Operation of Microwave Precision Fixed Attenuator Dice up to 40 GHz

(AN-70-019)

I. Introduction

Mini-Circuits' YAT-D-series MMIC attenuator dice (RoHS compliant) are fixed value, absorptive attenuators fabricated using highly repetitive MMIC processing with thin film resistors on silicon substrates. They contain through-wafer Cu metallization vias to realize low thermal resistance and very wideband operation. YAT attenuator dice are available from stock with nominal attenuation values of 0 to 10 dB (in 1 dB steps), and 12, 15, 20, and 30 dB. YAT die are specified to operate to 26.5 GHz with excellent attenuation flatness and Return loss.

However, the specified performance is characterized with a continuous ground plane underneath the entire die. A simple modification to the ground plane allows the attenuator to achieve excellent return loss and attenuation flatness up to 40 GHz. In this article, we explain this method of expanding the usability of YAT-3-D+ MMIC attenuator dice for applications up to 40 GHz. These results are applicable to other attenuator values, as well.

II. Modification to Expand Performance to 40 GHz:

Figure 1 shows the mechanical dimensions and bonding pad positions of a YAT-D attenuator die. Table 1 summarizes the critical dimensions of the die, and Table 2 shows the Die ID of the entire family of YAT dice. The die and the ground plane essentially form parallel plates which create unintended capacitance expressed by the parallel plate capacitance equation:

$$C = \frac{\varepsilon_0 A}{d}$$

Where:

ε_0 = permeability of the material between the two plates
A = overlapping surface area of the plates, and
d = distance between the plates (PCB thickness)

Capacitive reactance becomes smaller and smaller as frequency increases above 26.5 GHz, and the attenuator becomes increasingly sensitive to the capacitance between the die and ground plane at high frequency. This effect is primarily what limits the frequency range of the attenuator die. Reducing the capacitance between the die and the ground plane, however, would expand performance to higher frequencies.

It is evident from equation 1 that capacitance is inversely proportional to the gap, d, between the two plates – in this case, the distance between the top of the die and the bottom of the ground plane. Therefore, one way to reduce the capacitance is by widening that gap. This is achieved by creating a small trench in the ground plane 0.5mm deep and 0.25 mm wide, running directly under the series signal path. The modified ground plane is represented in Figure 2, and the layout of the die on both continuous and split ground planes is shown in Figure 3.

