Using an MPAC Device to Create a High Resolution Phase Shifter

Application Note 59

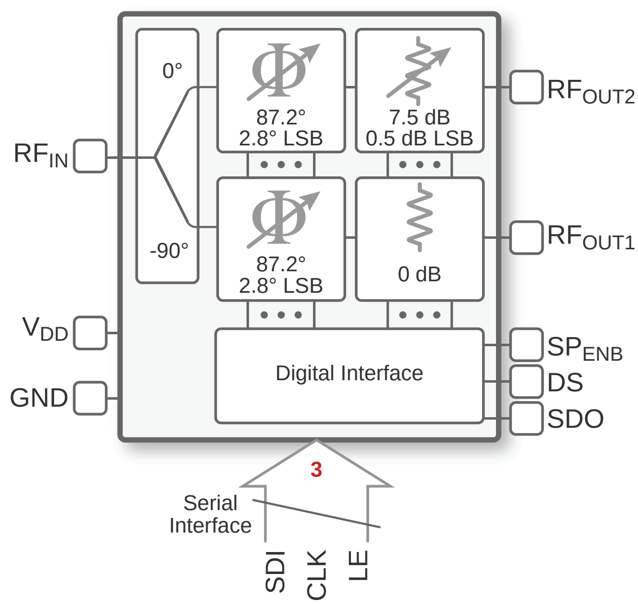
Summary

The PE46120 is one of Peregrine's monolithic phase and amplitude control (MPAC)—Doherty devices. It is designed for equalization and optimization of the signal paths for the peaking and carrier amplifiers used in a Doherty or similar configuration. The integrated functionality also allows the device to be configured as a very high resolution phase shifter with a ±45° range.

Introduction

The PE46120 is designed to equalize the signal paths of a PA configured for Doherty operation. It can also be configured to allow operation in other systems. This note describes how this device can be configured to give a very high resolution phase shifter and how to achieve this. The integrated digital step attenuator (DSA) also offers the ability to increase or decrease the phase resolution as required. Figure 1 shows the functional diagram for the PE46120.

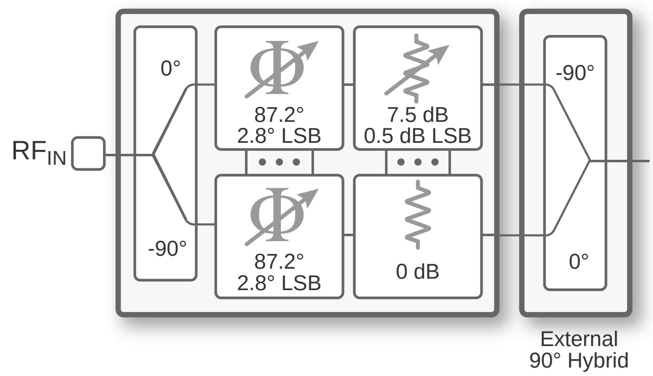
Figure 1 • *PE46120 Functional Diagram*



Configuration Details

Figure 2 shows the phase shifter configuration.

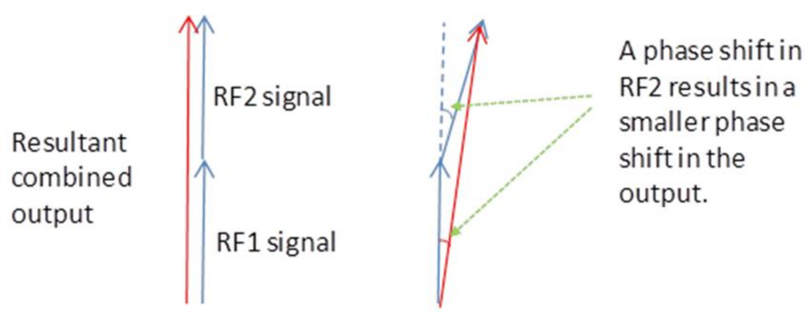
Figure 2 • *Phase Shifter Configuration*



With the RF path attenuator set to 0 dB, and with the phase length in each arm identical such that the signals combine correctly, any phase step in either of the RF1 or RF2 path phase shifter will result in a total signal phase shift of about half the step size of each individual RF path, or about 1.4° in this case, thereby increasing the phase shifter resolution.

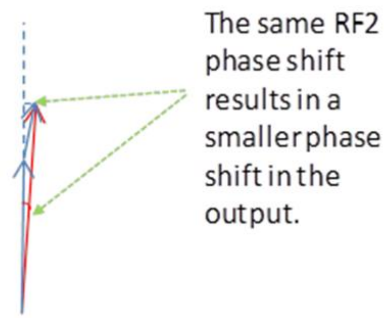
Figure 3 shows the vector diagram explaining the phase shift.

Figure 3 • *Vector Addition of Signal, Equal Signal Amplitude*



Using the internal DSA in RF2 arm to set 7 dB, any phase step in the RF2 phase shifter will result in a much smaller phase change in the output. The penalty is the reduced level of the signal from the RF2 arm, resulting in an increased insertion loss for the whole phase shifter. This is shown in Figure 4 as a shorter resultant signal vector. The 7 dB DSA setting and 2.8° RF2 phase resolution results in an output phase step resolution of 0.8°.

Figure 4 • *Vector Addition of Signal, Unequal Signal Amplitude*

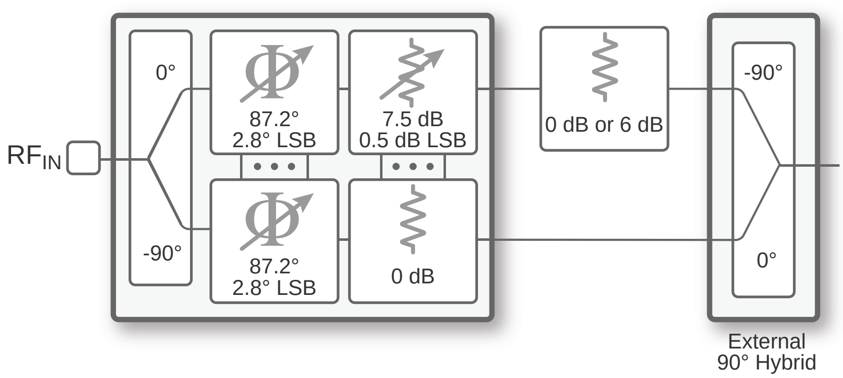


This methodology for obtaining finer resolution can be continued by adding an external attenuator to the RF2 path. With an even smaller signal coming from RF2, the resultant phase shifter signal will tend toward the RF1 signal level, with changes in the RF2 phase setting resulting in even finer phase shifter resolution.

