

Attracting Tomorrow



# Low profile metallic foil-based capacitor for high frequency operation

Kenichi Yoshida<sup>1</sup>, Hitoshi Saita<sup>1</sup>, Daiki Ishii<sup>1</sup>, Takashi Kariya<sup>1</sup>, Tom Motoki<sup>2</sup>

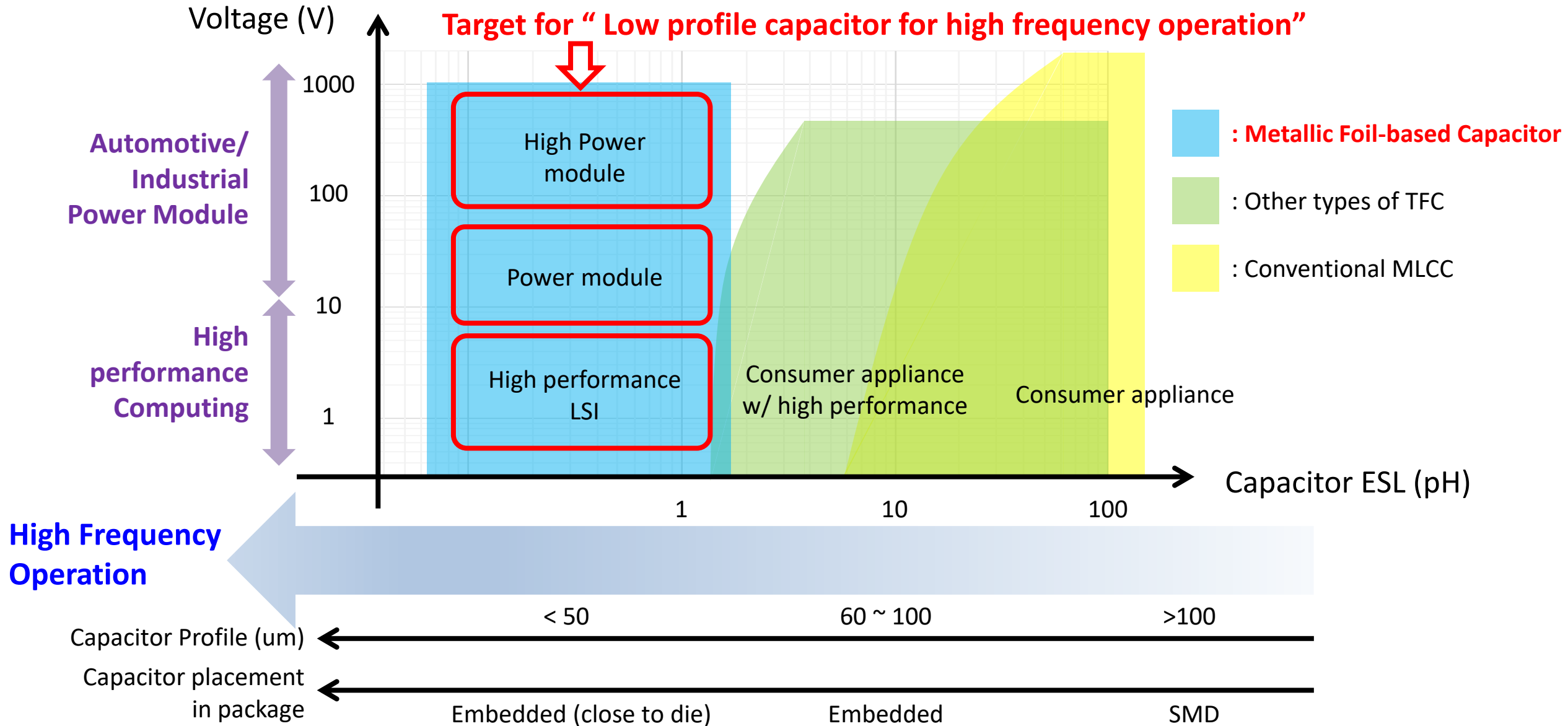
<sup>1</sup>TDK Corporation, Yamanashi, Japan