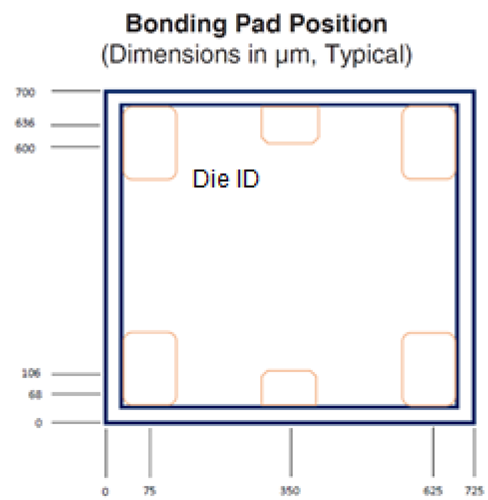


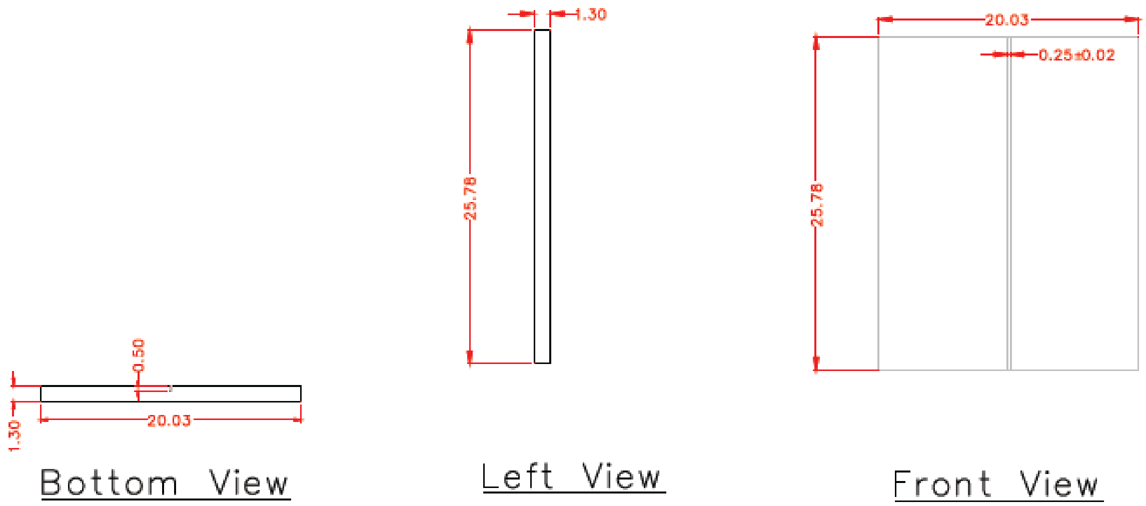
Figure 1: Die Dimensions and Bonding Pad Positions

Table 1 Critical Dimensions of the Die

Parameter	Values
Die Thickness, µm	100
Die Width, µm	725
Die Length, µm	700
RF IN and RF OUT Bond Pad Size, µm	110 x 75
Ground Bond Pad Size, µm	110 x 150

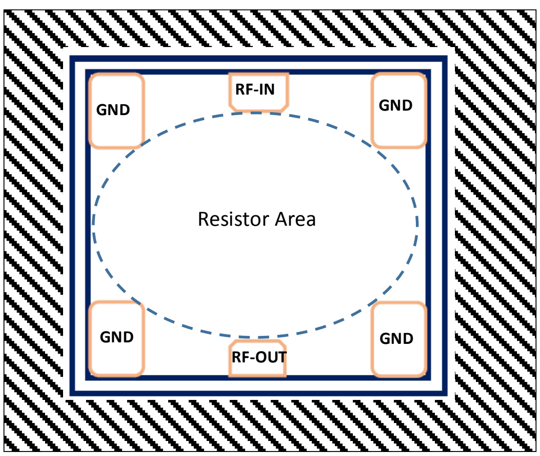
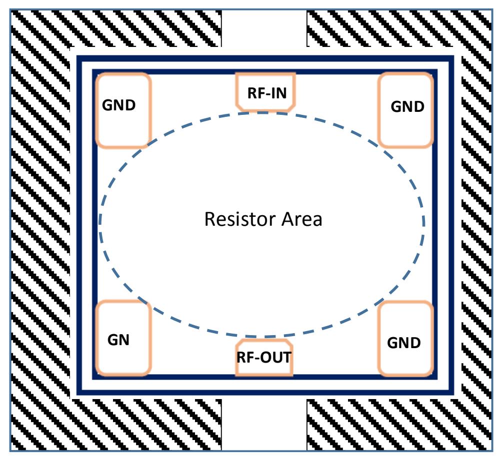
Table 2 Die ID

Model	Die ID
YAT-0-DG+	0DB
YAT-1-DG+	1DB
YAT-2-DG+	2DB
YAT-3-DG+	3DB
YAT-4-DG+	4DB
YAT-5-DG+	5DB
YAT-6-DG+	06DB
YAT-7-DG+	07DB
YAT-8-DG+	8DB
YAT-9-DG+	09DB
YAT-10-DG+	10DB
YAT-12-DG+	12DB
YAT-15-DG+	15DB
YAT-20-DG	20DB
YAT-30-DG+	30DB



All Dimensions in mm

Figure 2: Modification to ground plane to reduce capacitance.

	Combined Ground	Split Ground
Ground (Shaded area) Layout		
Description	Full Ground Plane underneath the Die	Split Ground Plane underneath the Die

Drawing is not to scale.

Figure 3 Combined and Split Ground under DUT

Note that the width of the gap in the ground plane is very small, and application of conductive epoxy must be such that the integrity of the split is maintained in order to achieve the desired effect.

