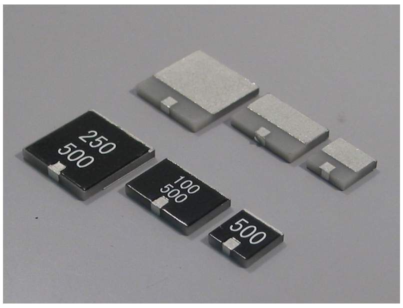
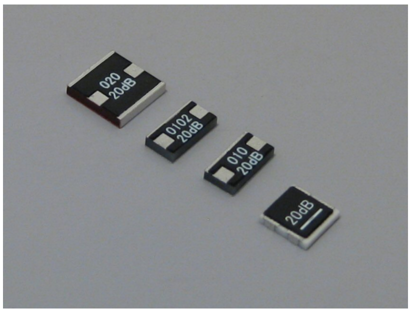
Capability Brochure, Microwave 012e

Attenuators
Terminations
Resistors

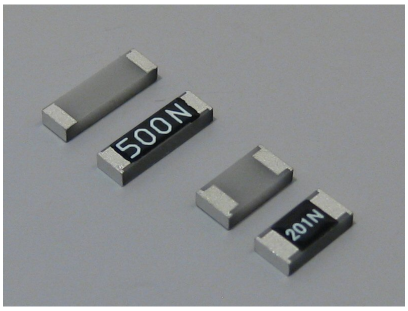
Nikkohm



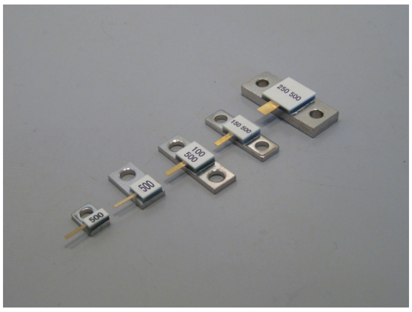
SMD Terminations



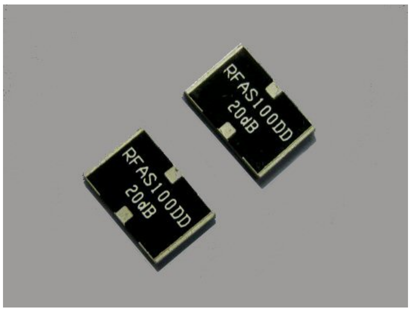
SMD Attenuators



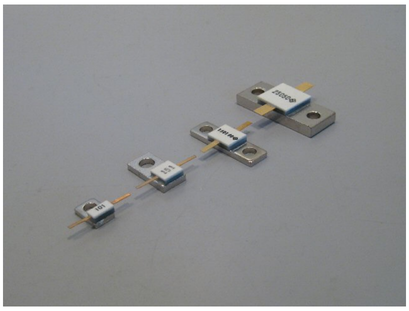
SMD Resistors



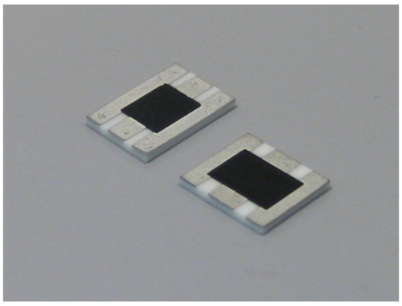
Flanged Terminations



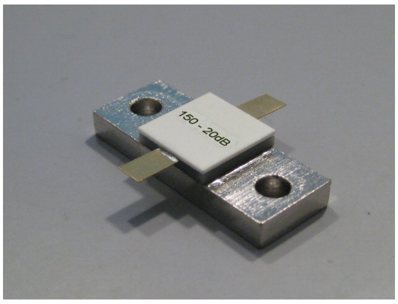
Power Chip Attenuators



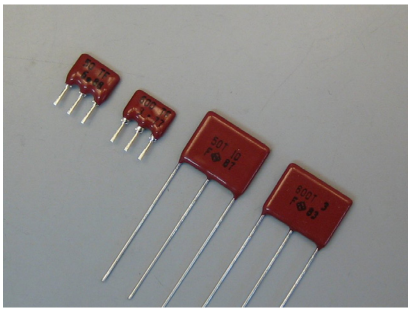
Flanged Resistors



Coaxial Attenuators



Flanged Attenuators



Through-hole Attenuators

1. Direct Current (dc) and Alternative Current (ac)

In the world of electricity and electronics energy and signals are transmitted from one location to another in applications ranging from large-energy power distribution to small-signal transmission. In terms of the signal variation over time when observed at a fixed position, there is the case of the direct current (dc), with which the amplitude does not change in time, and there is the alternating current (ac), with which the amplitude changes sinusoidally. In the case of ac, it may be represented by a diagram with a time axis as well as by a diagram with a frequency axis.

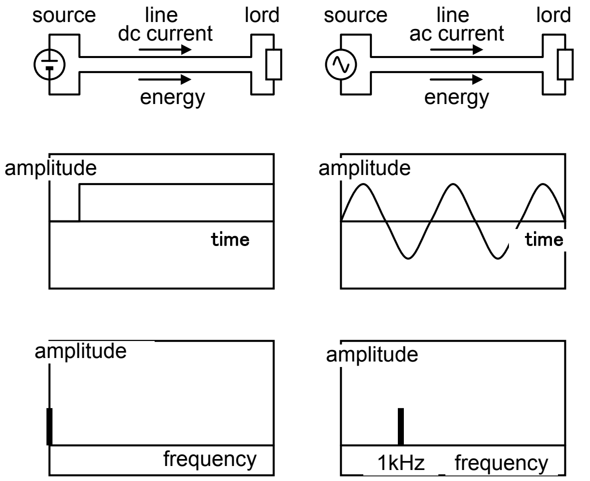


FIG1. dc and ac transmitting in the line.