<sup>2</sup>TDK Corporation of America, California, USA

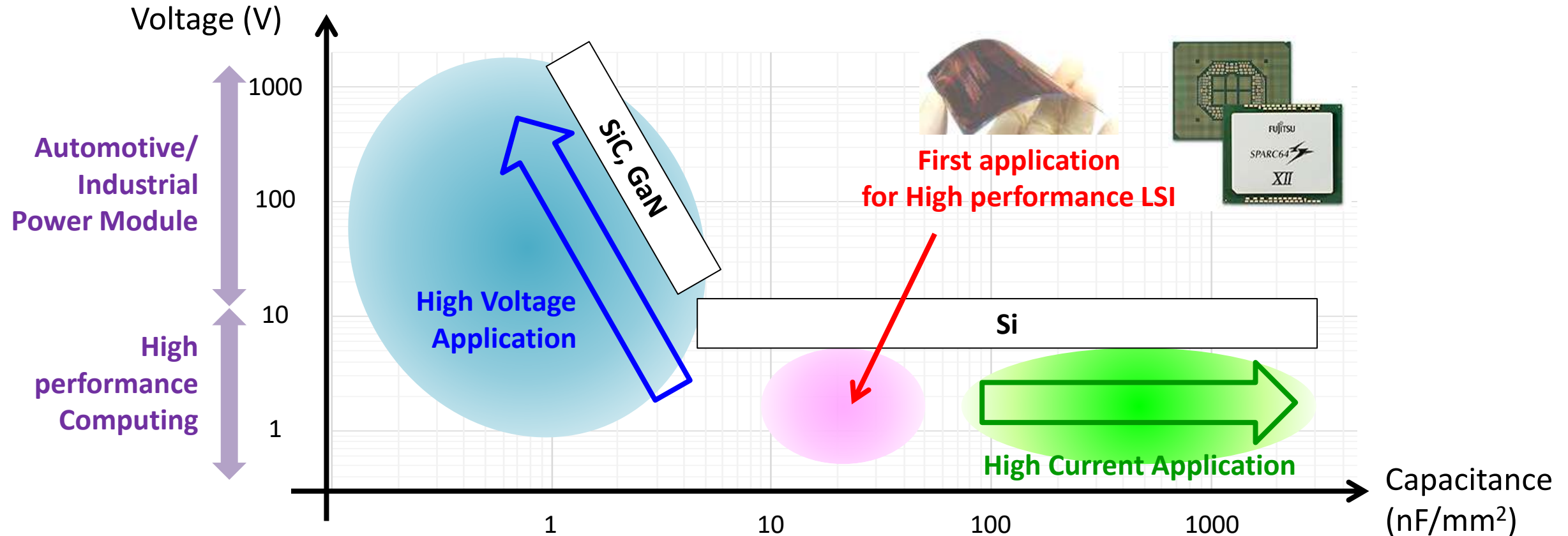
# Contents

1. Background
2. Introduction of TFCP
3. Introduction of Z-Leveler<sup>®</sup>
4. Summary

# Thin film capacitor for high frequency



# Growing Metallic Foil-based Capacitor



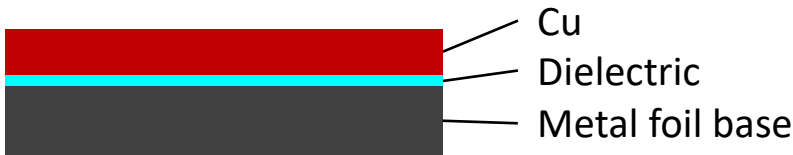
- ✓ Metallic foil-based capacitor in TDK has been released for high performance LSI application.
  - Continue to develop for
    1. High voltage application
    2. High current (high capacitance) application

# Overview of TDK's Thin Film Capacitor

## TFCP-S (Sheet type)

Sheet Capacitor



Mass Production

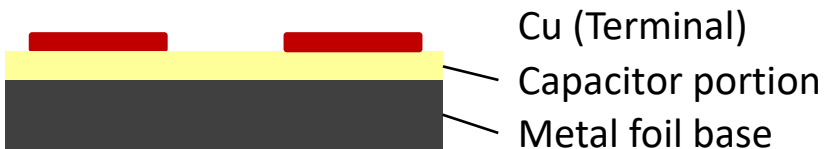
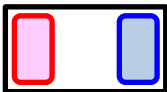


## Z-Leveler® (Discrete type)

Two terminal capacitor

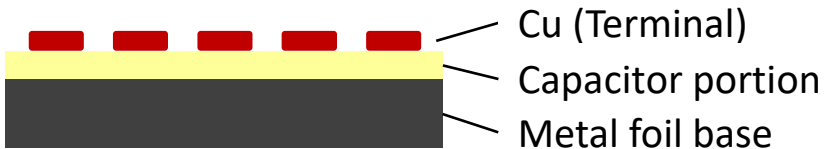
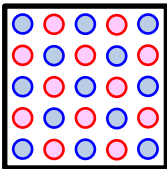
Under development

< Terminal type >  
 power     ground



Multi terminal capacitor

Under development



# Contents

1. Background

2. Introduction of TFCP

3. Introduction of Z-Leveler<sup>®</sup>

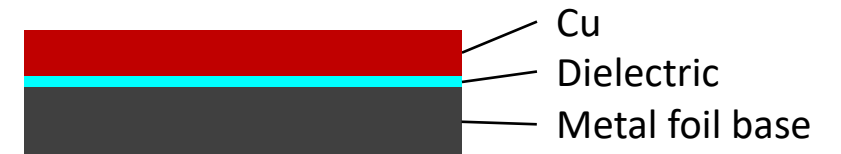
4. Summary

# Overview of TDK's Thin Film Capacitor

## TFCP-S (Sheet type)

Sheet Capacitor

Mass Production



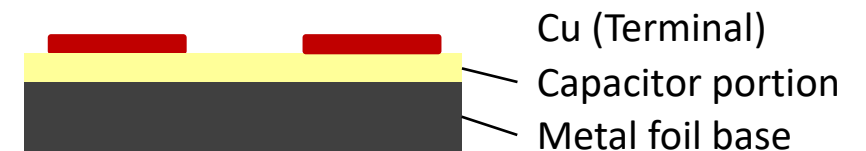
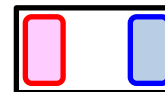
## Z-Leveler® (Discrete type)

Two terminal capacitor

Under development

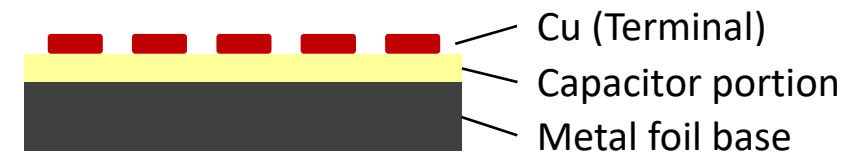
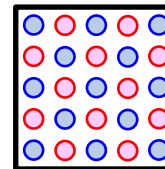
< Terminal type >

