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1. Introduction

Along with the miniaturization and high performance of electronic equipment, miniaturization, high performance and high reliability are required at all times for electronic parts used in the electric circuits. Rubycon responds to its market requirements and offers a new type of multi-layer film capacitor PMLCAP which greatly miniaturizes conventional multi-layer film capacitors.

PMLCAP has great features such as small size, light weight, high capacitance, excellent frequency / bias characteristics, low dielectric absorption, low leakage current, high heat resistance, etc., and it can contribute to creating high-value added of various applications such as audio & visual equipment, communication equipment, wearable equipment, environmental power generation, etc.

2. What is PMLCAP?

Polymer Multi – Layer Capacitor = PMLCAP

PMLCAP is the abbreviation for Polymer Multi-Layer Capacitor, a surface-mount capacitor made up of multiple polymer layers. The conventional film capacitor also has a surface mount type, but the point where PMLCAP differs greatly is in the type of dielectric, and furthermore on its manufacturing method.

The dielectric thickness of PMLCAP is 1 μm or less, which is difficult to manufacture with biaxially stretched film used for conventional film capacitors.

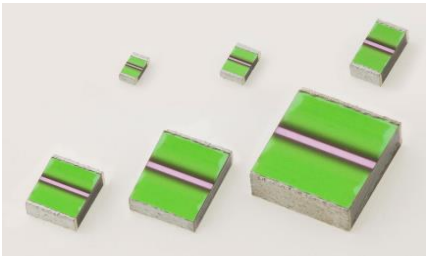


Photo.1 PMLCAP appearance

Rubycon succeeded in manufacturing a revolutionary high capacity and small film capacitor by establishing the technology to form this thin film dielectric layer. In addition, the dielectric resin used in PMLCAP is a thermosetting resin with high heat resistance, and it has better heat resistance than conventional film capacitor using thermoplastic resin.

3. Manufacturing Technology

Conventional film capacitors are manufactured as lead wire type, cylindrical type, box type, chip type by winding or stacking a metallized film on which metal is vapor-deposited on films such as PP, PET, PPS, PEN, etc. (metallized type)., or a set of either of these films and metal foil (foil type).

However, with such a manufacturing method, since it uses a commercially available film, there is inherent limitation in pursuing its miniaturization (thinner film thickness). Therefore, Rubycon began developing the manufacturing technology to form a thin dielectric layer that leads to miniaturization of film capacitors and succeeded in mass-producing PMLCAP in 2006.

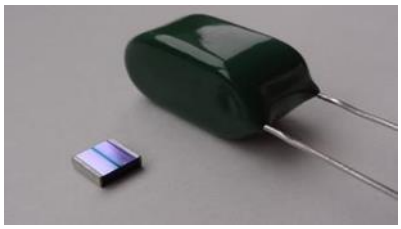


Photo. 2 Size comparison example with film capacitor (10μF item)

PMLCAP employs electron beam curing resin as the dielectric material and vacuum deposition polymerization technology as manufacturing method. Specifically, a vacuum chamber is used to polymerize the dielectric layer, onto which the inner electrode layers (aluminum) are formed in patterns. These processes are continuously alternated to build up the layered structure that will be used as the element for capacitors. This element is cut to the requisite product size, and the electrode layer is formed to complete the product. Using the vapor deposition polymerization method allows the dielectric layer to remain pinhole free and evenly layered, even at sub-micron thickness. The number of layers is also high, ranging from several thousand to more than 10,000 layers.

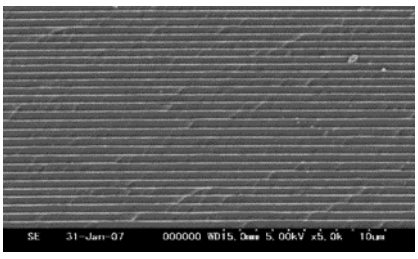


Photo. 3 Stacking structurer
Dielectric layer thickness 0.4μm
(Electron microscope photo : x5,000)

4. PMLCAP structure

The element part (internal structure) of PMLCAP is composed only of dielectric and internal electrode, and acrylic polymer is adopted as dielectric material. The external electrode is made of multiple metal layers and consists of tin plating, copper plating, and brass metal spray (metallicon) from the outside. Metallicon is responsible for connection with the element part. By adopting a material with high heat resistance for the dielectric, we guarantee two times lead free reflow soldering at 260℃ peak.

Failure mode is "open" because of having a self-healing effect like the conventional film capacitor. In addition, it does not contain environmental burden substances and complies with RoHS regulations.

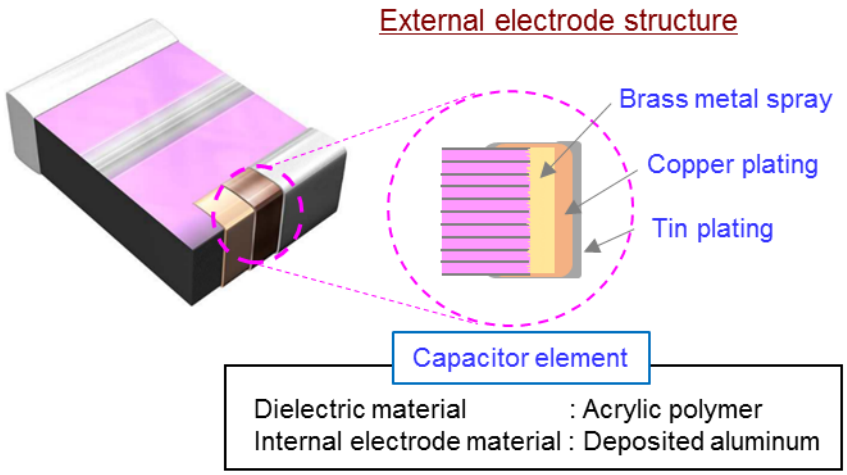


Fig. 1 External electrode structure

5. Comparison between PMLCAP and other multi-layer capacitors

The electrical characteristics of PMLCAP are almost equivalent to polyester film capacitor.

Since one layer thickness of PMLCAP is thinner compared with general multi-layer film capacitors, it achieves small in size at the same voltage and capacity and line-up large capacity (Max. 22 μF).

Compared with a high dielectric constant type multi-layer ceramic capacitors (MLCC) with piezoelectric effect, PMLCAP has great feature such as less beat sound and no capacity reduction by applying DC bias, small dielectric absorption, etc.