2. Impedance and Characteristic Impedance

In the case of the alternating current, for the case of a purely resistive load *(R)*, the relationship between the voltage *(E)* and the current *(I)* applied to the load is such that their amplitudes are proportional to each other and their phases are in phase with each other. For the case of a load with a reactive component *(Z)*, the phases of the voltage and the current are out of phase with each other.

In the case of a sinusoidal alternating current, the sine wave is represented as follows in terms of complex exponential functions:

$$e^{j\omega t} = \cos\omega t + j\sin\omega t$$

$$e^{-\omega t} = \cos\omega t - j\sin\omega t$$

The relationship between the voltage and the current supplied to the load is represented by the following equations:

$$I = \frac{E}{R}$$

$$Z = R + jX$$

$$i = \frac{e}{Z} = \frac{E\sin(\omega t + \theta)}{R + jX}$$

Z, the lumped-element impedance, can be expressed with circuit elements such as resistance *(R)*, inductance *(L)* and capacitance *(C)*. In the case that the dimensions of the transmission line and the impedance elements are not negligible with respect to the wavelength of the alternating current, in other words, **at high frequencies of the alternating current**, the impedance elements and the transmission line are considered as distributed constant elements and a distributed constant line. The ratio of the voltage to the current in each part of the distributed constant elements is called the characteristic impedance *(Z_0)*. In the same way, the ratio between the electric field and the magnetic field of the distributed constant line is also called the characteristic impedance *(Z_0)*.

If the direct-current resistance, the series inductance, the parallel conductance and the parallel capacitance of the transmission line per unit length are *RLGC*, the characteristic impedance *(Z_0)* of the transmission line is expressed by the following equation:

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

For a loss-less transmission line, this can be expressed as follows:

$$Z_0 = \sqrt{\frac{L}{C}}$$

Representative transmission lines are shown in Fig.2. The characteristic impedance of a parallel two-wire line in vacuum (air) is determined by its dimensions as in the following equation:

$$Z_0 = 277\log_{10}\frac{2D}{d} .....(ohm)$$

The characteristic impedance of the coaxial line shown in Fig.2 is determined by its dimensions and the relative dielectric constant of the insulator:

$$Z_0 = \frac{138}{\sqrt{\varepsilon_r}}\log_{10}\frac{D}{d} .....(ohm)$$

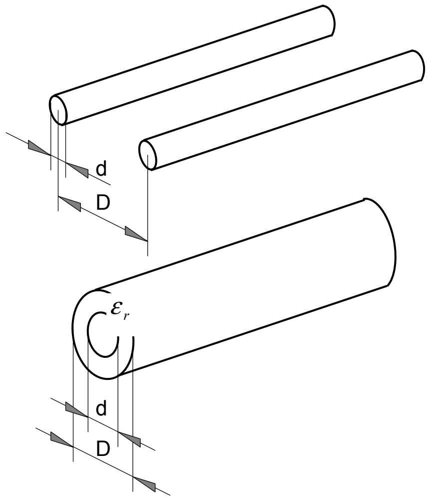


FIG 2. Characteristic impedance
of a parallel wire line and a coaxial line.

3 Impedance Matching

As shown in Fig.3, when a signal source is connected to a load through a transmission line to supply the signal power without loss to the load, the signal is reflected at the junction between the transmission line and the load if there is a difference in impedance between the transmission line and the load. The means of minimizing this reflection is called impedance matching. The reflected wave is also similarly reflected at the signal source.

The degree of impedance matching is represented by the magnitude of the reflection. The ratio of the reflected wave to the travelling wave is defined as the voltage reflection coefficient ρ. Further, the degree of matching is sometimes expressed as the voltage standing wave ratio VSWR.

When the voltage of the travelling wave is Vi, the voltage of the reflected wave is Vr, the load impedance is Z and the characteristic impedance of the transmission line is Z_0, the voltage reflection coefficient *(ρ)* and the voltage standing wave ratio (VSWR) are expressed as follows.

$$\rho = \frac{Vr}{Vi} = \frac{Z - Z_0}{Z + Z_0}$$

$$VSWR = \frac{1 + |\rho|}{1 - |\rho|}$$

It is possible to determine the standing wave ratio VSWR by inserting a probe in the line and measuring the variation in the RMS value of the electric field with position, as shown in Fig.4. This principle is used in the measurement of the load impedance Z_0.

Impedance matching is required for efficient power transmission from the signal source to the load. As illustrated in Fig.5, the problem of efficiently supplying the signal source power directly to the load and the problem of supplying a signal to the load through a transmission line with a particular characteristic impedance are similar problems.

