Application Note for Vector Modulator, VM-MCM-1.9G

Introduction:

Combining a phase shifter and variable attenuator into one unit, Merrimac's vector modulator, VM-MCM-1.9G, is ideal for cancellation loops in feed forward applications and amplifier linearization. A significant reduction in size is accomplished through the use of Merrimac's Pico products. Three quadrature hybrids (QHD-2Z-1.9G) and one power divider (PDD-2Z-2.0G) are used in the configuration shown in Figure 1. In addition to the size reduction, this vector modulator has the advantage that each vector state can be achieved without the delays associated with a conventional phase shifter and with a single control change instead of separate adjustments on the phase shifter and variable attenuator. Accurate phase and amplitude control are achieved through the two current controlled inputs, I & Q.

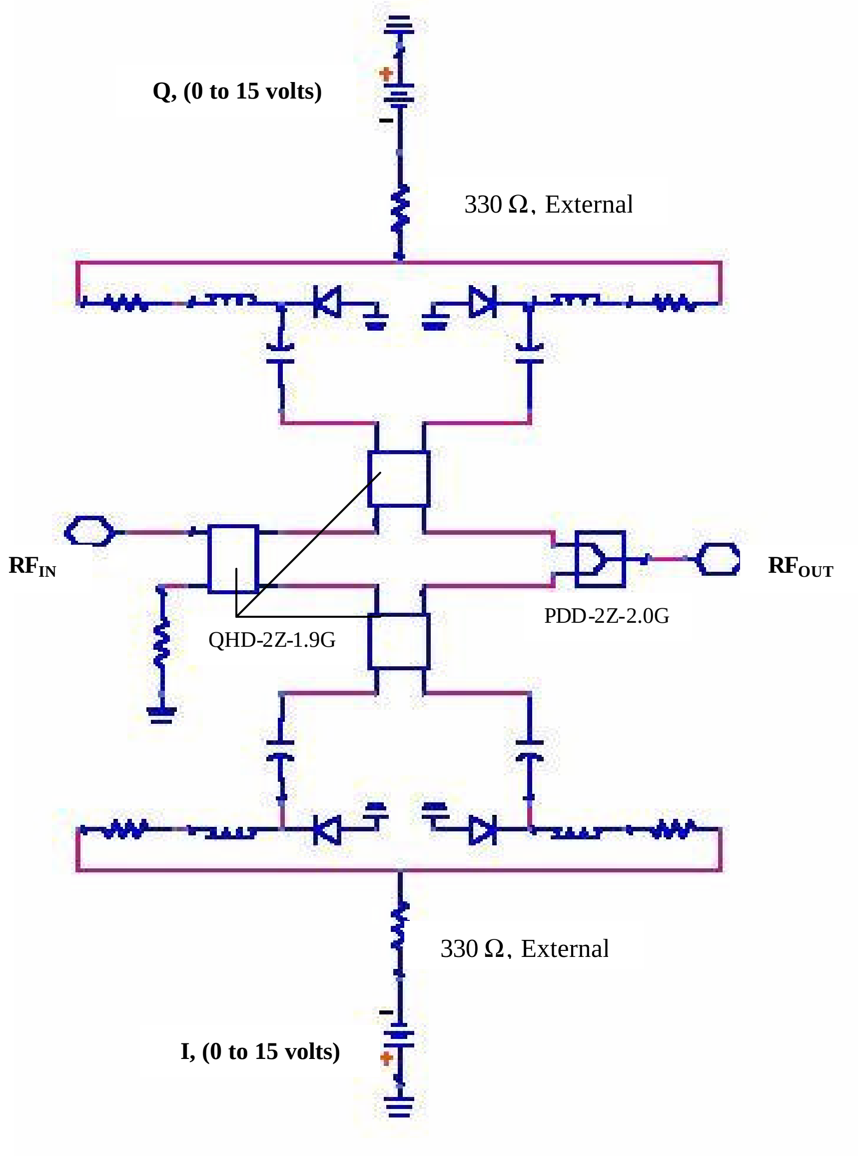


Figure 1: Schematic of the circuit

Theory of Operation:

The schematic shown in Figure 1 can be reduced to the schematic shown in Figure 2 for analysis. The current into I & Q, controls the series resistance in the pin diodes creating a terminating resistance on the two quadrature hybrids, shown as R_1 and R_2. The same resistance value is shown on the two legs due to their common source connection.