III. Qualifying Performance to 40 GHz

To validate the performance of YAT-D dice with split ground to 40 GHz, a sample of 5 YAT-3-D+ dice were tested on continuous ground plane and another 5 were tested on a split ground plane for S-Parameters from DC to 40 GHz. The split ground improved the return loss at 40 GHz from 13 dB to 19 dB typical and insertion loss flatness to from ±0.7 dB to ±0.5 dB. The test results are presented in Figures 4 – 7 and in Table 4.

Table 3 Tabular Summary of Performance: Split vs. Combined Ground.

YAT-3-D+	Freq (MHz)		5 Units of YAT-3-D+ Split Ground			5 Units of YAT-3-D+ Combined Ground		
	From	To	Min.	Avg.	Max.	Min.	Typ.	Max.
Input Return Loss (dB)	10	5000	38.0	48.2	54.4	25.6	41.6	47.7
	5000	15000	27.7	34.0	41.7	16.6	21.0	26.8
	15000	18000	26.1	29.1	31.1	15.4	16.7	17.8
	18000	27000	23.1	26.5	29.4	13.2	14.8	16.6
	40000	40000	18.5	19.4	21.0	12.3	13.0	14.2
Output Return Loss (dB)	10	5000	36.9	51.5	59.9	25.4	39.9	44.8
	5000	15000	27.7	32.8	40.9	16.4	20.8	26.5
	15000	18000	26.4	27.9	30.1	15.3	16.5	17.6
	18000	27000	23.1	25.5	28.6	13.1	14.6	16.4
	40000	40000	18.0	19.2	20.0	12.2	13.2	14.4
RETURN LOSS (Worse of In & Out) (dB)	10	5000	36.9	48.2	54.4	25.4	39.9	44.8
	5000	15000	27.7	32.8	40.9	16.4	20.8	26.5
	15000	18000	26.1	27.9	30.1	15.3	16.5	17.6
	18000	27000	23.1	25.5	28.6	13.1	14.6	16.4
	40000	40000	18.0	19.2	20.0	12.2	13.0	14.2
Insertion Loss In-Out (dB)	10	5000	3.0	3.0	3.1	3.0	3.0	3.0
	5000	15000	3.0	3.1	3.2	3.0	3.1	3.3
	15000	18000	3.1	3.1	3.2	3.2	3.3	3.3
	18000	27000	3.1	3.2	3.3	3.3	3.5	3.7
	40000	40000	3.4	3.6	3.7	4.0	4.3	4.5
Insertion Loss Out-In (dB)	10	5000	3.0	3.0	3.1	3.0	3.0	3.0
	5000	15000	3.0	3.1	3.2	3.0	3.1	3.2
	15000	18000	3.1	3.1	3.2	3.2	3.3	3.4
	18000	27000	3.1	3.2	3.3	3.3	3.5	3.6
	40000	40000	3.8	4.0	4.1	4.1	4.4	4.7
INSERTION LOSS Worse of In-Out/Out-In (dB)	10	5000	3.0	3.0	3.1	3.0	3.0	3.0
	5000	15000	3.0	3.1	3.2	3.0	3.1	3.3
	15000	18000	3.1	3.1	3.2	3.2	3.3	3.4
	18000	27000	3.1	3.2	3.3	3.3	3.5	3.7
	40000	40000	3.8	4.0	4.1	4.1	4.4	4.7
Insertion Loss Flatness (dB)	10-27000	10-27000	0.1	0.1	0.2	0.3	0.3	0.3
	10-40000	10-40000	0.4	0.5	0.5	0.6	0.7	0.9

NOTE: YAT die electrical characteristics are measured on die using MPI Titan Series 250 µm pitch GSG probe.