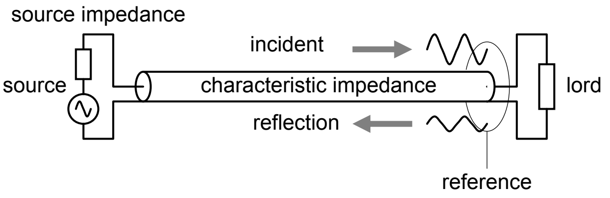


FIG 3. Characteristic impedance of a parallel wire line and a coaxial line.

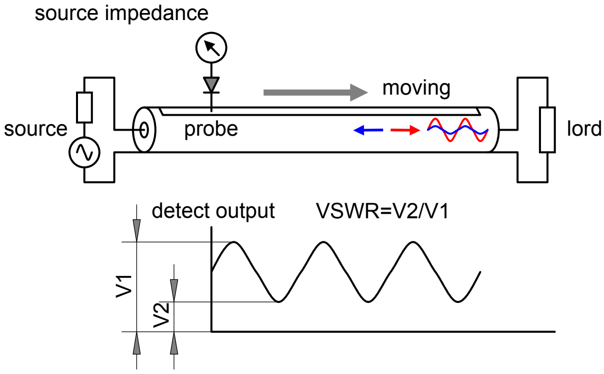
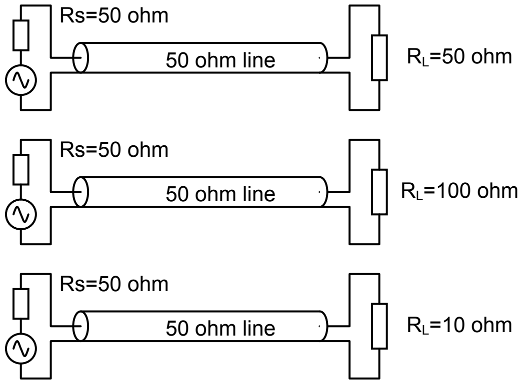


FIG 4. Characteristic impedance of a parallel wire line and a coaxial line.



input volt	current	power in R_L
100V	1A	50W
100V	0.67A	44W
100V	0.17A	28W

FIG 5. Example of power transfer efficiency.

4. Transmission Line and Micro-Strip

With regard to transmission lines for pulses containing frequency components in the microwave range or in a broad range, losses are required to be small and the electromagnetic radiation into the surrounding environment is required to be small. Parallel lines and twisted-pair lines are used in the low-frequency, not high-frequency range, because of their large electromagnetic radiation. The coaxial cable is an excellent transmission line, with the internal electromagnetic field in the TEM mode, but has the disadvantage of inconvenience in implementation. The microstrip and the coplanar line, with configurations as shown in Fig.6, are used as transmission lines similar to the coaxial line. Their characteristic impedances are determined by the relative dielectric constant and the dimensions of the insulator.

When a stub is formed at an intermediate position of a microstrip with a characteristic impedance of 50 ohms, and its length is L, if L is 1/4 of the wavelength in the microstrip, it acts capacitively in the case of an open stub, and inductively in the case of a short stub. If a small 50-ohm resistor is connected to the terminal end of a microstrip with a characteristic impedance of 50 ohms, it acts as a non-reflecting termination with little reflection. (Fig.7)

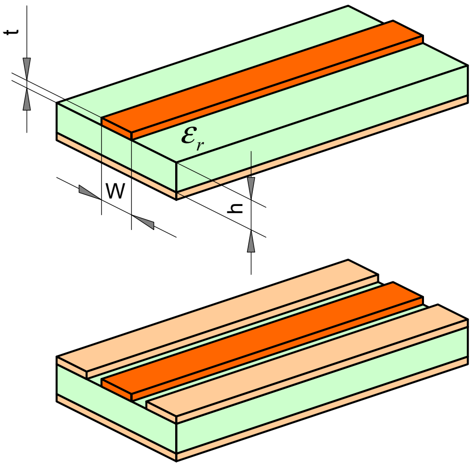


FIG 6. Micro strip (upper) and co-planer line (lower).

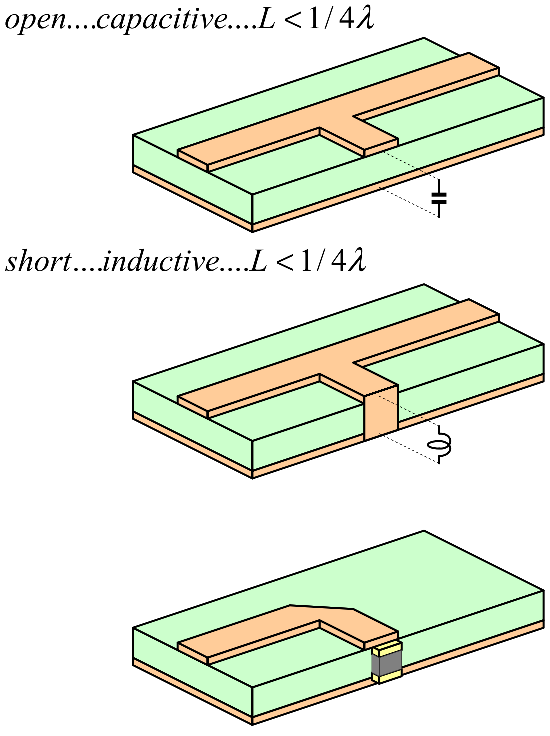


FIG 7. Open stub, short stub and termination.