 power  ground



Multi terminal capacitor

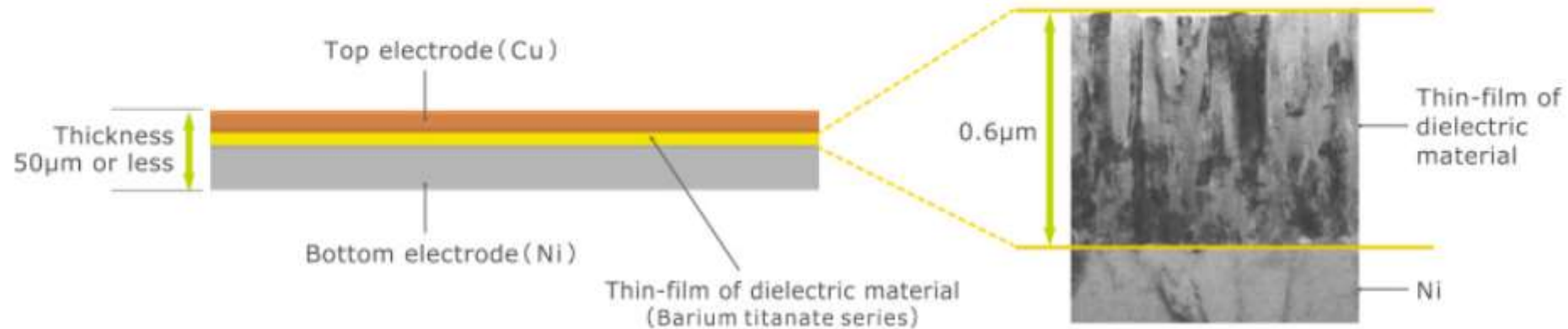
Under development



# Outline of Thin Film Capacitor (TFCP) in TDK

## 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.



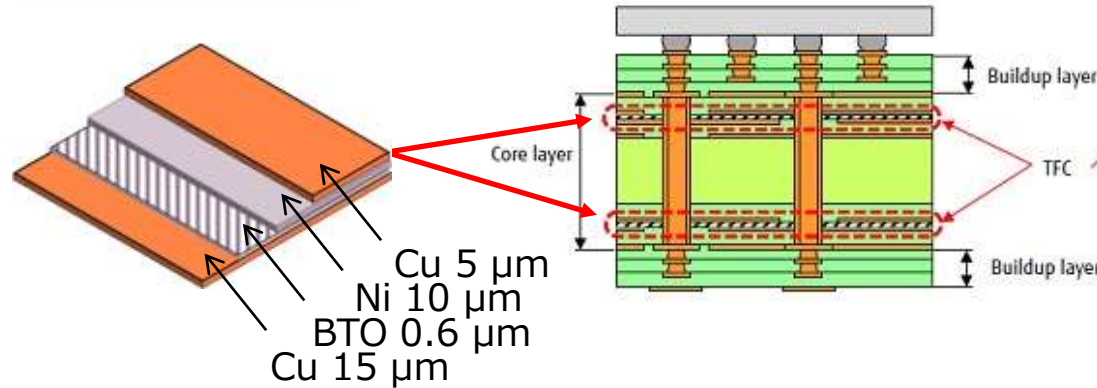
From TDK Home page

<https://product.tdk.com/info/en/techlibrary/developing/tfcp/index.html>

# Electrical Properties of TFCP Sheet

Characteristics	C/A ~ 1.0μF/cm <sup>2</sup> Mass production	C/A ~ 2.0μF/cm <sup>2</sup> Completed development	C/A ~ 4.0μF/cm <sup>2</sup> Under development
Temperature dependence of Capacitance	X7S (-55 ~ 125°C ±22%)	X7S (-55 ~ 125°C ±22%)	X7S (-55 ~ 125°C ±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/cm <sup>2</sup> ) CR ≥ 100 Ω F 4Vdc, room temperature	IR ≥ 100MΩ (1/cm <sup>2</sup> ) CR ≥ 100 Ω F 4Vdc, room temperature	IR ≥ 100MΩ (1/cm <sup>2</sup> ) CR ≥ 100 Ω F 2.5Vdc, room temperature

# Current Status of TFCP Sheet



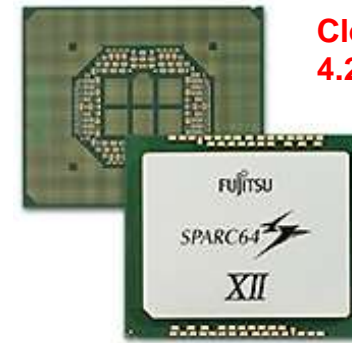
Structure embedded TFCP

Source:

FUJITSU INTERCONNECT TECHNOLOGIES LIMITED Home Page

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

2017.4.4 World wide release



SPARC64XII

**Clock speed  
4.25 GHz (Max)**



Fujitsu SPARC M12 Server

Source:

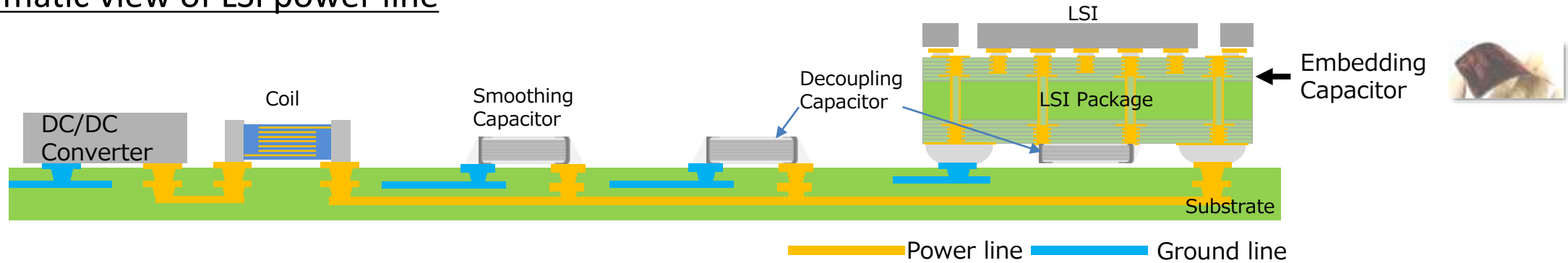
Fujitsu Home Pages

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

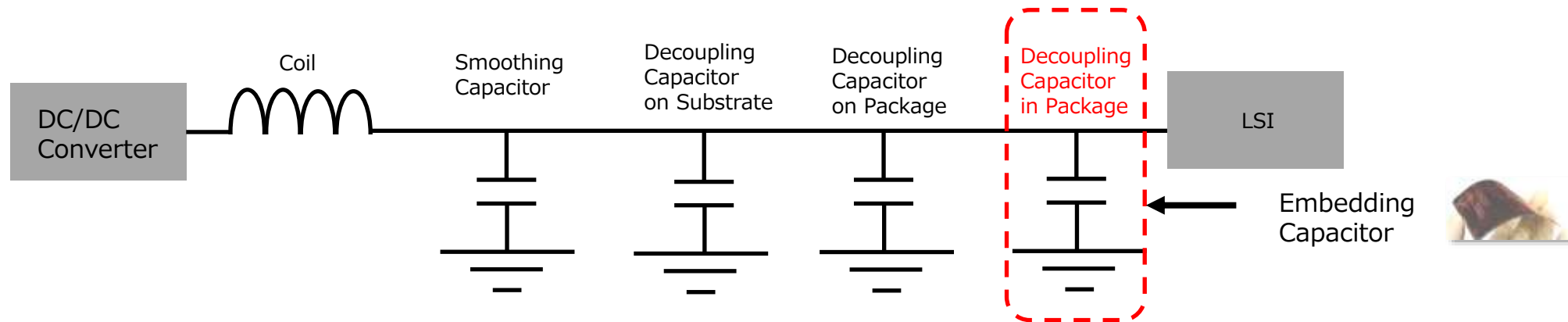
2016~ 1μF/cm<sup>2</sup> capacitor has been in mass production for Fujitsu M12 Server.

