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Power Ratings of RF Thin Film Resistive Attenuators

By F. R. Smith

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RESISTIVE ATTENUATORS

By F. R. Smith

Published June 1980

Topical Report
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Technical Communications

Kansas City
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Most radio frequency (RF) assemblies built using hybrid micro-circuit technology employ thin film attenuators. These attenuators are subject to moderate RF peak power and to moderate average power. Because of intracircuit mismatch, extra considerations of power requirements must be given. To meet these requirements, selected thin film resistive attenuators operated under large RF power conditions were investigated, and the power margin in which these attenuators can be used was defined.

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SUMMARY

Although thin film resistors are common to hybrid microcircuits, consideration of the extra reflected power normally is not done. For reliable and consistent circuit operation, power margins must be established for the attenuators used in radio frequency circuits.

Simple attenuators were fabricated and characterized in a previous endeavor. The experiment applied an extreme level (4-to-1 overstress) of pulsed microwave power to a low power attenuator, then an empirically defined margin was established from the overstress effects on the attenuator microwave characteristics.

Production demands required that a similar experiment be conducted to evaluate a low value chip resistor used as a current limiter for pulsed radio frequency Class-C amplifiers. To meet these demands, an experimental method was designed to ensure confidence in two types of a passive element used in radar product development. This endeavor established the power level for thin film resistors and resolved problems with chip resistance failures.

DISCUSSION

SCOPE AND PURPOSE

During development work on packaging techniques for microwave hybrid microcircuits, the fabrication process used to produce these circuits was found to require tedious and time-consuming adjustments and rework--largely because of an incomplete understanding of the radio frequency (RF) characteristics. The microwave characteristics of each hybrid microcircuit element are the result of the combined effects of the individual component characteristics, the geometry, and the attachment to the microcircuit. These effects are often referred to as parasitics.

PRIOR WORK

Previous effort was directed toward evaluation of thin film microstrip attenuators at microwave frequencies.¹ This effort defined a resistive attenuator's geometric and electrical characteristics and established the need for the evaluation of pulse power characteristics of small value chip resistors.

ACTIVITY

Power Rating of Thin Film Resistors

Product manufacturability is improved when circuit elements are replaced without adverse effects to circuit operation. Unpredictable microwave characteristics for components operated at radio frequencies do not allow indiscrete component replacement. Excessive mismatch interaction between a tuned circuit coupled to another tuned circuit can cause undesirable operation. Tedious and time-consuming tuning will bring coupled tuned circuits to a desirable operating condition. Once tuning accomplishes good circuit operation, component or circuit replacement usually requires retuning. For efficient manufacturing, this type of tuning operation must be eliminated or kept to a minimum.

Microwave tuned amplifiers are common to hybrid microcircuit technology. One method to reduce mismatch interaction between amplifiers is to couple these stages with a low value attenuator. The attenuator not only reduces amplifier gain, but also reduces mismatch multiplication between the stages. Therefore, a degree of intercircuit isolation can be achieved for microwave tuned amplifiers when coupled by an attenuator.

Tuned circuits for RF assembly are usually used in high gain amplifiers that produce large peak RF power with low pulse duty time. The attenuators will be subject to the low magnitude of average RF power. Thin film resistive attenuators are ideally suited for this type of hybrid microcircuit application. Microstrip attenuators normally have low power ratings, low attenuation values, and small physical dimensions. Consideration of the resistive power rating of thin film attenuator resistors used to couple RF power amplifier stages must include the reflected power between stages, which adds more dissipation to the resistors.

Radio frequency microstrip attenuators have geometries which can be readily manufactured and will result in a predictable manner. The Π resistive network shown in Figure 1 represents the basic electrical circuit of an attenuator. The discrete resistors R_1 , R_2 , and R_3 are well defined and can be used to describe the power rating, attenuation, and physical geometry.

