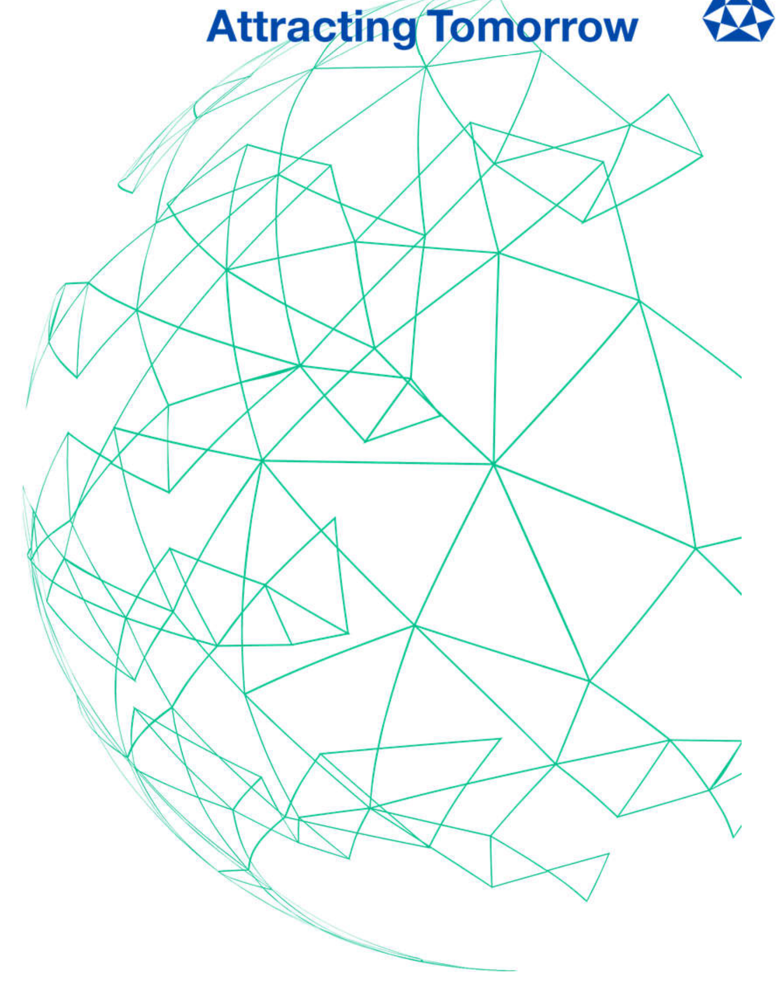
Attracting Tomorrow TDK



Introduction of Metal Foil-based Capacitor for Embedding Solution

TDK Corporation of America
A TDK Group Company

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Contents

1. Background
2. Introduction of TFCP
3. Introduction of Z-Leveler®
4. Summary

Tom Motoki

Product Marketing Manager
Application Marketing

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Background:

- Product marketing manager at TDK Corporation of America (Cypress, CA) with over 20 years' experience with passive component applications.
- Master's degree in electronic chemistry from Tokyo Institute of Technology.

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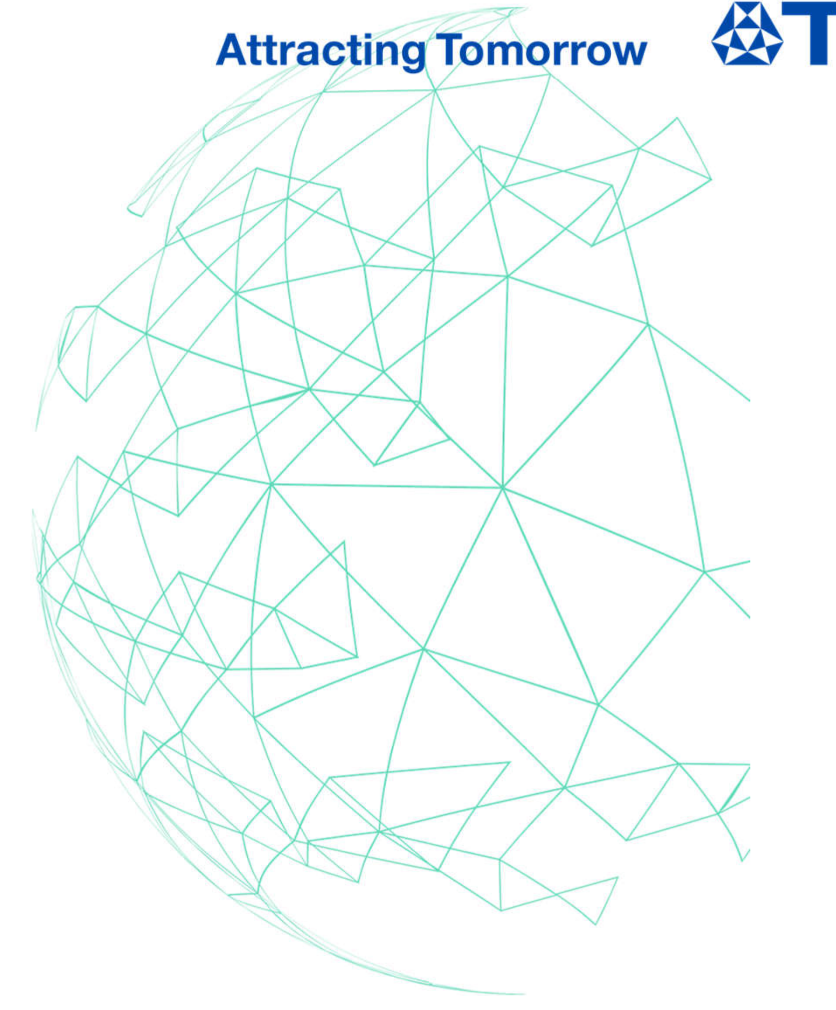

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Background

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Power Delivery Network (PDN)

A large number of decoupling capacitors are used on the power supply line in order to make the voltage to the LSI stable.

DC-DC converter
Smoothing circuit
Power line
Decoupling capacitor
LSI chip

It is better to put decoupling capacitor as close to the LSI as possible for PI especially in higher frequency.

If the PI (Power integrity; quality of power) is bad, it may cause the LSI performance unstable, resulting in malfunction and increase in noise.

From TDK Home page
https://product.tdk.com/info/en/techlibrary/developing/tfcp/index.html

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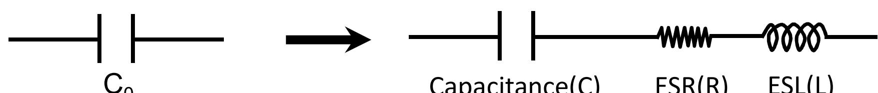
Background

Equivalent Series Inductance (ESL)

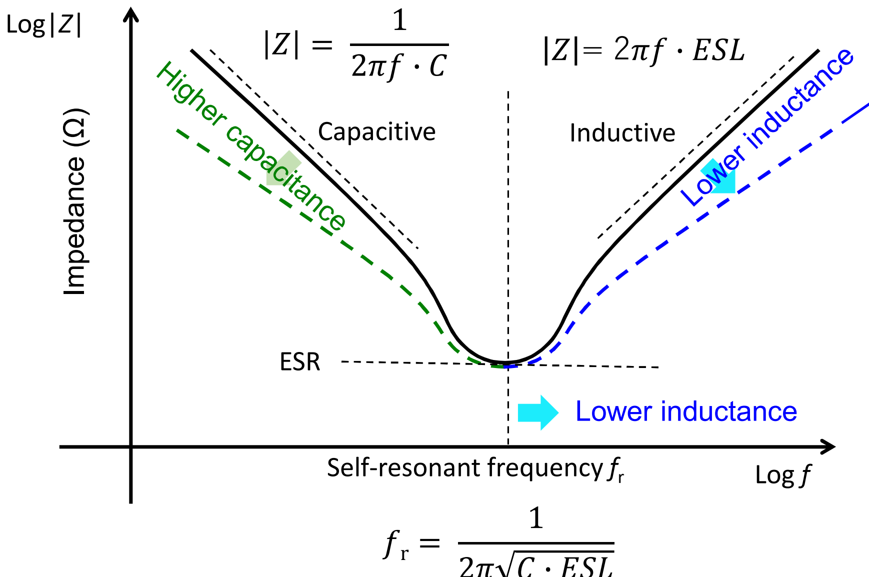
- ✓ PCB and package substrate has resistance and inductance elements.