# LSI Power Line Integrity Improvement

## Schematic view of LSI power line



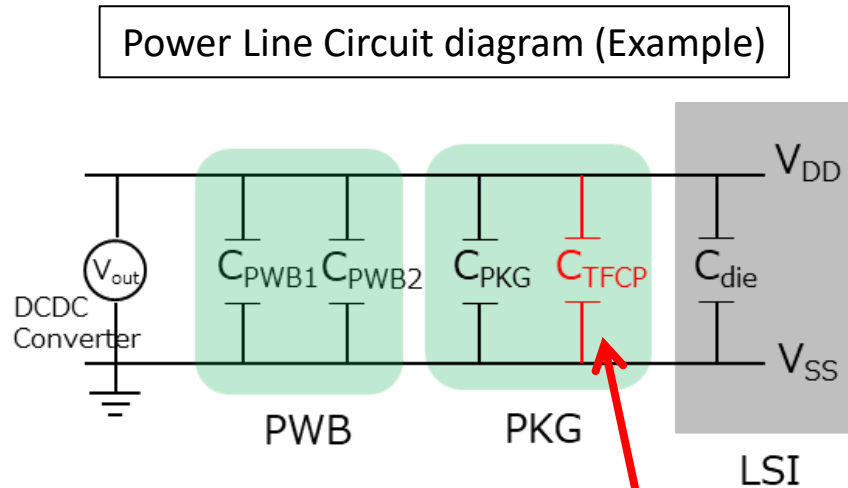
## Equivalent Circuit of LSI power line



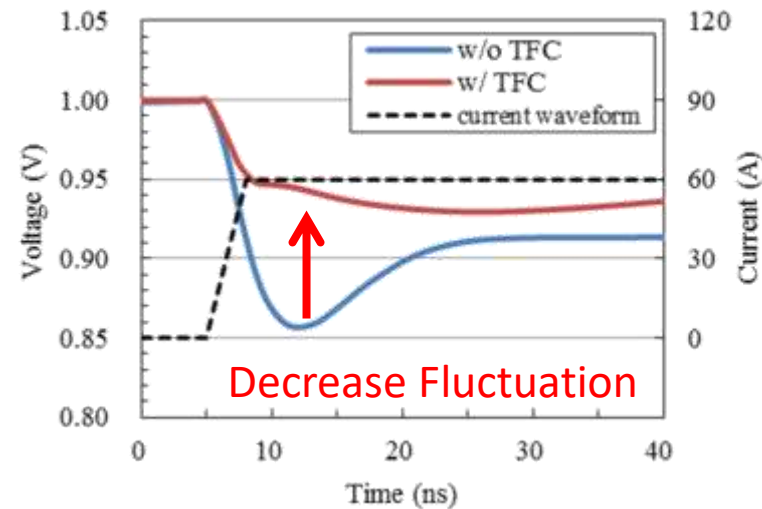
- ✓ We would like to improve the power line integrity by embedding the thin film capacitor. (Lower impedance, lower voltage fluctuation, and quick response of current)

# LSI Power Line Integrity Improvement

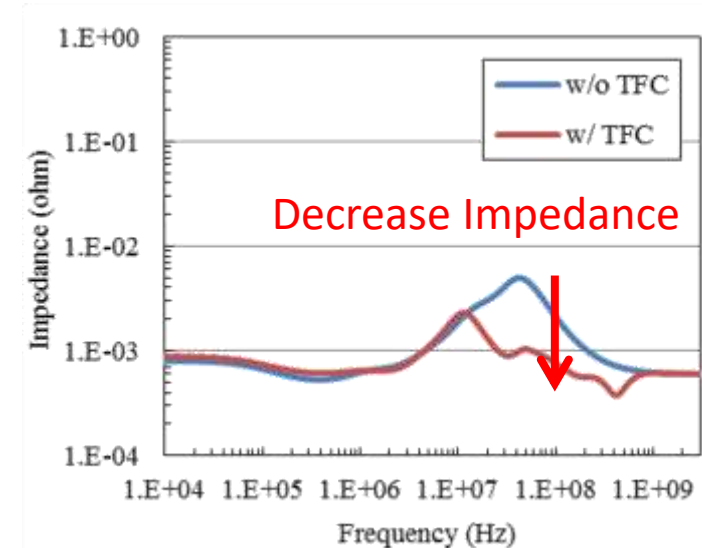
## ➤ Decoupling for LSI application (Demonstrated with TFCP)



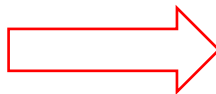
Voltage fluctuation under LSI operating



Power line Impedance (Z)



- ✓  $C_{TFCP}$  Implementation close to LSI
- ✓ Low ESL  $C_{TFCP}$



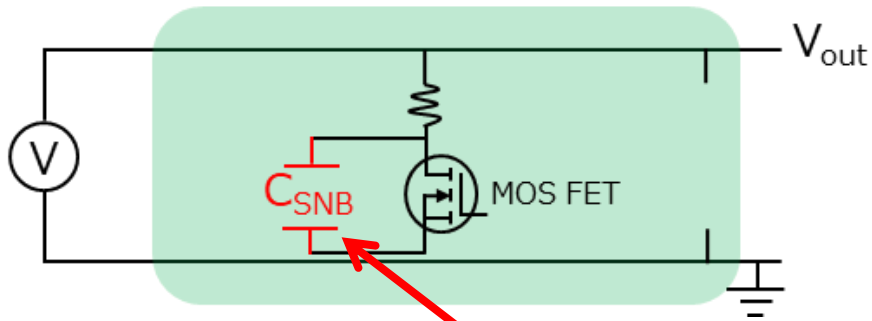
- ✓ Power line impedance @ 10 ~ 100MHz can be decreased.  
→ Voltage fluctuation can be decreased.

Source: Proceedings of Electronic Components & Technology Conference (ECTC), May. 2017, pp. 179.