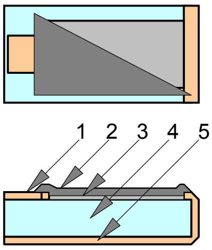
5. Terminations

A terminating component is used with such devices as directional couplers, filters, circulators, isolators and antenna-coupling circuits. The termination is a resistor. It is required to be a pure resistor with little reactive component. For 50-ohm termination of a signal circuit, a small chip resistor with a resistance of 50 ohms is suitable. However, if the signal to be terminated is of high power such as 5W to 800W, it is necessary to use power termination. In large power termination, the dimensions become large in order to dissipate power, and thus the equivalent parallel capacitance or inductance becomes large, and since the structure is designed to conduct the heat generated by Joule losses for cooling, some form of an external cooling mechanism must be provided.

The cross-sectional structure of a typical power terminator is shown in Fig.8. In Fig.8, the heat generated by the resistive element #3 is conducted to the rear face by a ceramic material with high thermal conductivity, and the heat is dissipated to the outside from the rear face.

The rear face of the terminator is cooled by either directly joining to a metal plate with solder, or by conducting the heat to a metal heat sink through a printed circuit board.

As power terminators there are, a product in the form of a chip as in Fig.8, as well as a flange terminator which is a chip mounted on a metal flange. Fig.9 shows methods of cooling the chip, and Table 1 shows the capacitive and inductive components of the chip. Fig. 10 shows methods of cooling the flange. As the heat conduction in power terminators is the same as the heat conduction in power resistors, please refer to the separate brochure. For reference, the thermal resistances are shown in Table 2.



No.	substance	material
1	conductor +	Cu
2	passivation	resin
3	resistor	Ni-Cr
4	substrate	ceramics
5	conductor -	Cu

FIG 8. Structure and material of power termination

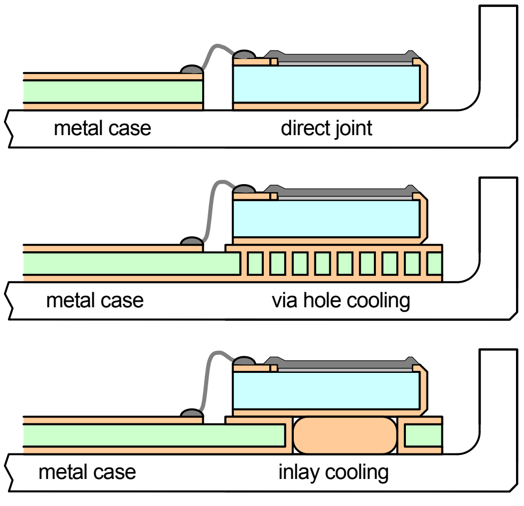


FIG 9. Installation, termination chips.

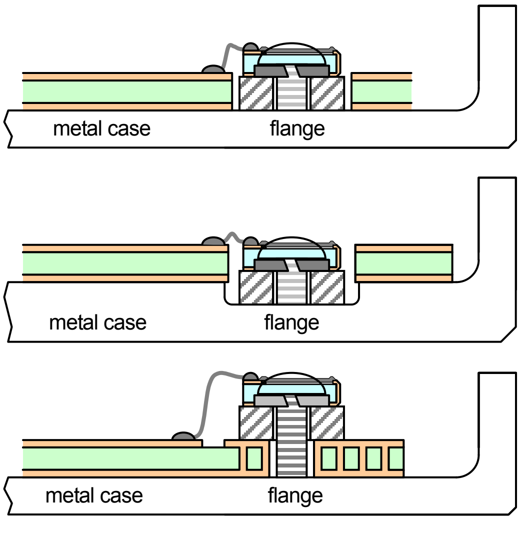


FIG 10. Installation, flange termination.

model	rated power	char. imp.	parallel C	**series L**
RFT010	10W	50 ohms	2.4pF	2.0nH
RFT050	50W	50 ohms	3.3pF	3.5nH
RFT100	100W	50 ohms	5.4pF	4.1nH
RFT150	150W	50 ohms	5.5pF	4.2nH
RFT250	200W	50 ohms	7.4pF	5.4nH
RFT400	400W	50 ohms	–	–
RFT800	800W	50 ohms	–	–

Table 1. Parallel capacitance and series inductance of power terminations, typical.

model	rated power	char. imp.	Heat resistance
RFT010	10W	50 ohms	5.5℃/W
RFT050	50W	50 ohms	1.1℃/W
RFT100	100W	50 ohms	0.55℃/W
RFT150	150W	50 ohms	0.36℃/W
RFT250	200W	50 ohms	0.22℃/W
RFT400	400W	50 ohms	0.137℃/W
RFT800	800W	50 ohms	0.068℃/W

Table 2. Heat resistance of power terminations, typical.

6. Attenuator

The attenuator is a resistive voltage attenuator with two input terminals and two output terminals. The attenuator is used to match impedances or to adjust input and output levels.

As shown in Fig.11, the magnitude of attenuation of an attenuator is sometimes indicated in terms of naper, the natural logarithm. In general, the common logarithm, dB, is used. Since a signal diminishes by passing through an attenuator, the magnitude of attenuation is, of course, negative.