Table 1 Capacitor characteristics comparison

Capacitor	PMLCAP	Multi-layer film capacitors	MLCC
Dielectric	Electron beam curable resin (Acryl)	Resin film (PEN, PPS)	High permittivity ceramic ($BaTiO_3$)
Dielectric thickness	<1μm/layer	≧3μm/layer	<1μm/layer
Dielectric constant	Approx. 3	Approx. 3	2,000～5,000
Internal electrode	Deposited aluminum	Deposited aluminum	Nickel paste
Rated voltage	16Vdc to 200Vdc	16Vdc to 630Vdc	2Vdc to 3,150Vdc
Capacitance	0.0001μF to 22μF	0.0001μF to 1μF	51pF to 470μF
Temperature range	-55℃ to +125℃	-55℃ to +125℃	-55℃ to +150℃(X8R)
Size	Middle	Large	Small
Features	Less beat sound and excellent DC bias characteristic because of no piezoelectric effect.	Less beat sound and excellent DC bias characteristic because of no piezoelectric effect.	Poor DC bias characteristics because of no piezoelectric effect. Temperature compensation type has good DC bias characteristic but with large size.

6. PMLCAP characteristics and features

Noteworthy characteristics of the PMLCAP include ″no capacitance change due to DC bias application″, ″little capacitance change due to temperature change″, ″ small beat sound or small harmonic distortion caused by the extremely low piezoelectric effect ″,″ small dielectric absorption ″,″ low leakage current in high temperature region ″, and so on.. And PMLCAP structure also has resistant against applied instantaneous pulse overcurrent. These characteristics make the PMLCAP suited for diverse uses such as those for equipment requiring sound quality improvement and silent design in the audio field, shortening the lockup time of the PLL loop filter due to low dielectric absorption characteristics, and for energy harvesting where low leakage current is required. In addition, it is attracting attention as parts for automotive equipment. We offer to replace multilayer ceramic capacitors (MLCC) or tantalum capacitors.

The characteristics and features of PMLCAP will be mainly explained by comparison with the high dielectric constant type multi-layer ceramic capacitor (MLCC)., as follows.

≪Impedance/ESR characteristics≫

As an example, the frequency characteristics of impedance and equivalent series resistance (ESR) of 35 V 10 μF (5750 size) is shown. PMLCAP has excellent frequency characteristics of low ESR and equivalent series inductance (ESL).

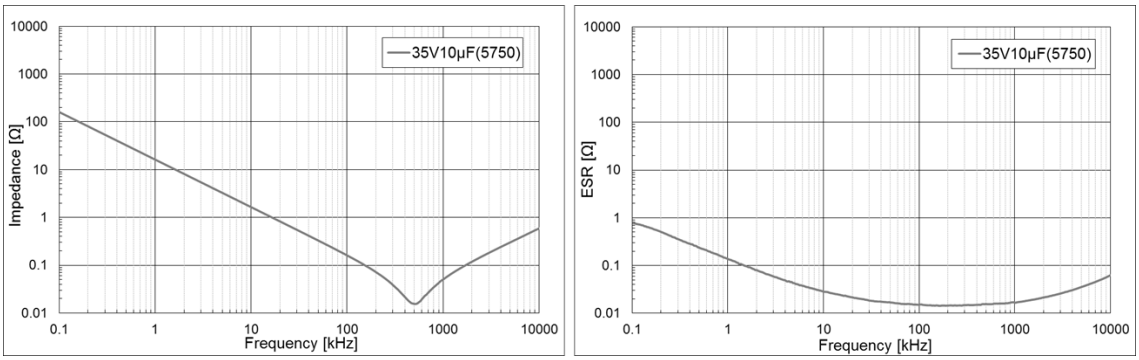


Fig.2 Impedance and ESR characteristic

≪DC bias characteristics≫

PMLCAP is a capacitor with excellent characteristic stability without decreasing electrostatic capacity due to piezoelectric effect as seen in high dielectric constant type MLCC even when DC bias is applied.

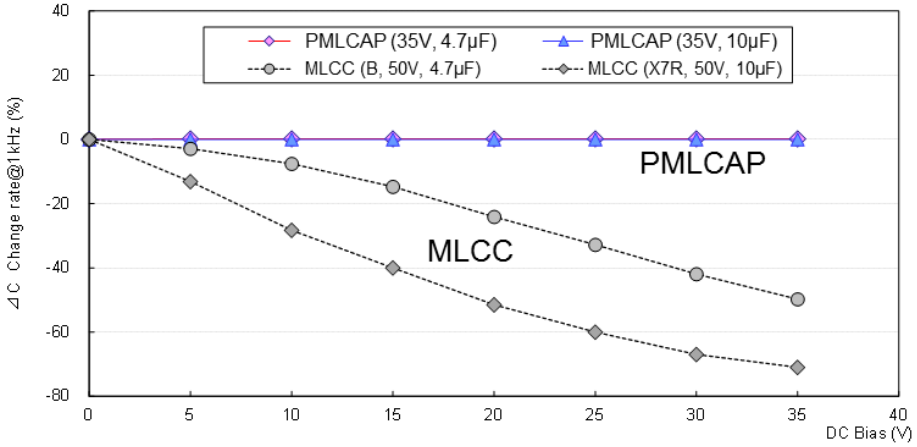


Fig. 3 Capacitance change at DC bias application

In addition, PMLCAP does not change the impedance characteristics when applying DC bias, while on the other hand high dielectric constant type MLCC shifts impedance curve due to DC bias application and may appear flexion point on its impedance characteristics.

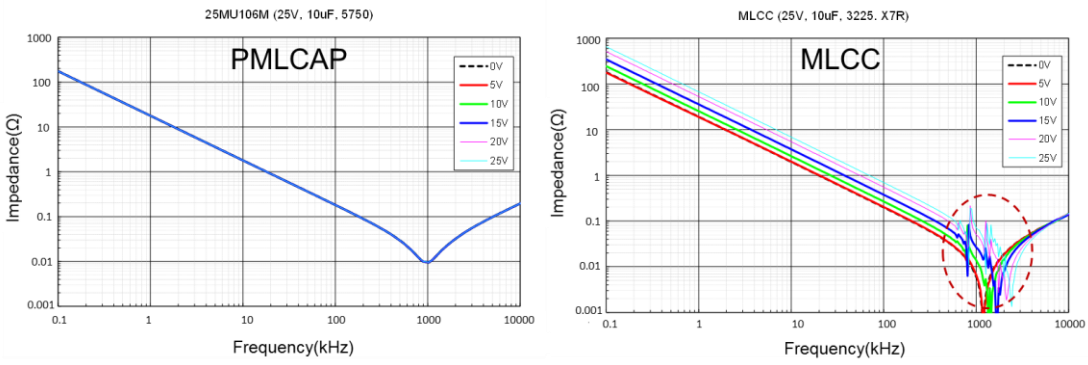


Fig. 4 Impedance characteristics when applying DC bias

≪Temperature characteristics≫

The temperature coefficient at −55℃ to + 125℃ of PMLCAP is about + 520 ppm /℃.

