Power Film Resistors
NIKKOHM

|			
RNP-10S, 20W	RNP-10, 20W	RNP-20S, 35W	RNP-50U, 50W
RNP-20D, 35W	RNP-20E, 35W	RNP-20F, 35W	RNP-50F, 50W
RNP-50S, 100W	RNP-100S, 140W	RPL300, 300W	RPL310, 300W
RPM200, 200W	RPM300, 300W	RPM600, 600W	RPK900, 600W
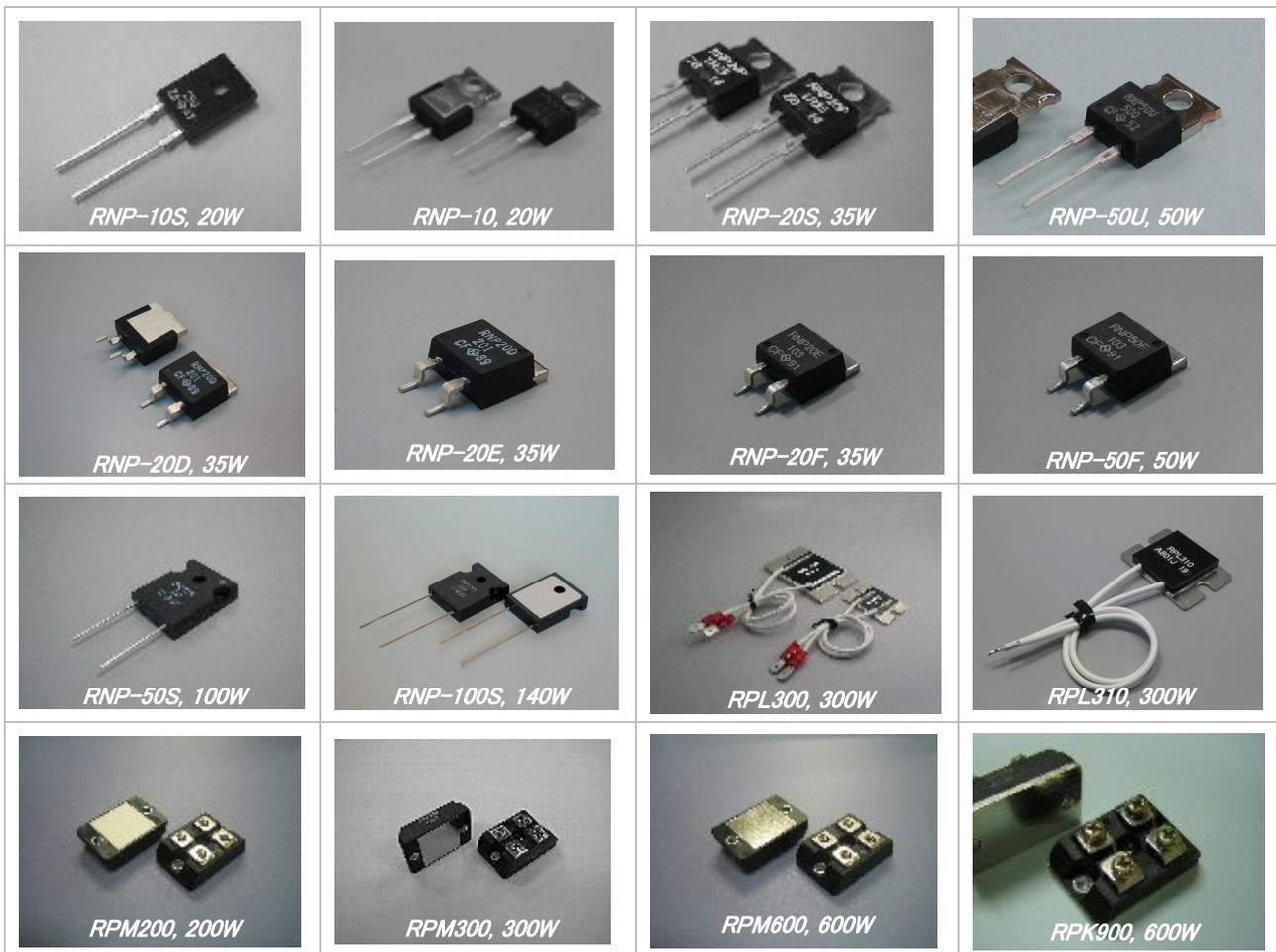
Capability Brochure, Power-Film Resistors, Series RNP, RPM, RPL

