Optimizing the Phase Accuracy of the PE44820 Phase Shifter

Application Note 45

Introduction

The PE44820 8-bit RF digital phase shifter maintains 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, and frequencies in the 1.0–3.0 GHz range, well beyond the PE44820's default 8-bit binary bandwidth.

Summary

- The 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 ninth 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 phase accuracy improvement when using the OPT bit, as compared to using the default binary states over the entire 1.7–2.2 GHz band.

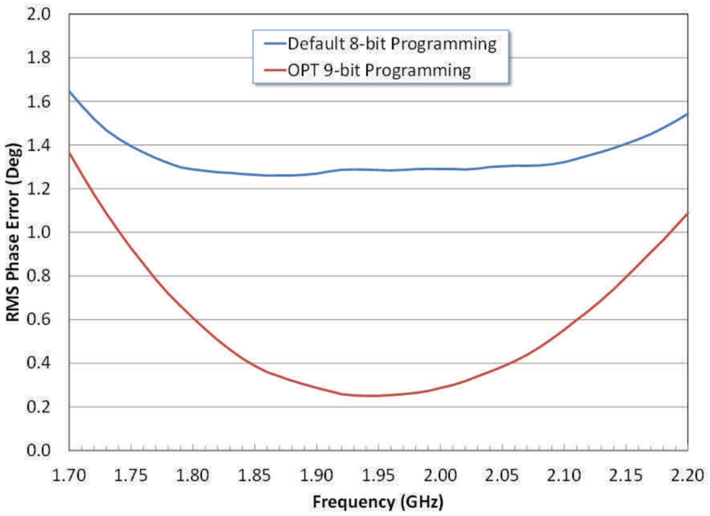

Figure 1. RMS phase error vs. frequency over the default broadband vs. narrowband optimized bit settings

Narrowband optimization

The optimization bit can also be used if an application requires minimum RMS phase error over a specific frequency range.

- Figure 2 shows the response at 1.57 GHz.
- 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.

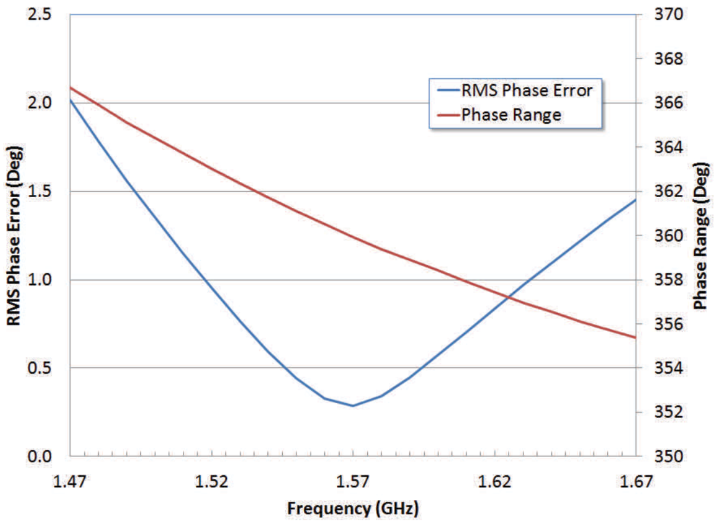

Figure 2. RMS phase error and phase range vs. frequency using 1.57 GHz optimized bit settings

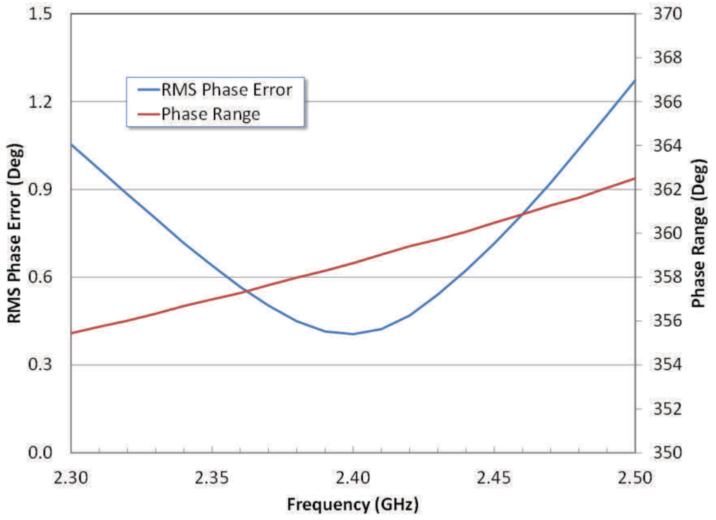

Figure 3. RMS phase error and phase range vs. frequency using 2.4 GHz optimized bit settings

Extended-band optimization

Narrowband RMS phase error and phase range can exceed 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.