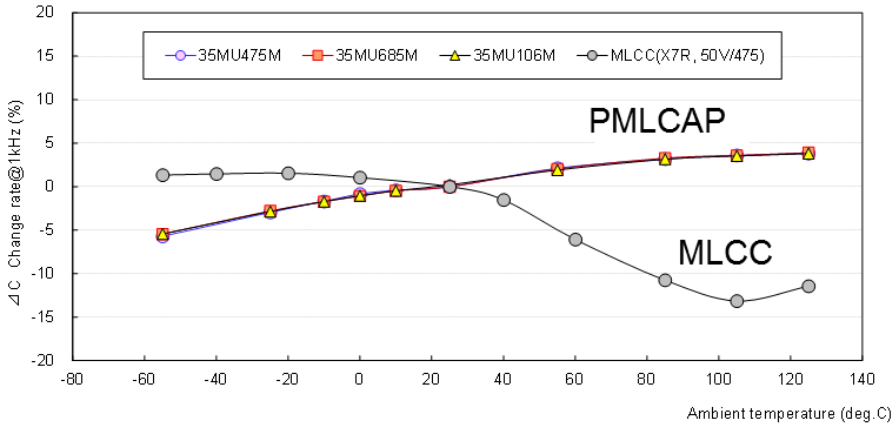
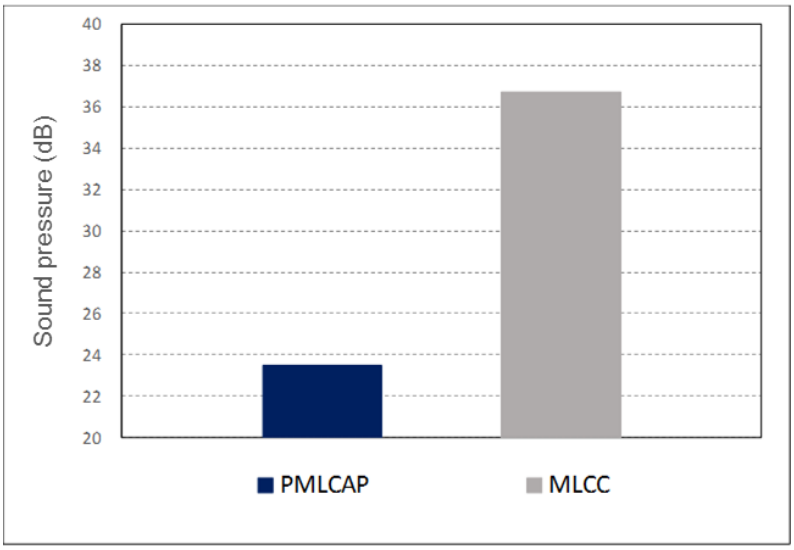


Fig. 5 Capacitance change with temperature

≪Beat sound characteristics≫

PMLCAP does not have electrostrictive effect. This makes it possible to suppress beat sound drastically and to achieve silence of equipment. In contrast, high dielectric constant type MLCC has electrostrictive effect, so in a circuit with a large amplitude pulse signal, the capacitor vibrates and can cause beat sound.



Capacitor : 1μF, 3216size
Applied voltage : 10Vp-p square-wave/1.4kHz

Fig. 6 Beat sound comparison

Fig. 7 shows a result of beat sound–frequency characteristic when capacitor is mounted to a LCD backlight circuit. Noise of high dielectric constant type MLCC increases in the middle frequency range over 1kHz due to piezoelectric effect. Thus PML CAP is superior to MLCC, because noise in the range between 1kHz and 10kHz is audible to humans so that capacitors with less noise in this range are preferable.

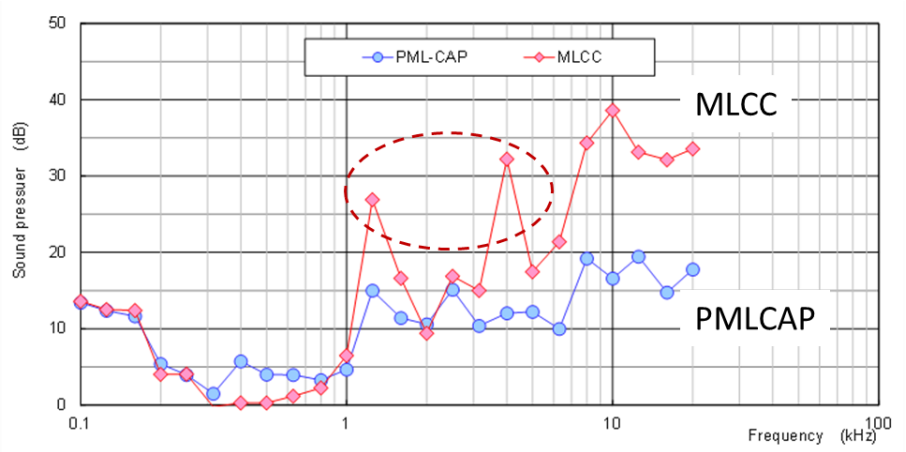


Fig. 7 Beat sound-frequency characteristic on LCD backlight circuit

≪Harmonic distortion ratio≫

In audio equipment, distortion characteristics can be a hindering factor in playback of the original sound, so low distortion PMLCAP is increasingly adopted, especially for high quality audio equipment that prioritizes sound quality.

In contrast to PMLCAP, high dielectric constant type MLCC tends to have higher harmonic distortion rate due to voltage dependent impedance change.

PMLCAP is effective in improving sound quality since it has a structure with a very high interlayer adhesion by a laminate production technique by continuous vapor deposition of a dielectric layer and an internal electrode layer in a vacuum, and furthermore, it is made up of the external electrode excluding the magnetic material.