Test Configuration

Figure 5 shows the test configuration of the MPAC device.

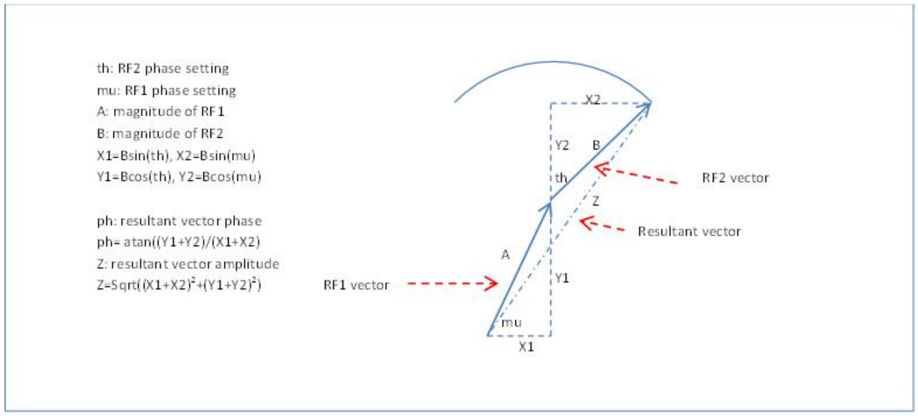
Figure 5 • *Test Configuration*



Analysis

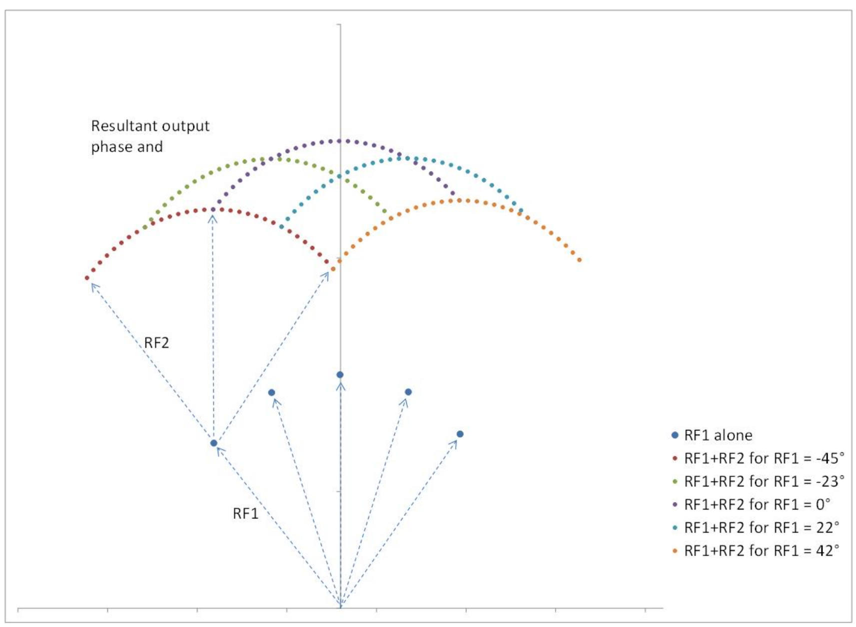
Figure 6 shows the relationship between the RF2 attenuation and the phase resolution achievable. The RF1 path phase shifter applies the course phase shift with the RF2 path applying the fine resolution phase shift.

Figure 6 • *Configuration Analysis*



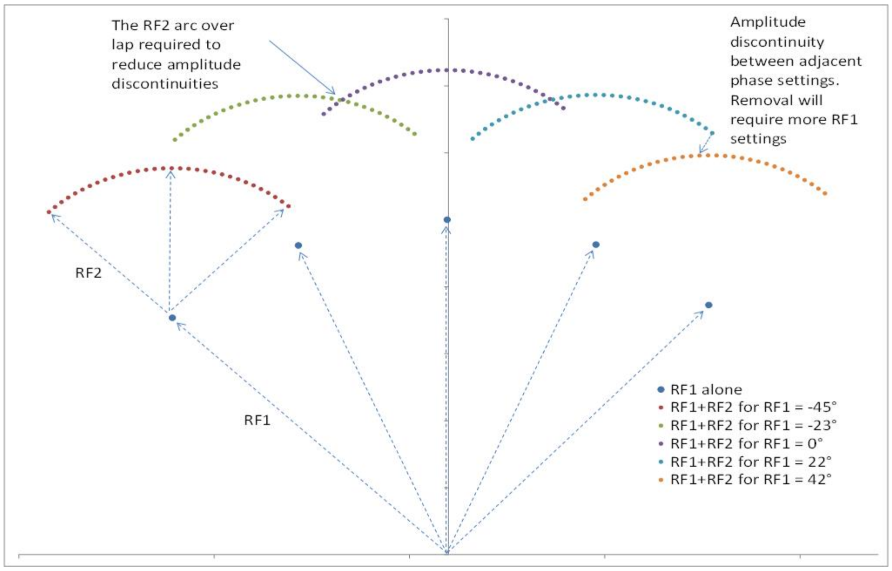
Using this configuration analysis model, the resultant output phase range and resolution can be visualized in the following figures, as shown in **Figure 7** and **Figure 8**.