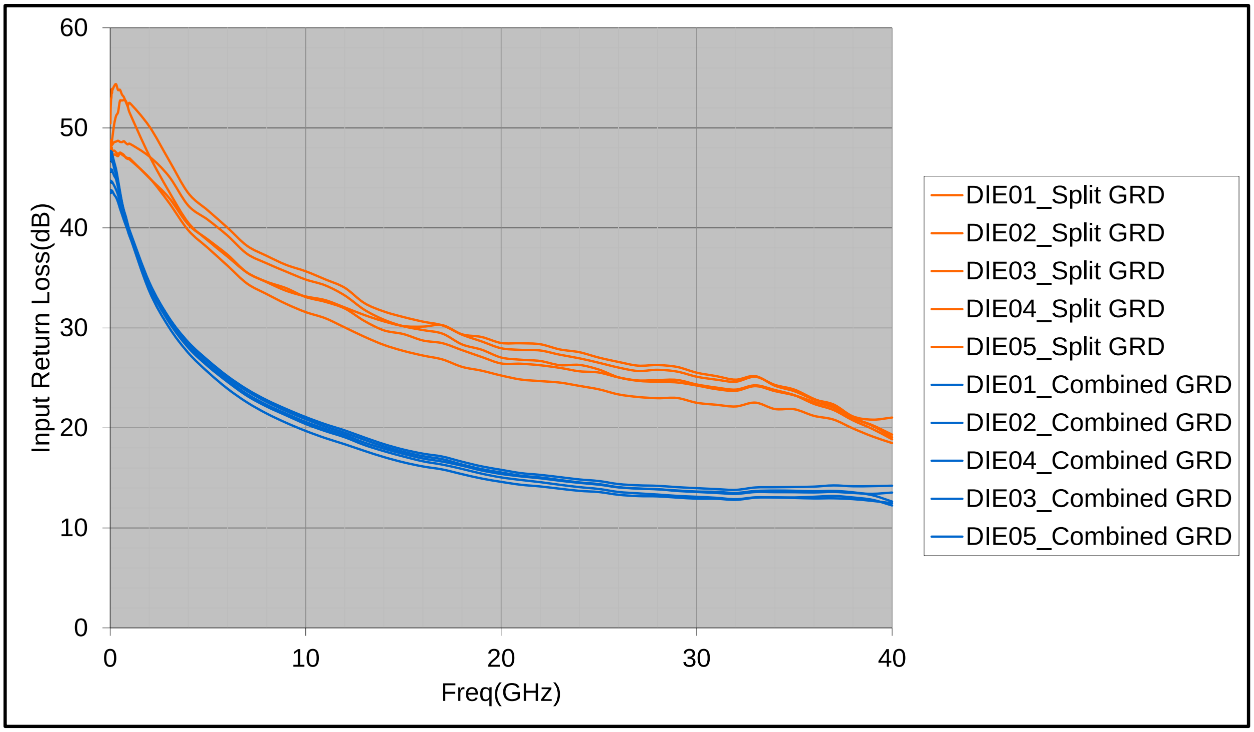


Figure 4: Input Return Loss (-S11 dB) vs. Frequency of Combined Ground and Split Ground