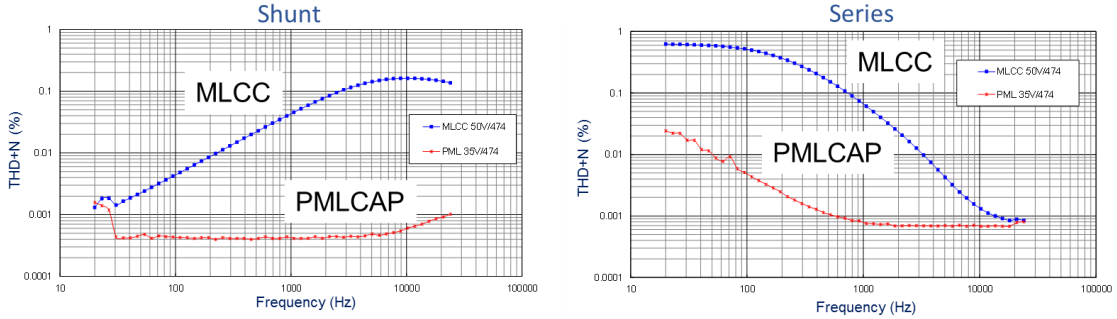


Fig. 8 Comparison in harmonic distortion ratio

≪Influence of vibration on C/N ratio≫

Fig. 9 shows a comparison example of VCO C/N ratio of PLL synthesizer when vibration is added to the circuit. Since PMLCAP does not have a piezoelectric effect, deterioration of C/N ratio is not observed. But deterioration of C/N ratio is seen in high dielectric constant type MLCC due to piezoelectric effect and this causes deterioration of wireless communication quality.

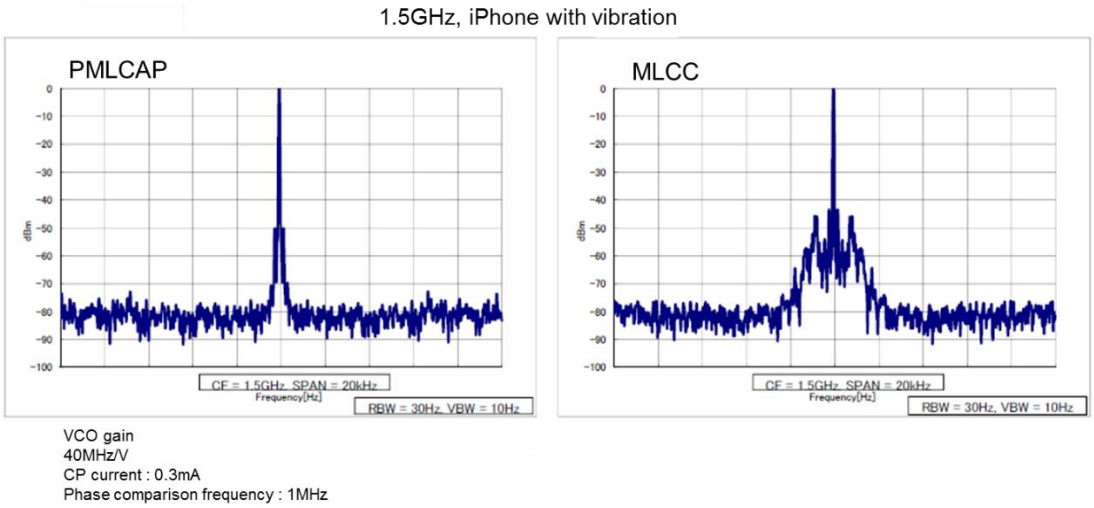


Fig. 9 Influence of vibration on C/N ratio

≪Dielectric absorption characteristics≫

Dielectric absorption happens due to delayed polarization of dielectric.

PMLCAP has small dielectric absorption (almost equal to that of polyester film capacitors), and it is much better than high dielectric constant type MLCC. Therefore it is effective for shortening the lockup time of PLL synthesizer and so on.

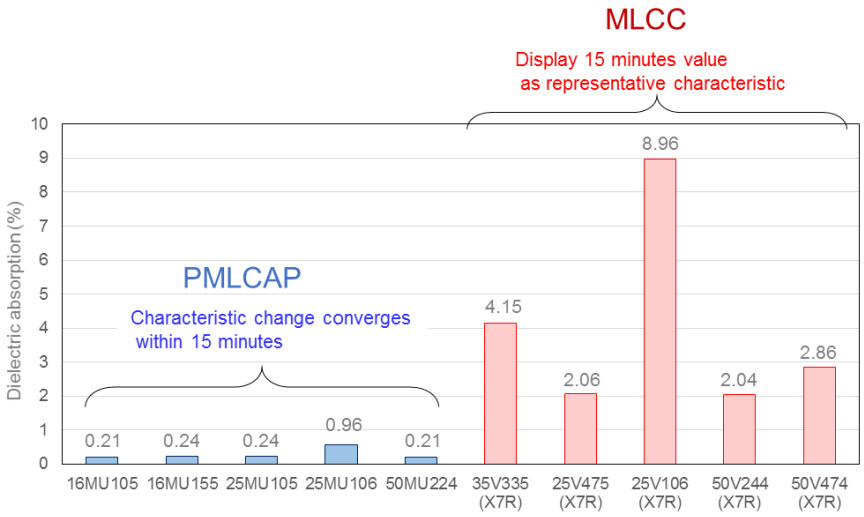


Fig. 10 Comparison of dielectric absorption

Fig. 11 shows a comparison of lockup time when frequency is switched from 1.4 GHz to 1.5 GHz by PLL synthesizer. Although PMLCAP converges to 1.5 GHz in a short time, MLCC does not converge to 1.5 GHz.