In the case of an attenuator with attenuation α, at first *k* is determined by the following equation:

$$\alpha_{db} = 20\log_{10} k \qquad k = 10^{\frac{\alpha}{20}}$$

Next, in the case of a T-type attenuator, the branch resistances *Ra*, *Rb* and *Rc* are obtained using the equations:

$$Ra = Rb = Z\frac{k-1}{k+1}....ohm$$

$$Rc = 2Z\frac{k}{k^2-1}....ohm$$

And, in the case of aπI type attenuator, using the equations:

$$Ra = Rb = Z_0\frac{k+1}{k-1}....ohm$$

$$Rc = \frac{Z_0}{2}\frac{k^2-1}{k}....ohm$$

$$attenuation..\alpha_{np}....\alpha_{dB}$$

$$\alpha_{np} = \log_e k.....naper$$

$$\alpha_{db} = 20\log_{10}\frac{eo}{ei}....dB$$

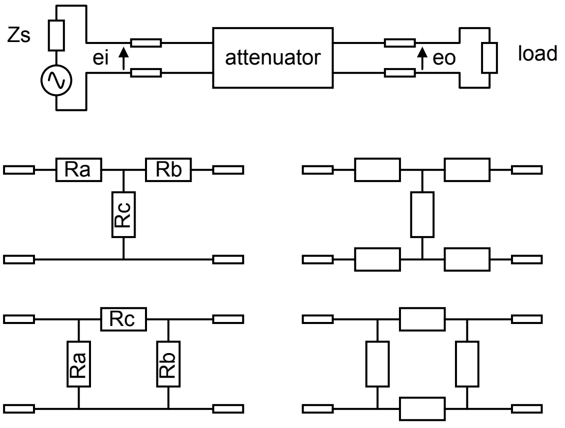


FIG 11. T-attenuator and pi attenuator, Balance circuit and un-balance circuit.

An attenuator attenuates the input signal inside the attenuator and applies it to the load connected to the output terminals. Therefore power is consumed and heat is generated inside the attenuator. Table 3 shows examples of the power consumed by each branch resistor when 70.7V (power: 100W) is applied to the input terminals of an attenuator with an impedance of 50 ohms. When the attenuation is -6dB, approximately 75% of the power is consumed in the attenuator and 25% of the power is supplied to the load. On the other hand, when the attenuation is large, if it is -20dB, 99% of the power is consumed in the attenuator so that it is necessary to consider the method of cooling the heat generated in the attenuator.

The structures of chip attenuators are shown in Fig.12. They are attenuators with flanges, except for Fig.12(d). Cooling is by heat conduction from the rear face. The method of mounting is the same as for the power attenuators in Fig.9. Fig.13 shows the method of mounting the coaxial attenuator shown in Fig.12(d).

T	Ra	Rb	Rc	Pra	Prb	Prc
	(ohm)	(ohm)	(ohm)	(W)	(W)	(W)
-6dB	16.6	16.6	66.9	33.2	8.34	33.3
-20dB	40.9	40.9	10.1	81.8	0.818	16.36
Pi	Ra	Rb	Rc	Pra	Prb	Prc
	(ohm)	(ohm)	(ohm)	(W)	(W)	(W)
-6dB	150.4	150.4	37.35	33.2	8.34	33.3
-20dB	61.11	61.11	247.5	81.8	0.818	16.36

TABLE 3. Branch resistance and power consumption, 50ohm T attenuator and PI attenuator, at 70.7V input voltage (100W)

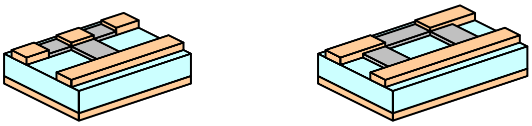


FIG12(a)
T type power attenuator

FIG 12(b)
PI type power attenuator

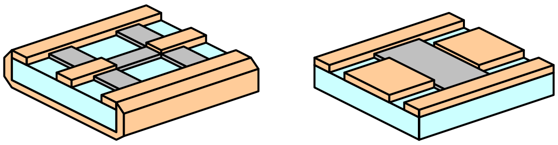


FIG12(c)
Balanced PI type
power attenuator

FIG 12(d)
Distributed circuit
power attenuator for
coaxial application

FIG 12. Typical structured power attenuator chips

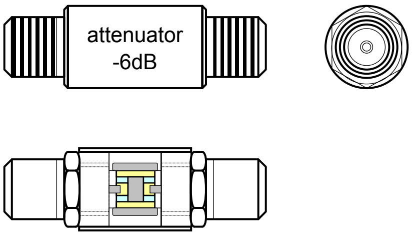


FIG 13. Coaxial attenuator structure

model	power	feature	attenuation
RFA001	1W	ALO chip	1dB-20dB
RFA010	10W	ALN chip	10, 20, 30dB
RFA020	20W	ALN chip	10, 20, 30dB
RFA050	50W	ALN chip	10, 20, 30dB
RFA100	100W	ALN chip	10, 20, 30dB
RFA150	150W	ALN chip	10, 20, 30dB
RFA54	0.25W	ALO coaxial	2db-30db
RFA55	0.50W	ALO coaxial	2db-30db
RFA67	1.00W	ALO coaxial	2db-30db
RFA50TF	0.25W	through-hole	1db-30db
RFA50T	0.50W	through-hole	1db-30db

TABLE 4. Typical attenuators

7. Resistor

The outside appearance of a microwave resistor is the usual chip resistor. However, it has characteristic features such as the small equivalent parallel capacitance and inductance, the capability to handle large power consumption with a small size and the structure in which consideration is given to thermal conduction.