- ✓ A capacitor consists of not only capacitance but also resistance and Inductance.

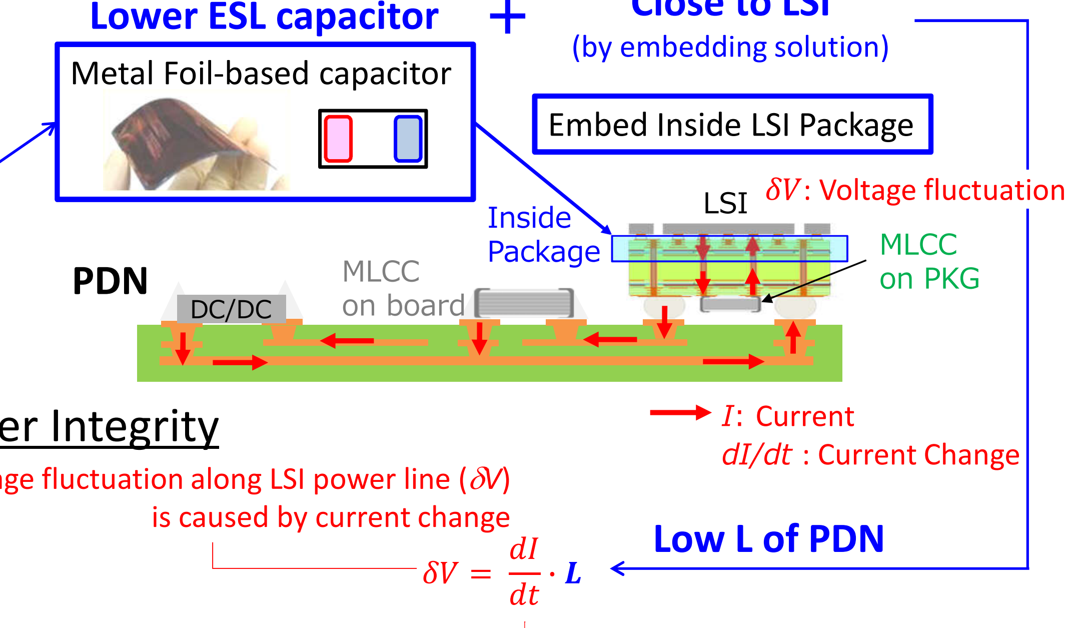


ESR: Equivalent Series of Resistance
ESL: Equivalent Series of Inductance

Impedance of capacitor



$$f_r = \frac{1}{2\pi\sqrt{C \cdot ESL}}$$



Power Integrity

Voltage fluctuation along LSI power line (δV) is caused by current change

$$\delta V = \frac{dI}{dt} \cdot L$$

Lower L is preferable to reduce δV
(Especially in high frequency ($dt \rightarrow 0$))

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Overview of TDK Thin Film Capacitor

Attracting Tomorrow TDK

TFCP

Sheet Capacitor

Mass Production

Cu
Dielectric material
Ni foil

Z-Leveler® (Discrete type)

< Terminal type >
power ground

Two terminal capacitor

Under development

Cu (Terminal)
Capacitor portion
Metal foil base

Multi terminal capacitor

Under development

Cu (Terminal)
Capacitor portion
Metal foil base

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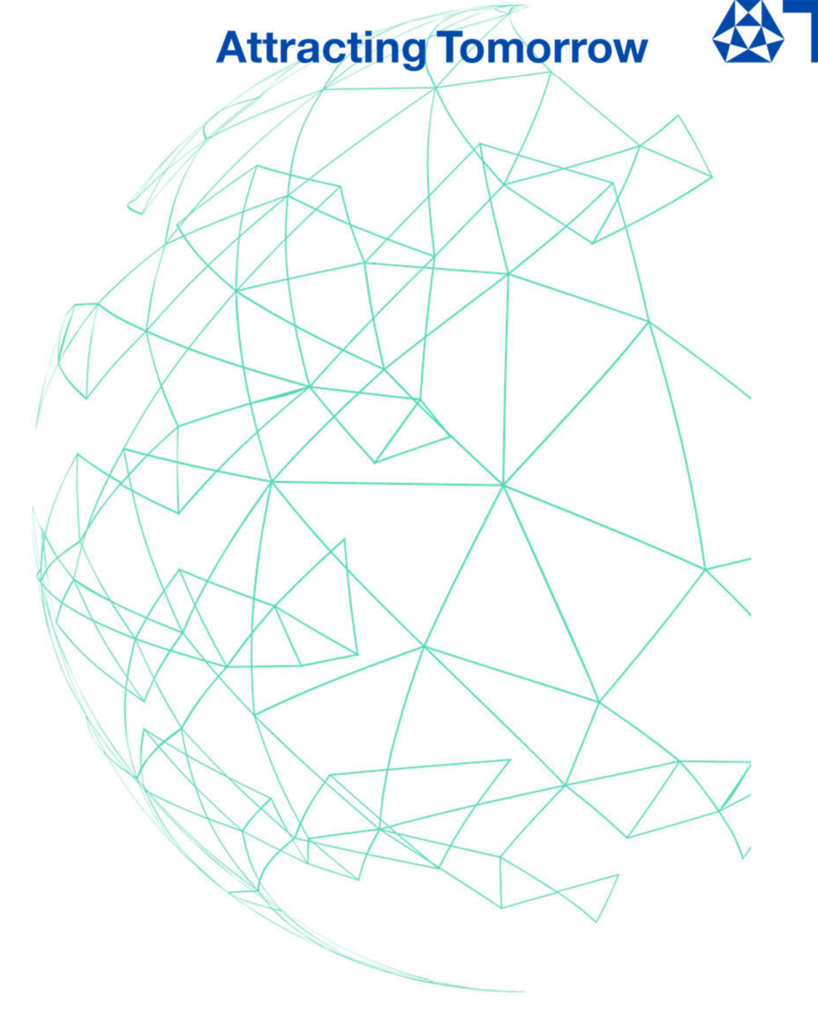

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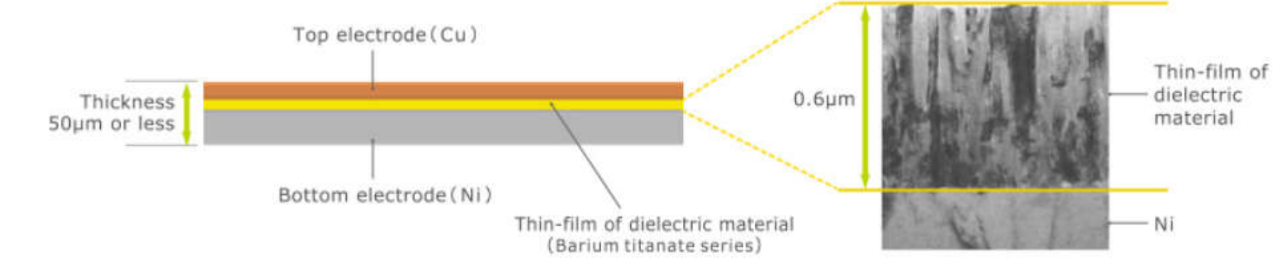
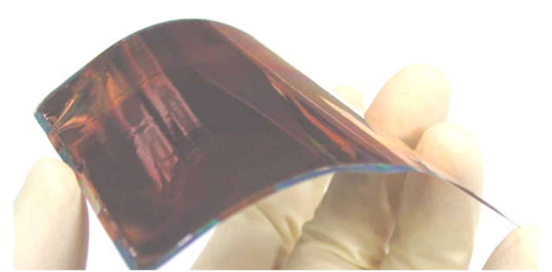
Outline of Thin Film Capacitor (TFCP) in TDK Home Page

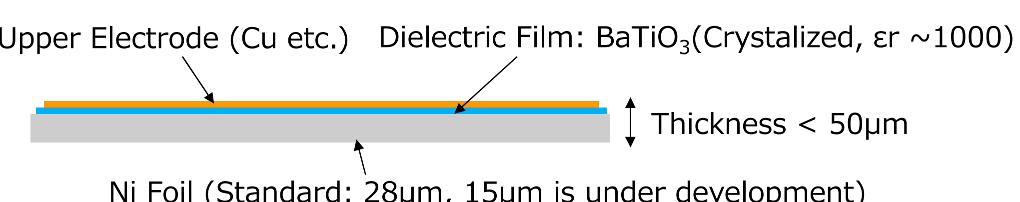
Optimizing Thin-Film Capacitors (TFCPs) with TDK's Materials and Thin-film Technologies for use as Built-in Capacitors in Circuit Boards

TFCPs from TDK have a structure where a thin dielectric film is sandwiched between two thin metals (see Figure 3). During the manufacturing process, nickel foil with a high degree of purity is used to form the bottom electrode; a thin dielectric film made of barium titanate formed by a proprietary sputtering method forms the middle; and the copper top electrode is superimposed by thin-film formation.