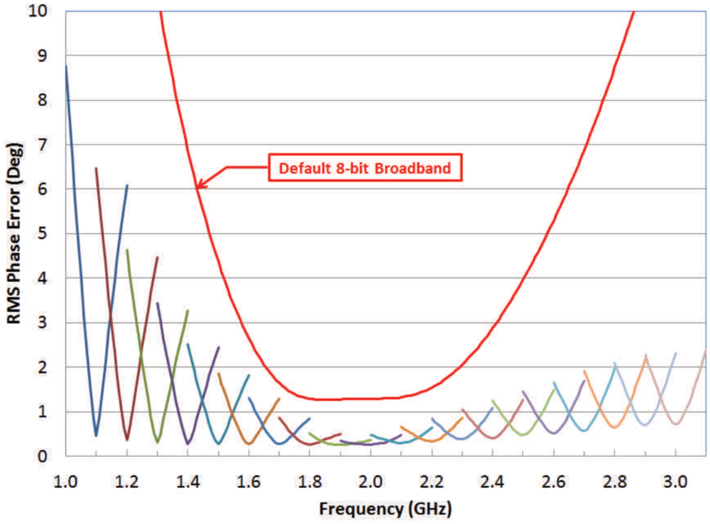

Figure 4. RMS phase error vs. frequency over default broadband vs. narrowband optimized bit settings

Figure 5 shows that a 360° phase control range is maintained at each center frequency.

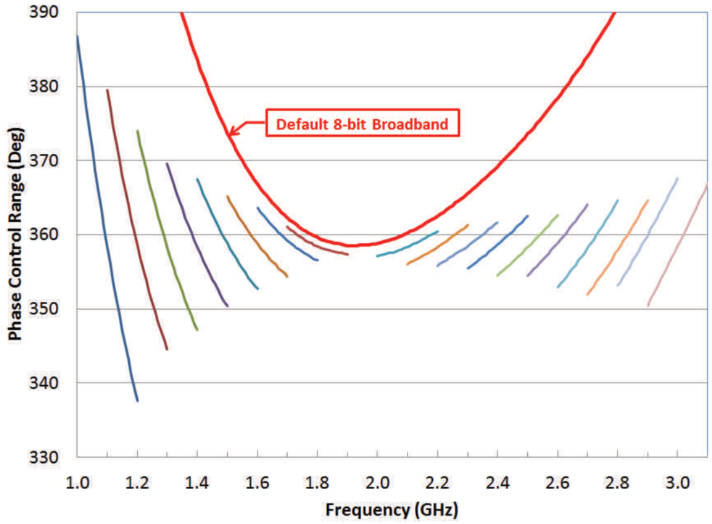

Figure 5. RMS phase control range vs. frequency over default broadband vs. narrowband optimized bit settings

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. The minimum and maximum insertion loss remain similar to the default 8-bit broadband response as shown in Figure 6.

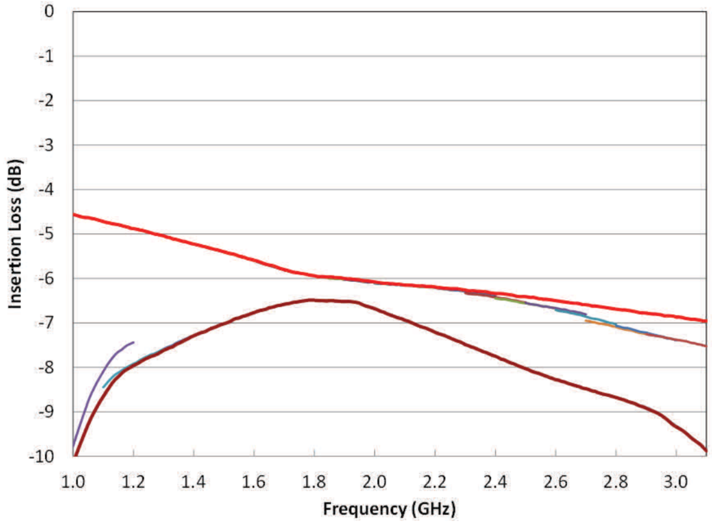

Figure 6. Minimum and maximum insertion loss over default broadband vs. narrowband optimized bit settings

However, the amplitude variation degrades with both decreasing and increasing frequencies outside the 1.7–2.2 GHz default band. This is shown in the Figure 7 RMS amplitude error plot.