The structure of the resistor and its lumped constant equivalent circuit are shown in Fig.14. The high-frequency characteristics of the resistor can be expressed by an equivalent model with resistance *Rs*, parallel capacitance *Cs* and parallel inductance *Ls*.

The impedance of the resistor can be expressed by the following equation:

$$Z = \frac{(R + j\omega L)}{1 - \omega^2 LC + j\omega RC} ...ohm$$

The stray capacitance and stray inductance in the equivalent circuit of Fig.14 for various resistors are shown in Table 5. Especially in the case of high-frequency resistors, resistors with small capacitances give good performance. It is also necessary to cool the heat generated in the resistor by thermal conduction from the rear face or the two terminals.

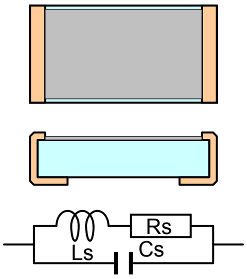


FIG 14. Microwave resistor,
structure and equivalent circuit

model	power	feature	Res.	**Cs**	**Ls**
RFH52	10W	ALN chip	See note1	2.3pF	1.4nH
RFH72	20W	ALN chip	See note1	2.5pF	2.6nH
RFR010	10W	ALN chip	See note1	2.2pF	1.1nH
RFR020	20W	ALN chip	See note1	–	–
RFR050	50W	ALN chip	See note1	3.3pF	1.6nH
RFR100	100W	ALN chip	See note1	–	–
RFR150	150W	ALN chip	See note1	5.5pF	2.5nH
RFR250	250W	ALN chip	See note1	7.6pF	4.2nH

Note 1. 16.67, 50, 100, 150, 200, 250, 300, 400, 600, 800 ohm

TABLE 5. Typical microwave resistors.

The microwave resistor is used when multiple circuits are made to function with one signal source. This is done by using such devices as power splitters, power dividers and power combiners. Products are available which are able to withstand power (heat generation) from 10W to 250W, depending on the power to be passed through. Since the values of resistance are determined by the circuit type of the devices such as splitters, discrete resistance values are available as standard values, such as 16.67 ohms, 100 ohms, 150 ohms, 200 ohms, 250 ohms, 300 ohms, 400 ohms, 600 ohms and 800 ohms. In addition, it is possible to supply other values of resistance which are required by other circuit types, according to customer specifications.

A power splitter, a power divider and a combiner formed by resistor networks are shown in Fig.15. These circuits have the advantage of flat frequency response characteristics, but they have the disadvantage that there is always a loss of -6dB. Examples of a two-way Wilkinson power splitter and a combiner using 1/4-wavelength transmission lines are shown in Fig.16. Wilkinson splitters have the advantage of smaller losses compared to resistive circuits, but they have the disadvantage that the width of the pass-band is very narrow. Therefore, when using these splitters and combiners it is necessary to devise means to make the bandwidth wider.

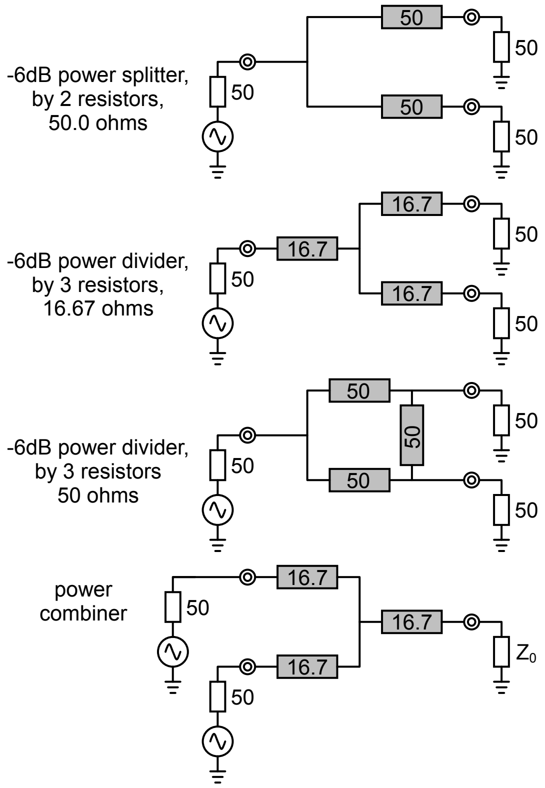


FIG 15. Microwave resistor applications, power splitter, divider and combiner, have a simple design and flat frequency response, but isolation and -6dB insertion loss is not good. Unit: ohm.

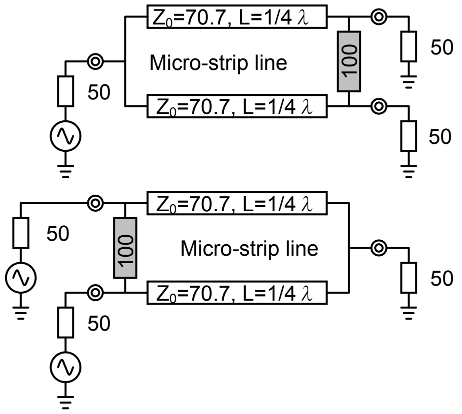


FIG 16. Microwave resistor applications, Absorption resistor in Wilkinson splitter and combiner, Unit ohm

8. Transmission Characteristics of a 2-port Network

One of the network parameters used to represent the characteristics of a high-frequency electronic component or a high-frequency electronic circuit is the scattering parameter, the scattering matrix (*S* parameter). The *S* parameter represents the high-frequency characteristics of transmission and reflection in the transmission network. In addition to the *S* parameter, there are the impedance parameter *Z* and the admittance parameter *Y*.