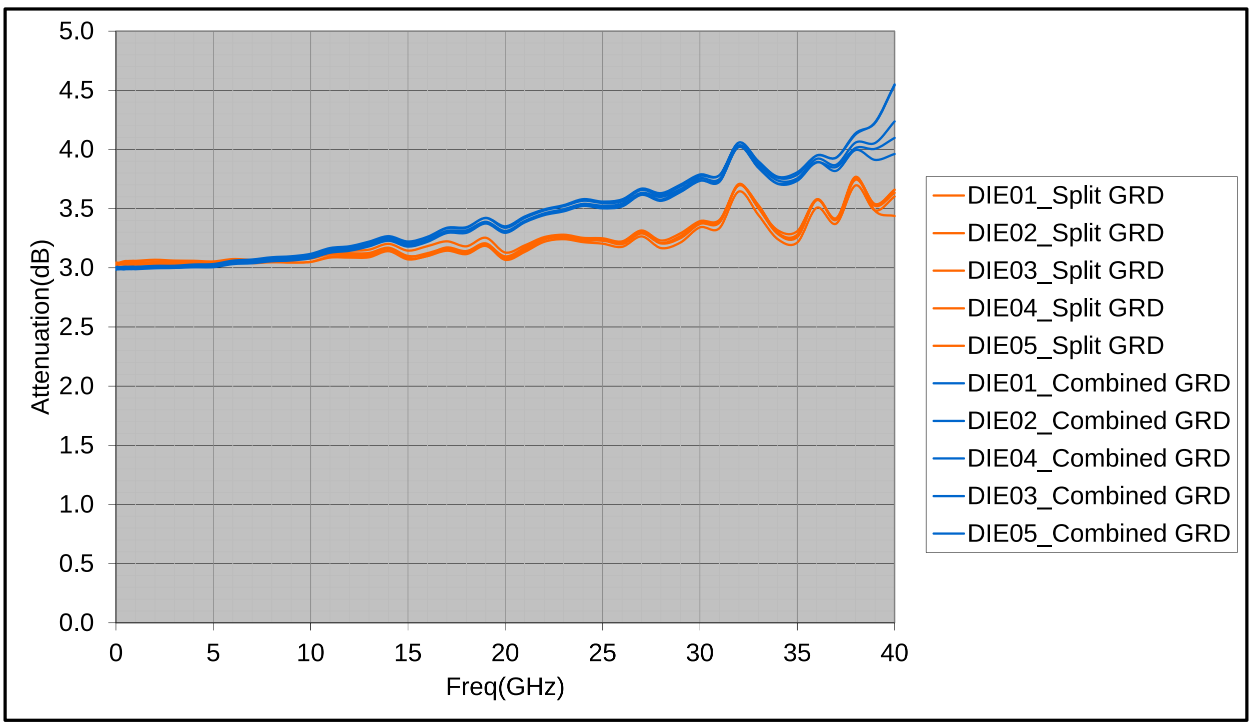


Figure 5: Attenuation (-S21 dB) vs. Frequency of Combined Ground and Split Ground

