USING THE HMC199MS8
AS A LOW COST 1-BIT ATTENUATOR

General Description

The HMC199MS8 is a low-cost dual SPDT GaAs “bypass” switch in an 8-lead MSOP package covering DC to 2.5 GHz. This four RF port component integrates two SPDT switches and a through line onto a single IC. The design provides low insertion loss of less than 0.5 dB while switching passive or active external circuit components in and out of the signal path. Port to port isolations are typically 25 to 30 dB. On-chip circuitry enables positive voltage control operation at very low DC currents with control inputs compatible with CMOS and most TTL logic families. A few applications include LNA or filter bypass switching and single bit attenuator switching.

Application Problem

In today’s environment, there are multiple sources of radiation from a variety of systems, which could interfere with signal reception. This interference could result in poor reception, no reception or possible receiver damage depending on proximity to the transmitter. Out of band, signals are rejected through traditional filtering techniques. However, in band signals present a unique state of affairs in that they cannot be filtered. In order to minimize these effects from a strong, in band interference, many applications apply attenuation prior the first gain stage of the receiver. This attenuation reduces the signal level to a manageable level, consequently avoiding receiver saturation or possible damage. Since the first receiver gain stage is a Low Noise Amplifier (LNA), any loss introduced before the LNA will contribute directly to the receivers overall noise figure. This degradation in noise figure could adversely affect the overall performance of the receiver. In addition, LNA’s are susceptible to damage when exposed to large input signals.

Figure 1 reflects a receiver channel for a typical system. The receiver consists of multiple filters, amplifiers, mixers, detector, front-end attenuator and switches. The location of the individual parts, of course, will vary from architecture to architecture but for discussion purposes, this outline will suffice. Until now, the only way to dynamically attenuate the input signal was by either using a digital/voltage variable attenuator or two switches with either a PI or Tee pad attenuator (as shown in figure 1). The trouble with using a digital or voltage variable attenuator is that the required value of attenuation may not be readily available and the amount of insertion loss associated with the attenuator could range from 1.5 to 3 dB. Using two switches will allow for custom attenuation values but insertion loss will still be an issue. Typical insertion loss of a SPDT switch can range from 0.5 dB to 1.0 dB, which results in an overall insertion loss of 1 dB to 2 dB. As previously mentioned, these losses contribute directly to the receivers noise figure.

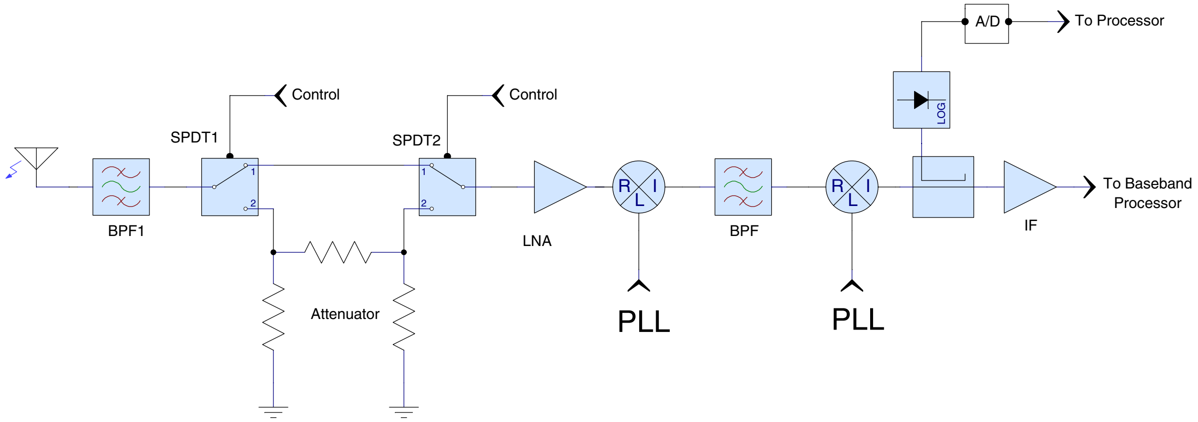

Figure 1 - General receiver diagram

Hittite recommends using the HMC199MS8, ”Dual SPDT Bypass Switch”, because the losses associated with the bypass path are a low, 0.2 dB to 0.6 dB depending on the frequency. This improvement translates directly to improved system noise figure and hence performance. In addition, since the HMC199MS8 has an integrated bypass path only one switch is required instead of two, consequently reducing cost and board space.