Figure 7 • *RF2 DSA Setting = 0 dB (No External Attenuator)*



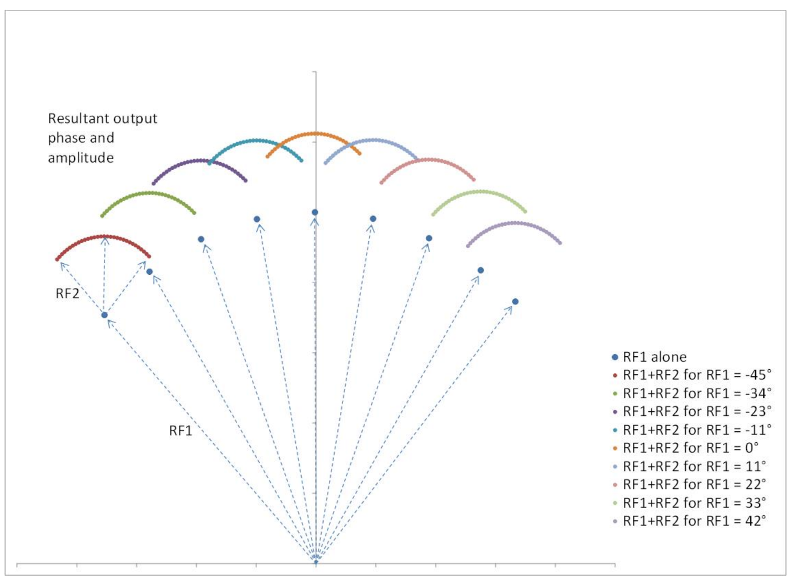
An overlap in the RF2 arcs is necessary to reduce the amplitude variation across the full ±45° range.

Figure 8 • *RF2 DSA Setting = 3 dB (No External Attenuator)*



As the phase range and amplitude of RF1 is the same as RF2, the resultant minimum phase step is reduced from 2.8° to 1.4°. To remove any amplitude discontinuities the number of RF1 settings will need to be increased, as shown in **Figure 9**.

Figure 9 • *RF2 DSA Setting = 7 dB (Phase Resolution Is 0.85°)*



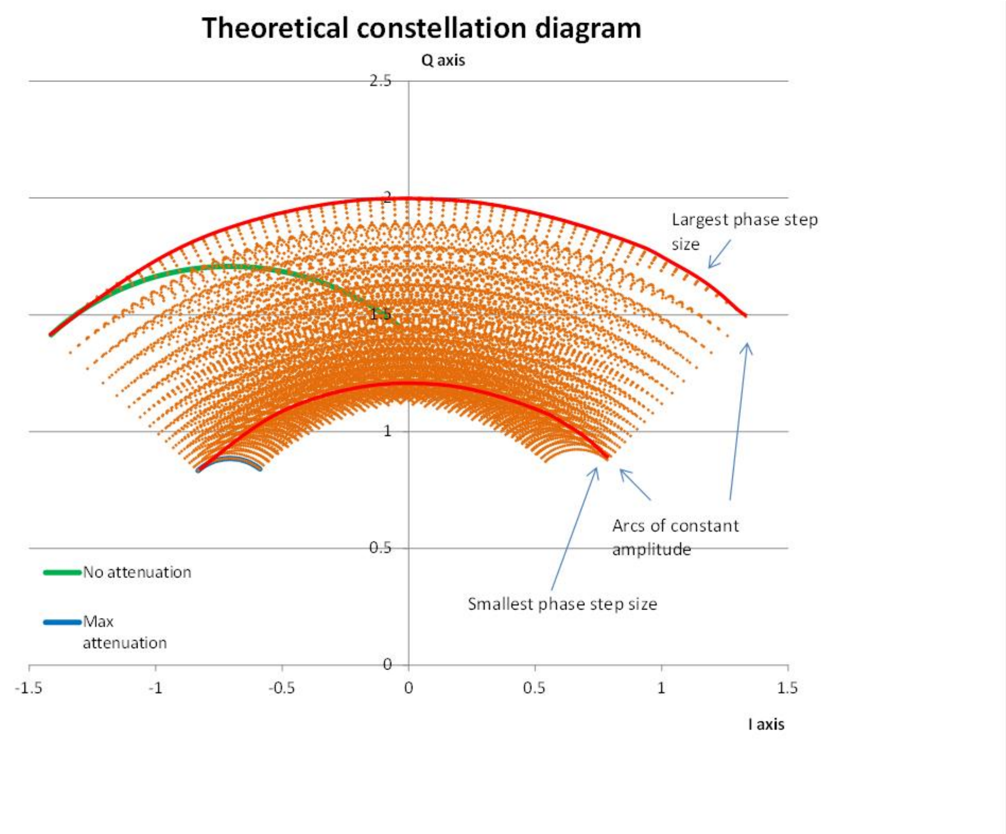
With the RF2 DSA set to 7 dB, the resultant RF2 vector is 0.44. This means the total insertion loss is increased by approximately 2.2 dB, but the resultant output phase resolution is 0.84°.

With the RF2 DSA set to 7 dB with an added external 6 dB attenuator, the resultant RF2 vector is 0.22. This means the total insertion loss is increased by approximately 2.8 dB, but the resultant output phase resolution is theoretically 0.5°.

Theoretical Complete Set of Phase/Amplitude Combinations

For all RF1 phases, all RF2 phases and all attenuation settings are with a fixed external 6 dB attenuator. **Figure 10** shows the theoretical constellation diagram.

Figure 10 • *Theoretical Constellation Diagram*



Note that the RF2 arcs remain vertical for all RF1 phase angles. This means that care must be taken to align RF2 arcs, especially at each end of the RF1 phase range. A theoretical algorithm has been determined to align the RF2 curves in order to achieve monotonic phase control, but the PE46120 design contains unavoidable random differential non-monotonicity at certain steps. The overlap factor can be used to compensate for any non-monotonicity.

The Algorithm

Assumption: Desired angle range is –45° to +45°, resolution = 87.2 / (31 × [Loss+1])

Code for calculating PH1 and PH2 settings for fixed attenuation

Where

ExtAtt is the external attenuation in dB

Att_RF2 is the internal RF2 attenuator setting (0–14)

{OverlapFactor} is an option and can be used to allow PH2 settings to overlap between adjacent PH1 settings. This might be used to measure the entire phase range while allowing for the non-monotonicity mentioned above.

