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Optimizing the Phase Accuracy of the PE44820 Phase Shifter

Introduction

The PE44820 8-bit RF digital phase shifter is capable of maintaining excellent phase and amplitude accuracy from 1.7–2.2 GHz. However, the phase accuracy can be improved by using the phase accuracy optimization bit with a programming lookup table. This application note demonstrates the improvement in RMS phase error performance based on collected data. The examples indicate the possibilities of phase accuracy improvement over narrow or broadband applications, as well as frequencies in the 1.0–3.0 GHz range, well beyond the PE44820's default 8-bit binary bandwidth.

Summary

- Phase accuracy can be improved by using the OPT bit.
- The phase error can be optimized over the entire operating bandwidth, within sub -bands or beyond the operating bandwidth.
- The optimized bit states are available in a lookup table.

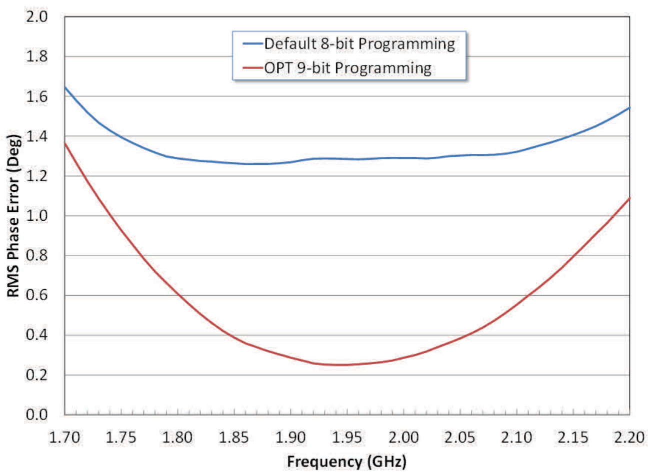
Phase Accuracy Optimization

The PE44820 phase shifter's RMS phase error can be improved with the use of the optimization (OPT) bit. Under normal operation, the OPT bit is synchronized to the 90° bit to improve its overall accuracy. However, the phase accuracy can be optimized across all states by using the OPT bit and a phase programming lookup table. In this case, the OPT pin acts as a 9th bit that is simply a duplicate LSB. This allows the optimum phase error performance at a given frequency to be calculated by characterizing the PE44820 with the OPT bit and its binary states. The additional OPT bit can improve the phase accuracy over the 1.7–2.2 GHz operating bandwidth, narrower bandwidths within the part's total design bandwidth or even at frequencies in the 1.0–3.0 GHz range that are outside of the PE44820's default 8-bit binary bandwidth.

Wideband Optimization

Figure 1 shows the improvement in the phase accuracy when using the OPT bit compared to using the default binary states over the entire 1.7–2.2 GHz band.

Figure 1. RMS Phase Error vs Frequency Over Default Broadband vs Narrowband Optimized Bit Settings



Narrowband Optimization

The optimization bit can also be used where an application may require minimum RMS phase error over a specific frequency range. *Figure 2* shows the response at 1.57 GHz and *Figure 3* shows the response at 2.4 GHz. Both conditions were optimized outside of the 1.7–2.2 GHz default operating frequency range over a 200 MHz bandwidth.

Figure 2. RMS Phase Error and Phase Range vs Frequency Using 1.57 GHz Optimized Bit Settings