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Application Solution

This product note will principally address the utilization of the HMC199MS8 as a 1-BIT attenuator. Although the design may seem straightforward, there are many idiosyncrasies, which can adversely affect performance. In particular, operation above 1.0 GHz can be compromised due to parasitic effects, VSWR, and phase differences between signal paths.

Theory of Operation

Figure 2 shows a schematic of the evaluation board used in characterizing the performance of HMC199MS8 as a 1-BIT attenuator. The HMC199MS8 itself consists of two integrated SPDT switches with one of the paths connected together internally and the other paths provided as external connections. The switch is controlled by two control lines, A and B, which are either 0V or +5V.

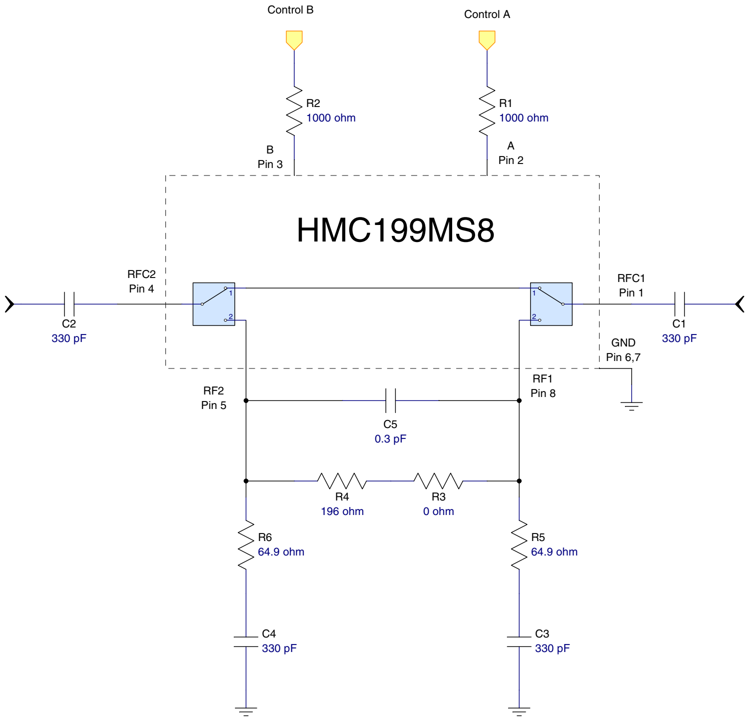


Figure 2 - HMC199MS8 schematic diagram with PI attenuator

Positive control is achieved by floating the source grounds of the switch FET's located on the die. As a result, capacitors C1, C2, C3 and C4 are required to isolate the control voltage from ground. Capacitors C3 and C4 should provide a sufficiently low reactance to ground. Resistors R3, R4, R5 and R6 make up the PI pad attenuator. In this particular application discrete components are used for the attenuator. However, an integrated thin film attenuator or thermal pad for gain compensation can be easily implemented. The results are similar and are shown in Appendix A of this product note. Capacitor C5 is used to equalize the attenuation at the higher frequencies. Finally, resistors R1 and R2 provide isolation for the control lines.

Signal Recombination

One phenomenon that is often overlooked in RF design is the recombination of signals at common nodes. At lower frequencies, this is usually not an issue since the wavelength of the signal is relatively large compared to the signal path. However, at higher frequencies, where wavelengths are smaller, the path length may approach or surpass the actual wavelength. Figure 3 shows a switch in which one pair of the ports are tied together and the other ports pass through a phase shifter.