1. Electric Resistance

By applying either plus or minus voltage to the resistor and which causes electric current, the straight line characteristics of voltage and current such as Fig.1 are observed. The resistance of the resistor is 1K OHM if 5mA current is observed under the condition of 5V voltage applying. Resistor has a resistance value (unit :OHM). Resistance indicates the resistivity for electric current flow. Relation of resistance R (OHM) and voltage E (volt) and current I (Ampere) is shown as below.,

$$I = \frac{E}{R}(Ampere)$$

Fig.1 Voltage-current characteristic of resistor, dotted line shows non-linearity
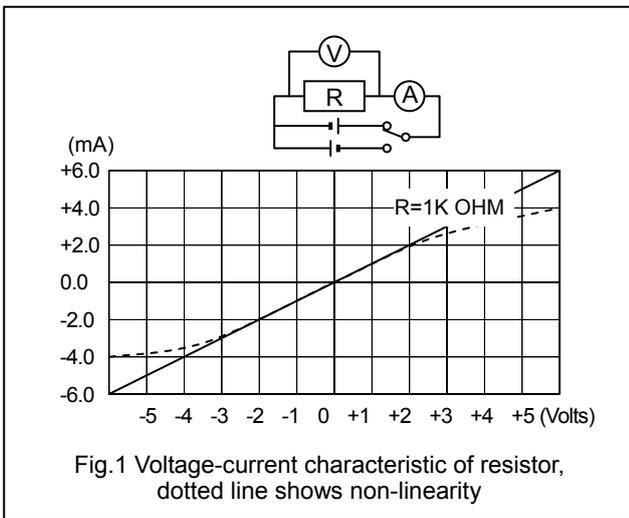
In most of cases, the resistor is made with metal resistive materials which have resistivity ρ as peculiar properties of physical fixed number.
By cutting the board-shaped metal resistive material in Fig.2, resistance between the both sides of the resistive material is calculated as below.

$$R = \rho \frac{L}{W \times T}(ohm)$$

Fig.2 Resistance of metal resistive material
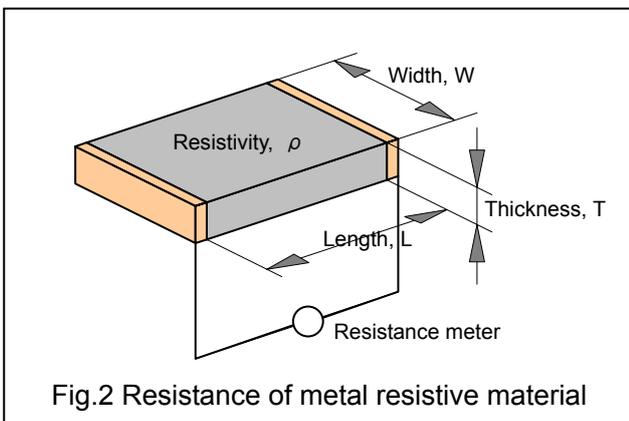
By the calculation of resistance of the metal which is cut 10mm square with 0.1mm thickness, a resistance between the both side points of the metal is calculated as Table1.