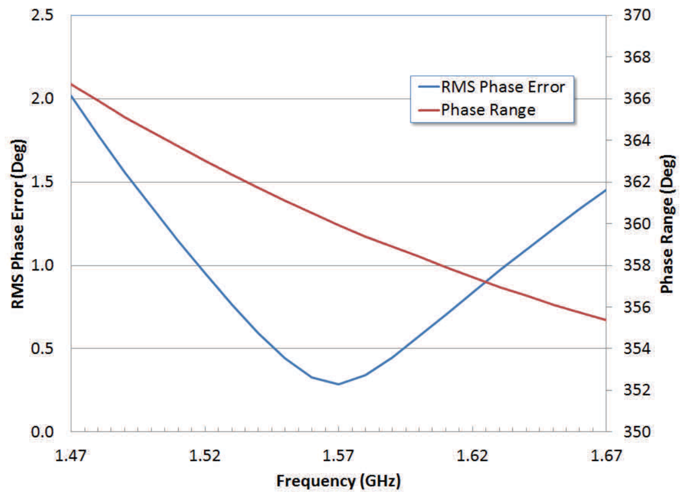
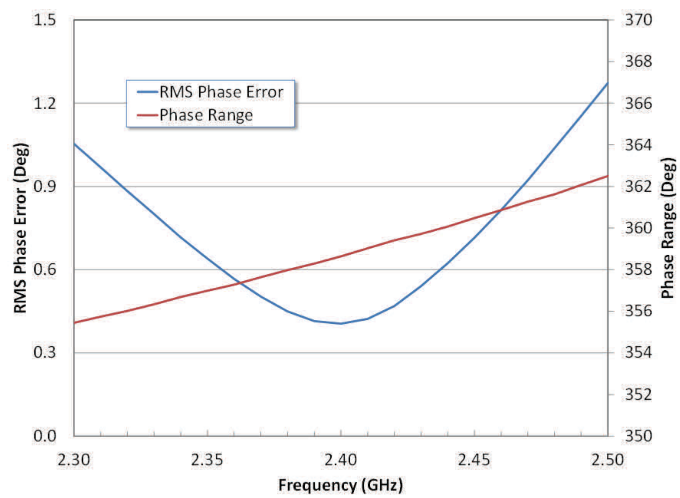


Figure 3. RMS Phase Error and Phase Range vs Frequency Using 2.4 GHz Optimized Bit Settings



Extended-band Optimization

Narrowband RMS phase error and phase range can be greatly improved beyond the default bandwidth of 1.7–2.2 GHz. In *Figure 4*, the center frequency is stepped from 1.1 to 3.0 GHz while the bandwidth remains at 200 MHz at each center frequency. *Figure 5* indicates that a 360° phase control range is maintained at each center frequency.

Figure 4. RMS Phase Error vs Frequency Over Default Broadband vs Narrowband Optimized Bit Settings

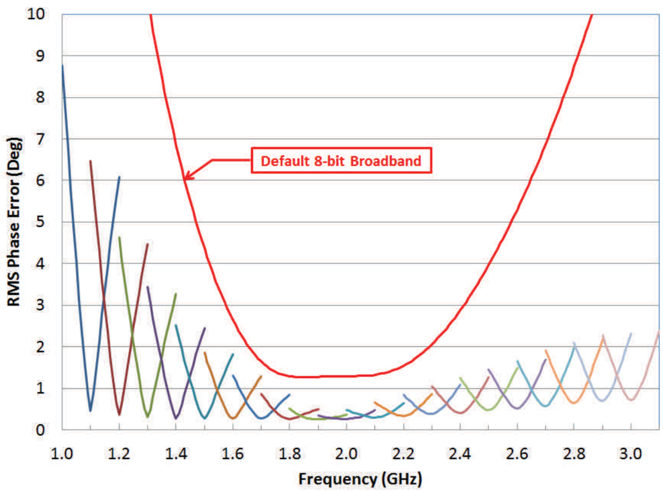


Figure 5. RMS Phase Control Range vs Frequency Over Default Broadband vs Narrowband Optimized Bit Settings

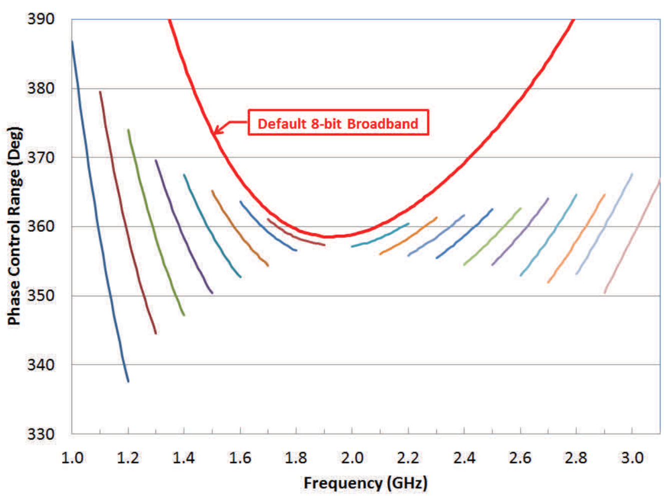


Figure 6. Minimum and Maximum Insertion Loss Over Default Broadband vs Narrowband Optimized Bit Settings