# Suppression of Voltage Fluctuation

## ➤ Snubber for High Voltage Application

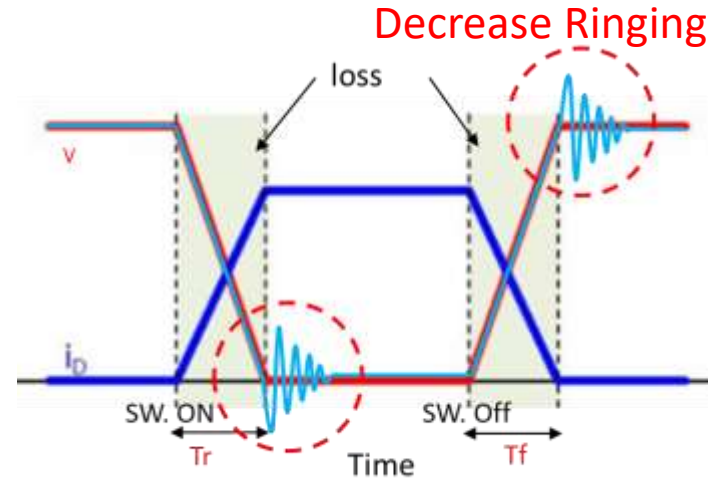
Switching Circuit diagram (Example)



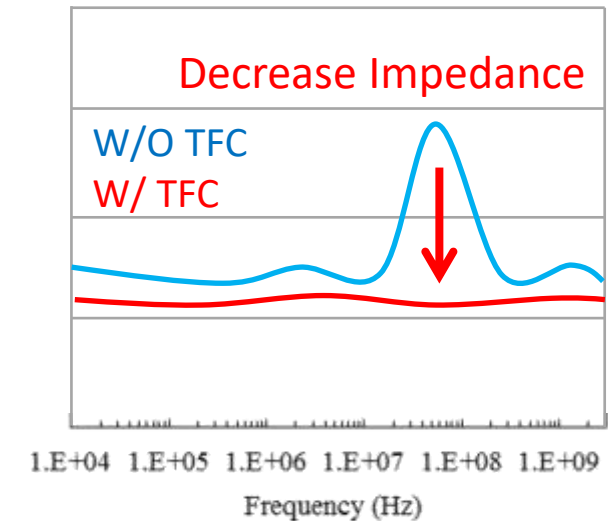
- ✓  $C_{SNB}$  Implementation close to MOS FET
- ✓ Low ESL  $C_{SNB}$
- ✓  $C_{SNB}$  for High Voltage Use

Material for high voltage use is required.

Time Domain Chart (Image)



Switching Impedance (Z) (Image)



- ✓ Is switching impedance @ 10 ~ 100MHz decreased?  
→ Is ringing suppressed?

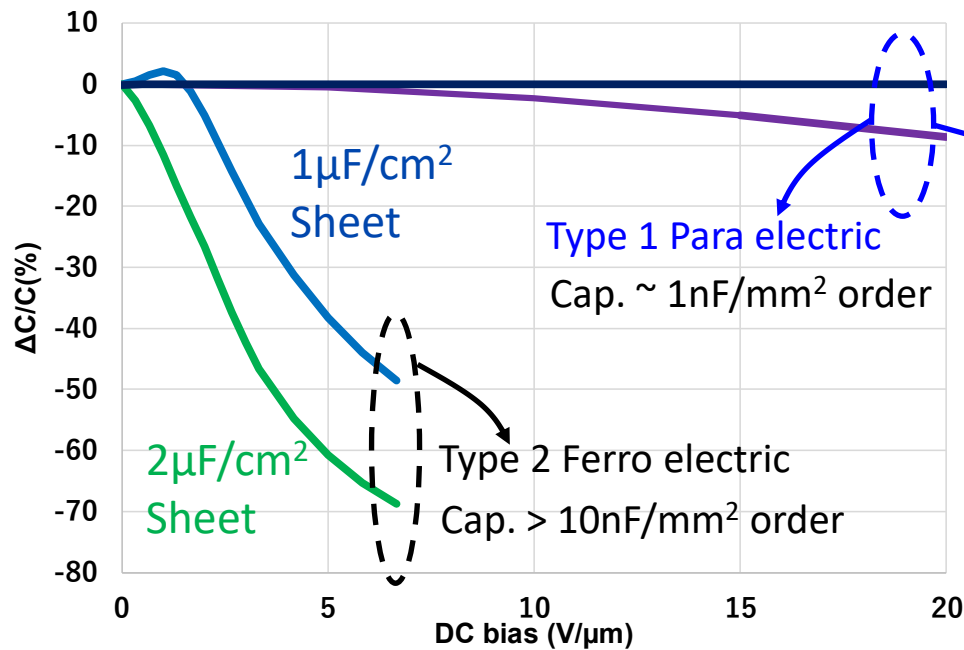
# Material for High Voltage Use

Under development

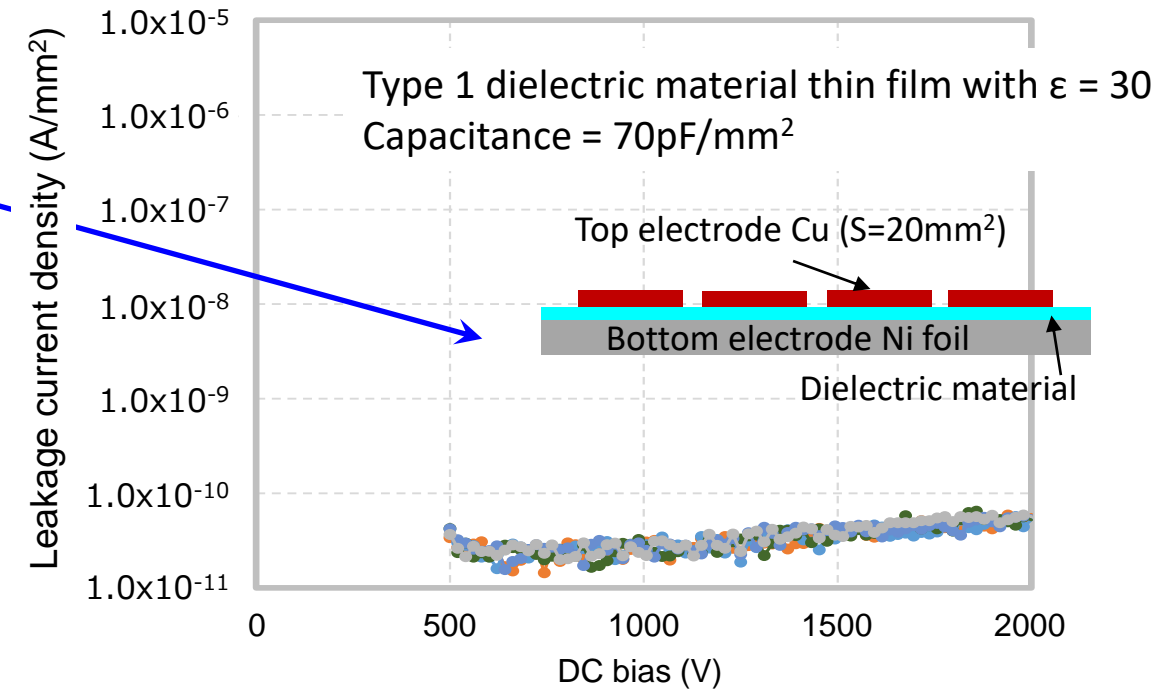
Attracting Tomorrow 

## ➤ Dielectric material for high voltage application

DC bias dependance of Capacitance



Leakage Current Measurement



\* 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.