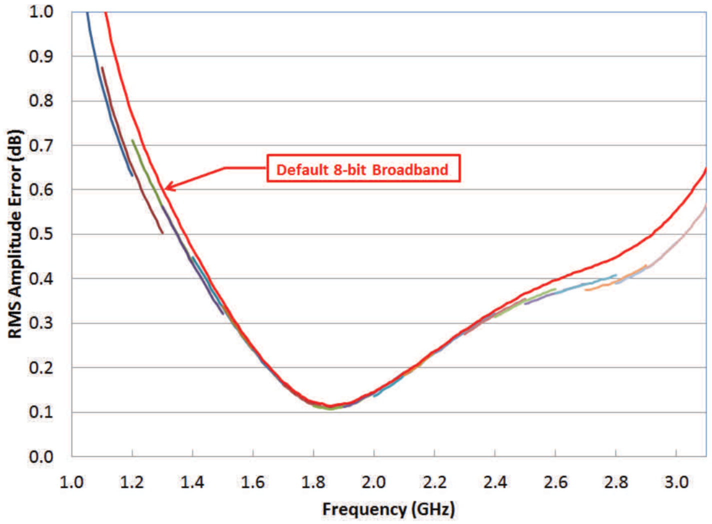

Figure 7. RMS amplitude error over default broadband vs. narrowband optimized bit settings

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 preferred phase state combinations are determined using the programming map in Table 1.

Table 1. PE44820 truth table

Parallel control setting									**Preferred 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 ninth bit HIGH. The ninth 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 shown in Figure 8 as the difference between the raw phases of the two states at the preferred frequency.

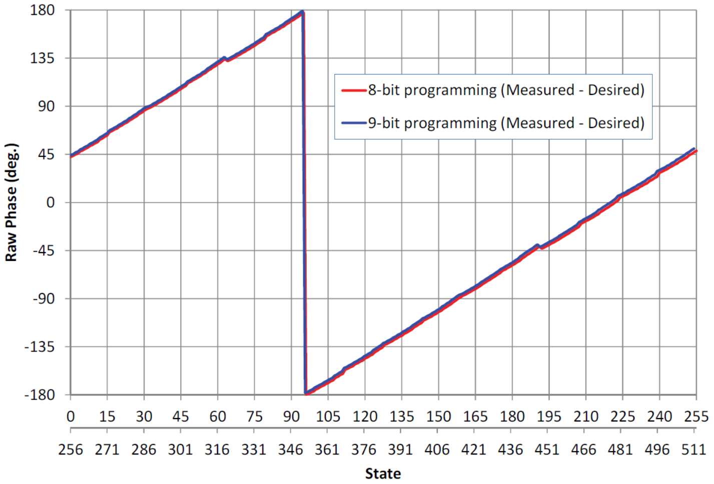

Figure 8. Difference in the 8-bit and 9-bit raw phase states at 1.6 GHz

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

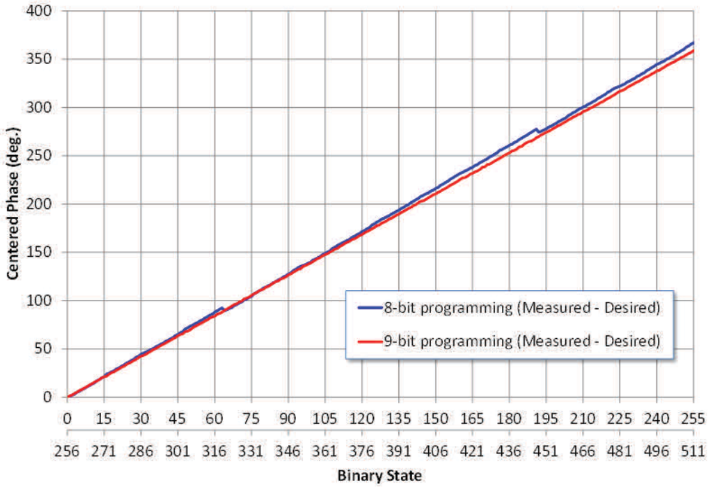

Figure 9. Centered phase of 8-bit and 9-bit programming states at 1.6 GHz(*)

* Centered phase state = MOD (MOD [raw phase state, 360]—MOD [preferred phase state, 360] 360).