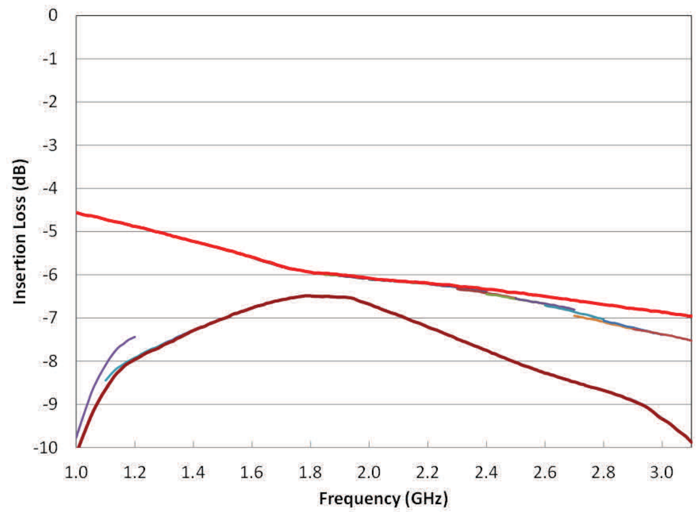
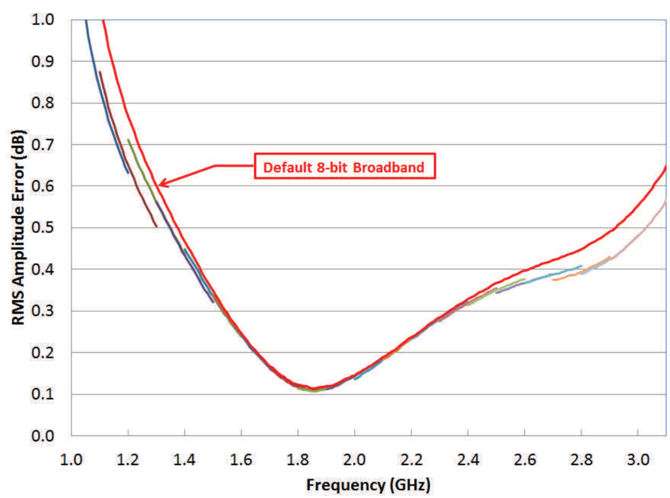


Figure 7. RMS Amplitude Error Over Default Broadband vs Narrowband Optimized Bit Settings



These examples clearly show the benefits of using the OPT bit for minimum RMS phase error over narrowband or wideband applications. The OPT bit does not degrade the PE44820's return loss performance. Note that the minimum and maximum insertion loss remain similar to the default 8-bit broadband response as shown in *Figure 6*. However, the amplitude variation will degrade with both decreasing and increasing frequencies outside the 1.7–2.2 GHz default band. The is indicated in the RMS amplitude error plot in *Figure 7.*

Determining the Optimum Phase

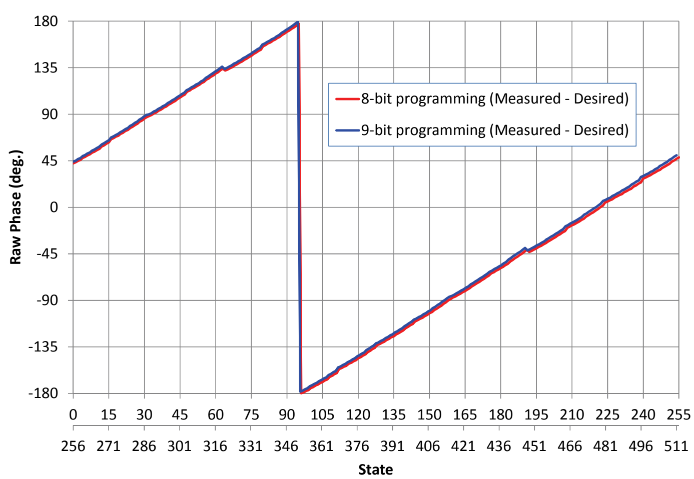
In this third example, 1.6 GHz is chosen as the center frequency for optimizing the 9-bit programming. Initially, raw data is collected from a device at all possible phase state combinations. The desired phase state combinations are determined using the programming map shown in *Table 1.*