Materials	Resistivity (ohm·m)	W (mm)	T	L (mm)	R (OHM)
Const.	0.49x10^-6	10	1mm	10	0.00049
Manganin	0.44x10^-6	10	1mm	10	0.00044
Ni-Cr	1.10x10^-6	10	1mm	10	0.0011
Ni-Cr	1.10x10^-6	10	1um	10	1.10
Ni-Cr	1.10x10^-6	10	0.1um	10	11.0
Ni-Cr	1.10x10^-6	10	0.01um	10	110.0

Table 1. 10mm x10mm area resistance

The resistance metal plate size 10mm x 10mm x 1mm can be used for milli-ohm level resistor, on the other hand the resistance metal less than 0.1um thickness can be used for thin film resistor.
As shown in Table1, the resistance of square type resistive material depends on only the thickness of resistive material, and that resistance is called as Area Resistance which is utilized for the parts product design.
Area Resistance is utilized as an index value for the film thickness in both thin film resistor and thick film resistor.

2. Heating of resistor

By applying voltage E to resistor, current I flows through inside and Joule loss so called Electricity loss P is generated and becomes to heat.
Electric power P (W) is shown as below.

$$P = I \times E(W)$$

$$P = I^2 \times R(W)$$

$$P = \frac{E^2}{R}(W)$$

Heat of resistor is released to the air by air convection from metal surface or heat radiation in major resistor cases, however metal flange equipped resistor assists heat release through radiator in the case of power film resistor.
The structure and heat conduction of power film resistor is shown in Fig.3.

Fig.3 Resistance of metal resistive material
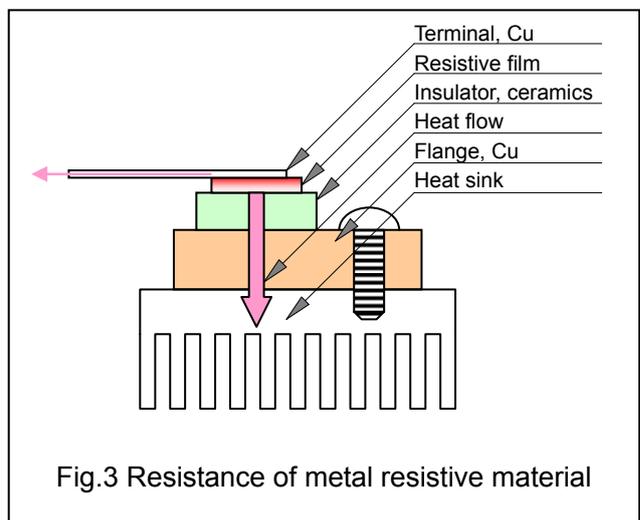
As shown in Fig.3, heat P(W) generated in resistor is partly released from the resistor through terminal, however major parts of heat is radiated from radiator (metal plate, aluminum board, aluminum block) through isolated ceramics (alumina board) and copper flange to the air. Performance of the power resistor is characterized by less thermal resistance between resistive material and flange. Alumina board and flange are connected by solder and which realize very small negligible thermal resistance. Thermal resistance of copper flange is also so small as to be negligible. Radiator has a capability of transmitting heat of flange to the air, and the thermal resistance is specified in data sheet for commercial resistor products, and which is inversely proportional to surface area of the radiator. Let's set thermal resistance between resistive material and flange as θrf, thermal resistance of radiator versus air as θh, and temperature of the air inside of the electronics equipment box as Ta, then temperature of resistive material Tr with electric power consumption P in the resistor is expressed as below.

$$Tr = (\theta rf + \theta h)P + Ta \leq 155 \deg C (\deg C)$$

Rating power Pr is expressed as below, with considering Pr to give some safety margin under the condition of flange temperature at 25 degree, and set maximum operation temperature of resistive material as 155 degree.

$$Pr = \frac{(155 - 25)}{\theta rf}(W)$$

Unit of thermal resistance is deg.C/W.
Table2 shows some specific thermal resistance which is between resistive material and flange in power resistor.

