JFE TECHNICAL REPORT
No. 6 (Oct. 2005)

# Ultra-thin Inductors for DC/DC Converters†

## 1. Introduction

In recent years, demand for small portable electronic devices represented by cellular phones and PDA has increased rapidly. These small portable devices are equipped with a power supply which converts the battery voltage to the driving voltage of parts such as the CPU, LCD module, and telecommunications power amplifier. High efficiency in power conversion, a thin shape, and compact size are strongly required in power supplies for portable devices. To meet these needs, JFE Mineral developed ultra-thin inductors (thickness, 0.6 mm; hereinafter referred to as planar inductor) for DC/DC converters.

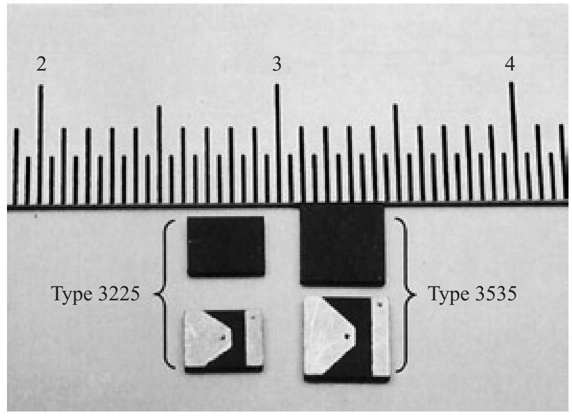


Photo 1  Planar inductor

## 2. Structure of Planar Inductors

Planar inductors have a structure in which a spiral-shaped copper coil is sandwiched between upper and lower sintered ferrite layers, and the spaces in the copper coil are filled with a magnetic material consisting of a mixture of ferrite powder and resin. It is known that this distinctive closed magnetic circuit structure reduces the eddy current loss of the conductor[1]. **Photo 1** shows the appearance of the planar inductors; **Fig. 1** shows a schematic diagram. The conductor coil and external electrodes are connected by copper plating in through-holes (in Fig. 1, parts shown by slanted lines at two places on the lower ferrite layer) provided in the lower ferrite layer.

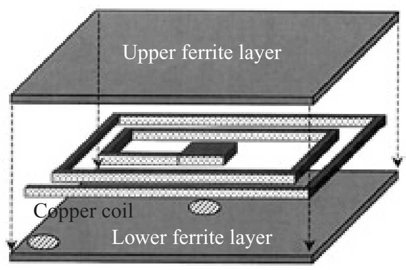


Fig. 1  Structure of planar inductors

## 3. Characteristics of Planar Inductors

**Table 1** shows the specifications of the planar inductor products. **Figure 2** shows their dimensions. Products are broadly classified as Type 3225, which has outer dimensions of 3.2 × 2.5 mm, and Type 3535, which has dimensions of 3.5 × 3.5 mm. Inductance ($L$ value) was

Table 1  Specifications of planar inductors

| Type | Part number | Inductance* ($\mu$H) | DC resistance ($\Omega$) | $Q$ factor* | DC current at $\Delta L/L = -20/-30\%$ (mA) | DC current at $\Delta T/T = 40°C$ (mA) |
|---|---|---|---|---|---|---|
| 3225 | 32R4560 | 4.5 | 0.46 | 21 | 450/ 620 | 650 |
| | 32R2760 | 2.7 | 0.23 | 23 | 430/ 600 | 950 |
| | 32R1560 | 1.5 | 0.13 | 18 | 600/ 830 | 1 250 |
| | 32R1160 | 1.1 | 0.09 | 14 | 700/ 970 | 1 550 |
| | 32R0560 | 0.5 | 0.05 | 15 | 900/1 340 | 2 100 |
| 3535 | 35S4260 | 4.2 | 0.22 | 10 | 420/ 620 | 1 000 |
| | 35S1060 | 1.0 | 0.06 | 8 | 700/1 100 | 1 800 |

* $I_{ac}$ = 0.5 mA,  Test frequency = 2 MHz

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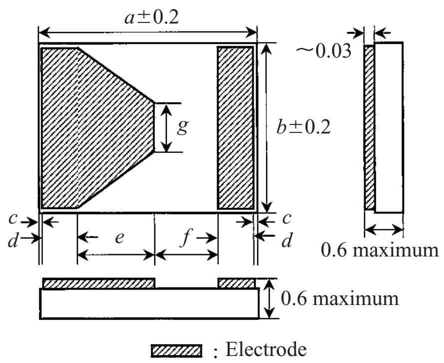
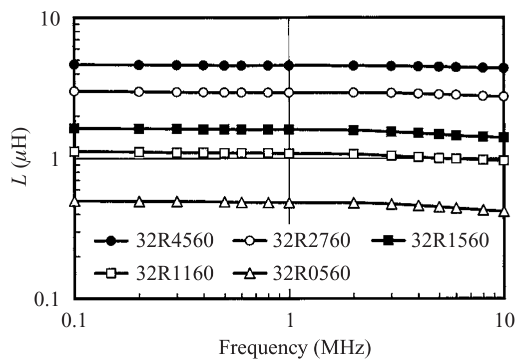


