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Handset PA-Duplexer Interaction When the Isolator is Eliminated

By Raymond W. Waugh
Wireless Semiconductor Division
Agilent Technologies

This article describes the impedance matching issues that arise when size and cost constraints result in the elimination of the isolator between the handset power amplifier and the duplexer

In many of today's CDMA handsets, the last three components in the transmit chain are the power amplifier, duplexer and antenna. Because of space limitations in the smallest handsets, there is no room for the isolator traditionally found between PA and duplexer. Because the antenna, duplexer and power amplifier interact strongly with each other, the elimination of the isolator creates more work for the handset designer.

While the data in many duplexer data sheets tends to focus on performance at 25°C, performance at hot and cold temperatures cannot be neglected. The purpose of this note is to examine the impact of temperature upon the duplexer-power amplifier interface when no isolator is used.

Input Impedance of FBAR Duplexers

Film bulk acoustic resonator (FBAR) duplexers have recently become available in the miniature 5 × 5 mm format. Three port S-parameters were obtained from engineering samples of miniature FBAR duplexers, with both frequency and temperature as variables. By way of definition, duplexer port 1 is the Tx (transmit) port, port 2 is the Rx (receive) and port 3 is the antenna port. Simulations were performed using these S3P files in ADS [1]. The simulation assumed that the spacing between the output pin of the power amplifier and the input pin of the duplexer's Tx port was 0.200 inches (5 mm). This detail will vary from one handset design to another.

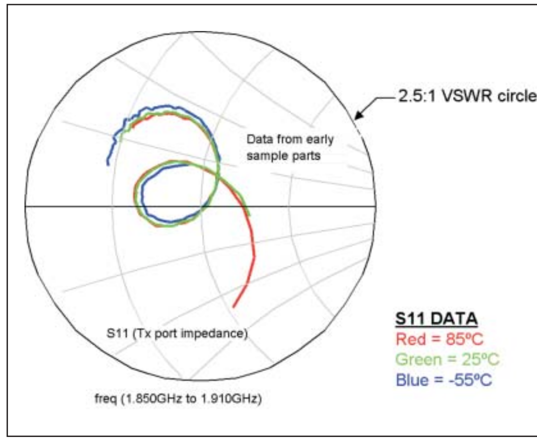

Figure 1 · Duplexer S11 vs. frequency and temperature.

Care was taken in the measurement of S-parameters to keep the duplexer case temperature at +85°C, +25°C and –55°C. In the real world of handsets, the PA dumps a lot of heat into the circuit board next to the duplexer and the thermal resistance from circuit board to the exterior of the handset is not zero, so these measurements do not correspond to handset case temperatures of +85°C, +25°C and –55°C. Taking all of the very complex thermal considerations of a handset into account is beyond the scope of this (or any practical) note. Thus I will stick to duplexer case temperature in my discussions.

Results of the simulations can be seen in Figure 1, where only S11 is displayed over the CDMA Tx band of frequencies. These values of duplexer input reflection coefficient assume an antenna impedance of 50 +j0 ohms. Note that the duplexer's S11 fits into a 2.0:1 VSWR circle at all frequencies and temperatures. The duplexer's S11 exhibits some strong variation in impedance with temperature at 1910 MHz, the top of the band, where the shift of the filter skirt with temperature affects the Tx port input impedance.

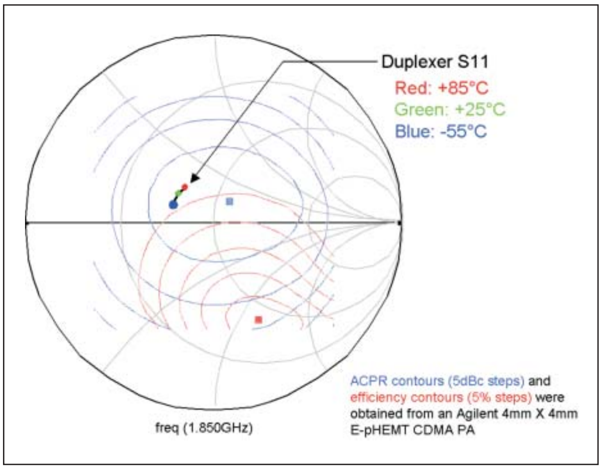

Figure 2 · S11 vs. temperature at 1850 MHz.