Calculations

Loss = {OverlapFactor} × 10 ^ {(ExtAtt + [Att_RF2 × 0.5]) / 10}

Calculate PH1 = INT (32 × [DesiredAngle + 45] / 87.2)

Calculate PH1Angle = PH1 × 87.2 / 31

Calculate PH2 = INT (31 × (DesiredAngle + 45 + Asin [Loss × Sin {DesiredAngle + 45 – PH1Angle}]) / 87.2)

It is suggested that the algorithm may be used with the Overlap factor to perform a calibration routine, which will determine the optimum phase settings on a part-by-part basis. The algorithm (with Overlap factor) minimizes the number of measurements required. The measurements are then processed to remove non-monotonic points.

Figure 11 shows an example of the raw data collected, with the Overlap factor = 2.

Figure 11 • *Raw Data Collected (Overlap Factor = 2)*

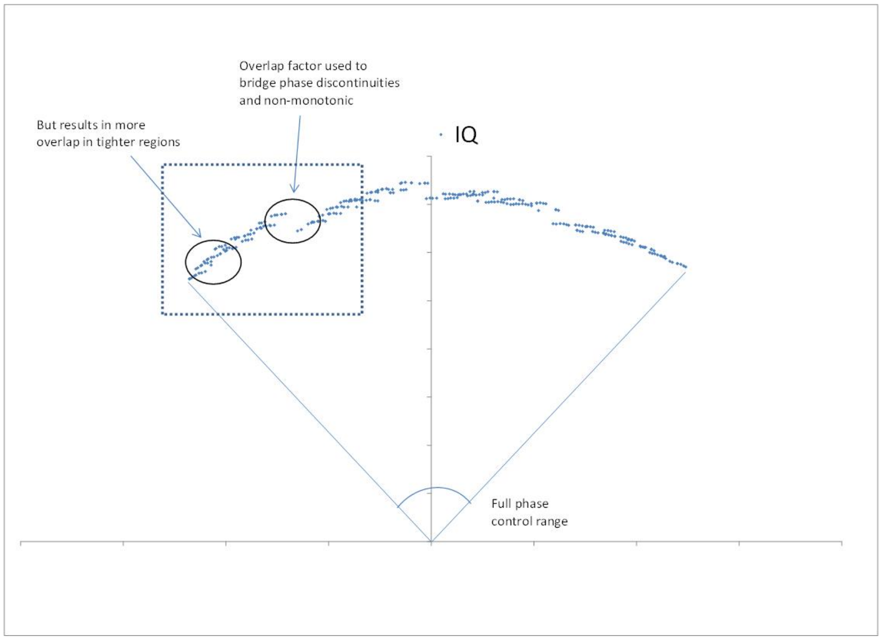
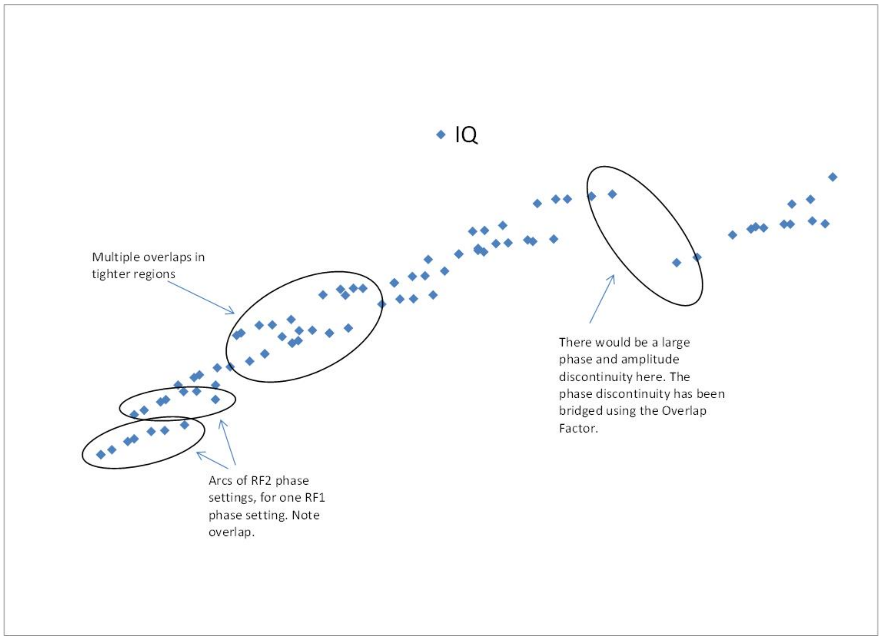


Figure 12 • *Raw Data Collected Showing Phase and Amplitude (Overlap Factor = 2)*

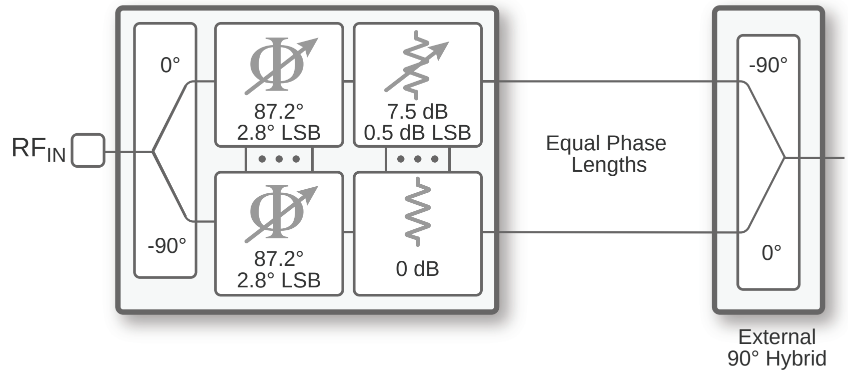


The resulting data shows the non-monotonic behavior, but the gaps have been bridged by use of the Overlap factor. The Overlap factor can be tuned to minimize the number of measurements while bridging the gaps.