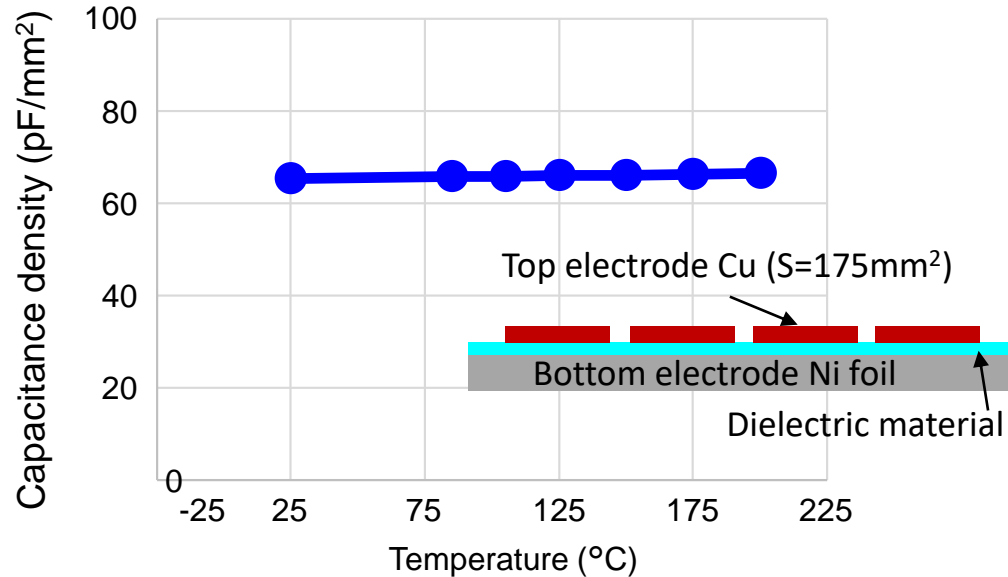
# Material for High Voltage Use

Under development

Attracting Tomorrow 

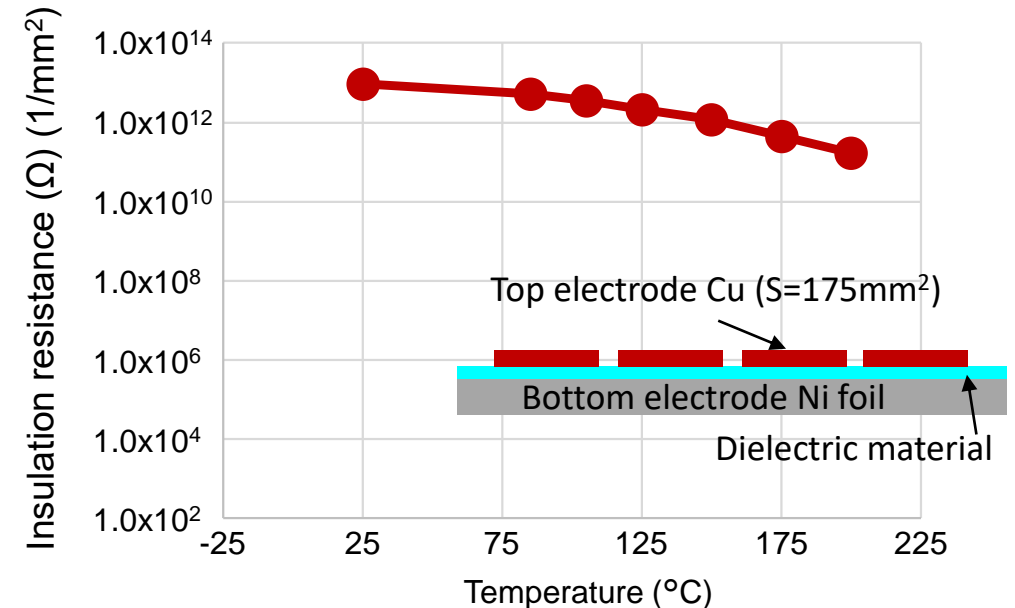
## ➤ Electrical Properties of Type1 dielectric material

### Temperature dependance of Capacitance



\* 4282A 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

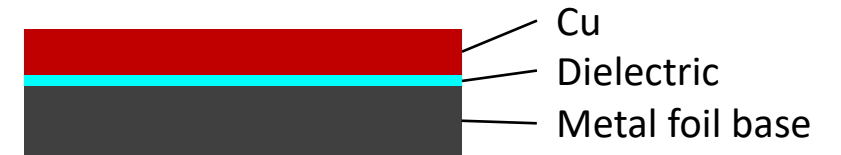
1. Background
2. Introduction of TFCP
3. Introduction of Z-Leveler<sup>®</sup>
4. Summary

# Overview of TDK's Thin Film Capacitor

## TFCP-S (Sheet type)

Sheet Capacitor



Mass Production

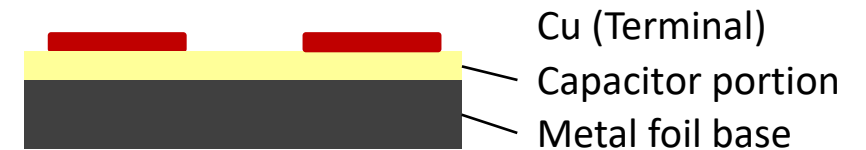
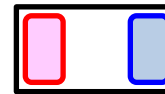