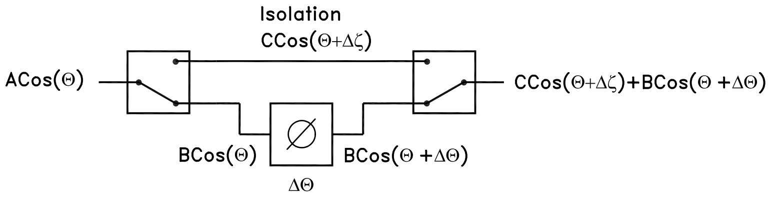


Figure 3 - Phase interference

If signal Acos(Θ) is applied to the input of the first switch it will split and pass through both arms of the switch. The signal passing through the isolated arm will be of amplitude “C” and phase “Θ + Δζ” while the signal passing through the phase shifter arm will have amplitude of “B” and phase “Θ + ΔΘ”. These two signals will recombine at the output and, depending on the phase and amplitude, could cancel each other out. What is important to keep in mind when designing the attenuator is to minimize the distance between the components and switch. This will reduce the effects from the interfering signal emanating from the isolated path.

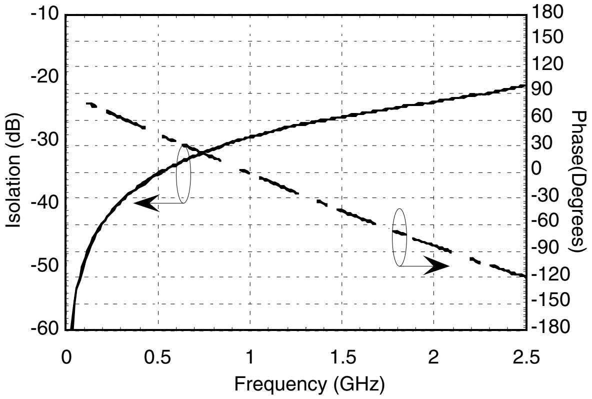


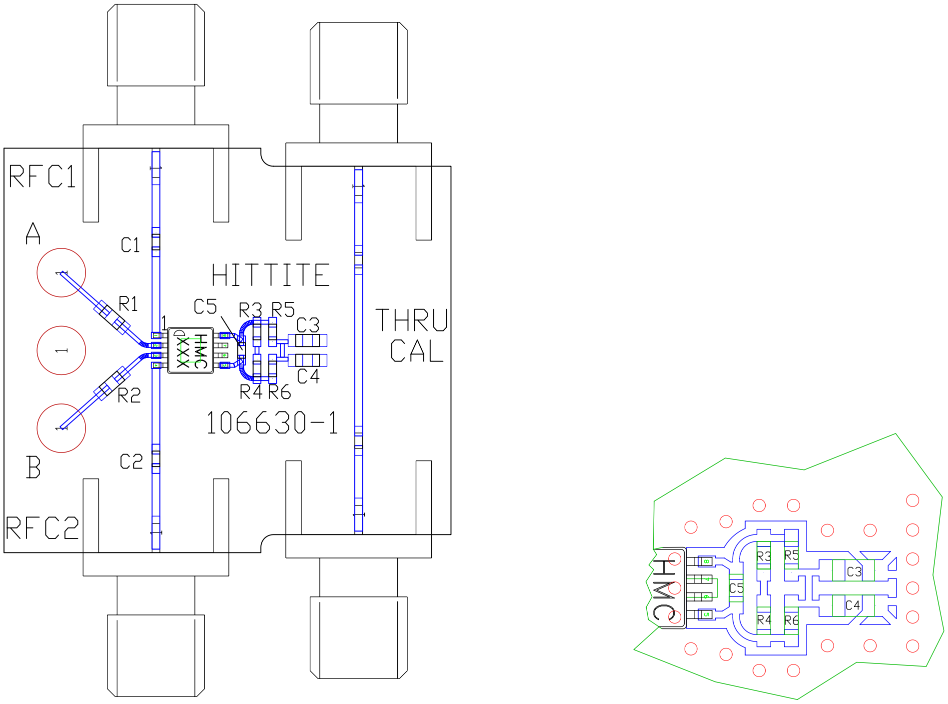
Figure 4 - Isolation, phase versus frequency

Figure 4 shows the isolation and phase of the HMC199MS8 bypass switch. The plot shows that across the band there is approximately 95 degrees of phase shift (in the isolation path) with the isolation changing from -60 dB to approximately -22 dB. It is apparent that as the attenuation approaches 20 dB the effects of recombination cannot be neglected. These effects are all taken into consideration during the design and layout of the evaluation board.