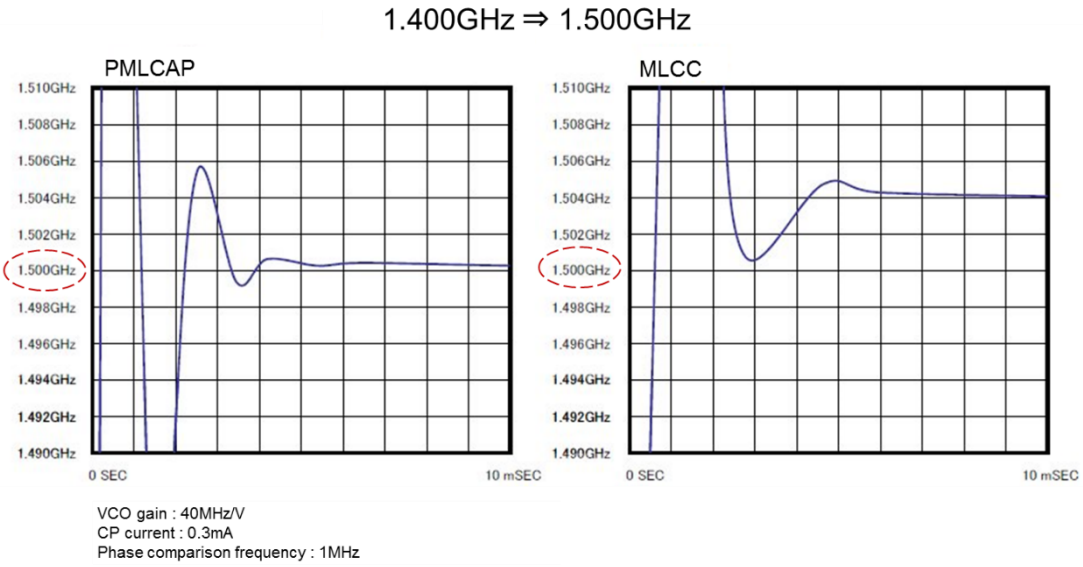


Fig. 11 Comparison of lockup time in PLL synthesizer

≪Leakage current characteristics≫

Compared with MLCC, aluminum electrolytic capacitors and tantalum electrolytic capacitors, PMLCAP has low leakage current characteristics due to its high insulation resistance even in high temperature range. Therefore, it can be said that PMLCAP is an excellent energy storage device for energy harvest handling small electric power.

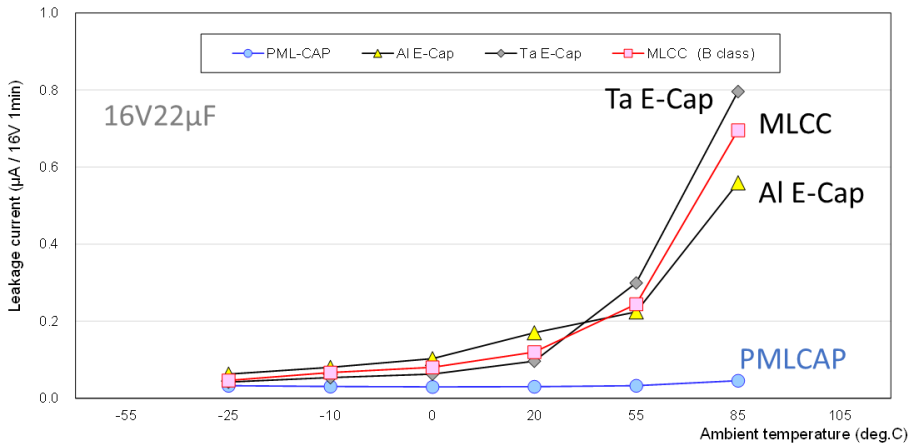


Fig. 12 Temperature characteristics comparison of leakage current

Figure 13 compares the output voltage of environmental power generation when applying pulse current (0 to 10V, 1 kHz, duty 50%) at 25℃ and 85℃.

PMLCAP, shows no change in the output voltage (8V) regardless of the temperature, whereas in the case of MLCC, an output voltage drop of about 1 V is observed with the increase in the leakage current at high temperature (85℃).

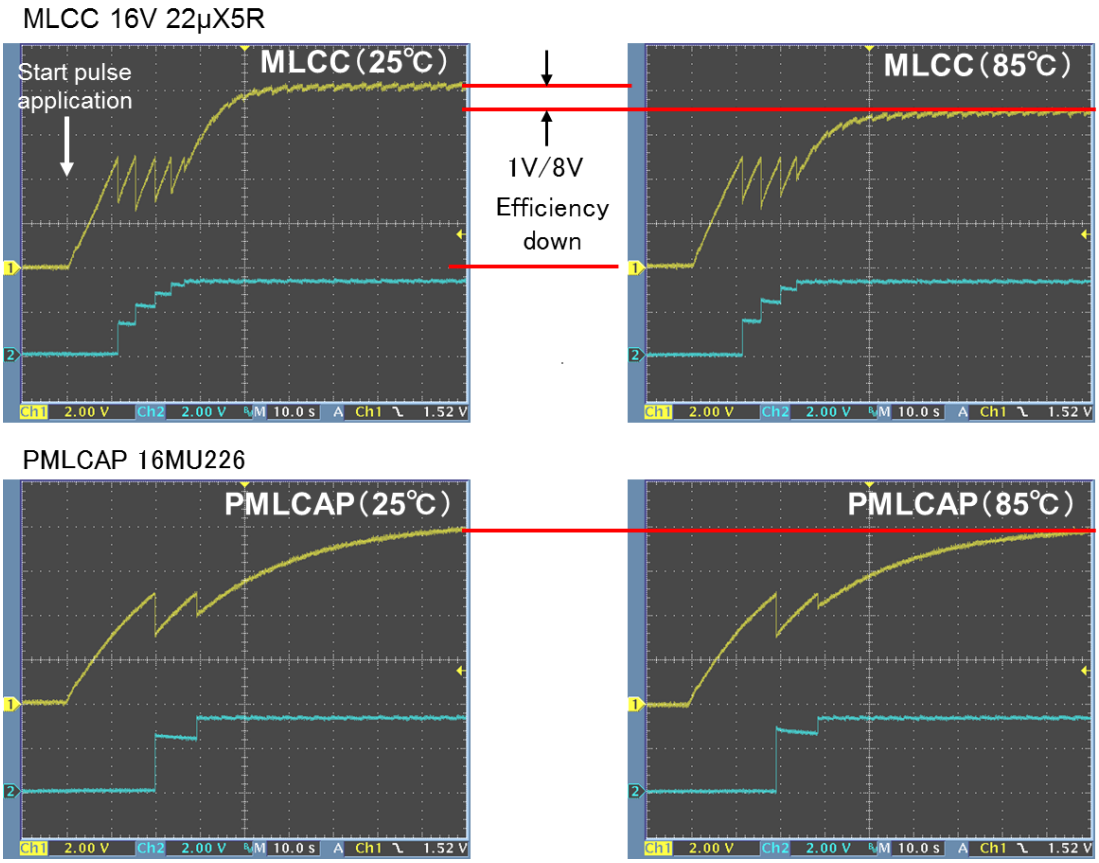


Fig. 13 Comparison of output voltage when pulse current is applied

≪Solder heat resistance≫

With the thermally hardened polymer (decomposition temperature of about 400℃) as dielectric material, PMLCAP has very high heat resistance as compared to general surface-mount multi-layer film capacitors. When a soldering iron is brought into contact with the product body for 5 seconds, a usual multi-layer film capacitor will cause short-circuit failure due to dissolution of the contact portion, but PMLCAP retains its characteristics. In addition, it can deal with various mounting methods such as reflow, flow and hand soldering, contributing to improvement of flexibility in designs with such power supply boards and miniaturization of devices.