Type	Package	Heat Resistance
RNP-20D/E/F	TO263	3.3 (deg C/W)
RNP-10S	TO126	5.9 (deg C/W)
RNP-10	TO220	5.9 (deg C/W)
RNP-20S	TO220	3.3 (deg C/W)
RNP-50U	TO220	2.3 (deg C/W)
RNP-50S	TO247	1.3 (deg C/W)
RNP-80S	TO247	1.3 (deg C/W)
RNP-100S	TO247	0.9 (deg C/W)
RPM-200	SOT227	0.50 (deg C/W)
RPM-300	SOT227	0.32 (deg C/W)
RPL 300/310	---	0.32 (deg C/W)
RPM-600	SOT227	0.11 (deg C/W)
RPK-900	SOT227	0.10 (deg C/W)
RPL1200	---	0.10 (deg C/W)

TABLE 2. Heat Resistance, resistor-flange, Typical

3. Temperature rising of resistor

Temperature of all portion in resistor are started rising once voltage is started to apply for power resistor which equips radiator as shown in Fig.3. Fig.4 shows one specific measurement result of the temperature rising. Unlike to general air-cooling type resistor, flange power resistor which has less ability of heat conduction radiation from the surface of resistor, there is a linear shaped relation between applied voltage and temperature rising. Fig.4(a) shows the relation of temperature rising of flange

and resistive material which is inside of resistor, under the condition to use power resistor of 140W rating equipped on the radiator which thermal resistance is 0.2degC/W.
By subtraction the rising temperature of radiator from the temperature rising of flange, temperature rising of resistive material are indicated which is based on a flange temperature.
The slope of the straight line indicates the cooling performance of the power resistor and thermal resistance between resistive material and flange which shows 0.9degC/W in Fig4(b).
Maximum rating temperature of resistor is defined by the materials which consist of resistor, and which is 155 deg C for these power resistors, and derating curve can be provided by pulling straight line of the slope of thermal resistance from the point of maximum temperature rating as shown in Fig.4(c).
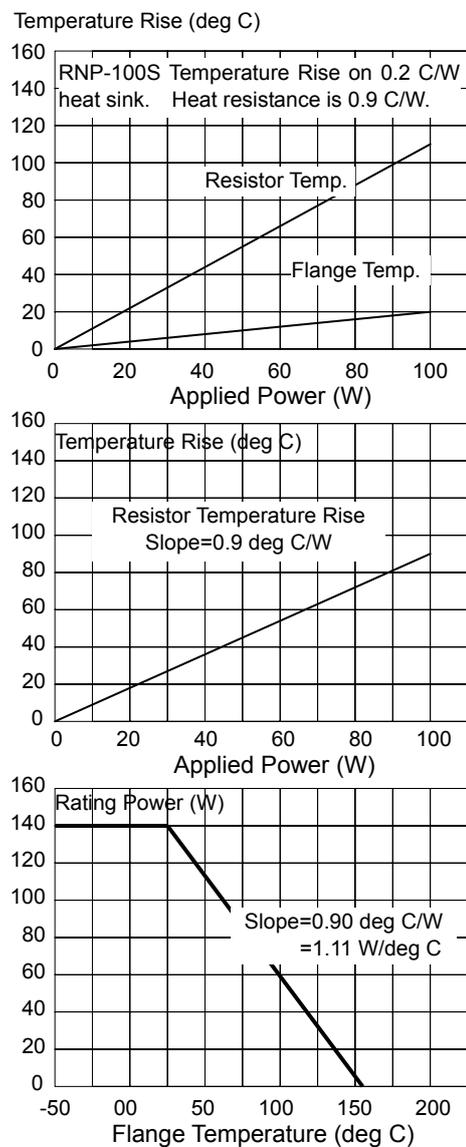

Fig 4. Temperature rise and power derating
From upper, Fig 4(a)-(b)-(c)

4. Power derating of resistor

The power derating curve of resistor shown in Fig4(c) indicates the safety operation area with border line. In other words, temperature of resistive material in side of resistor reaches maximum temperature on the power derating curve. It is required to let power resistor operate under the condition not on the borderline but inside of the power derating curve which correspond to the use of load reduction, and which purpose is improvement of the apparatus operation reliability. Though load reduction depends on the design standard of each system designer, it may be common to set load reduction around 25% or 50%.