External Circuit Design

Figure 5a shows the evaluation board containing the HMC199MS8 and corresponding PI attenuator. The board is constructed using Rogers 4350 high frequency laminate with ½ ounce copper clad and a board height of 10 mil. To provide stiffness, additional layers of Rogers 4403 and 4350 are used.

Figure 5b is a close-up of the PI pad. The distances between components are made as short as possible while maintaining accepted manufacturing practices. The PI attenuator layout is designed for versatility to permit realization of other circuits such as, filters, tee attenuator, equalizer and phase shifter, just to name a few. Associated with the evaluation board is a calibration line used to determine line, connector and blocking capacitor losses. These losses are then used to correct the measured data.



(a) (b)

Figure 5 - (a) One bit attenuator evaluation board,
(b) Close up of pad layout

Figure 6 shows a PI attenuator which consists of two parallel resistors connected by a series resistor forming a shape representative of the Greek symbol Π. The values of the resistors are chosen to provide the desired attenuation and input/output impedance. Using equation 1 the resistor values can be calculated for a given attenuation “n” and characteristic impedance “Z”.

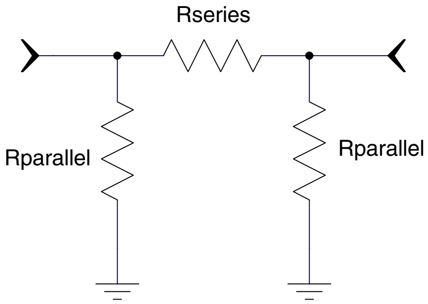


Figure 6 - PI attenuator

$$Rseries = \frac{Z}{2}\cdot\left[\frac{10^{\frac{2n}{20}}-1}{10^{\frac{n}{20}}}\right]\Omega \qquad Rparallel = Z\cdot\left[\frac{10^{\frac{n}{20}}+1}{10^{\frac{n}{20}}-1}\right]\Omega$$

Equation (1)

n=attenuation in dB, Z=characteristic impedance in ohms

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The required resistor values for an 18 dB PI attenuator are calculated to be: R4= 195.4Ω, R3= 0Ω, R5, R6= 64.4Ω. The actual values differ slightly from the calculated and are shown in figure 2.

To assist in the design, a behavioral model is created using =GENESYS=[1] linear simulation software. The model is shown in figure 7, which consists of the linear system elements of a switch, attenuator, time delay, and phase shifter. The model is broken down into two major blocks. The first block describes the behavior of the HMC199MS8 and the second, the external attenuator. In the HMC199MS8 block, there are two switches and three phase shifters. The phase shifters are used to mimic the phase shift through the switch.

The attenuator block contains an attenuator and a time delay, which adds a linear phase shift equal to $e^{-j\omega T}$.