## Z-Leveler® (Discrete type)

Two terminal capacitor

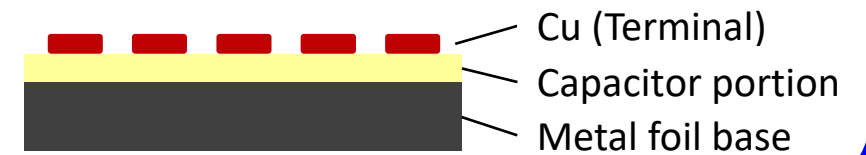
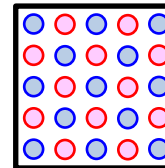
Under development

< Terminal type >  
 power  ground




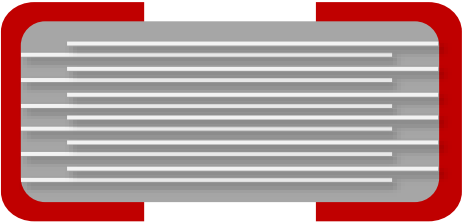








Multi terminal capacitor

Under development

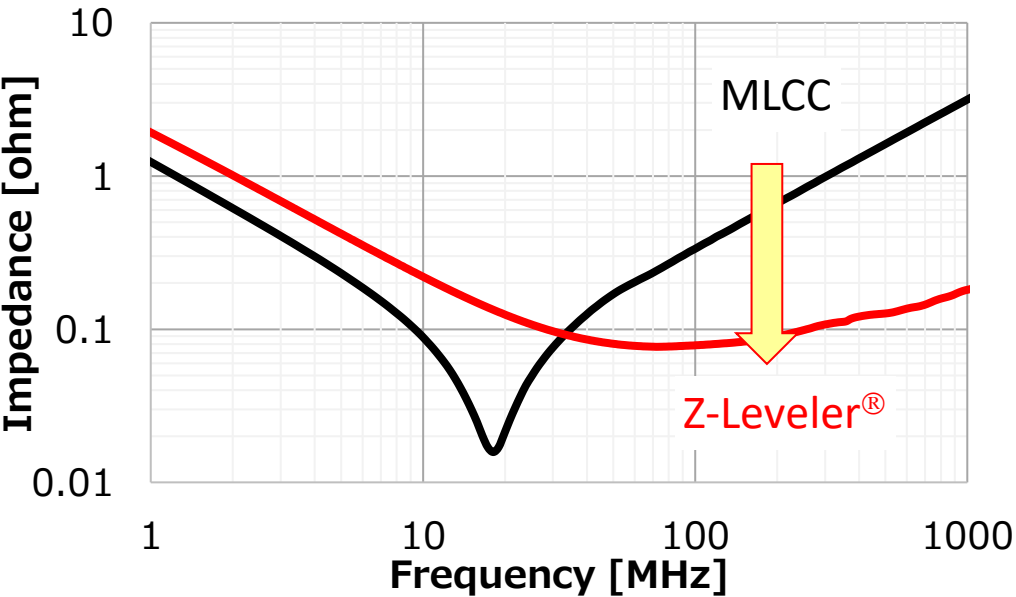


# Difference from MLCC

➤ Overview of ultra low profile thin film capacitor; Z-Leveler<sup>®</sup>

	Z-Leveler <sup>®</sup>	MLCC
Structure X-section		
Lower ESL		
Lower profile		
Fragility		
Higher Capacitance	 >350nF/mm2	

Impedance(Z) curves vs Frequency



Value proposition = Impedance leveler

Named Z-Leveler<sup>®</sup>

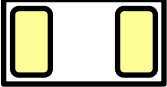
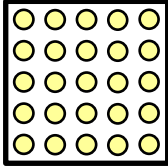
# Electrical Properties of Z-Leveler®

Under development

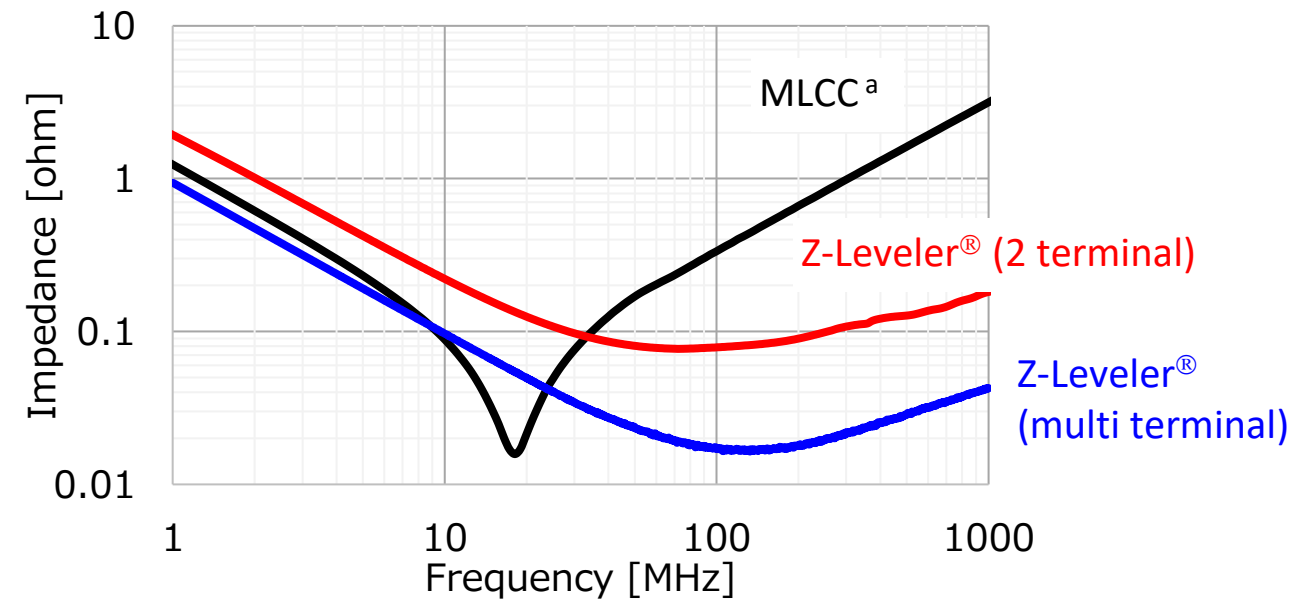
Attracting Tomorrow



## ➤ Basic parameters / properties

	<b>Z-Leveler® (2 terminal)</b>	<b>Z-Leveler® (multi terminal)</b>
		
Size [mm]	1.06 x 0.56	1.07 x 1.07
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

Impedance curves of Z-Leveler® and MLCC



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.