Table 1. PE44820 Truth Table

Parallel Control Setting									Desired Phase Shift Setting
OPT	D7	D6	D5	D4	D3	D2	D1	D0	
L	L	L	L	L	L	L	L	L	Reference Phase
L	L	L	L	L	L	L	L	H	1.4 deg
L	L	L	L	L	L	L	H	L	2.8 deg
L	L	L	L	L	L	H	L	L	5.6 deg
L	L	L	L	L	H	L	L	L	11.2 deg
L	L	L	L	H	L	L	L	L	22.5 deg
L	L	L	H	L	L	L	L	L	45 deg
L	L	H	L	L	L	L	L	L	90 deg
L	H	L	L	L	L	L	L	L	180 deg
L	H	H	H	H	H	H	H	H	358.6 deg
H	L	L	L	L	L	L	L	L	1.4 deg

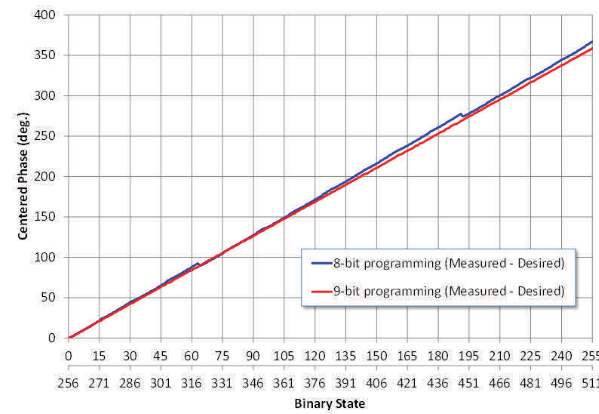
Data from the first 0–255 states is gathered from the 8-bit word. The second 256–511 states are the result of setting the 9th bit HIGH. The 9th bit operates as an additional LSB for the second 256 states to create a continuous progression in phase. This results in a second metric to help access the best phase. This concept is demonstrated in *Figure 8* as the difference between the raw phases of the two states at the frequency of interest.

Figure 8. Difference in 8-bit and 9-bit Raw Phase States at 1.6 GHz



The raw phase states are normalized by subtracting phase associated with test fixtures. The centered phase is calculated by subtracting the raw phase state from the desired phase state. To eliminate phase wrapping caused by straight subtraction between the two states, the MOD function is used as shown in *Figure 9.*

Figure 9. Centered Phase of 8-bit and 9-bit Programming States at 1.6 GHz*



Note: * Centered phase state = MOD (MOD [raw phase state, 360]—MOD [desired phase state, 360] 360).

The desired phase subtracted from the centered phase will determine the uncorrected phase error. The sum of the uncorrected phase errors divided by the total number of states is the average error. The corrected phase is now determined by subtracting the centered phase states from the average error. Finally, the corrected phase error is determined by subtracting the desired phase from the corrected phase.

The corrected phase associated with each the 8- and 9-bit states are compared against the desired phase. Each bit will have a phase error across the entire data set. The optimized phase is determined by subtracting the closest corrected phase from the desired phase.

Figure 10 shows the phase accuracy between the resulting 8-bit states and optimum 9-bit programming states (mapped to the 8-bit desired phase programming states) as compared to the desired phase states for all states. The final results are shown in *Figure 11.*

Figure 10. Phase Accuracy Between 8-bit and OPT 9-bit Mapped to 8-bit index at 1.6 GHz