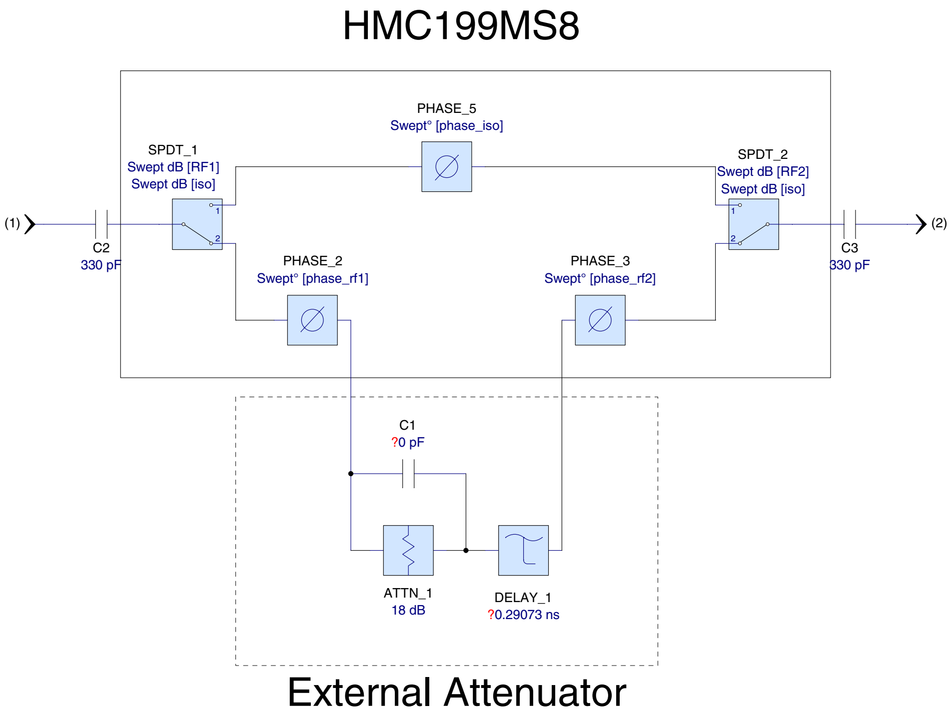

Figure 7 - One bit attenuator behavioral model

Measured data from the switch (HMC199MS8) is curve fitted using polynomials. These polynomials are then used to describe the parameters of the elements in the behavioral model of the HMC199MS8. For example, the switch element contains parameters for insertion loss, isolation, and input and output impedance. The isolation data is curved fitted to a sixth order polynomial:

$$Isolation = -62.1 + 133.3 \cdot X - 274.1 \cdot X^2 + 307.8 \cdot X^3 - 183.8 \cdot X^4 + 55.0 \cdot X^5 - 6.5 \cdot X^6$$

Where X is frequency in GHz. Figure 8 shows a close to ideal fit between the measured isolation and polynominial fit.

The polynomials are entered into an equation block in =GENESYS= and set equal to variables for all the elements in the behavioral model associated with the HMC199MS8 switch. These variables are then used to define the parameters of the switch and phase shifter elements. The only parameter of the switch that could not be described with a polynomial is the open port impedance of the switch in the thru path. These ports are internal to the package and not accessible for measurements. However, the measured isolation data and phase reflect the effects of the open port and therefore are not required. Consequently, the ports are set to 50Ω.

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The attenuation value for the attenuator element in the external attenuator behavioral model is set to 18 dB. The output port impedance parameter to the attenuator element is initially set to 50Ω. Finally, the time delay is set to an arbitrary value. The simulation is initially run without capacitor C1 (C5 in figure 2) to establish a baseline. The final delay and output impedance parameters are tuned using the tuning capabilities in =GENESYS= to best fit the measured data. The results are shown figure 9.

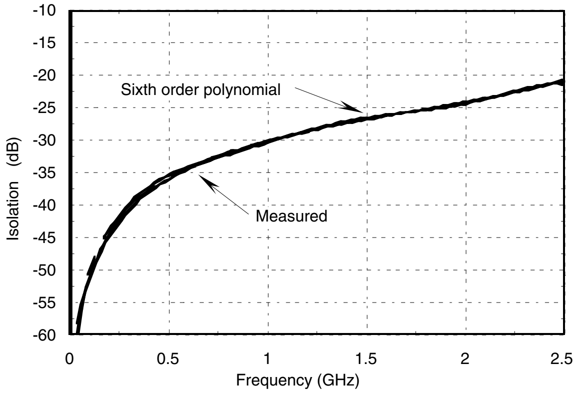


Figure 8 - Measured isolation fitted to second order polynomial

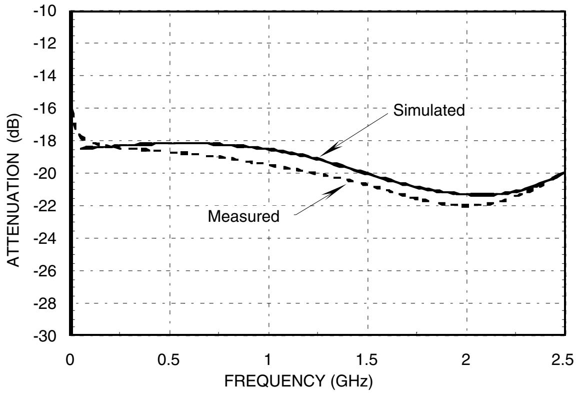


Figure 9 - Measured attenuation versus simulated

The simulated and measured data agree remarkably well considering the simplicity of the behavioral model. The only exception is the measured attenuation near 0 Hz, which reduces asymptotically due to capacitors C3 and C4. These capacitors provide the RF ground to the shunt resistors of the attenuator. At very low frequencies, the reactance to ground becomes high essentially isolating the ground path. Increasing the capacitance of C3 and C4 will reduce the operating frequency. Capacitors C3 and C4 are not represented in the behavioral model and therefore this divergence near 0 Hz is not observed. Since the intent in the model is to predict the behavior of the HMC199MS8, this minor difference is acceptable.