The discrete and composite Π microstrip attenuator pads used in this study are shown in Figures 2 and 3. Two discrete and two composite Π attenuators were constructed to evaluate power limitations. The discrete Π attenuators branch resistors power ratings may be calculated by using Equations 1 and 2.

$$P = \frac{W^2 \times D \times R}{\rho_s} \text{ (in mW)} \quad (1)$$

$$L = N \times W \text{ (in } \mu\text{m)} \quad (2)$$

where

R = Resistance Value ($k\Omega$),

D = Power Density of substrate and metallization (W/mm^2),

ρ_s = Sheet Resistivity of resistive thin film (Ω/sq),

N = Ohmic value/ mm^2 ,

L = Length (mm), and

W = Width (mm).

Table 1 lists the calculated rating for the given dimensions of the discrete branch resistances of Figure 3. The equivalent branch resistors for the composite Π resistances (R_{13} , R_{23} , and R_{12}), must be empirically determined by approximating the discrete branch resistors R_1 , R_2 , and R_3 . The method to determine the approximate discrete branch resistors for the composite Π attenuators are outlined in a previous report.¹ The

Figure 1. Basic Π Electrical Network

Figure 2. Discrete Π Thin Film Microstrip Attenuator

Figure 3. Composite II Thin Film Microstrip Attenuator

calculations for the discrete resistance of the composite II attenuators were performed and are listed in Table 1.

Load Effect on Thin Film Attenuators

Whenever thin film resistors are operated under load conditions, the microwave characteristics must remain constant. Microwave parameters (S_{21} , S_{11} , and S_{22}) were previously characterized for the four attenuator types. These parameters were remeasured for experimental consistency, but they are not listed as a part of this endeavor. The experiment was to apply 1.0 and 20.0 watts peak power to the thin film attenuators terminated by 50 Ω impedance. The input power exceeded normal radar conditions by a factor of 4-to-1 for the attenuator operated into a 3-to-1 mismatch. Table 2 shows the approximate power the branch resistors needed to dissipate for an attenuator to operate under the test conditions. The rated power is also shown in Table 2 for comparison to the average and peak power dissipated by the branch resistors. After an extended duration (160 hours) of applied RF power, the scattering parameters were remeasured. The results were that with extreme values of input power (400 times rated power) applied to the low power rating resistances, the microwave characteristics (S_{21} , S_{11} , and S_{22}) showed less than 1 percent change. The average RF power dissipated in the 5 dB attenuator exceeded the rated power by 400-to-1 and the peak RF power exceeded the rated average power by 8000 times. Normally, the low power attenuators should never be expected to operate with overstress conditions of this magnitude.

Table 1. Power Ratings for Π Attenuator

	Composite Π		Discrete Π	
	3 dB	5 dB	4 dB	3 dB
Length (mm)				
L ₁	0.127	0.152	0.203	0.203
L ₂	1.219	0.762	0.889	2.159
Width (mm)				
W ₁	0.711	0.508	0.787	1.092
W ₂	0.432	0.432	0.406	0.737
Resistance* (Ω)				
R ₁	17.6	30.4	23.9	17.6
R ₂ = R ₃	292.4	178.5	221.0	292.4
Power Rating (mW)				
P of R ₁	2.8	2.4	4.7	6.4
P of R ₂ and R ₃	15.8	10.0	11.0	49.0
*R ₁ , R ₂ , and R ₃ for Composite Π are model approximations.				

Chip Resistors

Radio frequency power amplifiers are constructed on aluminum oxide (Al₂O₃) ceramic substrates for high density circuit packaging and reliability. Therefore, the small physical dimensions of chip resistors are ideal for microcircuit applications.