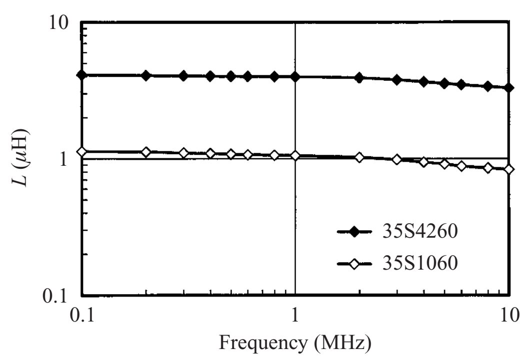

(mm)

| Part number | $a$ | $b$ | $c$ | $d$ | $e$ | $f$ | $g$ |
|---|---|---|---|---|---|---|---|
| 32RXX60 | 3.2 | 2.5 | 0.05 | 0.6 | 1.2 | 0.7 | 0.7 |
| 35SXX60 | 3.5 | 3.5 | 0.05 | 0.6 | 1.4 | 0.8 | 0.7 |

Fig. 2  Dimensions of planar inductor

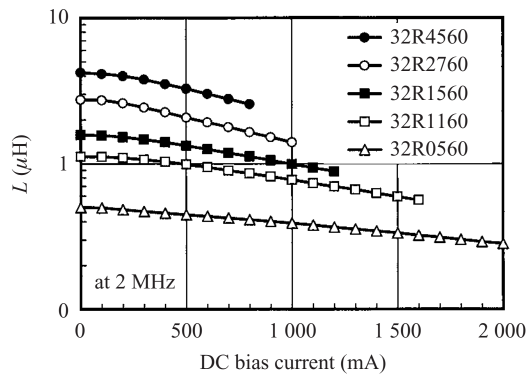



(a) Type 3225

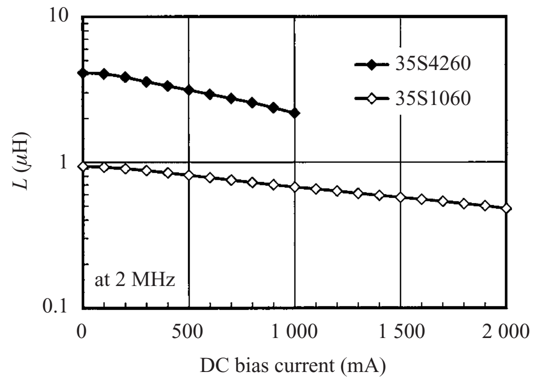



(b) Type 3535

Fig. 3  Frequency dependence of inductance

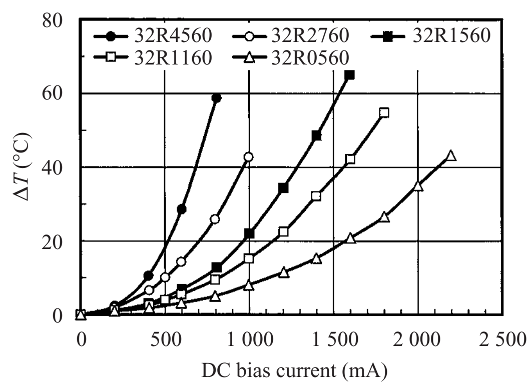



(a) Type 3225

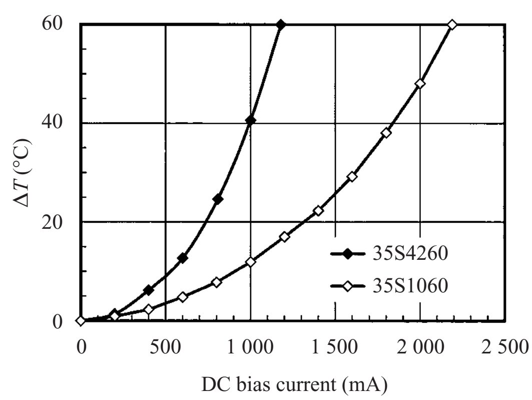



(b) Type 3535

Fig. 4  Inductance vs. DC bias current




(a) Type 3225




(b) Type 3535

Fig. 5  Temperature rise characteristics

optimized for switching frequencies in the mega hertz region, and were set at 0.5–4.5 $\mu$H. **Figure 3** shows the frequency dependence of inductance. The constant $L$ value is maintained at frequencies from 0.1 MHz to 10 MHz. **Figure 4** shows the superimposed DC current characteristics at a frequency of 2 MHz. The $L$ value gradually decreases as the superimposed DC current increases. The superimposed DC current characteristics were measured until the temperature rise of the products exceeded 40°C. **Figure 5** shows the temperature rise characteristics of the products with DC bias current. The slope of the temperature rise is smaller in products with lower DC resistance. **Table 2** shows the reliability test results of the 32R1560 product. In each conditions, the change in the $L$ value is within 10%.