Fig.17 is a typical 2-port network with an input port and an output port. Here, two travelling waves, *a1* and *a2*, and two reflected waves, *b1* and *b2*, are defined and the relationships between the travelling waves and the reflected waves are represented by the following equations:

$$\begin{vmatrix} b1 \\ b2 \end{vmatrix} = \begin{vmatrix} S11 & S12 \\ S21 & S22 \end{vmatrix} \cdot \begin{vmatrix} a1 \\ a2 \end{vmatrix}$$

$$b1 = S11 \cdot a1 + S12 \cdot a2$$
$$b2 = S21 \cdot a1 + S22 \cdot a2$$

For example, if the load Z_L is matched with the output impedance of the network, the reflection at the output terminus becomes zero and *a2*=0, so that S11 becomes as in the following:

$$S11 = \frac{b1}{a1}$$

*S*11 is also called the return loss.

The meanings of *a1*, *a2*, *b1* and *b2* are as follows:

$|a1|^2$ = power incident to the input of the circuit
$|a2|^2$ = power incident to the output of the circuit
$|b1|^2$ = power reflected from the input of the circuit
$|b2|^2$ = power reflected from the output of the circuit

The physical meanings of $S11$, $S12$, $S21$, $S22$ are:

$$|S11|^2 = \frac{power\ reflected\ at\ the\ input\ of\ the\ circuit}{power\ incident\ at\ the\ input\ of\ the\ circuit}$$

$$|S22|^2 = \frac{power\ reflected\ at\ the\ output\ of\ the\ circuit}{power\ incident\ at\ the\ output\ of\ the\ circuit}$$

$|S21|^2$ = power gain when both the signal source and the load are Z_0 (matched)

$|S12|^2$ = power gain in the direction opposite to $S21$

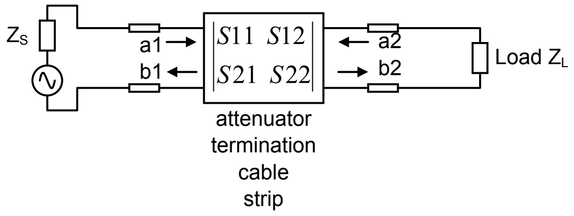


FIG 17. S parameter in 2 port circuit

The reflection coefficient at the input terminus is,

$$\Gamma s = \frac{a1}{b1}$$

The reflection coefficient at the output terminus is,

$$\Gamma_L = \frac{a2}{b2}$$

When the characteristic impedance of the circuit is Z_0, the impedance of the signal source is Z_S, and the impedance of the load is Z_L, the reflection coefficients are represented by the following equations:

$$\Gamma s = \frac{(Zs - Z_0)}{(Zs + Z_0)}$$

$$\Gamma_L = \frac{(Z_L - Z_0)}{(Z_L + Z_0)}$$

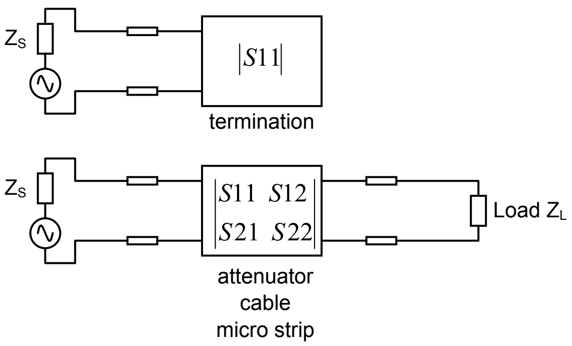


FIG 18. S parameter in termination and attenuator

9. Microwave Measurements

The performances of microwave circuits or microwave devices with 2 ports, 3 ports, etc., such as terminators, attenuators, circulators, isolators, filters, power dividers and power combiners can be measured by the method shown in Fig.19 using a scalar or vector network analyzer (transmission characteristic test equipment). In the case of 2 ports, $S11$ and $S21$, and $S22$ and $S12$ can be measured. If the input and output of the circuit or device are by coaxial connectors, they may be directly connected to the analyzer. If the circuit or device is a chip, measurements are made by mounting it on a measurement jig such as the one shown in Fig.20. The results of a measurement of the high-frequency characteristics of an attenuator are shown in Fig.21 and FIG.22. The attenuator which was used in the measurement is an attenuator with maximum input power 10W and attenuation -20dB, RFA010 010 20dB.