One circuit application for radars using microstrip technology is low power rating chip resistors in series with the dc supply of Class-C power amplifiers. Basically, the chip resistors are current limiters for the large video pulse currents that occur with pulsed Class-C RF power amplifiers. The chip resistors of most microcircuit radars have video currents of moderate amplitude and low repetition rate. This equates to an average power dissipation equivalent to or lower than the chip resistors' average power rating. A common occurring problem for the Class-C RF amplifier during radar development was the eventual electrical degradation of the chip resistors after continued circuit operation. Therefore, a short term evaluation was devised to em-

Table 2. Approximate Power Dissipation for Branch Resistors

Peak Power Input (W)	Power Dissipated (W)								
	R ₁			R ₂			R ₃		
	Rated	Average	Peak	Rated	Average	Peak	Rated	Average	Peak
Composite Type II Attenuator (3 dB)									
20.0	0.0028	0.48	9.6	0.0158	0.34	6.8	0.0158	0.17	3.4
1.0	0.0028	0.024	0.5	0.0158	0.017	0.3	0.0158	0.009	0.2
Composite Type II Attenuator (5 dB)									
20.0	0.0024	0.995	19.9	0.010	0.884	17.7	0.010	0.28	5.6
1.0	0.0024	0.05	1.0	0.010	0.044	0.9	0.010	0.014	0.3
Discrete Type II Attenuator (4 dB)									
20.0	0.0047	0.71	14.2	0.011	0.567	11.3	0.011	0.23	4.6
1.0	0.0047	0.036	7.2	0.011	0.028	0.6	0.011	0.11	0.2
Discrete Type II Attenuator (3 dB)									
20.0	0.0064	0.48	9.6	0.049	0.34	6.8	0.049	0.17	3.4
1.0	0.0064	0.024	0.5	0.049	0.017	3.4	0.049	0.009	0.2

pirically determine the power effect on these low power chip resistors and to qualify the dissipation margin for reliable circuit operation.

The experiment was to pulse a quantity of selected chip resistors with peak currents higher than the radio frequency amplifiers required. The average power dissipation resulting from the repetitive peak currents was set to equal or exceed the resistors' power rating. The power dissipation rating may be determined when resistor failure did not occur from extended overpowering. The effort was not to determine absolute peak current ratings, but to establish a margin of 10 times the average power rating.

The chip resistances selected were 1, 2, and 10 Ω with power ratings of 0.125 and 0.25 W. The maximum amplitude of pulse current applied to the 1, 2, and 10 Ω resistors was 5, 2.5, and 0.5 A, respectively, for a period of 2.5 μ s. The power applied to the respective resistors was 25 peak watts and a corresponding 1.25 average watts. Each resistor had power supplied for a duration of 20 hours before remeasuring their resistance. The life test showed no measurable change in the chip resistors values. Further investigation of the Class-C RF power amplifiers demonstrated that higher than expected peak currents were occurring in the chip resistors. The excessive peak currents were a result of marginal transistor characteristics and caused the resistor failures. The chip resistor evaluation confirms the chip resistor can operate in Class-C RF power amplifiers as current limiters provided the pulse power does not exceed 10 times their average power rating.

ACCOMPLISHMENTS

The purpose of this task was to verify microwave component parameters which are subject to product requirements. The specific requirements of thin film microwave attenuators are circuit reliability, consistency, and continued operation. Hybrid microcircuit reliability can't be guaranteed if observation of the thin film resistors power capabilities is not done. Most RF assemblies built with hybrid microcircuit technology use thin film attenuation. The attenuators are subject to moderate radio frequency peak power and to moderate average power. Because of the intracircuit mismatch, extra consideration of power requirements must be given. To meet these requirements, selected thin film resistive attenuators operated in large RF power conditions were investigated, and the power margin in which these attenuators can be used was defined.

FUTURE WORK

No future work is planned for this particular phase of characterization of individual RF hybrid microcircuits at microwave frequencies. Additional work would require a complete analysis of RF circuits using thin film resistors and is not within the scope of this process development endeavor.

REFERENCE

¹F. R. Smith, Characterization of Thin Film Microstrip Attenuators at Microwave Frequencies (Topical Report). Bendix Kansas City: BDX-613-1857 (Rev.), November, 1978 (Available from NTIS).

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ELECTRICAL: Attenuation Characterization

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