Table 2 Reliability test results of 32R1560

| Test item | Condition | $\Delta L/L$ (%) |
|---|---|---|
| Thermal shock | −40/+125°C, 30 min each 100 cycle | within ± 10% |
| High temperature exposure | 125°C for 1 000 h | within ± 10% |
| Low temperature exposure | −40°C for 1 000 h | within ± 10% |
| High temperature exposure with load current | 125°C for 1 000 h with $I_{dc}$ = 350 mA | within ± 10% |
| Humidity exposure with load current | 40°C, 90–95%RH for 1 000 h with $I_{dc}$ = 350 mA | within ± 10% |
| Reflow soldering heat resistance | ≧235°C for 40 s and ≧250°C for 15 s | within ± 10% |
| Solvent resistance | Dip in IPA solvent for 10 min at room temperature | within ± 10% |

## 4. Power Loss Simulation

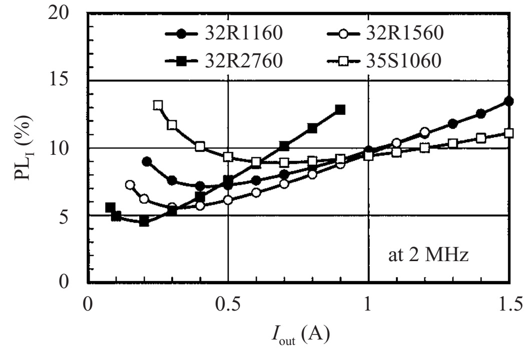
The main component parts of a power supply are semiconductor devices, inductors, and capacitors. In increasing power conversion efficiency, it is necessary to reduce the power loss of each of these components. In the case of a step-down type DC/DC converter, the power loss of the inductor itself can be calculated using the following Eq. (1)–(4). Due to the limitations of the measuring device, $R_s$ and $L$, which are necessary in calculating $PL_I$ using these equations, were measured assuming that $I_r$ is a sine wave (actually, $I_r$ is a triangular wave). For $R_{dc}$, the values in Table 1 were used.

$$PL_I = (P_{loss}/P_{in}) \times 100 \quad (1)$$
$$P_{loss} = I_{out}{}^2 \cdot R_{dc} + (I_r/\sqrt{3})^2 \cdot R_s \quad (2)$$
$$P_{in} = V_{in} \cdot I_{out} \cdot D \quad (3)$$
$$I_r = (V_{in} - V_{out}) \cdot V_{out}/(2f_s \cdot V_{in} \cdot L) \quad (4)$$

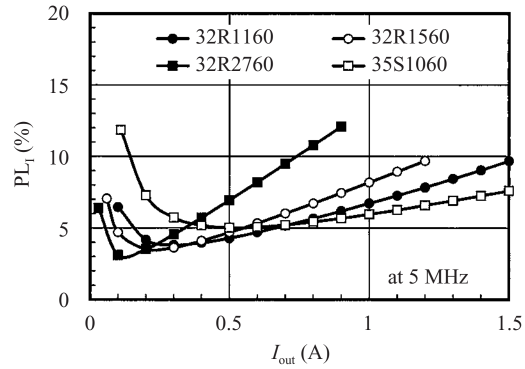
where,

$PL_I$: Power loss ratio of inductor (%)
$P_{loss}$: Power loss of inductor (W)
$P_{in}$: Input power (W)
$R_{dc}$: DC resistance (Ω)
$I_r$: Ripple current (A)
$R_s$: AC resistance (Ω)
$V_{in}$: Input voltage (V)
$V_{out}$: Output voltage (V)
$I_{out}$: Output current (A)
$D$: Duty ratio
$f_s$: Switching frequency (Hz)
$L$: Inductance (H)

The relationship between the output current and $PL_I$ calculated assuming $V_{in}$ = 3.6 V, $V_{out}$ = 1.8 V, and $D$ = 0.5 is shown in **Fig. 6**. If the frequency and the normal output current are set, the inductor of the product for the lowest $PL_I$ can be selected from this figure.




(a) $f_s$ = 2 MHz




(b) $f_s$ = 5 MHz

Fig. 6 Calculated power loss of inductors

## 5. Conclusion

This report has described the development of ultra-thin planar inductors (thickness: 0.6 mm), in which a spiral-shaped copper coil is sandwiched between upper and lower sintered ferrite layers, and the spaces in the copper coil are filled with a magnetic material consisting of a mixture of ferrite powder and resin. Further reduction in the thickness and size of these products is planned for the future.

The authors wish to thank the members of the KOA Corporation Protective Components/Inductors Center for their cooperation in the trial manufacture and reliability tests of the planar inductors.

### References

1) Fukuda, Y. IEEE Trans. Magn. vol. 39, 2003-07, p. 2057–2061.

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