5. Resistance value

Measurement position of Resistance is just the point 5.0mm apart from the bottom end of mold area or painting area of resistor, then measurement is executed by using Resistance Meter and Kelvin Probe. Resistor values like 1.0 OHM or 10.0 OHM etc. are not used continuation value but used discrete valid value from the rational standardization point. Those valid values are prescribed in JISC5063, IEC60063, etc., and E12 or E24 series are used for power resistor. Nikkohm has used numerical values of IEC standard with addition of 2.5 or 5.0 value as shown in Table 3.

Fig 5 Position of Resistance Measurement

Fig 6 Kelvin Probe, Resistance Measurement

E6+	E12+	E24+	
1.0	1.0	1.0	3.3
1.5	1.2	1.1	3.6
2.2	1.5	1.2	3.9
3.3	1.8	1.3	4.3
4.7	2.2	1.5	4.7
6.8	2.7	1.6	(5.0)
	3.3	1.8	5.1
	3.9	2.0	5.6
	4.7	2.2	6.2
	(5.0)	2.4	6.8
	5.6	(2.5)	7.5
	6.8	2.7	8.2
	8.2	3.0	9.1

Table 3. E6+, E12+, E24+, Significant Figures.

power supply circuit, which resistor tolerance of ±0.1% is so much useful. In some case, "B" means ±1% and "F" means ±5%, and it may be expressed like 0.1%,1%,5% without "±".

6. Temperature coefficient of resistance

Since materials of resistor are metal or alloy in general and which utilize the metal electrical conduction characteristics, resistance tends to be affected by the temperature of resistive material and temperature of environment. Therefore once the environment temperature of extra precision type resistor like 1000 OHM ± 0.000 OHM, its resistance will be shifted from 1000 OHM. If the shift value of resistance in 1 deg C change is expressed in ratio, temperature dependence is 0.005%/deg C or 50ppm/deg C in power resistor. This temperature dependence is called temperature coefficient of resistance "TCR". Both tolerance of resistance and temperature coefficient of resistance adopt the expression in ratio, tolerance of resistance is expressed in % and temperature coefficient of resistance is expressed in ppm/deg C respectively for the purpose of minimize a digit targeted to reduce the mistake of expression. In the case of 2 terminals type power resistor, the same as another type resistors, the effect of copper lead for TCR (temperature coefficient of resistance) is not negligible, therefore TCR tends to be increased following to the low resistance as shown in Fig7.
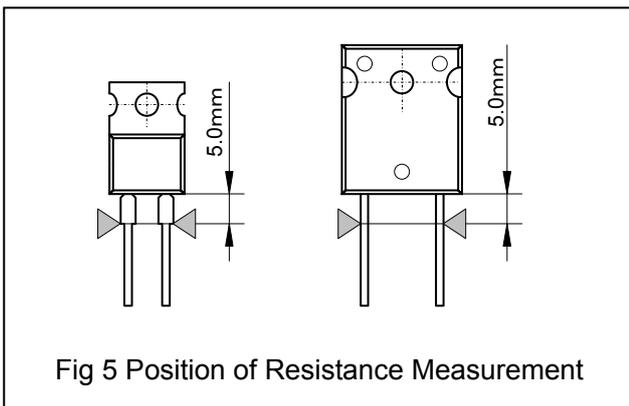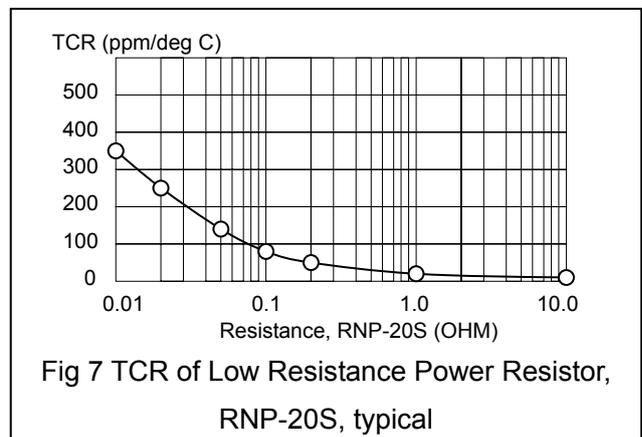