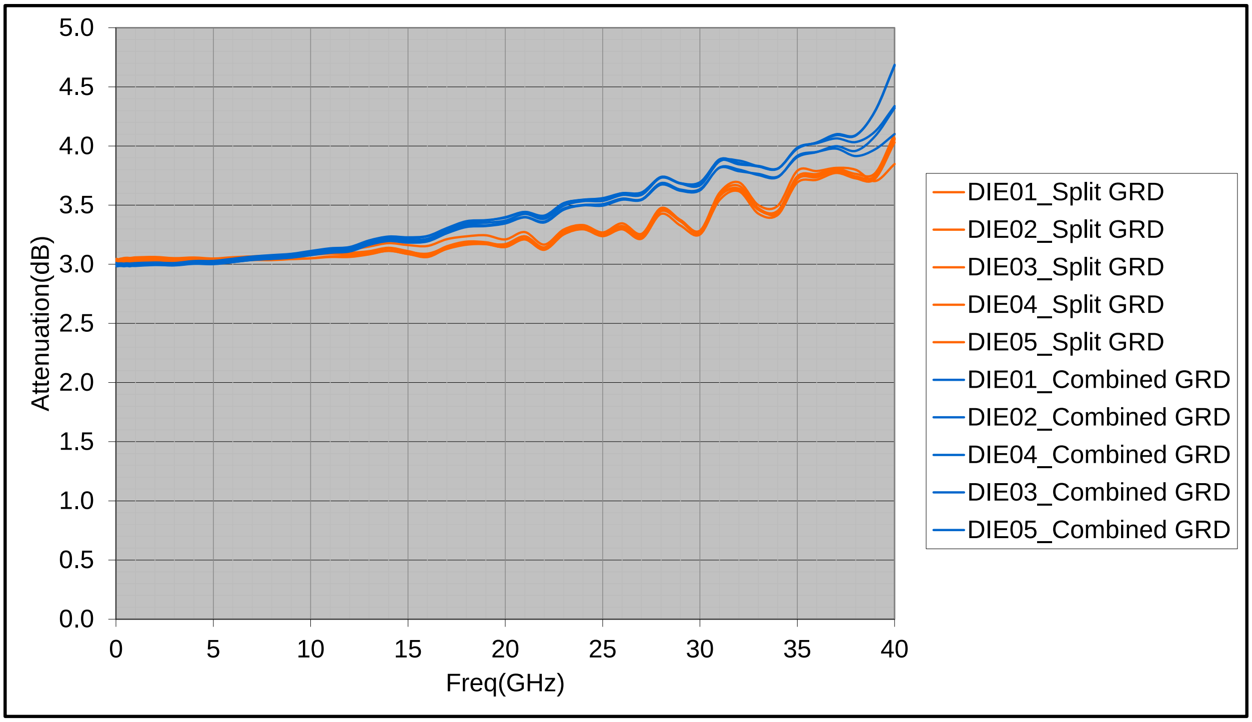


Figure 6 Attenuation (-S12 dB) vs. Frequency of Combined Ground and Split Ground

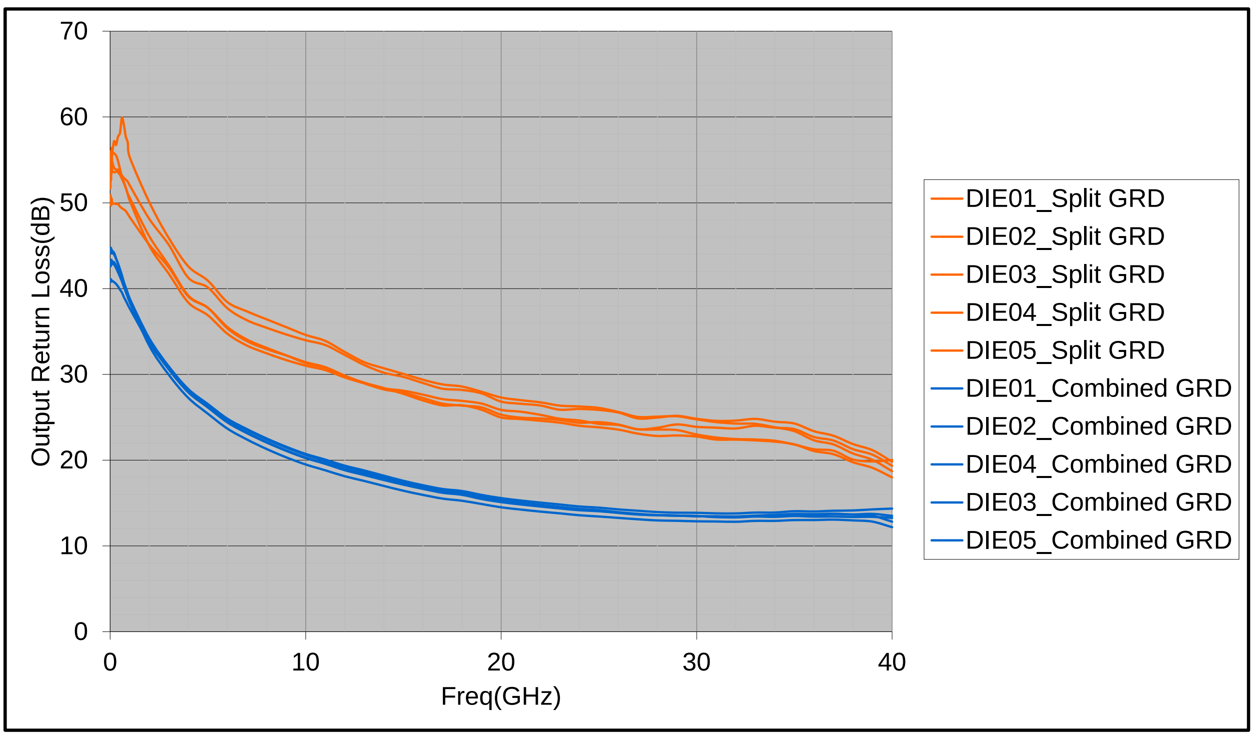


Figure 7: Output Return Loss (-S22 dB) vs. Frequency of Combined Ground and Split Ground

CONCLUSION

Mini-Circuits' YAT-D series MMIC attenuator dice provide precise fixed value attenuation with excellent flatness from DC to 26.5 GHz. For higher-frequency applications, the simple modification to the ground plane demonstrated here enables superb performance up to 40 GHz, making YAT-D series an extremely versatile building block for a vast range of systems.