g 331 = 330pF
R denotes decimal e.g
1R8 = 1.8pF

K

Tolerance

<10pF
A = +/- .05pF
B = +/- .10pF
C = +/- .25pF
D = +/- .50pF

>=10pF
F = +/- 1%
G = +/- 2%
J = +/- 5%
K = +/- 10%
M = +/- 20%
Z = +80, -20%

V

Termination

G = Gold
P = Palladium Silver
T = 95% Tin 5% Lead
V = 100% Tin
Y = Solderable Palladium Silver

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Marking

3 = Special Marking
4 = Unmarked
6 = EIA 2 digit code

E

Packaging

E = 7" Plastic Tape
H = High Reliability
R = 13" Paper Tape
S = Special
T = 7" Paper Tape
U = 13" Plastic Tape
W = Waffle Pack
None = Bulk Packaging

Dimensions

* = Standard Dimension
A = .005 N = .070
B = .010 O = .075
C = .015 P = .080
D = .020 Q = .085
E = .026 R = .090
F = .030 S = .095
G = .035 T = .100
H = .040 U = .110
I = .045 V = .120
J = .050 W = .130
K = .055 X = .140
L = .060 Y = .150
M = .065 Z = .160

- AA

Non Standard Code
Defines non standard requirements

Max End Band
Min End Band
Max Thickness
Min Thickness

This slide is for reference and shows the Johanson Dielectrics part number breakdown.



Summary

- Manufacturing process and basic structure of ceramic capacitors
- Material systems and basic specifications of ceramic capacitors
 - Precious Metal vs Base Metal
 - Critical Specifications of MLCCs
- Characteristics of ceramic chip capacitors
 - Low impedance, temperature coefficient, voltage coefficient, aging