Results

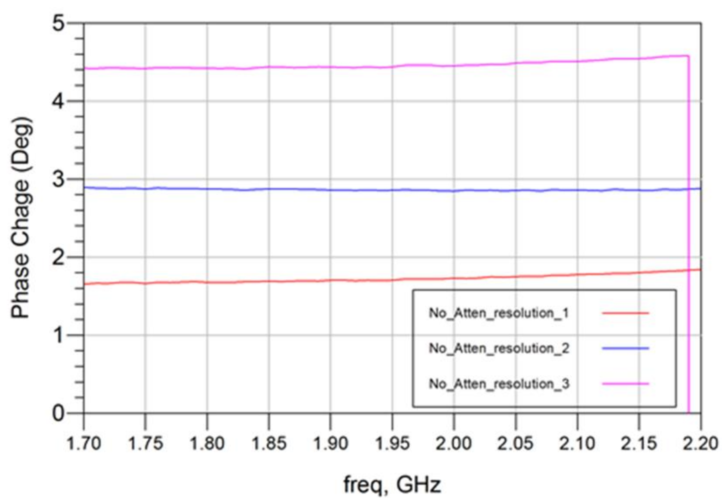
The following sections show the results with equal RF1 and RF2 phase paths, RF2 DSA set to 0 dB.

Figure 13 • *Equal RF Phase Paths with Hybrid Coupler*



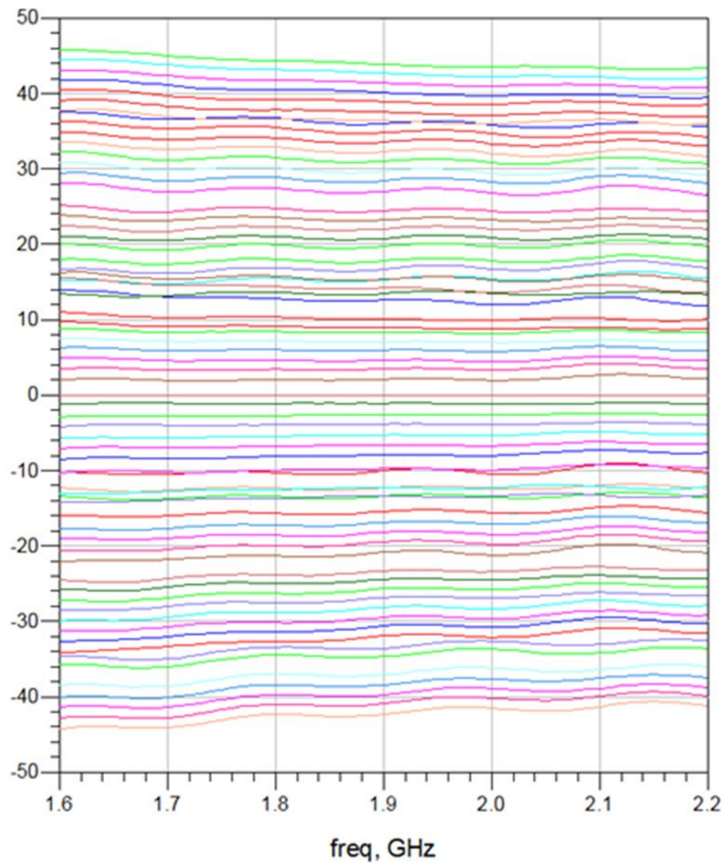
The following are the results of ADS analysis of phase resolution using measured MPAC s-parameters and an ideal ADS 90° combiner model. Figure 14 shows a phase resolution between 1.2° and 1.8°.

Figure 14 • *Typical Phase Resolution Between 1.2° and 1.8°*



The following shows the measured results using a 90° hybrid coupler, as shown in **Figure 15**.

Figure 15 • ***Measured Phase Range with Coupler***



This result is measured across the full RF1 ±45° phase range of using discrete RF1 phase settings with 20 discrete RF2 phase settings for each RF1 setting. **Figure 16** shows the phase step between adjacent states, with **Figure 17** showing the corresponding change in insertion loss between phase states.