Fig 7 TCR of Low Resistance Power Resistor,

RNP-20S, typical

7. Short time overload and pulse overload for power film resistor

Rigidness for the short time overload of power film resistor corresponds to power ratings, and the usage under that overload condition is strictly limited. Wire-wound resistor is specified to be used under the condition of short time overload which accepts 10 times higher than power ratings within 5 second. The reason of the above is because of the so large thermal capacity of the resistive material of wire-wound resistor than that of power film resistor. The short time overload characteristics within 0.1s to some seconds depends on the thermal time constant which is defined by both thermal capacity (m x C) and thermal conduction (θ) of resistive material.

Let's calculate to obtain a temperature of resistive material after t second passed from the heat start period (t=0) with applied heat power W. Thermal capacity (C) is expressed as follows assuming specific heat (c) and mass (m).

$$C(J/K) = m(kg) \times c(J/kg \cdot K)$$

Time constant (τ) is expressed as follows by using thermal resistance (θ) between resistive materials and surroundings.

$$\tau = \theta(K/W) \times C(J/K)...\sec onds$$

Temperature rising value per time change △ Tt during the resistive material heated by electric power P(W) is expressed as bellow.

$$\Delta Tt = \theta(K/W) \times P(W) \times |1 - e^{-t/\tau}|...\deg C$$

Temperature falling value per time change △ Tt during cooling resistive material by releasing electric power is expressed as bellow,

$$\Delta Tt = \theta(K/W) \times P(W) \times |e^{-t/\tau}|...\deg C$$

and which shows exponential function-like change.

To obtain the thermal capacity C of both power film resistor and metal clad wire wound resistor which power ratings is 100W and resistance is 10 OHM in each, wire wound thermal capacity is 65 times higher than that of power film resistor as shown in Table4.

Type	Power Film	Wire wound
P/N	RNP-50S	IRV100
Rated Power	100W	100W
Resistance (ohm)	10	10
Material	Ni-Cr	Ni-Cr
Specific Heat(J/kgK)	418	418
Mass (kg)	0.082x10^(-6)	5.3x10(^-3)
Heat Capacity (J/K)	0.034	2.2