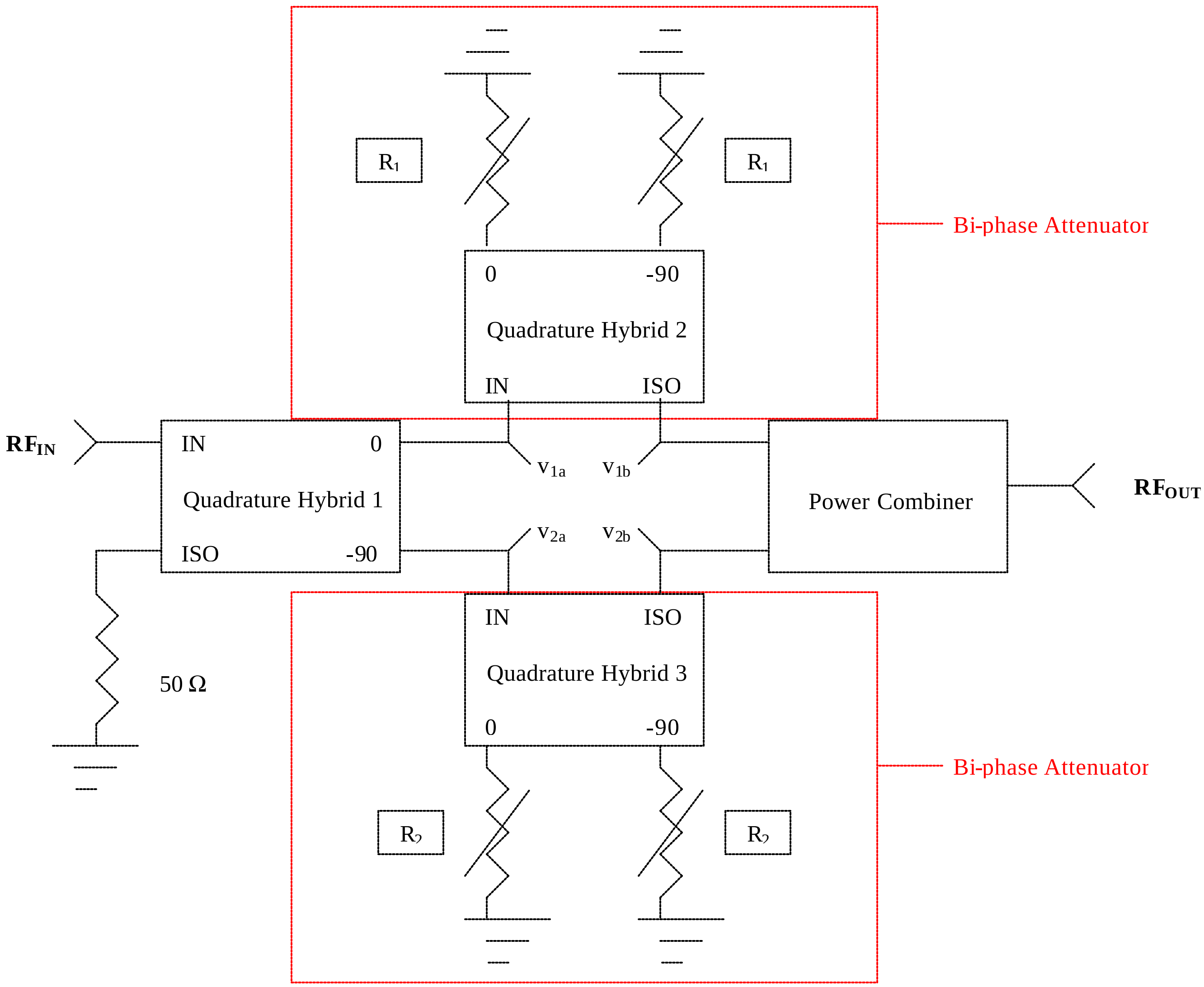


Figure 2: Simplified schematic for analysis

$$\Gamma_1 = \mathbf{g}_1 \angle q_1 \quad , \ \mathbf{g}_1 = \frac{|\mathbf{R}_1 - 50|}{(\mathbf{R}_1 + 50)}$$

$$\Gamma_2 = \mathbf{g}_2 \angle q_2 \quad , \ \mathbf{g}_2 = \frac{|\mathbf{R}_2 - 50|}{(\mathbf{R}_2 + 50)}$$

$$\mathbf{v}_{1a} = 0.707 \angle 0°$$

$$\mathbf{v}_{2a} = 0.707 \angle -90°\text{, using } \mathbf{v}_{in} = 1 \angle 0°$$

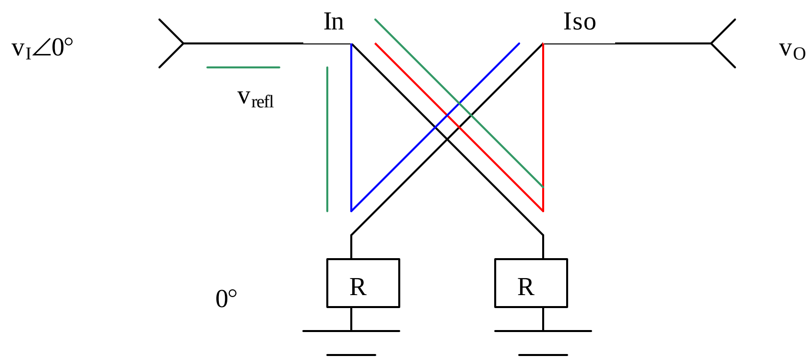


Figure 3: Bi-phase Attenuator

Looking at the bi-phase attenuator in detail:

Case 1:

R > 50 Ohms

Then $\Gamma = \mathbf{g}\angle 0°$

$$\mathbf{v_O} = (2 * \mathbf{v_I}(0.707 * \mathbf{g} * 0.707))\angle(-90°) = (\mathbf{v_I} * \mathbf{g})\angle(-90°)$$

$$\mathbf{v_{refl}} = (\mathbf{v_I} * (0.707 * \mathbf{g} * 0.707)) * (1\angle 0° + 1\angle 180°) = 0$$

Case 2:

R < 50 Ohms

Then $\Gamma = \mathbf{g}\angle 180°$

$$\mathbf{v_O} = (2 * (0.707 * \mathbf{g} * 0.707))\angle(90°) = (\mathbf{v_I} * \mathbf{g})\angle(90°)$$

$$\mathbf{v_{refl}} = (\mathbf{v_I} * (0.707 * \mathbf{g} * 0.707)) * (1\angle 180° + 1\angle 0°) = 0$$

Case 3:

R = 50 Ohms => $\Gamma = 0$ and $\mathbf{v_O} = 0$

Therefore the voltages after the bi-phase attenuators become:

Case A:

R_1 > 50 Ohms, R_2 > 50 Ohms

$$\mathbf{v_{1b}} = (0.707 * \mathbf{g}_1)\angle -90° = -\mathbf{j}(0.707 * \mathbf{g}_1)$$

$$\mathbf{v_{2b}} = (0.707 * \mathbf{g}_2)\angle 180° = -(0.707 * \mathbf{g}_2)$$

Case B:

R_1 < 50 Ohms, R_2 > 50 Ohms

$$\mathbf{v_{1b}} = (0.707 * \mathbf{g}_1)\angle 90° = \mathbf{j}(0.707 * \mathbf{g}_1)$$

$$\mathbf{v_{2b}} = (0.707 * \mathbf{g}_2)\angle 180° = -(0.707 * \mathbf{g}_2)$$

Case C:

R_1 > 50 Ohms, R_2 < 50 Ohms

$$\mathbf{v_{1b}} = (0.707 * \mathbf{g}_1)\angle -90° = -\mathbf{j}(0.707 * \mathbf{g}_1)$$

$$\mathbf{v_{2b}} = (0.707 * \mathbf{g}_2)\angle 0° = (0.707 * \mathbf{g}_2)$$

Case D:

R_1 < 50 Ohms, R_2 < 50 Ohms

$$\mathbf{v_{1b}} = (0.707 * \mathbf{g}_1)\angle 90° = \mathbf{j}(0.707 * \mathbf{g}_1)$$

$$\mathbf{v_{2b}} = (0.707 * \mathbf{g}_2)\angle 0° = (0.707 * \mathbf{g}_2)$$

Note:
If either resistance is 50 ohms, the corresponding **g** would be zero and any of the four cases would lead to the correct answer (phase becomes irrelevant since there is zero transmission on that side of the vector modulator).

Summing the 2 vectors at the power combiner:

$$\mathbf{v}_{\mathbf{out}} = 0.707 * (\mathbf{v}_{\mathbf{1b}} + \mathbf{v}_{\mathbf{2b}})$$

Case A:
$R_1 > 50$ Ohms, $R_2 > 50$ Ohms

$$\mathbf{v}_{\mathbf{out}} = (0.707)(-0.707 * \mathbf{g}_2 - \mathbf{j}(0.707 * \mathbf{g}_1)) = 0.5(-\mathbf{g}_2 - \mathbf{j}(\mathbf{g}_1)) = 0.5 * \sqrt{\mathbf{g}_1^{\,2} + \mathbf{g}_2^{\,2}} \angle \mathbf{tan}^{-1}\left(\frac{-\mathbf{g}_1}{-\mathbf{g}_2}\right)$$

Case B:
$R_1 < 50$ Ohms, $R_2 > 50$ Ohms

$$\mathbf{v}_{\mathbf{out}} = (0.707)(-0.707 * \mathbf{g}_2 + \mathbf{j}(0.707 * \mathbf{g}_1)) = 0.5(-\mathbf{g}_2 + \mathbf{j}(\mathbf{g}_1)) = 0.5 * \sqrt{\mathbf{g}_1^{\,2} + \mathbf{g}_2^{\,2}} \angle \mathbf{tan}^{-1}\left(\frac{\mathbf{g}_1}{-\mathbf{g}_2}\right)$$

Case C:
$R_1 > 50$ Ohms, $R_2 < 50$ Ohms

$$\mathbf{v}_{\mathbf{out}} = (0.707)(0.707 * \mathbf{g}_2 - \mathbf{j}(0.707 * \mathbf{g}_1)) = 0.5(\mathbf{g}_2 - \mathbf{j}(\mathbf{g}_1)) = 0.5 * \sqrt{\mathbf{g}_1^{\,2} + \mathbf{g}_2^{\,2}} \angle \mathbf{tan}^{-1}\left(\frac{-\mathbf{g}_1}{\mathbf{g}_2}\right)$$

Case D:
$R_1 < 50$ Ohms, $R_2 < 50$ Ohms

$$\mathbf{v}_{\mathbf{out}} = (0.707)(0.707 * \mathbf{g}_2 + \mathbf{j}(0.707 * \mathbf{g}_1)) = 0.5(\mathbf{g}_2 + \mathbf{j}(\mathbf{g}_1)) = 0.5 * \sqrt{\mathbf{g}_1^{\,2} + \mathbf{g}_2^{\,2}} \angle \mathbf{tan}^{-1}\left(\frac{\mathbf{g}_1}{\mathbf{g}_2}\right)$$