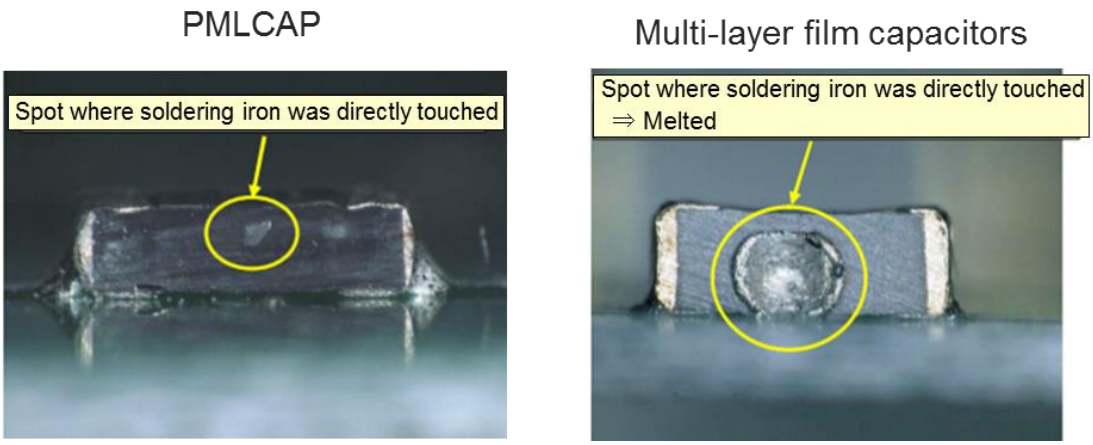


Photo 4 Comparison of soldering heat resistance

Table 2 Soldering conditions for PMLCAP MU series

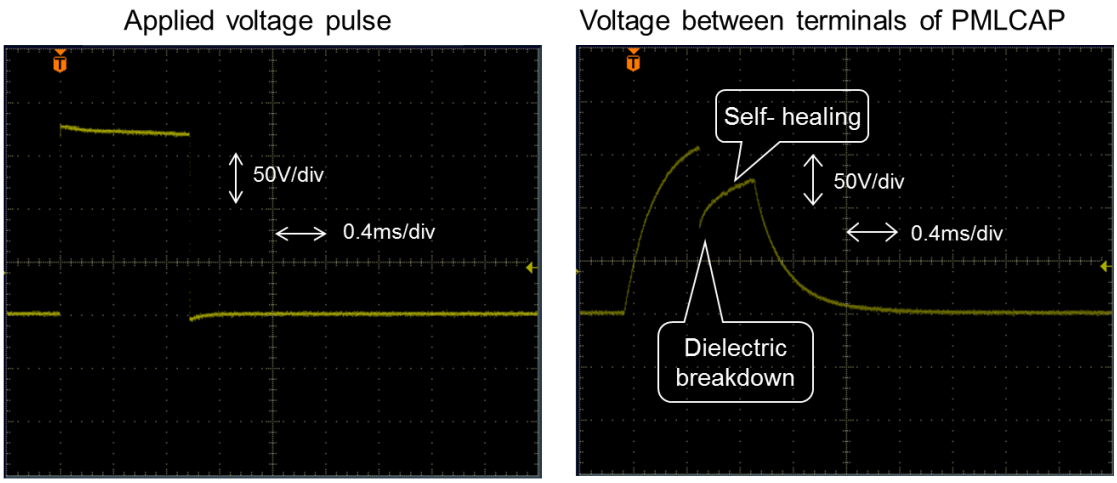
Reflow	Peak 260℃, 2 times
Flow	Peak 260℃, 2 times
Hand soldering	Iron head temperature 350℃

≪Self recovery≫

One of the technologies of the PMLCAP for ensuring reliability is self-healing ability. When a momentary excessive voltage or large current is applied to a capacitor, dielectric material and surrounding electrode material are eliminated at a defective or weak part due to Joule heat, restoring insulation properties. Also, even if a microscopic dielectric breakdown occurs there, no short circuit occurs and a certain level of resistance is maintained to prevent the circuit from breaking down completely.

Fig. 14 shows monitored waveform of the instantaneous applied voltage (186V) which far exceeds the rated voltage (35V) of the capacitor and the voltage between terminals of the PMLCAP when the voltage is applied to the PMLCAP via the resistor of 2Ω

At the moment the voltage is applied, the voltage between terminals of the PMLCAP decreases (insulation drop) once, but the voltage recovers instantaneously to the original level (self recovery).



Measure by applying a pulse of 186 Vpk / 1 ms to 35 V / 1 μF capacitor via 2 Ω series resistor

Fig. 14 Self recovery in applied overvoltage

≪Deflection durability≫

PMLCAP has high stress resistance against deflection due to the physical properties of the dielectric material and the external electrode structure. On the other hand, general multilayer ceramic capacitors do not have stress resistance due to low bendability of the dielectric, therefore short circuit may occur by cracking.