The preferred phase subtracted from the centered phase determines 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 of the 8- and 9-bit states are compared against the preferred phase. Each bit has a phase error across the entire data set. The optimized phase is determined by subtracting the closest corrected phase from the preferred phase.

Figure 10 shows the phase accuracy between the resulting 8-bit states and optimum 9-bit programming states (mapped to the 8-bit preferred phase programming states) as compared to the preferred phase states for all states.

Figure 11 shows the results.

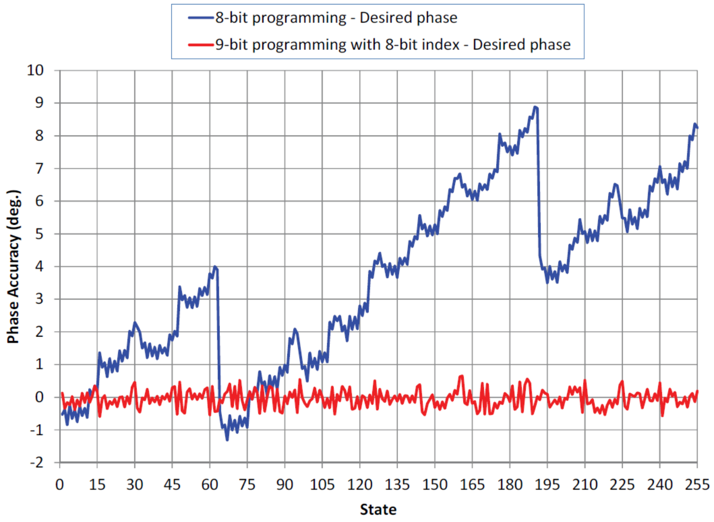

Figure 10. Phase accuracy between 8-bit and OPT 9-bit mapped to 8-bit index at 1.6 GHz

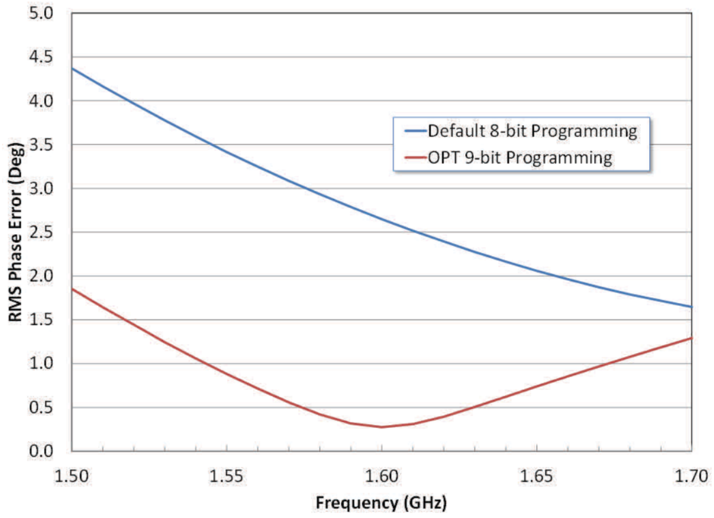

Figure 11. RMS phase error vs. frequency over default broadband vs. narrowband optimized bit settings at 1.6 GHz

Lookup table

The additional states generated by the OPT bit are programmatically compared with the 8-bit programming states at the preferred center frequency. Optimization is accomplished by choosing the best state for the preferred 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 preferred phase indicated by the optimum state at the preferred center frequency. The results are organized in a lookup table.

Table 2 shows the ten first and last states of the 8-bit lookup table for OPT 9-bit programming used to achieve the results in Figure 11. pSemi can provide custom lookup tables for specific applications upon request.

Table 2. Truncated 8-bit lookup table for OPT 9-bit programming at 1.6 GHz

State	**8-bit binary word**	**Preferred 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	36684	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 specification 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 for 1.57 GHz, 2.4 GHz, and 1.6 GHz. pSemi can supply the optimum bit state files for a given frequency upon request.

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