From TDK Home page
https://product.tdk.com/info/en/techlibrary/developing/tfcp/index.html





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Electrical Properties of TFCP Sheet

Characteristics	C/A ～ 1.0μF/cm² Mass production	C/A ～ 2.0μF/cm² Completed development	C/A ～ 4.0μF/cm² Under development
Temperature dependence of Capacitance	X7S (-55 ～ 125℃ ±22%)	X7S (-55 ～ 125℃ ±22%)	X7S (-55 ～ 125℃ ±22%)
Rated voltage	4Vdc	4Vdc	2.5Vdc
Dissipation factor (tanδ)	10% Max	10% typical	10% typical
Insulation resistance (IR) CR product (CR)	IR ≧ 100MΩ (1/cm²) CR ≧ 100 Ω F 4Vdc, room temperature	IR ≧ 100MΩ (1/cm²) CR ≧ 100 Ω F 4Vdc, room temperature	IR ≧ 100MΩ (1/cm²) CR ≧ 100 Ω F 2.5Vdc, room temperature

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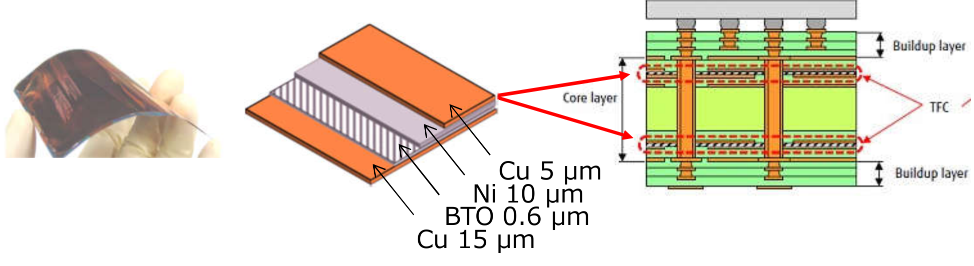
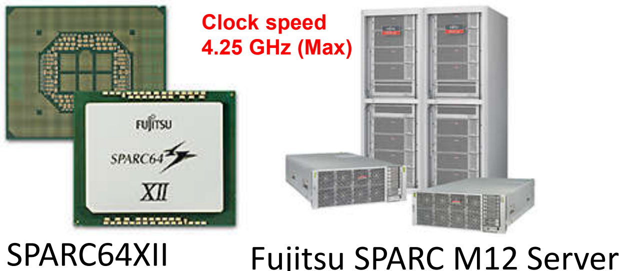
Current Status of TFCP Sheet



Structure embedded TFCP

2017.4.4 World wide release



SPARC64XII

Fujitsu SPARC M12 Server

Source:
FUJITSU INTERCONNECT TECHNOLOGIES LIMITED Home Page

https://www.fujitsu.com/jp/group/fict/en/products/devices/pcbs/substrate/gigamodule-ec/index.html

Source:
Fujitsu Home Pages

http://www.fujitsu.com/global/about/resources/news/press-releases/2017/0404-01.html

2016～ 1μF/cm^2 capacitor has been in mass production for Fujitsu M12 Server.

Manufacturing Process Flow of Embedding TFCP (Example)

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Thin-film capacitor (TFCP) sheet

Cu

Ni

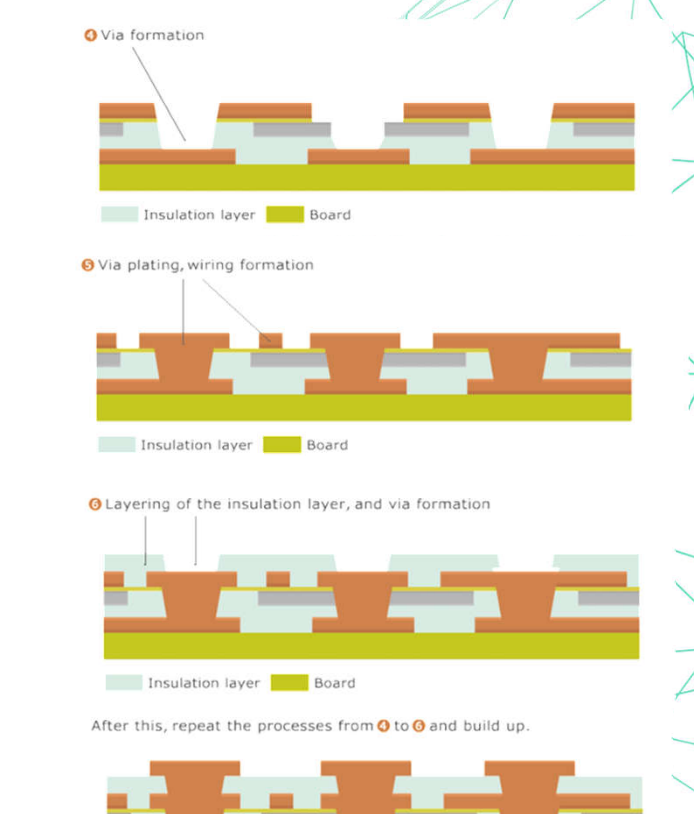
❶ Bottom electrode (Ni) patterning

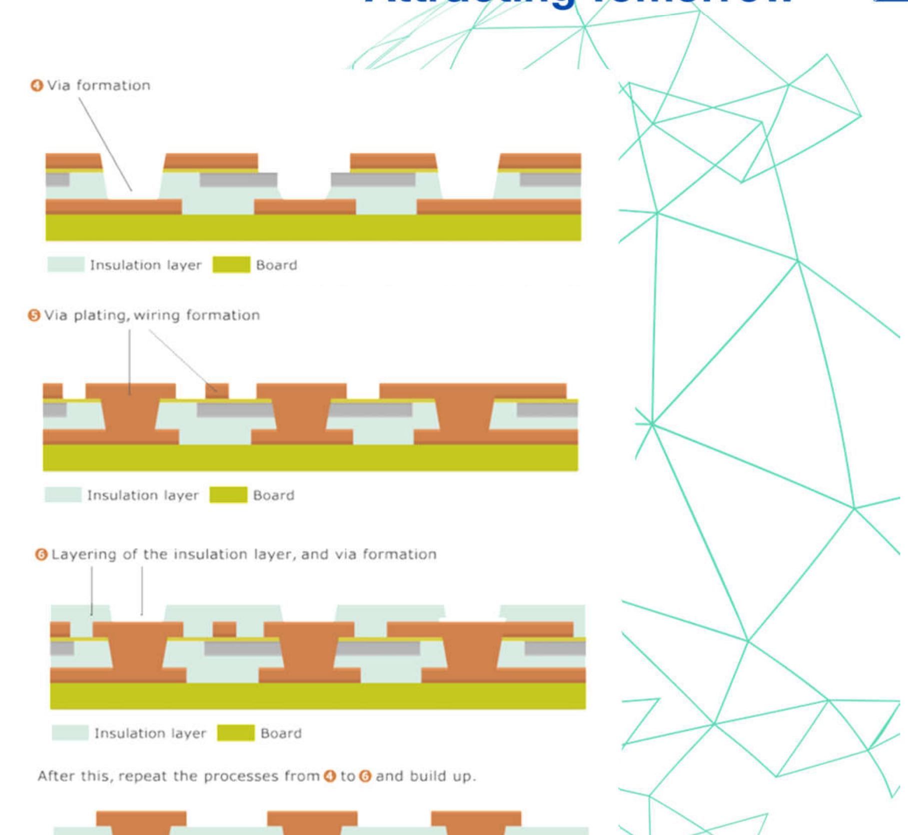
❷ Sandwich the insulation layer and layer on to the substrate.