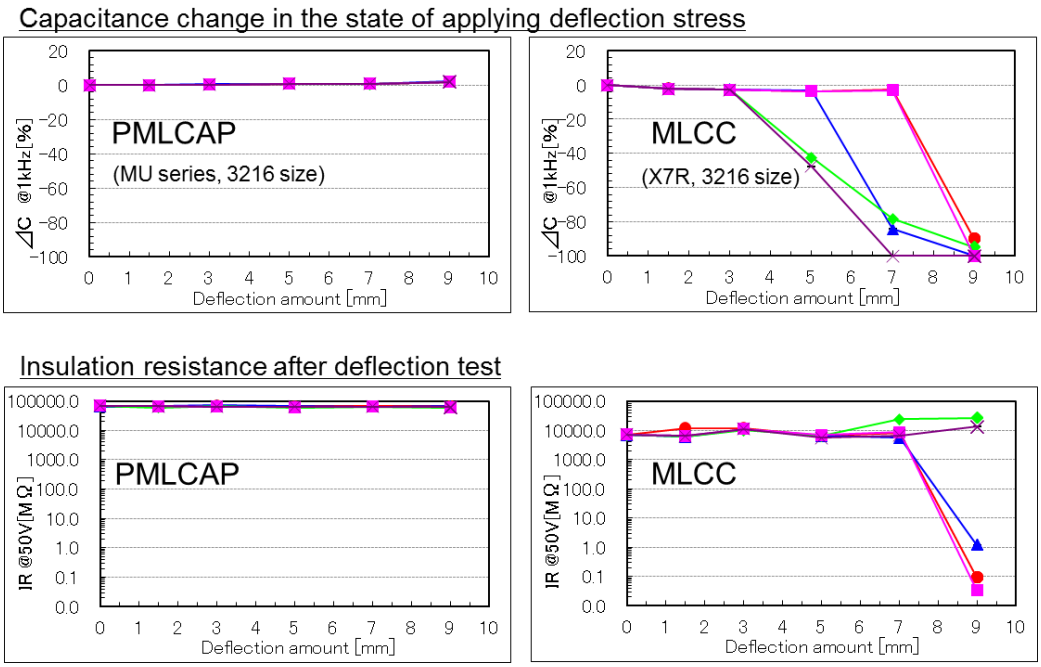


Fig. 15 Comparison of deflection durability

≪Humidity resistance≫

PMLCAP standard MU series are increasingly adopted in the market as compact and high heat resistant chip

film capacitors. However, since humidity resistance guarantee conditions are 40 ° C and 95% RH, improvement of moisture resistance performance has been desired. In response to this requirement, MS series of new dielectric materials with high moisture resistance have newly released.

Moisture resistance guarantee of the MS series is 85℃ 85% RH / 1,000 hours, and it has achieved significant improvement in moisture resistance compared with conventional products. As a result, it is expected that PMLCAP adoption will be expanded in automotive, communications and industrial equipment applications where high environmental resistance performance is required.

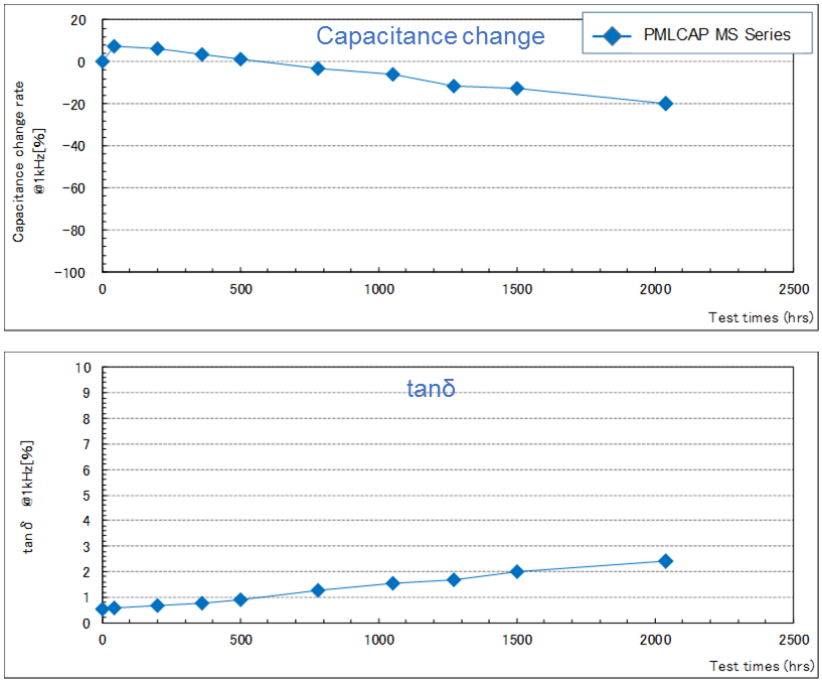


Fig. 16 Life test applied rated voltage under 85℃85%RH condition（PMLCAP MS series）

7. Typical applications

Typical applications of PML CAP include audio equipment making use of high sound quality, passing capacitor for power supply making use of less beat sound and loop filter for PLL (Phase Lock Loop) making use of less dielectric absorption and storage capacitor for Energy Harvesting making use of low leakage current.

≪Audio equipment≫

PMLCAP is good for coupling capacitors for direct current cutting of amplifiers and output filters of class D amplifiers. As the sound quality, the transparency of the middle-high range will increases. Use of PMLCAP to output filter reduces distortion and the sound quality improves, because of no capacitance fluctuation (no voltage dependence).

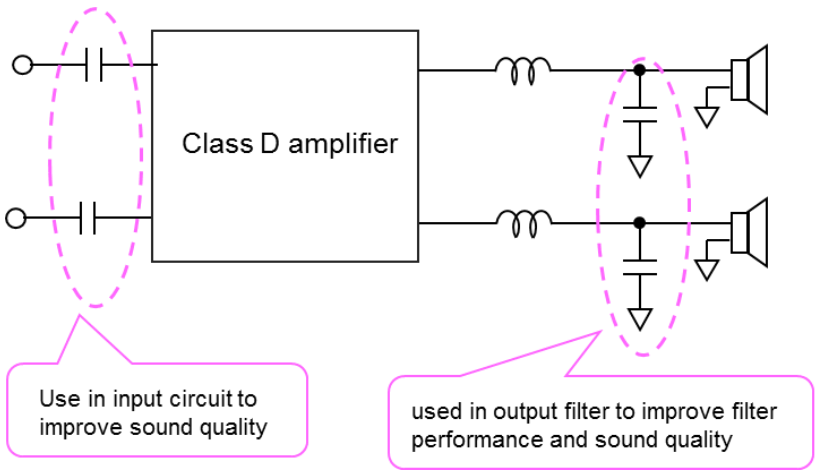


Fig. 17 Application for class D amplifier

≪LED backlight driver≫

Thin film as the dielectric of PML CAP has no piezoelectric effect so that beat sound is much less than MLCC. This property is ideal for passing capacitor in power supply handling large ripple current. In LED backlight using PWM (Pulse Width Modulation) in audible frequency range, use of MLCC may causes large beat sound. In following figure, PML CAP is used as passing capacitor for input and output of a boosting converter circuit, but in voltage reducing converter, PMLCAP`can be used to input passing capacitor.