Figure 16 • *RF2 Phase Step Resolution for Adjacent States (Degrees)*

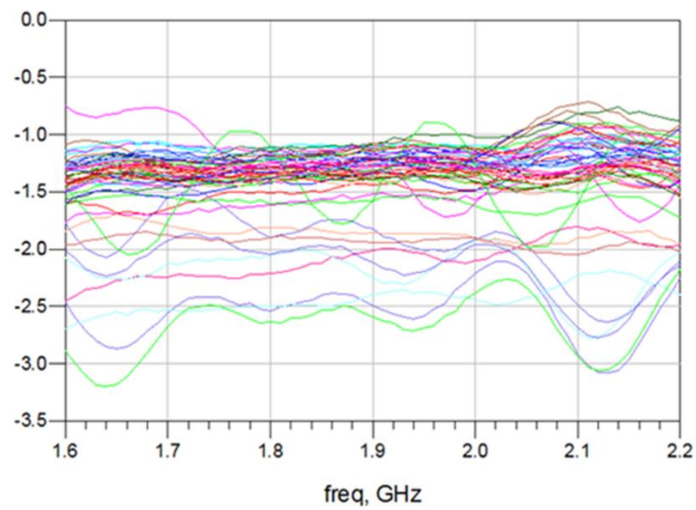


Figure 17 • *Insertion Loss Delta Between Adjacent Phase States (dB)*

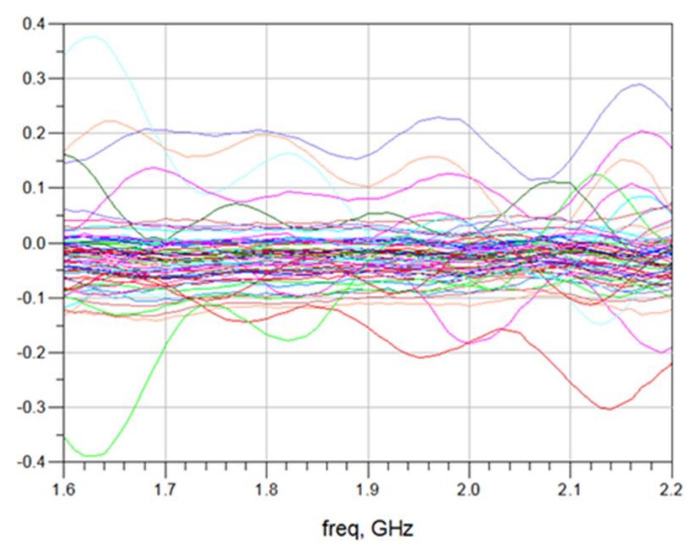


Figure 18–**Figure 20** show the overall performance; however, **Figure 16** and **Figure 17** exclude the transitions between RF1 states. This is because the transitions between RF1 states need to be carefully controlled to ensure they occur at the intersection of the RF2 arcs. Refer to **Figure 8**.

In general, the phase step is <1.5° and the resultant change in insertion loss between states is <0.1dB. Major deviations occur mostly at the 3rd MSB phase transition between RF2 states 7 and 8, 15 and 16 and 23 and 24 when used. These can be removed by selecting an appropriate adjacent RF1 state with corresponding adjusted RF2 state.

The following shows the results with equal RF1 and RF2 phase paths, RF2 DSA set to 7 dB.

Results of ADS analysis of phase resolution using measured MPAC s-parameters and an ideal ADS 90° combiner model as shown in **Figure 18** with a phase resolution between 0.7° and 1.1°.

Figure 18 • ***Typical Phase Resolution***

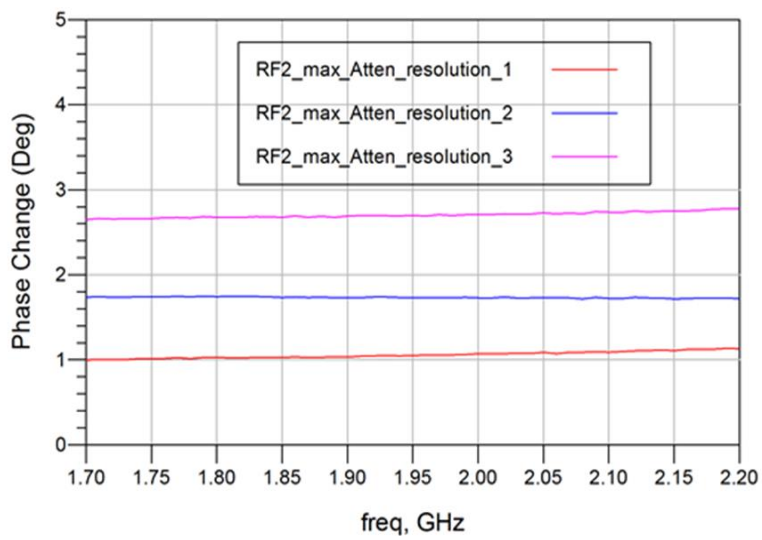
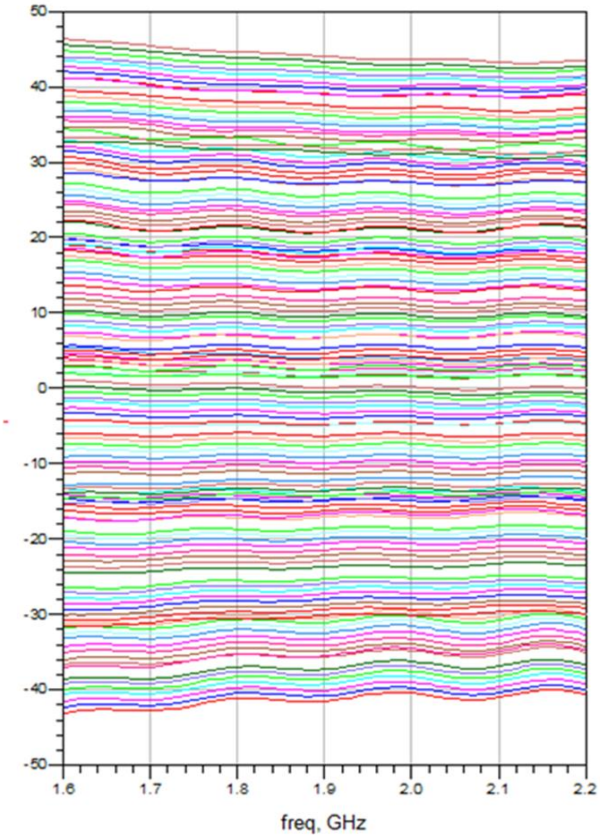


Figure 19 shows the measured results using a 90° hybrid coupler.

Figure 19 • *Measured Phase Range with a 90° Hybrid Coupler*



This result is measured across the full phase shift range of ±45° using 5 discrete RF1 phase settings with 24 RF2 phase settings for each RF1 phase setting.

Figure 20 • *RF2 Phase Step Resolution for Adjacent States (Degrees, MSB Removed)*