# Electrical Properties of Z-Leveler®

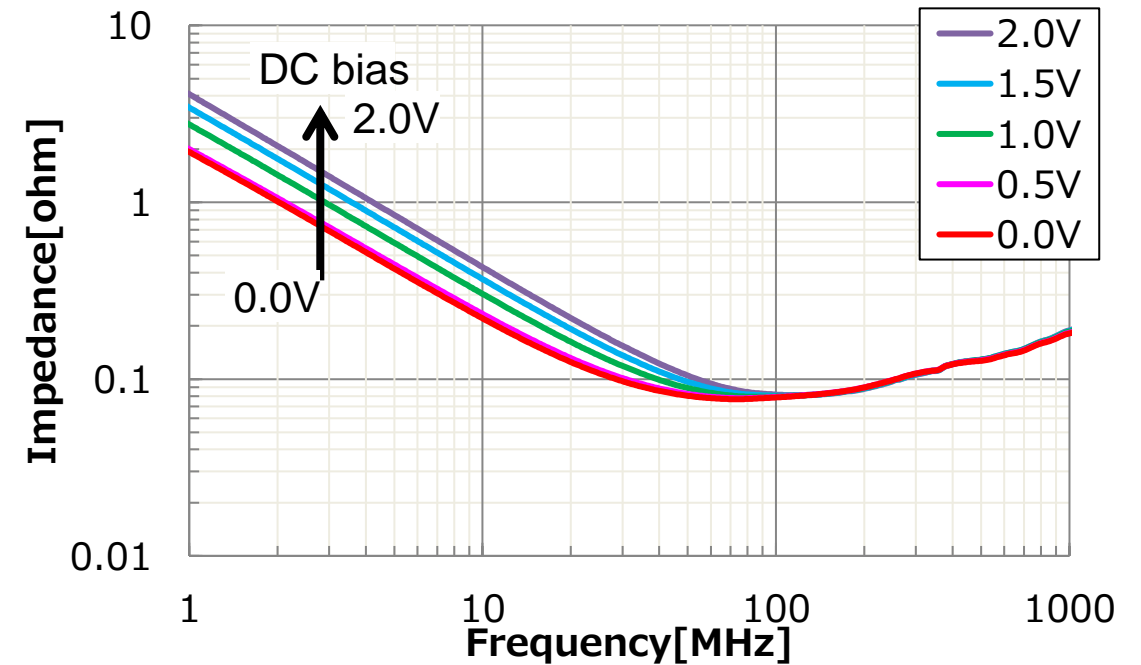
Under development

Attracting Tomorrow 

## ➤ DC Bias dependence

	Z-Leveler® (2 terminals)				
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

Impedance curves of Z-Leveler® under DC bias



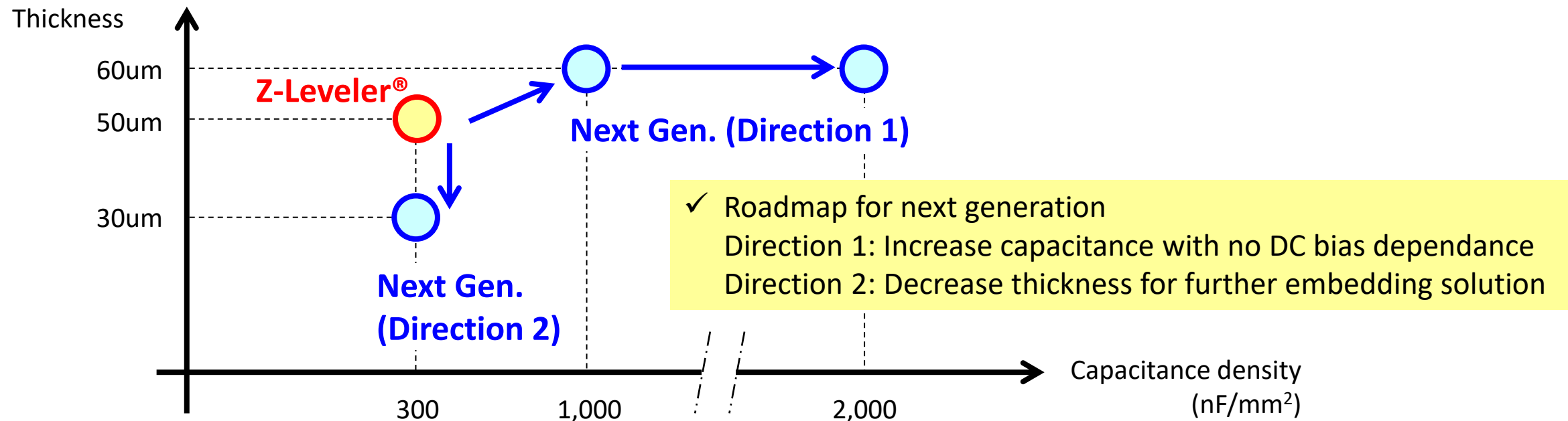
- ✓ Z-Leveler® has some DC bias dependence.  
However, impedance in high frequency can be kept low under DC bias.

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

# Roadmap for Next Generation

➤ Target specification for next generation development

	Z-Leveler®	Next generation	
Capacitance density (1kHz-1V)	300nF/mm <sup>2</sup>	1,000nF/mm <sup>2</sup> → 2,000nF/mm <sup>2</sup>	300nF/mm <sup>2</sup>
DC bias dependance	Some	None	None
Thickness	50um	60um	30um



# Contents

1. Background
2. Introduction of TFCP
3. Introduction of Z-Leveler<sup>®</sup>
4. Summary

- Metallic foil-based capacitor has been released as low profile thin film capacitor for high frequency application.
  - ✓ Realize low impedance of package in high frequency 10MHz ~ 100MHz.
    - ➔ Contribute to decrease voltage fluctuation of PDN for high performance LSI.
  
- Material for high voltage application has been developed for power modules.
  - ✓ Realize capacitance stability in > 500V.
    - ➔ Applicable to high frequency switching application under high voltage.
  
- Z-Leveler® has been developed for high capacitance density requirement.
  - ✓ Realize low ESL and low impedance in high frequency > 100MHz.
  - ✓ Further development is continued to have much higher capacitance.