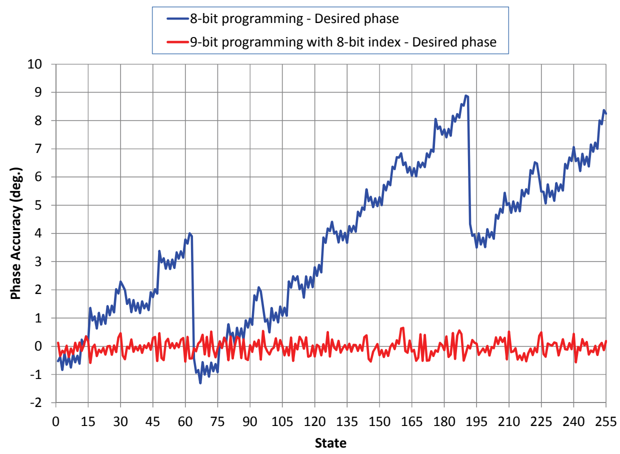
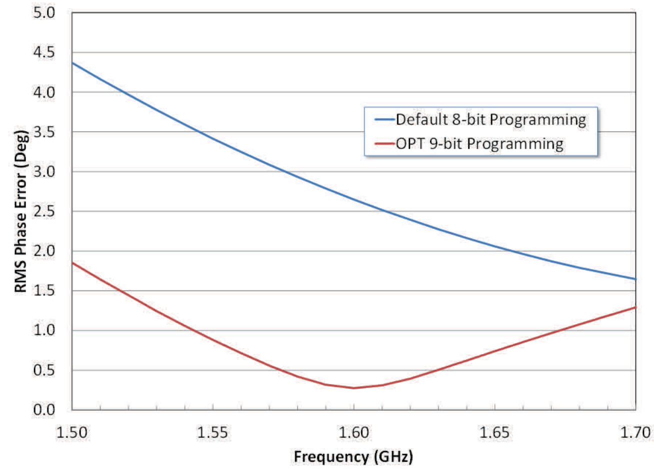


Figure 11. RMS Phase Error vs Frequency Over Default Broadband vs Narrowband Optimized Bit Settings at 1.6 GHz



Lookup Table

The additional states generated by the OPT bit are programmatically compared with the 8-bit programming states at the desired center frequency. Optimization is accomplished by choosing the best state for the desired phase value to compensate for phase errors due to finite phase inaccuracies per bit and bit-to-bit impedance variations. A program searches through the compiled matrix to find the closest value to the desired phase indicated by the optimum state at the desired center frequency. The results are organized in a lookup table.

Table 2 shows the 10 first and last states of the 8-bit lookup table for OPT 9-bit programming used to achieve the results in *Figure 11.* Custom lookup tables can be provided for specific customer applications by Peregrine Semiconductor upon request.

Table 2. Truncated 8-bit Lookup Table for OPT 9-bit Programming at 1.6 GHz

State	8-bit Binary Word	Desired Phase	Phase @ 1.6 GHz	Optimum State	9-bit Binary Word	Optimized Phase @ 1.6 GHz
0	0000 0000	0	0	0	0 0000 0000	0
1	0000 0001	1.41	0.88	256	1 0000 0000	1.53
2	0000 0010	2.81	2.44	257	1 0000 0001	2.47
3	0000 0011	4.22	3.38	258	1 0000 0010	4.06
4	0000 0100	5.63	5.39	4	0 0000 0100	5.39
5	0000 0101	7.03	6.38	260	1 0000 0100	7.05
6	0000 0110	8.44	8.06	6	0 0000 0110	8.06
7	0000 0111	9.84	9.09	262	1 0000 0110	9.76
8	0000 1000	11.25	10.98	8	0 0000 1000	10.98
9	0000 1001	12.66	12.09	264	1 0000 1000	12.78
—	—	—	—	—	—	—
246	1111 0110	345.94	352.66	496	1 1111 0000	346.09
247	1111 0111	347.34	353.72	497	1 1111 0001	347.05
248	1111 1000	348.75	355.90	498	1 1111 0010	348.60
249	1111 1001	350.16	357.05	244	0 1111 0100	349.95
250	1111 1010	351.56	358.78	500	1 1111 0100	351.58
251	1111 1011	352.97	359.97	246	0 1111 0110	352.66
252	1111 1100	354.38	362.38	502	1 1111 0110	354.40
253	1111 1101	355.78	363.65	248	0 1111 1000	355.90
254	1111 1110	357.19	365.56	249	0 1111 1001	357.05
255	1111 1111	358.59	366.84	250	0 1111 1010	358.78

Conclusion

The optimization bit can be used to optimize the phase accuracy across all states. By using the OPT bit with a programming lookup table, the phase performance can be significantly improved such that the part remains spec compliant for RMS phase and RMS amplitude error even outside the original design band. Narrowband optimization and operation have been shown for the entire frequency range of 1.0–3.0 GHz with detailed specific examples of 1.57 GHz, 2.4 GHz and 1.6 GHz. Peregrine Semiconductor can supply the optimum bit state files for a given frequency upon request.