Table 4. Heat capacity of
power film and wire wound resistors

Therefore it is desirable to adopt wire wound resistor to brake resistors for large sized motor, and to surge current control resistors for large power supply unit. In the case of applying pulse shorter than 100 micro second width to resistor, power film resistor has a capability to apply surge peak pulse which is exceeding Rating Power. Regarding pulse overload characteristics, there is rough expression which is not related with the above but based on the examination result. The examination is executed by setting a criteria of pulse destruction of threshold as ±1% resistance change which is followed the pulse applying with specific constant period by using pulse generator shown in Fig 8. The result of pulse destruction examination is shown by dotted line and rough pulse rigidness is shown by solid line in Fig 9. Since the aspect of resistor destruction are different in each case of applying electric power either the constant current case or the constant current case, peak electric power needs to be limited lower than the rating power, or recommended to proceed enough reliability examination with confirmation before the equipment on circuit board.
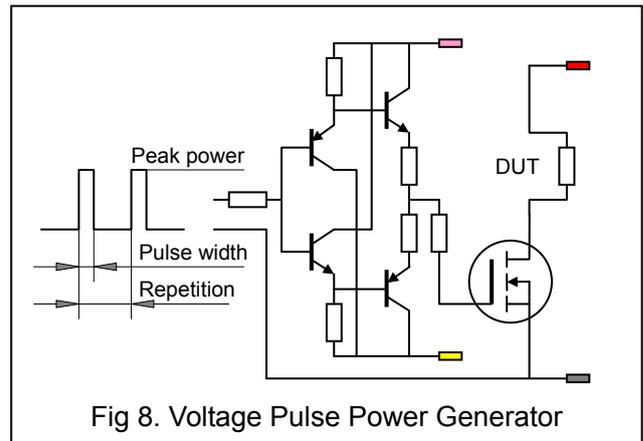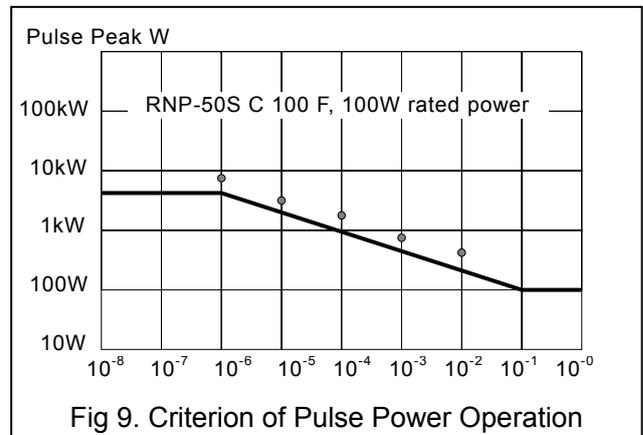

Fig 8. Voltage Pulse Power Generator

Fig 9. Criterion of Pulse Power Operation

8. Impedance frequency characteristics of power film resistor

Since power film resistor has a superior high frequency characteristics compare to the other resistors, power film resistor shows excellent characteristics in the pulse application circuit or high frequency circuit board which realizes wide frequency band and fast pulse rising time. In the case of alternating voltage application, there is a phase shift on sinusoidal wave in the relation of voltage and current from strict viewpoint, so impedance of resistor needs to be treated by both real number R and complex number Z. Impedance of power film resistor can be expressed by LCR equivalent circuit approximately, and which can express high frequency characteristics in specific band from DC to 1GHz. Both the equivalent parallel capacitance and equivalent series inductance of

power film resistor are shown in Table5.

$$Z = \frac{R}{1+\omega^2 R^2 C^2} + j\frac{\left(\omega L - \omega R^2 C + \omega^3 R^2 C^2 L\right)}{1+\omega^2 R^2 C^2}$$

$$|Z| = \frac{\sqrt{R^2 + \left(\omega L - \omega R^2 C + \omega^3 R^2 C^2 L\right)^2}}{(1+\omega^2 R^2 C^2)}...ohm$$

$$\theta = \tan^{-1}\left(\frac{\omega L - \omega C R^2 + \omega^3 R^2 C^2 L}{R}\right).....radian$$

The measurement result of TO220 power film resistor impedance characteristics is shown in Fig11. The characteristics show flat level from DC to 600MHz in the case of resistor 50 OHM through 200 OHM, and LC series resonance frequency can be observed at 700MHz.