Figure 9 shows the attenuation increasing with frequency. Capacitor C5 in figure 2 is used to equalize the attenuation at the higher frequencies by changing the input impedance of the PI attenuator. Figure 10 shows the PI attenuator with a capacitor in parallel with the series resistor. In addition, load and source resistances are represented.

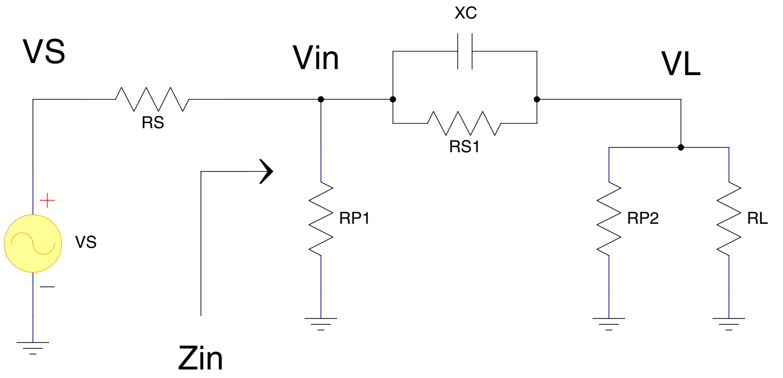


Figure 10 - PI pad with parallel capacitance for attenuation equalization

The circuit is analyzed using conventional circuit analysis techniques. Equation (2) is the transfer function from the source to the load.

$$\frac{VL}{VS}=\frac{VL}{Vin}\cdot\frac{Vin}{VS}=\left(\frac{RP2\|RL}{(RP2\|RL)+(XC\|RS1)}\right)\cdot\left(\frac{Zin}{Zin+RS}\right)\quad \text{Equation (2)}$$

Where:

$$Zin=((XC\|RS1)+(RP2\|RL))\|RP1\quad \text{Equation (3)}$$

Parallel reactance of Xc and RS1:

$$XC\|RS1=\frac{RS1}{(\omega\cdot C\cdot RS1)^2+1}-j\frac{\omega\cdot C\cdot RS1^2}{(\omega\cdot C\cdot RS1)^2+1}\quad \text{Equation (4)}$$

Parallel resistance of RP2 and RL:

$$RP2\|RL=\frac{RP2\cdot RL}{RP2+RL}\quad \text{Equation (5)}$$

Equation (6) is the insertion loss, or in this case the attenuation of the circuit. For completeness the return loss is calculated {Equation (7)} to insure that the circuit is still matched to 50Ω.

$$InsertionLoss=20\cdot Log(|S21|)=20\cdot Log\left(\left|2\cdot\frac{VL}{VS}\right|\right)\quad \text{Equation (6)}^{2}$$

In addition, the return loss is computed by:

$$ReturnLoss=20\cdot Log(|S11|)=20\cdot Log\left(\left|\frac{Zin-Zs}{Zin+Zs}\right|\right)\quad \text{Equation (7)}$$

Figure 11 is a plot of the attenuation as a function of capacitance and frequency. The plot shows that attenuation decreases with increased capacitance and frequency. Conversely, the measured data in figure 9 shows the attenuation increasing with frequency. Therefore, placing a capacitor in parallel with the series resistor will equalize the attenuation across the band.