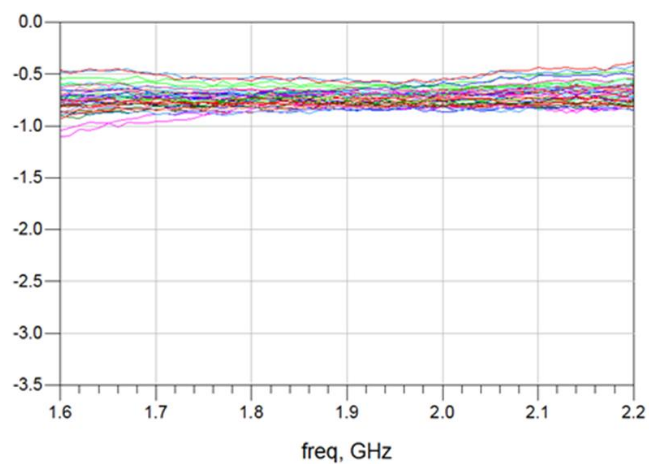


Figure 21 • *Insertion Loss Delta Between Adjacent States (dB, MSB Removed)*

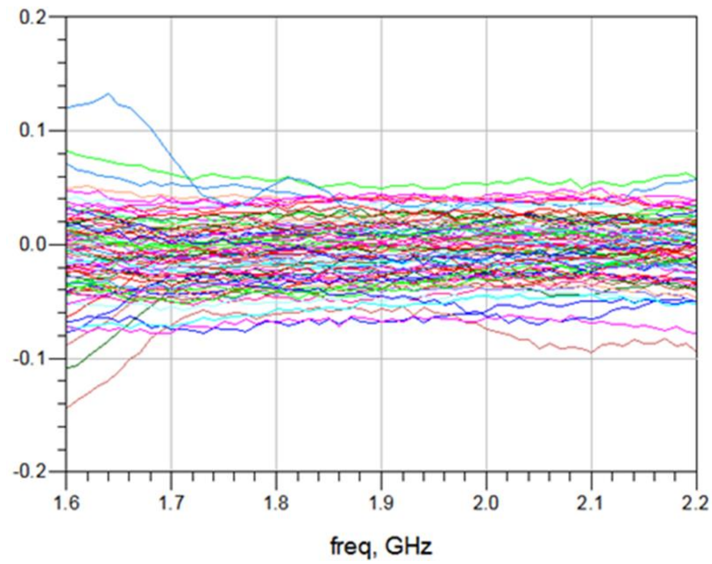
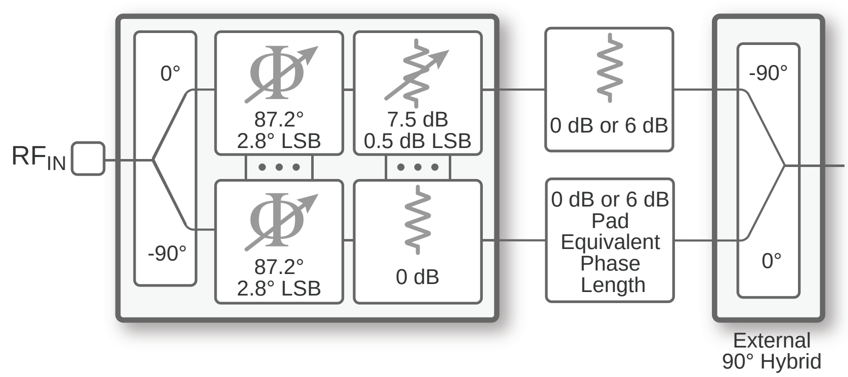


Figure 22–Figure 24 show the overall performance; however, Figure 23 and Figure 24 exclude the transitions between RF1 states. This is because the transitions between RF1 states need to be carefully controlled to ensure they occur at the intersection of the RF2 arcs.

In general, the phase step is <0.8° and the resultant change in insertion loss between states is <0.1dB. Major deviations occur mostly at the 3rd MSB phase transition between RF2 states 7 and 8, 15 and 16 and 23 and 24 when used. These can be removed by selecting an appropriate adjacent RF1 state with corresponding adjusted RF2 state.

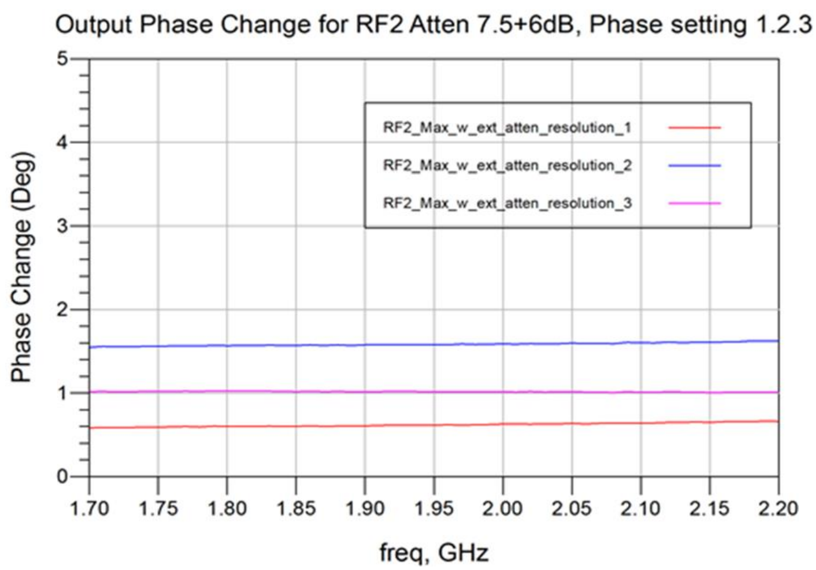
The following shows the results with unequal RF1 and RF2 phase paths, RF2 DSA set to 7 dB.

Figure 22 • *Equal RF Phase Paths with a 90° Hybrid Coupler and 6 dB Pad*



The following are results of ADS analysis of phase resolution using measured MPAC s-parameters and an ideal ADS 90° combiner and 6 dB attenuator model with a phase resolution between 0.4° and 0.6°.

Figure 23 • *Typical Phase Resolution—Output Phase Change for RF2 Attenuation*



The following are measured results using a 90° hybrid coupler, external 6 dB attenuator and internal attenuator set to 7 dB.

This is measured across the full phase shift range of ±45° assuming 31 discrete RF1 phase settings with 31 times RF2 phase settings for each RF1 phase setting. Algorithm used without Overlap factor demonstrating the non-monotonicity over frequency, with a phase resolution between 0.4° and 0.6°.