Insulation layer Board

❸ Patterning of the top electrode (Cu)

Insulation layer Board





From TDK Home page

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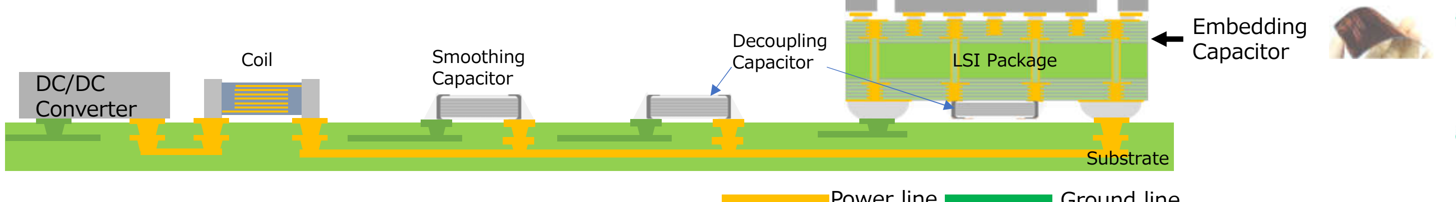
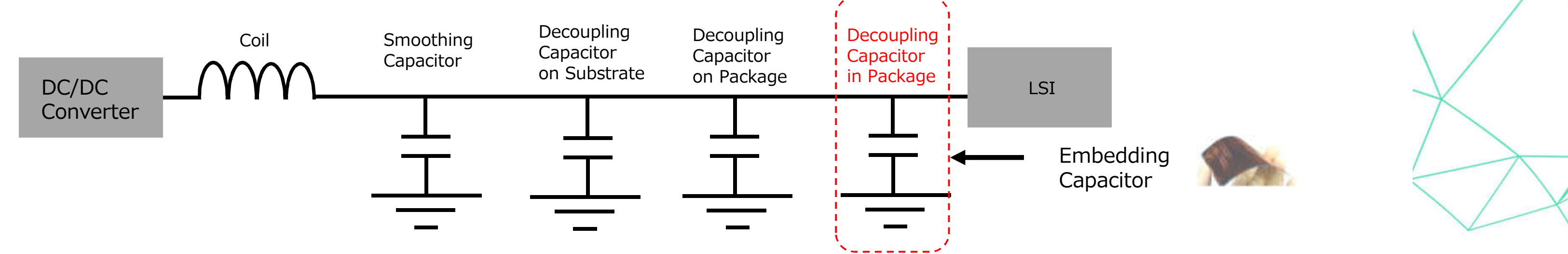
LSI Power Line Integrity Improvement



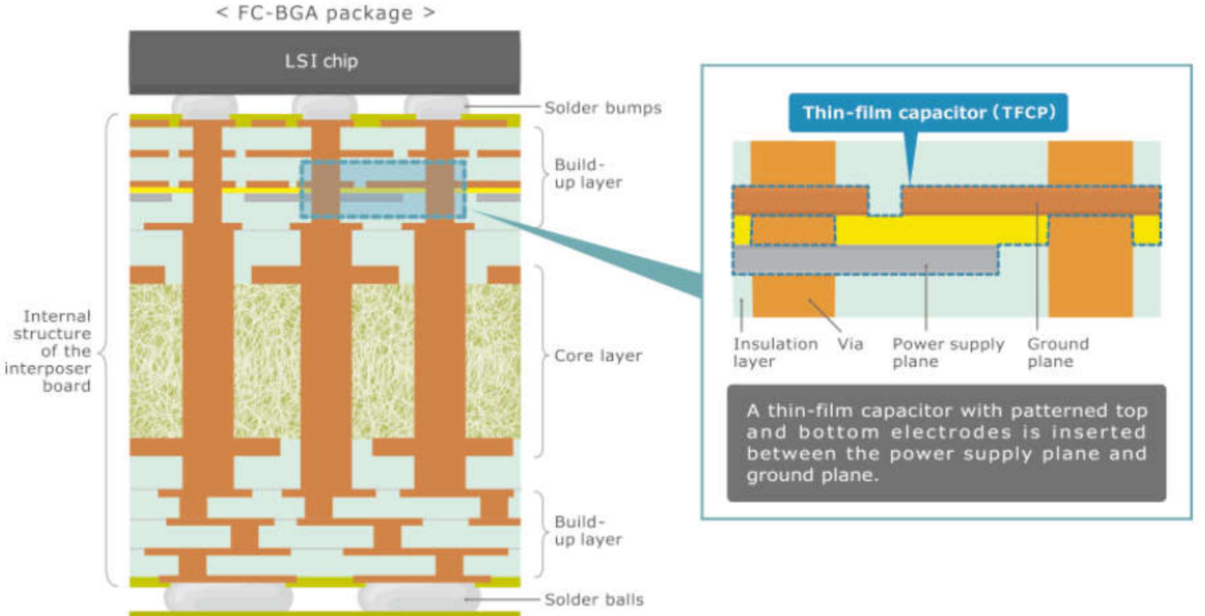
Equivalent Circuit of LSI power line



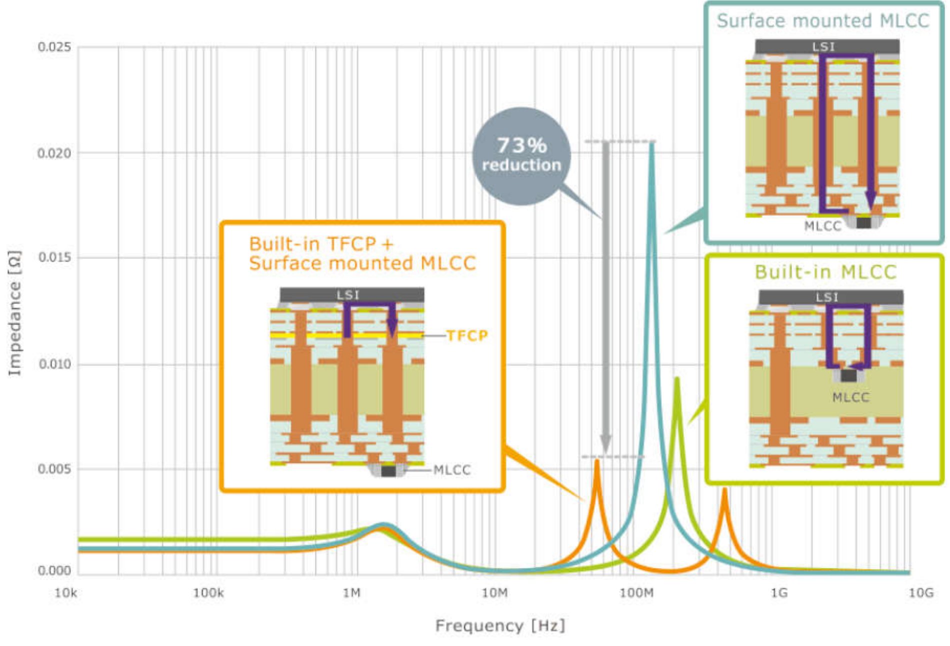
✓ We would like to improve the power line integrity by embedding the thin film capacitor. (Lower impedance, lower voltage fluctuation, and quick response of current)

LSI Power Line Integrity Improvement

Thin film capacitor sheet inside LSI Package



LSI Power line impedance



✓ Embedding the thin film capacitor has made LSI power line impedance lower, and has improved LSI power integrity.