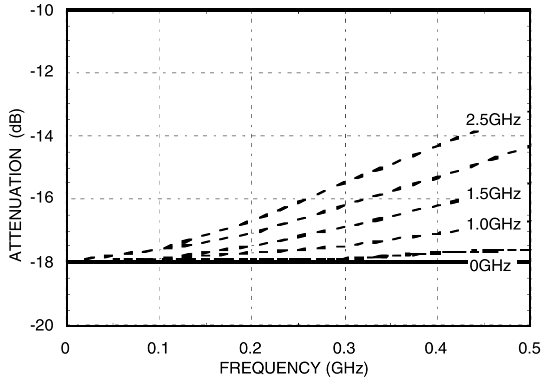


Figure 11 - Attenuation versus capacitance and frequency

The parallel capacitor is placed in the behavioral model in order to determine the optimum capacitor value. After tuning the capacitance using =GENESYS= it is determined that, the optimum value is 0.3 pF. The capacitor is placed in the evaluation board and then measured. Figure 12 shows the results of both the measured and simulated attenuation. For comparison purposes, the measured data with no capacitor is included.

To insure that the capacitor did not affect the match the input and output return losses are measured. The results for both measured and simulated are shown in figure 13. The effects of the blocking capacitors C1 and C2 are apparent at the lower frequencies.

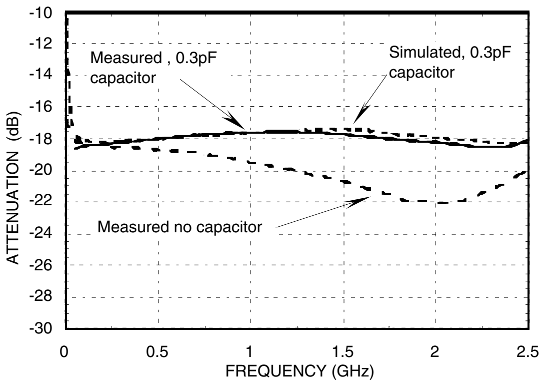


Figure 12 - Measured attenuation versus simulated with 0.3 pF parallel capacitor

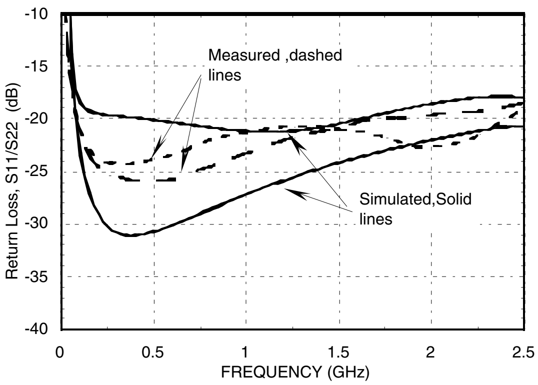


Figure 13 - Measured return loss versus Simulated with 0.3 pF parallel capacitor

Limitations and Trade-offs

The performance of the attenuator is most affected by the recombination of the signal from the isolated (thru path) path of the switch. As the attenuation of the pad is increased, the magnitude of the two signals approach equality. This inherently causes the attenuation to vary extensively across the band. Figure 14 shows the measured data for the HMC199MS8 with an external 30 dB attenuator on the output. The attenuation varies as much as 5 dB in the center of the band due to the strong signal from the isolated path recombining with the attenuated signal. Nevertheless, the attenuator can be used at lower frequencies if capacitor C5 is replaced with an inductor and the capacitance of C1 and C4 is increased.