Figure 24 • *Measured Phase Range*

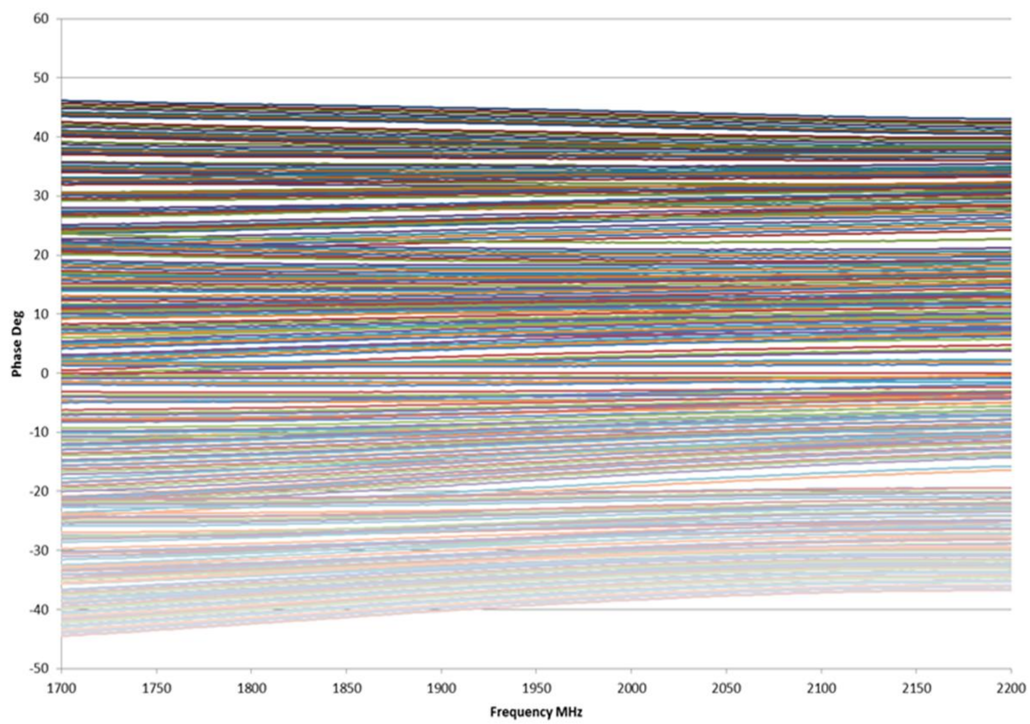


Figure 25 • *RF2 Phase Step Resolution for Adjacent States (Degrees)*

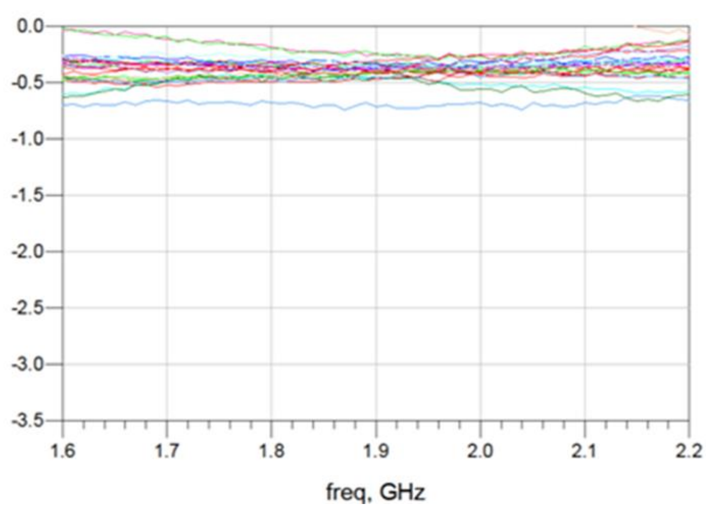
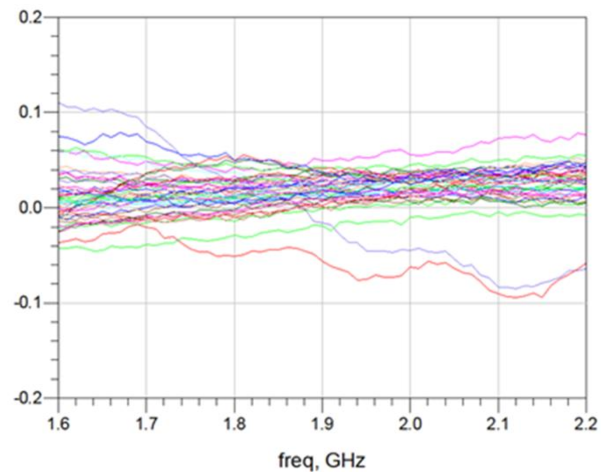


Figure 26 • *Insertion Loss Delta Between Adjacent Phase States (dB, MSB Removed)*

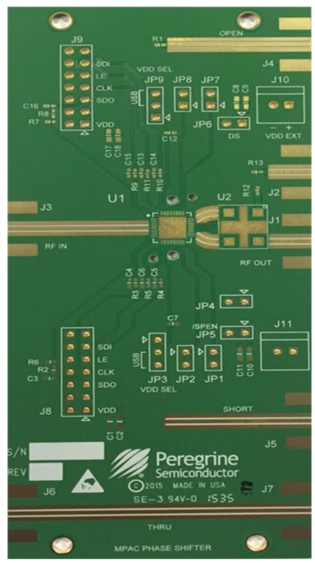


Conclusion

The Peregrine PE46120 MPAC—Doherty device covers a minimum frequency range of 1.8–2.2 GHz. It can successfully be configured to achieve a high resolution (<0.5° step) phase shifter with a full range of ±45°. The DSA is used to set the phase resolution, with the RF1 path phase shifter setting course phase setting with the RF2 phase shifter setting the fine phase setting. With careful control of the transitions between RF1 phase shifter settings, a continuous high resolution can be achieved across the whole ±45° phase range. Other parts in the product family, PE46130 and PE46140, can be configured similarly for fine resolution phase shifters in their respective bands.

A blank PCB for use with the PE46120 and XC X3C21P1–03S (0.25 × 0.2 inch) is available.

Figure 27 • *Blank PCB for Use with PE46120*



Sales Contact

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