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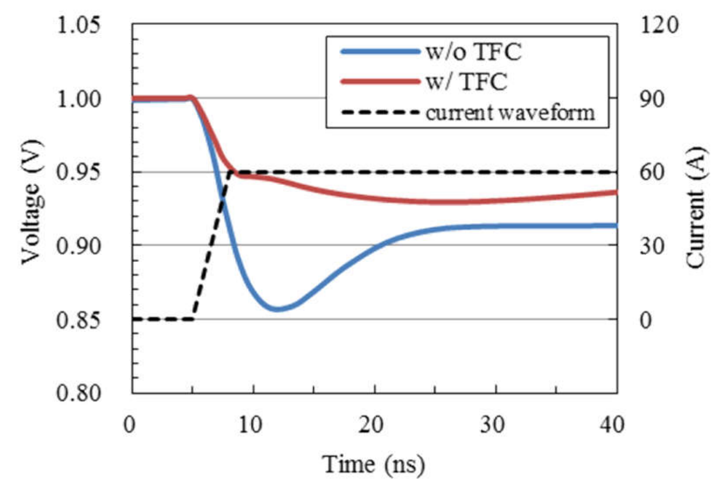
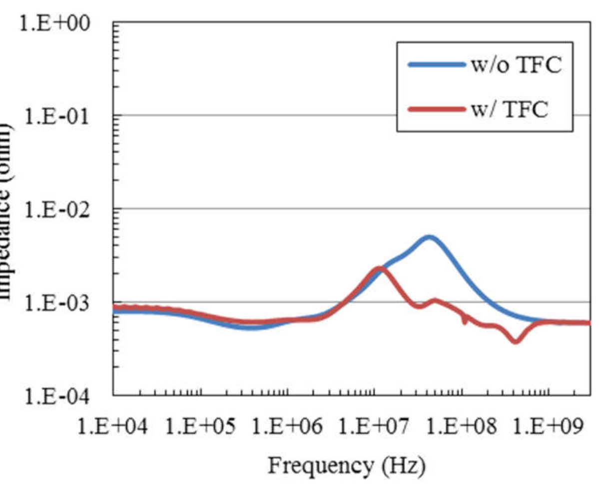
LSI Power Line Integrity Improvement

Decoupling for LSI application (Demonstrated with TFCP Sheet)

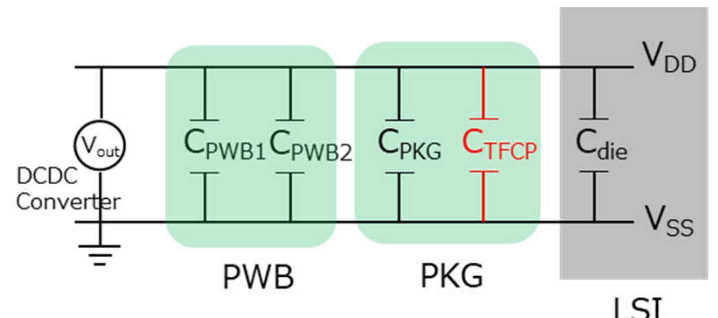
Decreasing voltage fluctuation under LSI operating



Decreasing power line Impedance (Z) 10-300MHz range



Source: T. Akahoshi *et-al.* 2017 IEEE 67th Electronic Components and Technology Conference, p179



Impedance decrease at 10 ~ 100MHz is required

- ✓ C_{TFCP} Implementation near LSI
- ✓ Low ESL C_{TFCP}

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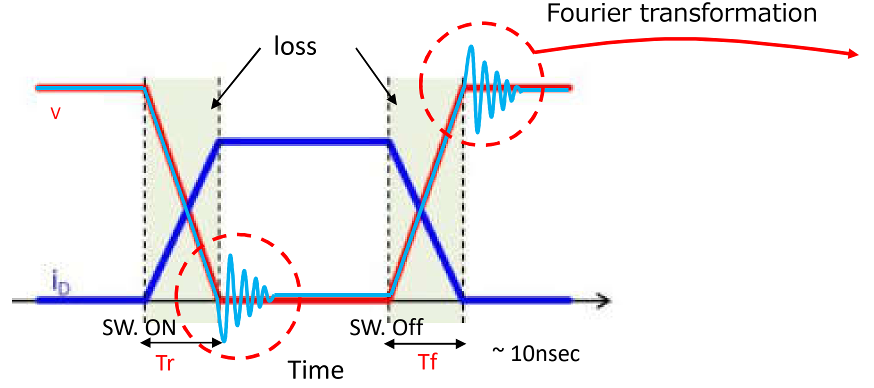
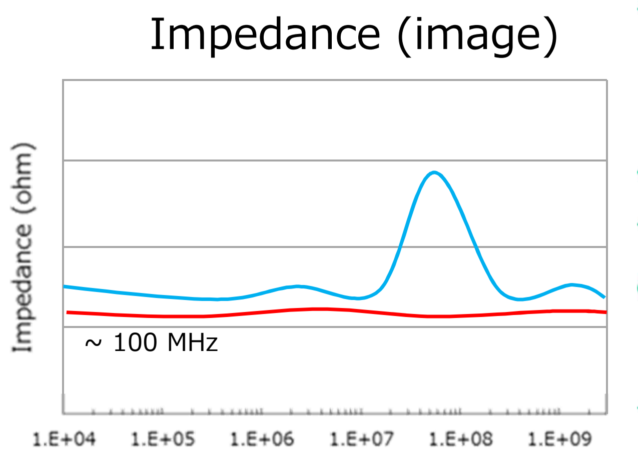
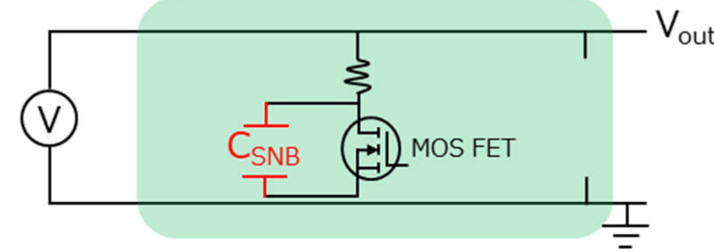
Suppression of Voltage Fluctuation

Snubber for High Voltage Application





Switching Circuit (Example)



Is impedance decrease at 10 ~ 100MHz required ?

✓ C_{SNB} implementation near MOS FET

✓ Low ESL C_{SNB}

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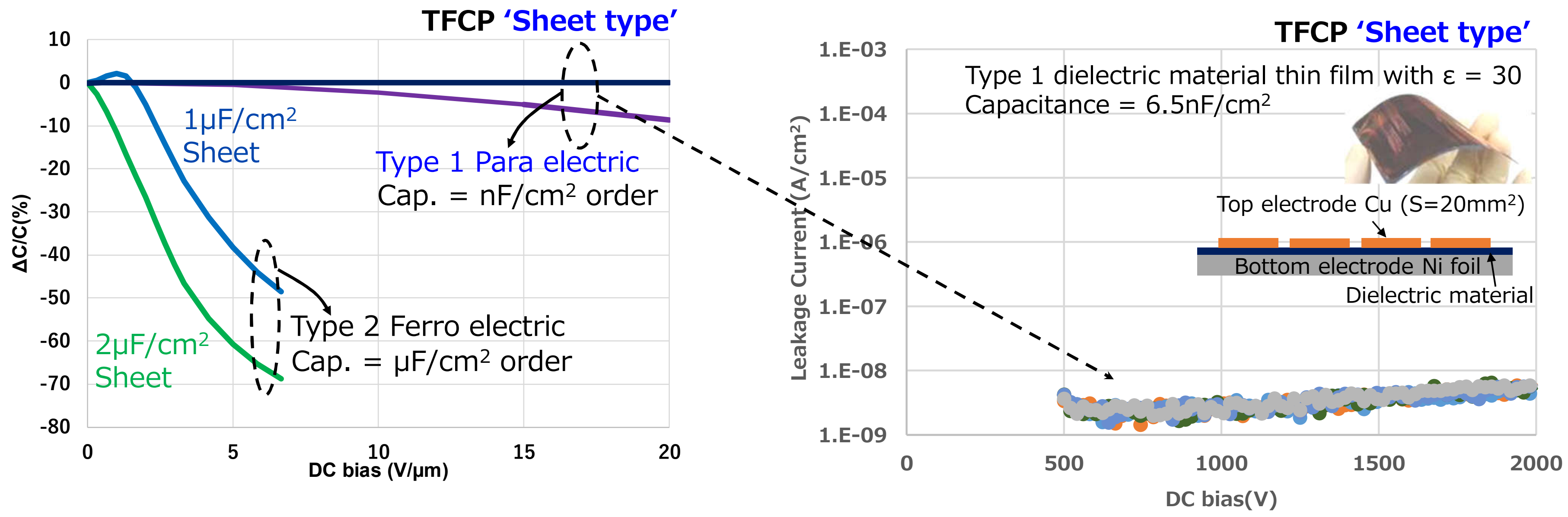
Thin Film Capacitor for High Voltage Use