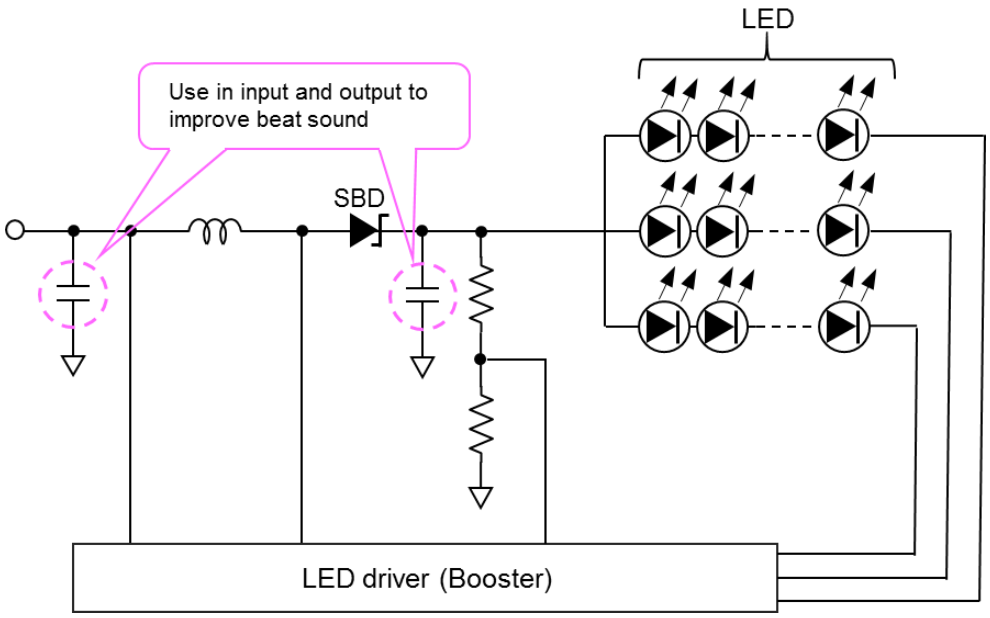


Fig. 18 Application for LED backlight driver

≪PLL synthesizer loop filter≫

When used as PLL synthesizer loop filter, since the dielectric absorption is smaller than that of high dielectric constant MLCC, switching time called the lock-up time can be greatly shortened. In addition, PMLCAP has no piezoelectric effect, so degradation of C/N ratio due to vibration is reduced.

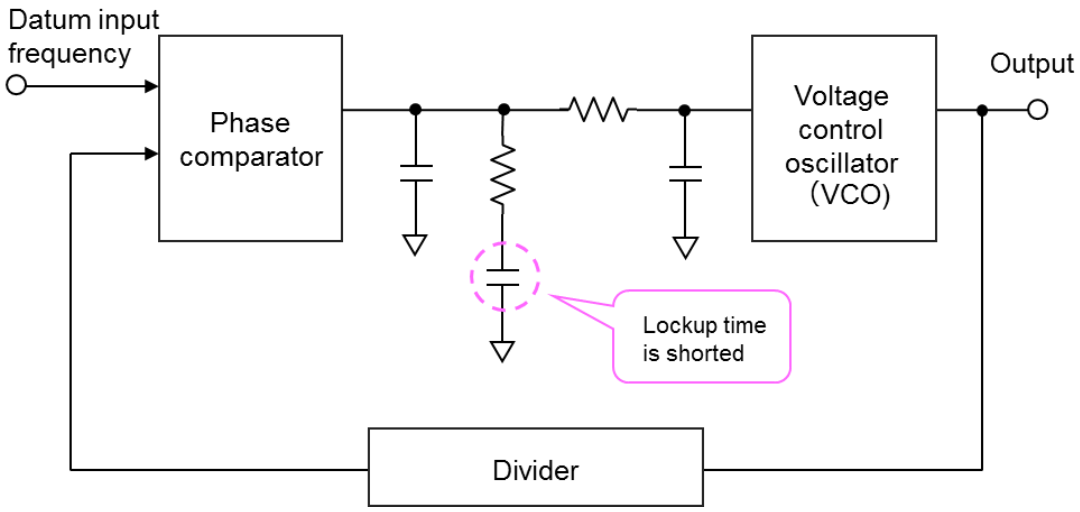


Fig. 19 Application for PLL synthesizer loop filter

≪Energy harvesting≫

Since PMLCAP forms dielectric layer with thin film, it has very small leakage current and is smaller size and larger capacity than conventional film capacitors. Therefore, it is suitable for energy harvesting ≪environmental power generation≫ storage capacitor to collect and save tiny amount of electric power.

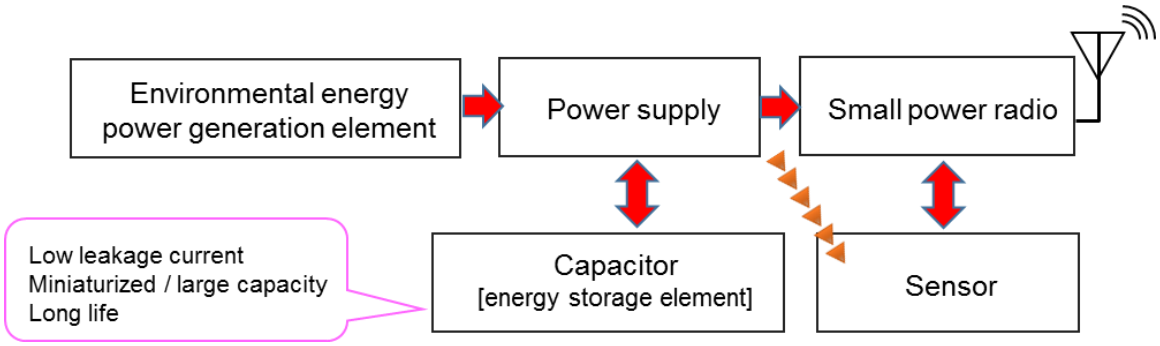


Fig. 20 Energy harvesting

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