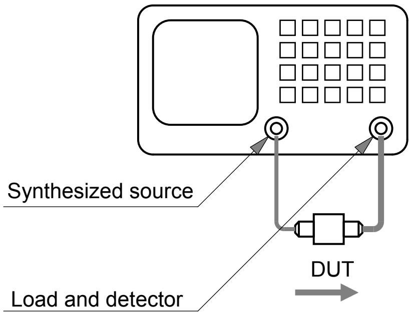


FIG 19. Network Analyzer and 2 port circuit

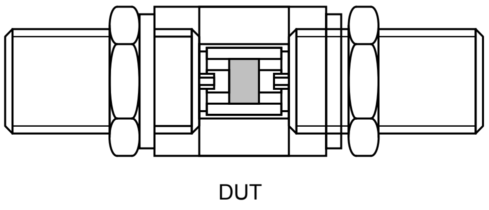


FIG 20. Fixture for Chip

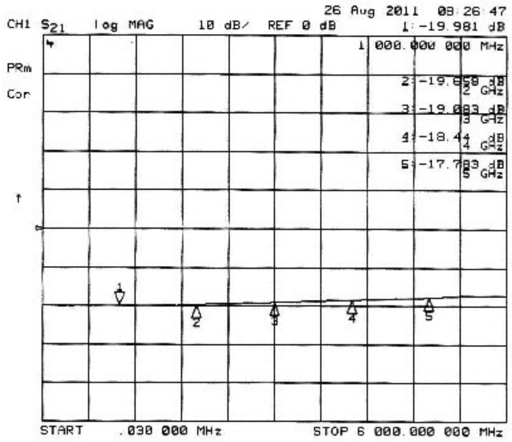


FIG 21, S21, RFA010 010 20dB

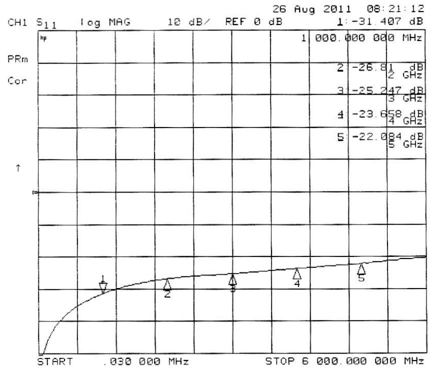


FIG 22. S11, RFA010 010 20dB

In case of 20W attenuator, RFA020 010 20dB, typical attenuation and S11 are as shown in FIG.23 and FIG.24.

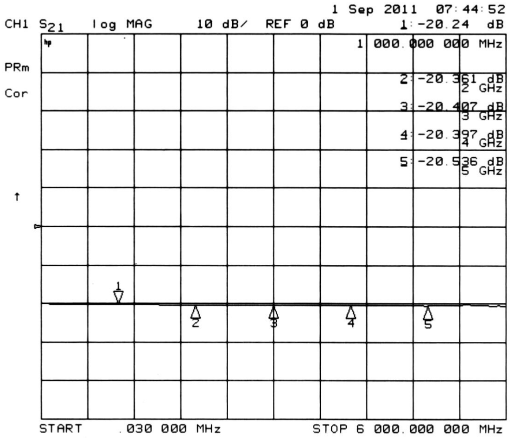


FIG 23. Attenuation, RFA020 010 20dB

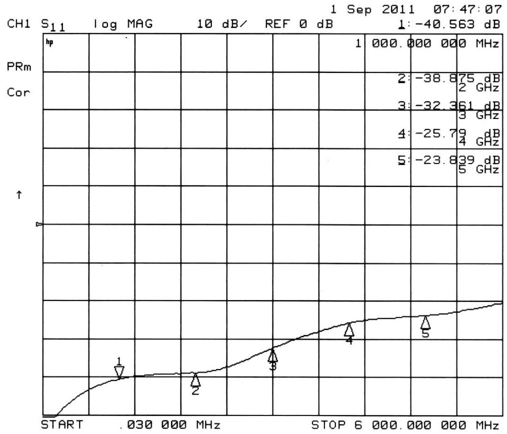


FIG 24. S11, RFA020 010 20dB

10. Reference

The relationships, which are frequently used in design and measurement, between the return loss, reflection coefficient and the voltage standing wave ratio are listed in Table 6.

S11(dB)	Γ	VSWR	S11(dB)	Γ	VSWR
1	1.122	17.391	31	35.481	1.058
2	1.259	8.724	32	39.811	1.052
3	1.413	5.848	33	44.668	1.046
4	1.585	4.419	34	50.119	1.041
5	1.778	3.570	35	56.234	1.036
6	1.995	3.010	36	63.096	1.032
7	2.239	2.615	37	70.795	1.029
8	2.512	2.323	38	79.433	1.026
9	2.818	2.100	39	89.125	1.023
10	3.162	1.925	40	100.000	1.020
11	3.548	1.785	41	112.202	1.018
12	3.981	1.671	42	125.893	1.016
13	4.467	1.577	43	141.254	1.014
14	5.012	1.499	44	158.489	1.013
15	5.623	1.433	45	177.828	1.011
16	6.310	1.377	46	199.526	1.010
17	7.079	1.329	47	223.872	1.009
18	7.943	1.288	48	251.189	1.008
19	8.913	1.253	49	281.838	1.007
20	10.000	1.222	50	316.228	1.006
21	11.220	1.196	51	354.813	1.006
22	12.589	1.173	52	398.107	1.005
23	14.125	1.152	53	446.684	1.005
24	15.849	1.135	54	501.187	1.004
25	17.783	1.119	55	562.341	1.004
26	19.953	1.106	56	630.957	1.003
27	22.387	1.094	57	707.946	1.003
28	25.119	1.083	58	794.328	1.003
29	28.184	1.074	59	891.251	1.002
30	31.623	1.065	60	1,000.0	1.002

Table 6. Return Loss, Reflection, VSWR

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