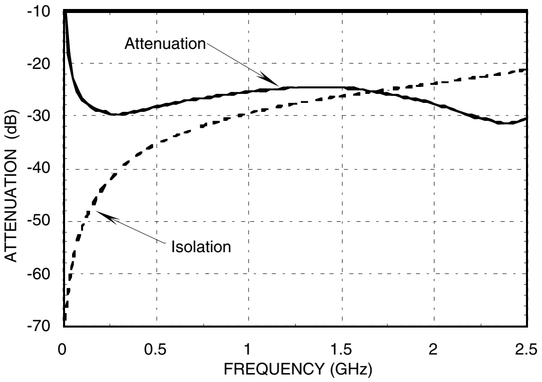


Figure 14 - Measured 30 dB attenuation and isolation

Other Applications

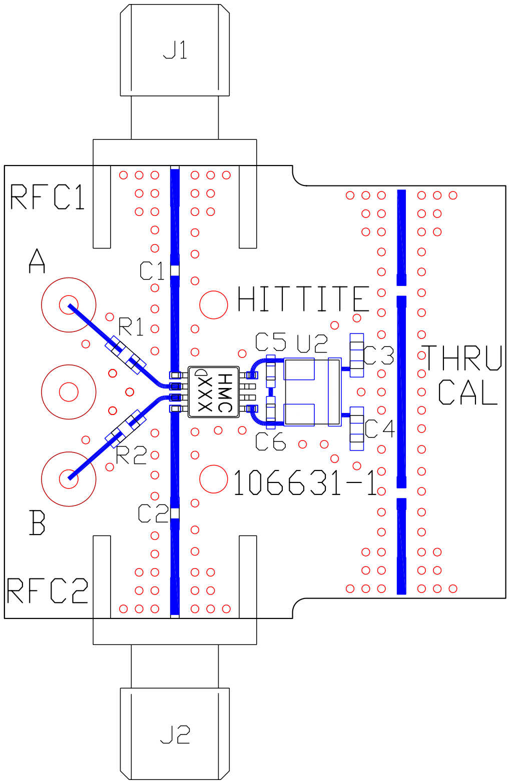
The HMC199MS8 can be used for a variety of other applications. Its versatility will allow a designer to easily implement switched filters, equalizers, or switched LNA's. The only limitation is the isolation of the switch, which will effect the maximum attenuation, or in the case of the switched filter, the stop band attenuation. Because the switches are integrated in one package, the thru loss is minimized and the cost is reduced, making it an ideal candidate when two switches and a thru line are required.

Conclusion

Using the HMC199MS8 bypass switch, a one-bit attenuator was built and tested. Careful analysis shows that interference from the isolated path will adversely affect the attenuators performance and maximum attenuation value. It was also shown, through analysis and testing, that these effects can be minimized by placing a capacitor in parallel with the series resistor. This low cost solution is diverse in that it allows the designer to customize attenuation values that may not be commercially available. Although this product note has concentrated on a one-bit attenuator, the HMC199MS8 can be used in an assortment of other applications.

For questions on this application or any other application, please contact Hitiite Microwave Corporation for further assistance.

APPENDIX A *One Bit Attenuator using thin film chip attenuator*



(a)

Ref	Description	Part Number	Manufacturer
R1, R2	Res, 100 Ohm, 0603	ERJ-3EKF1000V	Panasonic
C1, C2	Cap, 330pF, 0402	ECJ-OEB1H331K	Panasonic
C3, C4	Cap, 330pF, 0603	ECJ-1VC1H331K	Panasonic
C5	Cap, 1.0pF, 0603	ECJ-1VC1H010C	Panasonic
C6	Cap, 1.5pF, 0603	ECJ-1VC1H1R5C	Panasonic
U1	Hittite Dual SPDT	HMC199MS8	Hittite
U2	16 dB Attenuator	TS0316W3	EMC
J1, J2	SMA Connector	142-0701-851	Johnson

(b)

Figure A1. (a) One bit attenuator using a thin film attenuator pad (16dB attenuation). (b) Parts list

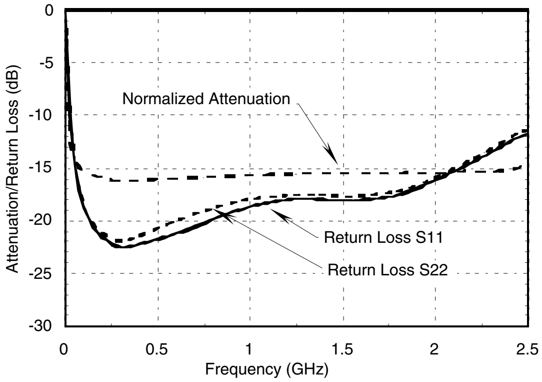


Figure A2. Attenuation, return loss vs. frequency

(Endnotes)

[1] Genesys V2002.09, RF and Microwave linear simulation software, Eagleware Corporation

[2] Guillermo Gonzalez, Microwave Transistor Amplifiers Analysis and Design, Prentice-Hall Inc., Englewood Cliffs, New Jersey, 1984.