Dielectric material for high voltage application

Under development

DC bias dependence of capacitance

Leakage current measurement from 500V to 2000V
(B1505A power device analyzer)



✓ Type1 dielectric material has low DC bias dependence of capacitance.
→ Leakage current can be kept low under high voltage from 500V to 2000V.

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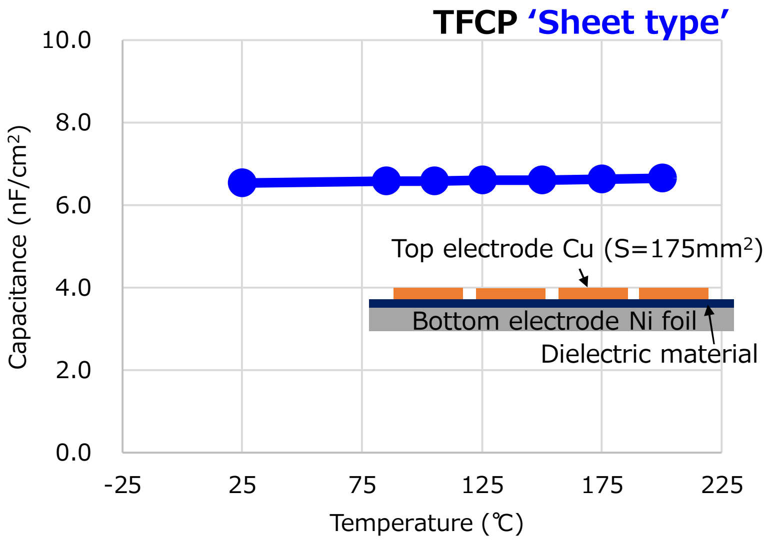
Thin Film Capacitor for High Voltage Use

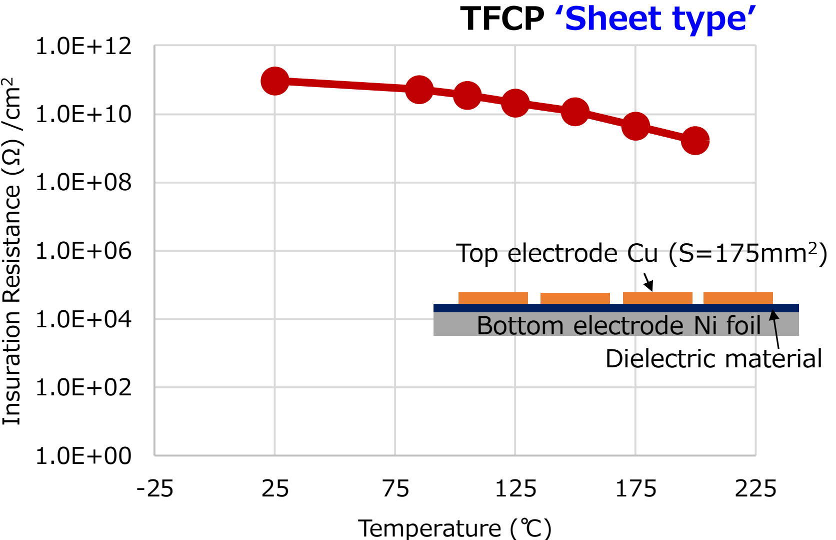
Electrical properties of Type 1 dielectric material

Under development

Temperature dependence of capacitance
(4284A LCR meter/@1kHz-1Vrms)

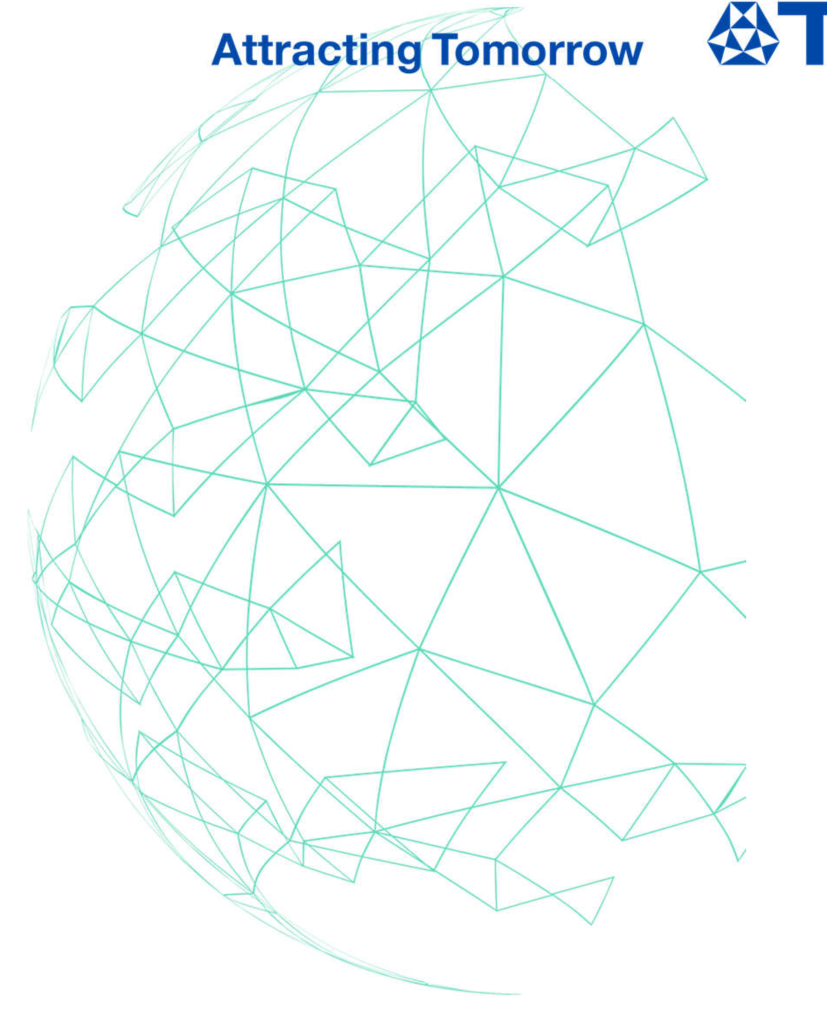


Temperature dependence of insulation resistance
(4339B High resistance meter/@600V)



✓ Type1 dielectric material has stable temperature dependence of capacitance.
✓ Insulation Resistance can be kept high up to 200 °C.