Fig 10. Equivalent Circuit of Power Film Resistor
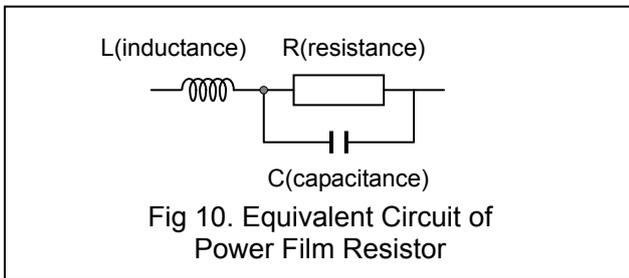
Type	Package	C(pF)	L(nH)
RNP-20D/E/F	TO263	1.44	8.38
RNP-10S	TO126	1.00	8.22
RNP-10	TO220	1.15	8.38
RNP-20S	TO220	1.44	8.38
RNP-50U	TO220	1.69	9.65
RNP-50S	TO247	2.35	11.72
RNP-80S	TO247	2.35	11.72
RNP-100S	TO247	3.68	12.52
RPM-200	SOT227	13.10	13.67
RPM-300	SOT227	13.10	13.67
RPL 300/310	---	13.10	13.67
RPM-600	SOT227	13.10	13.67
RPK-900	SOT227	13.10	13.67
RPL1200	---	---	---

Table 5. Equivalent Capacitance and Inductance of Power Film Resistor

Fig 11. Frequency Characteristics, Impedance of RNP-20S
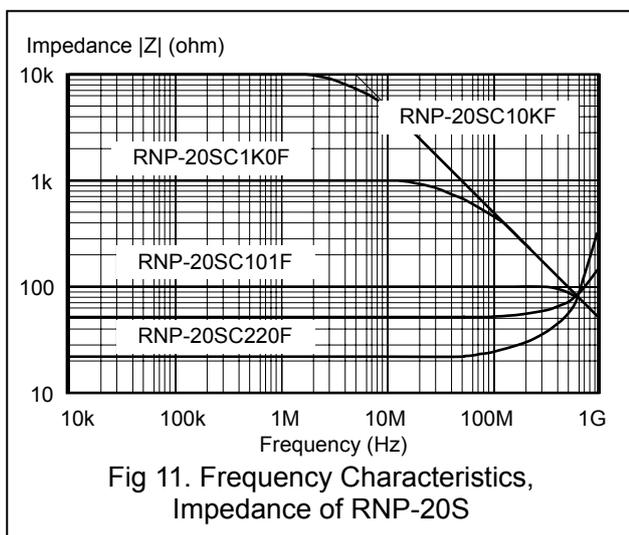
9. Implementation method of flange resistor
Implementation method of power film resistor which types are TO126, TO263, TO220, TO247 and SOT227 is explained as follows. Since metal flange for heat radiation of these all resistors which is isolated from resistive material and lead, there is no requirement for considering isolation (isolated heat radiation sheet) differs from transistor which equips exposed collector. Resistors TO126, TO220 and TO247 are connected with heat radiation plate or metal plate by clip or screw. Recommended torque of the screw is shown in Table6.

Type	Screw (mm)	Screw (inch)	Torque (Nxm)
RNP-10S	M3	No.4	0.6Nm
RNP-10	M3	No.4	0.6Nm
RNP-20S	M3	No.4	0.6Nm
RNP-50U	M3	No.4	0.6Nm
RNP-50S	M3	No.5	0.6Nm
RNP-80S	M3	No.5	0.6Nm
RNP-100S	M3	No.5	0.6Nm
RPM-200	M4	No.8	1.2Nm
RPM-300	M4	No.8	1.2Nm
RPL 300/310	M4	No.8	1.2Nm
RPM-600	M4	No.8	1.2Nm
RPK-900	M4	No.8	1.2Nm
RPL1200	M4	No.8	1.2Nm

Table 5. Equivalent Capacitance and Inductance of Power Film Resistor

Here are some implementation method of flange power film resistor shown in Fig.12.   //

Via hole thermal connection to heat-sink, RNP-20D/E/F, RNP-50F

Insertion cylinder thermal connection to heat-sink, RNP-20D/E/F, RNP-50F

Fig. 12   Installation, Power Film Resistors