The following table summarizes some different phase/amplitude states that can be achieved for a lossless system:

R1 (Ohms)	R2 (Ohms)	Gamma1	Gamma2	Amplitude (dB)	Phase (Degrees)
50	1.25	0.000	-0.951	-6.455	0.000
8.58	8.58	-0.707	-0.707	-6.021	45.000
1.25	50	-0.951	0.000	-6.455	90.000
8.58	291.3	-0.707	0.707	-6.021	134.997
50	2000	0.000	0.951	-6.455	-180.000
291.3	291.3	0.707	0.707	-6.022	-135.000
2000	50	0.951	0.000	-6.455	-90.000
291.3	8.58	0.707	-0.707	-6.021	-44.997

Implementation:

The VM-MCM-1.9G was assembled using coplanar lines on Rogers 4003 material, .060” thick. The overall board dimensions are (0.8 x 0.8) inches giving an outline and photograph which are shown in Figure 4. The module may be surface mounted or connectorized to suit one’s requirements.

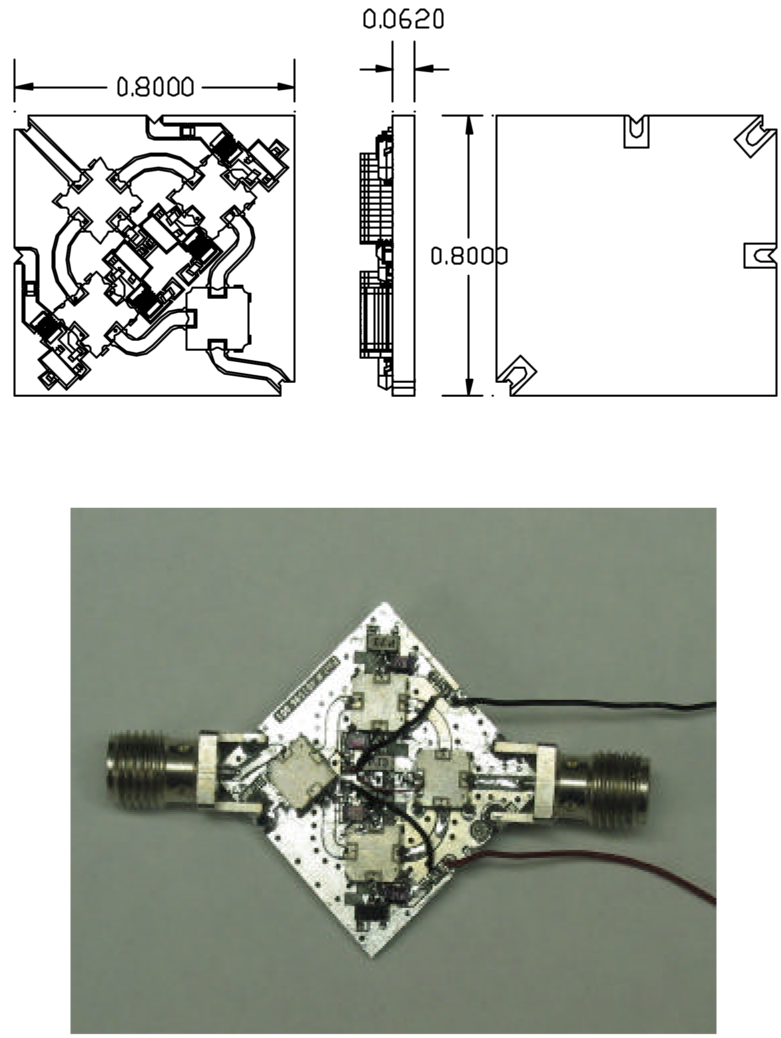


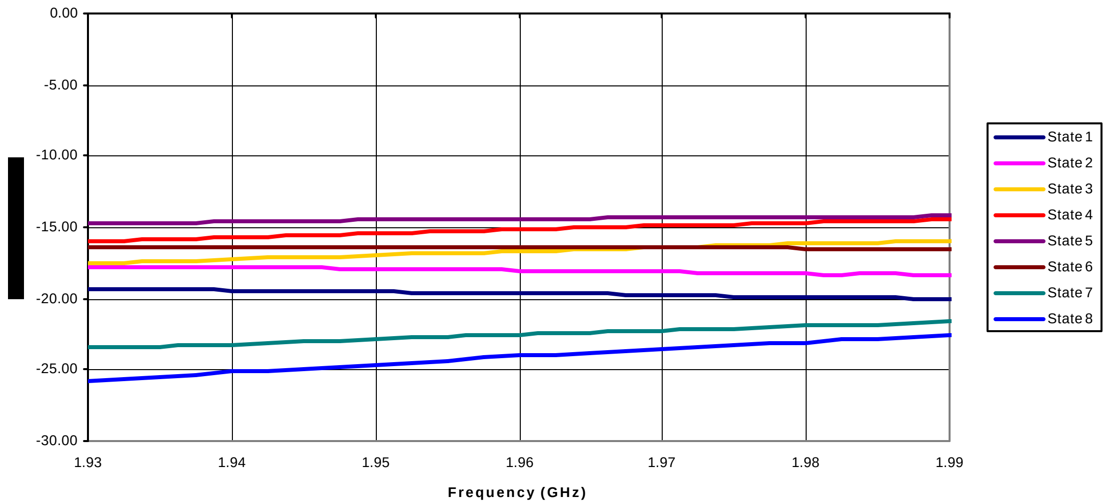
Figure 4: Outline drawing and photograph of a connectorized assembly

Results:

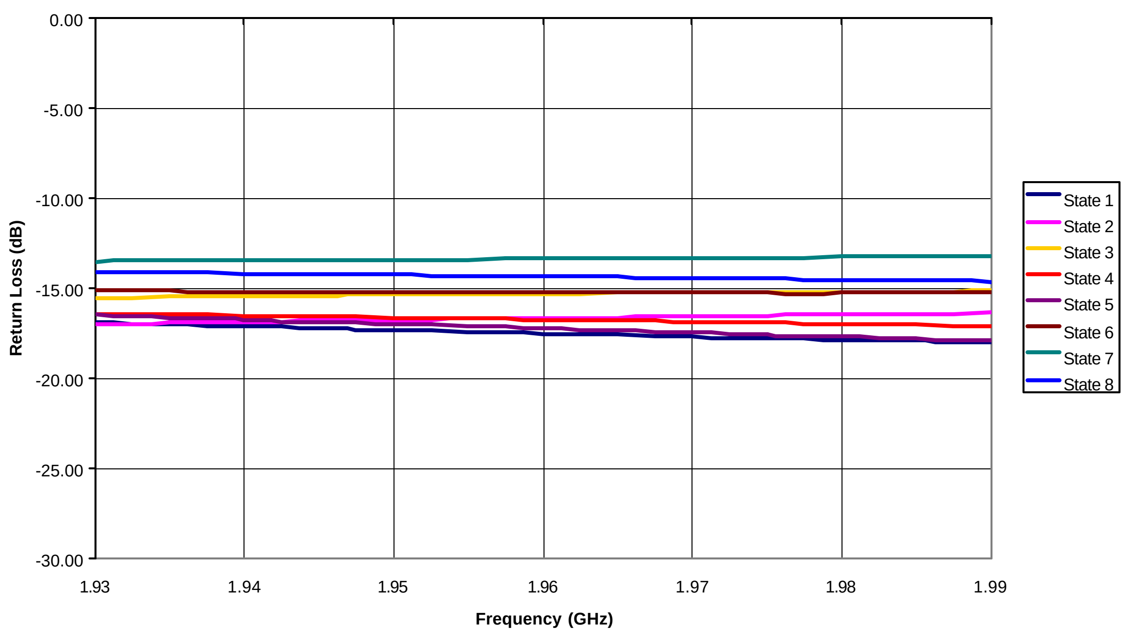
Upon implementation of the circuit shown in figure 1 the following results were achieved:

Frequency Range:	1.93 – 1.99 GHz
Impedance:	50 Ohms
I/Q Control Current:	0 to 45 mA
VSWR:	1.5:1
Insertion Loss:	12 dB
Amplitude Balance:	+/- 0.3 dB
Phase Balance:	+/- 3 degrees
Attenuation Range:	25 dB
Phase Range:	360 degrees
Input 1-dB Compression Point:	+ 30 dBm
Input Intercept Point (2 Tone, 3^{rd} Order):	+ 47 dBm
Switching Speed:	10 µs
Operating Temperature:	-55°C to 85°C

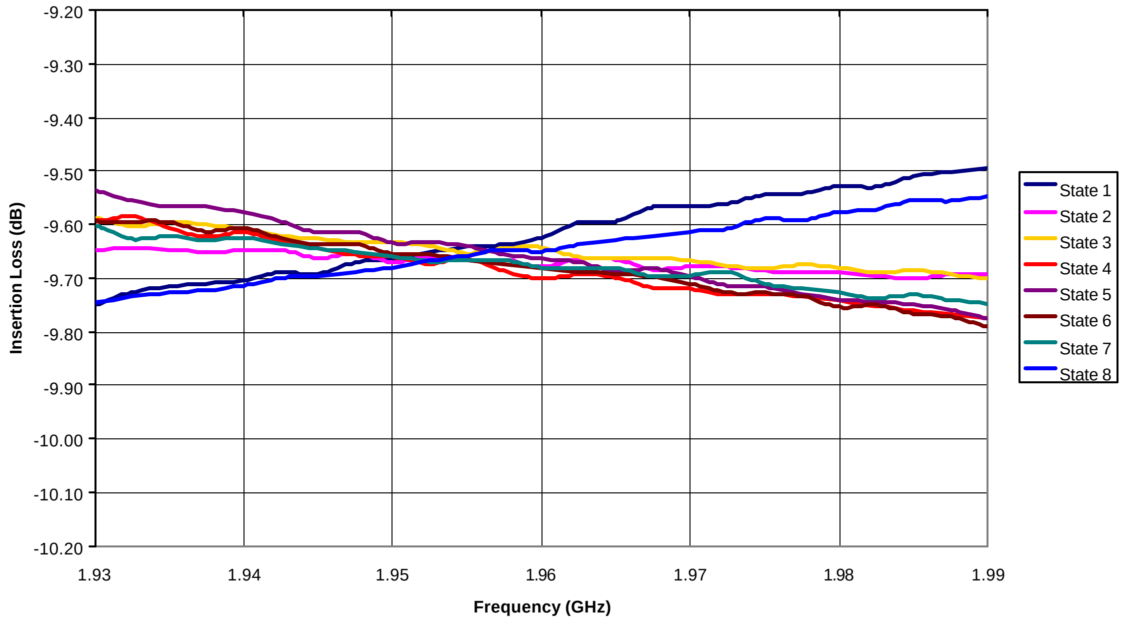
VM-MCM-1.9G
Unit #1 Fc=1.96 GHz
Return Loss - RF input



VM-MCM-1.9G
Unit #1 Fc=1.96 GHz
Return Loss - RF output



VM-MCM-1.9G
Unit #1 Fc=1.96 GHz
Insertion Loss / Balance



VM-MCM-1.9G
Unit #1 Fc=1.96 GHz
Phase Balance