Contents



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Overview of TDK Thin Film Capacitor

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TFCP

Sheet Capacitor

Mass Production

Cu
Dielectric material
Ni foil

Z-Leveler® (Discrete type)

< Terminal type >
power ground

Two terminal capacitor

Under development

Cu (Terminal)
Capacitor portion
Metal foil base

Multi terminal capacitor

Under development

Cu (Terminal)
Capacitor portion
Metal foil base

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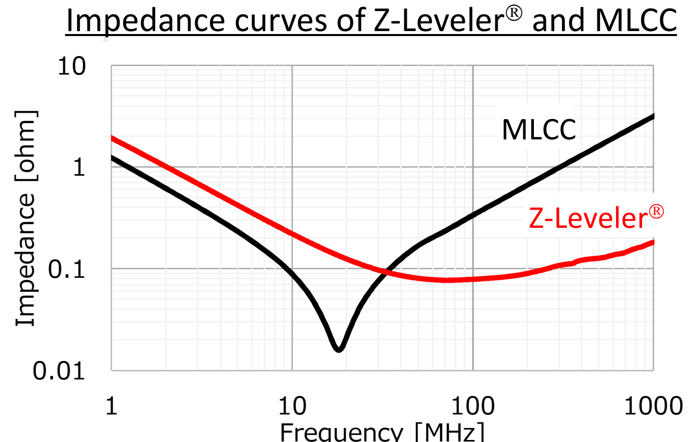
Difference from MLCC

Overview of ultra low profile thin film capacitor; Z-Leveler®

	Z-Leveler®	MLCC
Structure X-section		
Lower ESL	☺	☹
Lower profile	☺	☹
Fragility	☺	☹
Higher Capacitance	😐 >350nF/mm²	☺



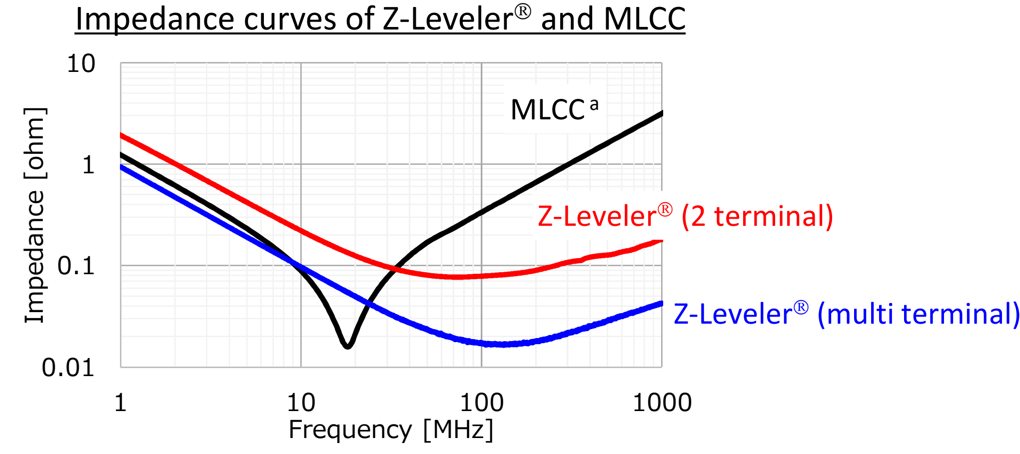
Value proposition = Impedance leveler in high frequency

Named ***Z-Leveler®***

Electrical Properties of Z-Leveler®

Electrical Properties of Z-Leveler®

	Z-Leveler® (2 terminal)	Z-Leveler® (multi terminal)
Size [mm]	1.06 x 0.56	1.07 x .07
Thickness [mm]	0.05	0.05
Terminal	2 terminals	25 terminals
C_{1k} [nF]	159	421
f_{SRF} [MHz]	91.9	133.2
L_{ESL} [pH]	18.9	3.4
R_{ESR} [mΩ]	78.1	16.8



a. TDK corporation product number: C1005X7R1A154M050BB

✓ Z-Leveler® has low ESL and low impedance in high frequency.
✓ Multi terminal type has much lower ESL and impedance.

Source: Proceedings of Electronic Components & Technology Conference (ECTC), May. 2020, pp. 414-418.

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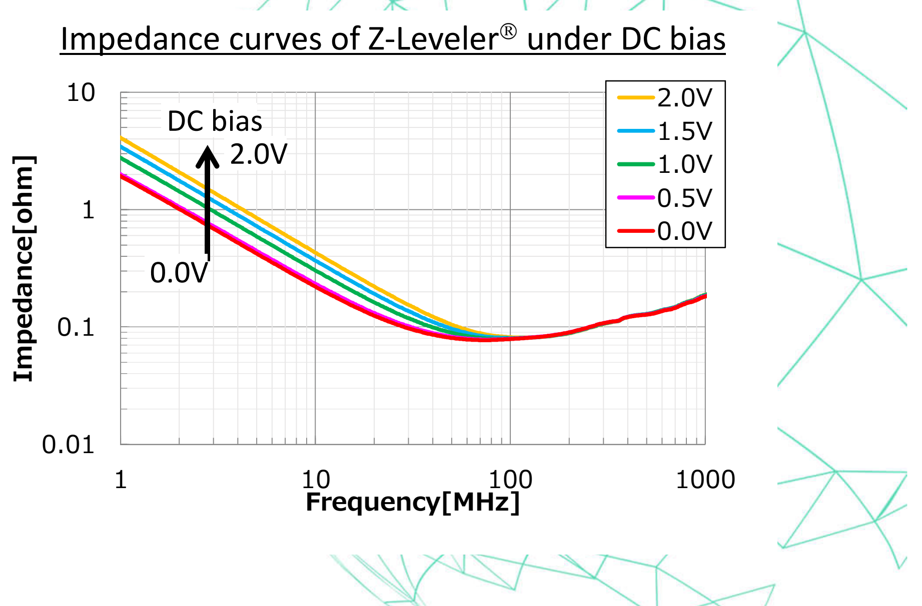
Electrical Properties of Z-Leveler®

DC bias dependence of Z-Leveler®

	Z-Leveler® (2 terminal)				
DC bias [V]	0.0	0.5	1.0	1.5	2.0
C_{1k} [nF]	159	149	119	87	65
f_{SRF} [MHz]	91.9	96.3	110.8	122.4	134.2
L_{ESL} [pH]	18.9	18.3	17.3	19.3	21.6
R_{ESR} [mΩ]	78.1	79.0	80.2	81.0	81.5



✓ Z-Leveler® has some DC bias dependence.
However, impedance in high frequency can be kept low under DC bias.

Source: Proceedings of Electronic Components & Technology Conference (ECTC), May. 2020, pp. 414-418.

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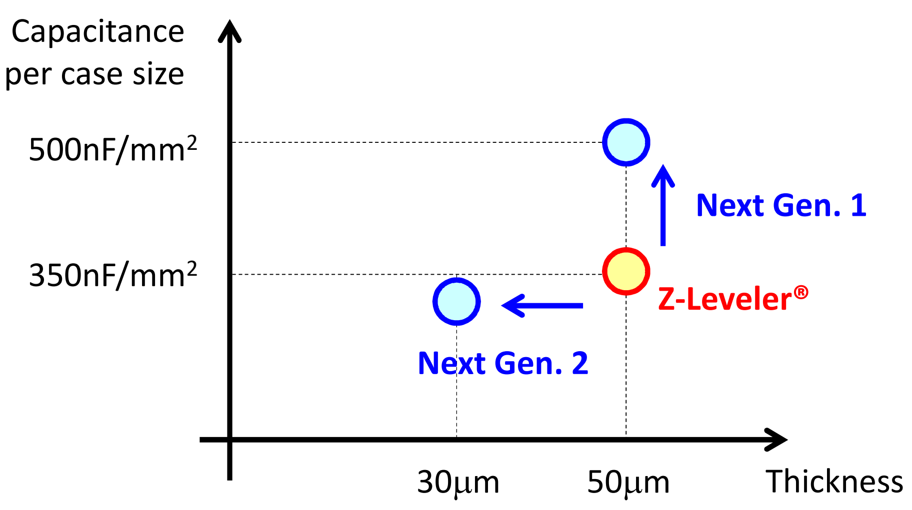
Roadmap for Next Generation

Target specification for next generation development

	Z-Leveler®	Next generation	
Capacitance per case size (1kHz-1V)	350nF/mm²	500nF/mm²	300nF/mm²
DC bias dependance	Some	None	None
Thickness	50um	50um	30um



✓ Roadmap for next generation
1. Increase capacitance with no DC bias dependance
2. Decrease thickness for further embedding solution

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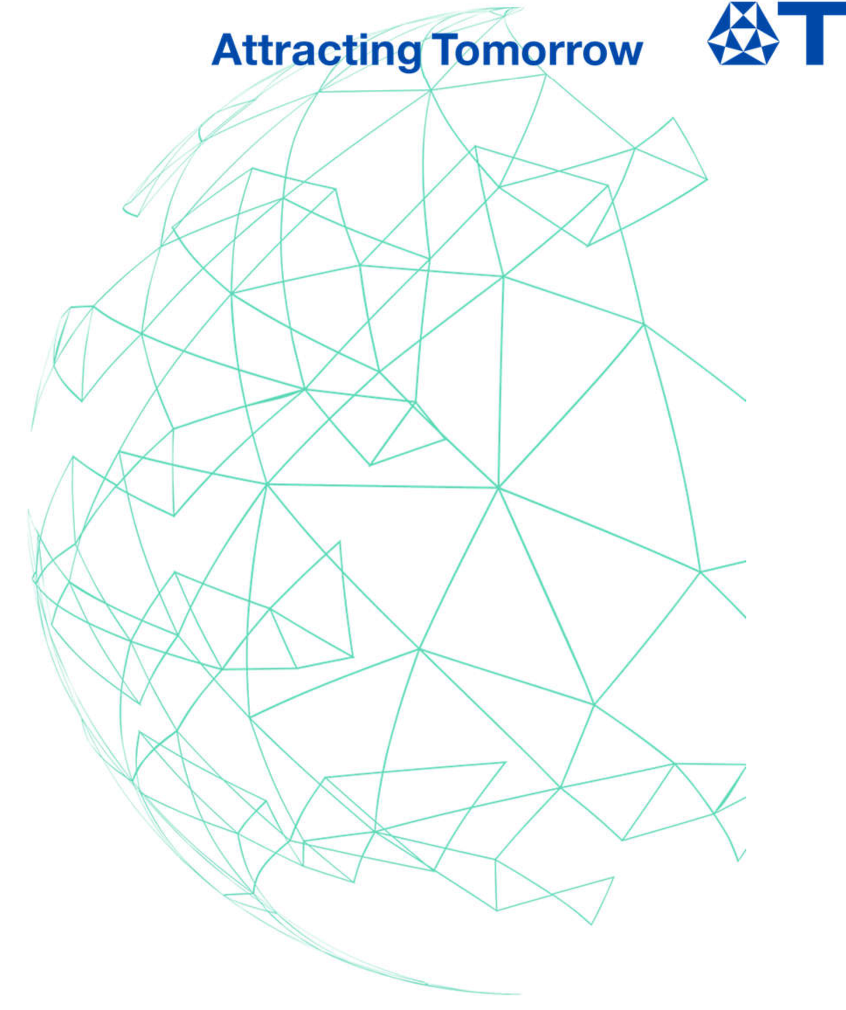

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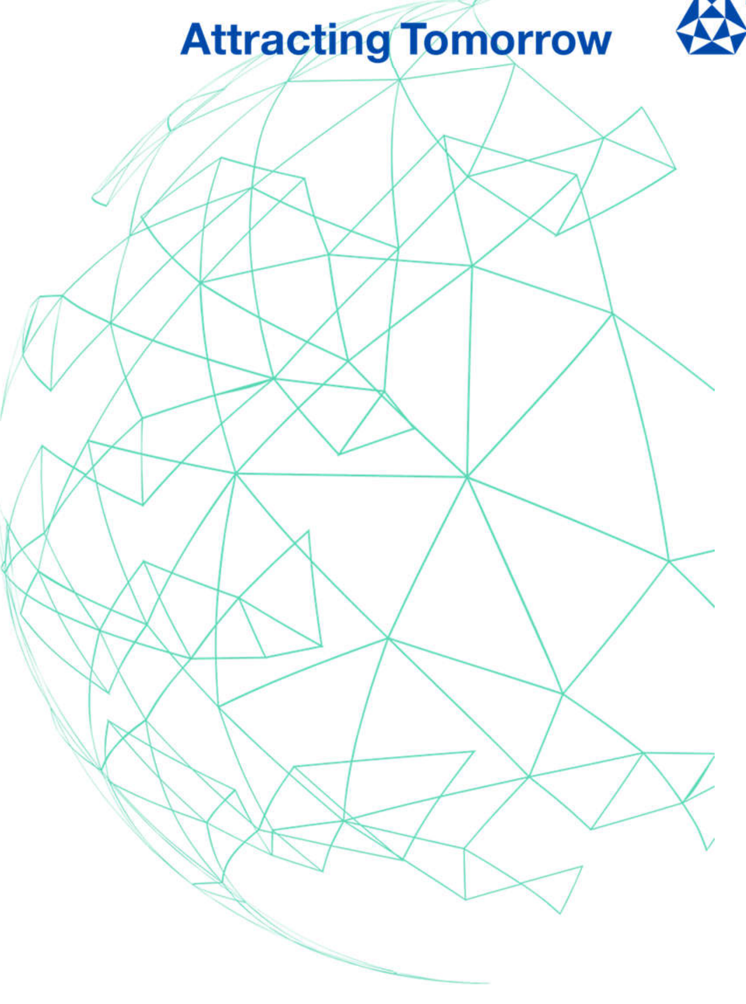

- Embedding capacitor inside LSI package substrate is effective to reduce ESL of PDN especially in high frequency.
- TDK has developed the metal foil-based thin film capacitor;
  - ✓ TFCP as sheet type capacitor
  - ✓ Z-Leveler® as discrete type capacitor
- TFCP and Z-Leveler® is suitable for embedding solution with;
  - ✓ Low profile less than 50μm
  - ✓ Low ESL
- TDK is continuing the development for higher capacitance / thinner profile.

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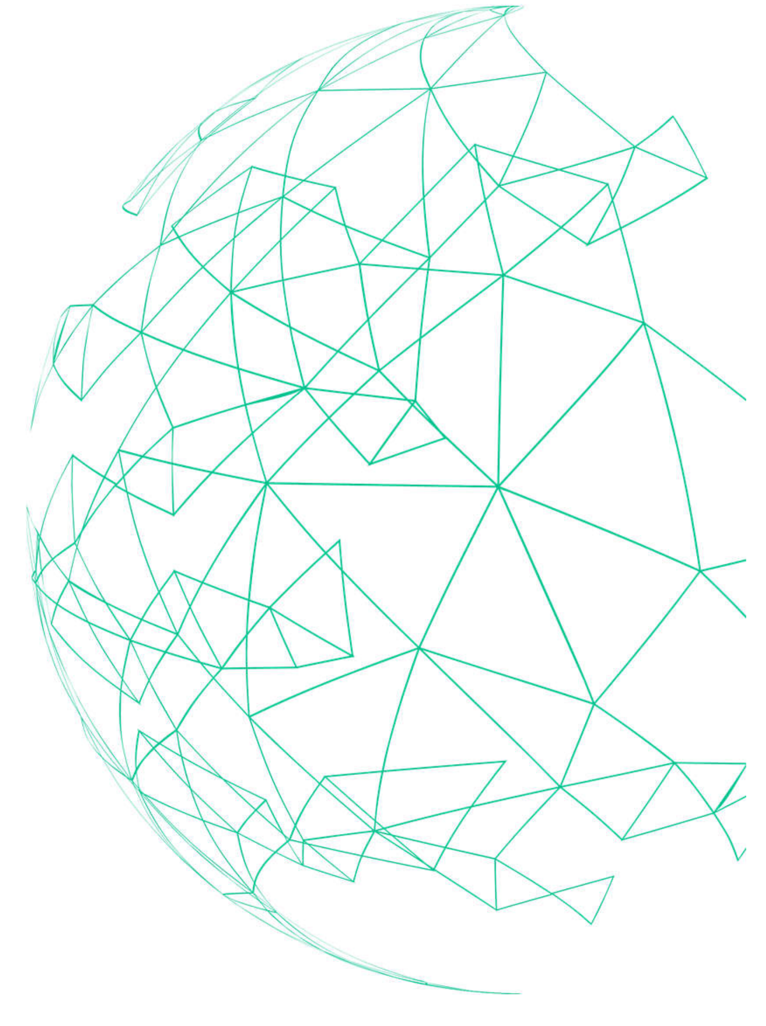

Thank you