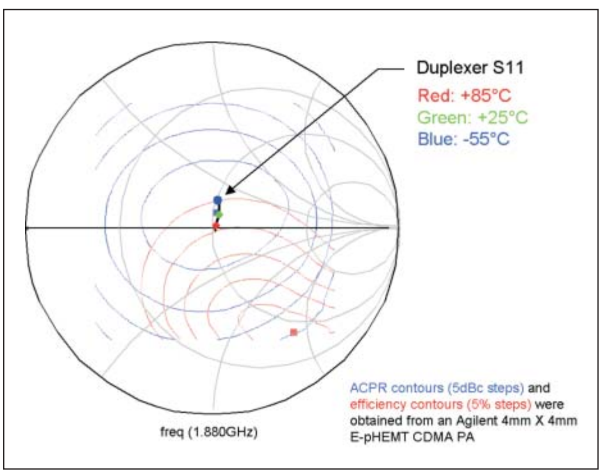

Figure 3 · S11 vs. temperature at 1880 MHz.

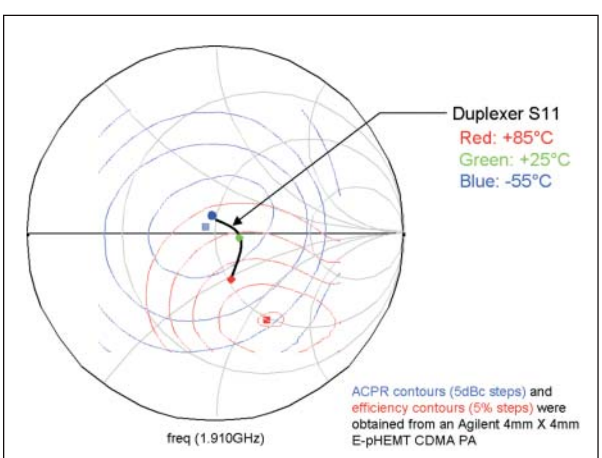

Figure 4 · S11 vs. temperature at 1910 MHz.

In order to bring some focus to these data, I plotted S11 versus temperature at the low end, mid band and high end of the Tx frequency range, and overlaid the ACPR and efficiency contours of an Agilent 4 × 4 mm power amplifier. These plots can be seen in Figures 2, 3 and 4. Note that no attempt was made to mismatch the duplexer S11 to maximize PA efficiency or linearity.

It can be seen in all three figures that the FBAR duplexer input impedance is relatively stable with temperature. Impedance variation is minor at 1850 MHz, but less so at midband, where PA efficiency drops by 5 percent as duplexer case temperature drops from +85°C to –55°C. Of course, this drop in efficiency translates into increased consumption of battery power and increased heating of the PA and its circuit board.

Because of the downward frequency shift in the passband skirt with increasing temperature, the effect is most pronounced at 1910 MHz. Again, PA efficiency rises with increasing temperature, with a delta or change of 11 percent. In all three plots, it can be seen that ACPR is little affected by the variation in duplexer impedance with temperature.

As mentioned earlier, a change in power amplifier manufacturer or model, or a change in the length of line between duplexer and PA, will substantially alter these conclusions. The point is that duplexer S11 is not constant with temperature and that this variation must be taken into account.

Impedance Variations Due to Antenna VSWR

When the load presented to port 3 (antenna) of the duplexer is other than 50 +j0 ohms, things get complicated very quickly. Consider the situation diagrammed in Figure 5. The load presented to port 3 of the duplexer is varied, with a magnitude of $\Gamma = 0.333$ (VSWR = 2:1) at all possible phase angles. The duplexer has some reflection coefficient $\neq 0$ at both ports 1 and 3. There is also an interaction between the variable load and S33. The result is transmitted back to port 1 with some loss and transmission phase shift, as well as some interaction with S11. The result is a circle on the Smith chart which is smaller and shifted, as shown. Since S11, S33 and S31 vary with temperature and frequency, the impedance presented by the duplexer to the PA output is highly variable under these conditions.

In Figure 6, I have plotted the loci of all values of S11 corresponding to an antenna VSWR of 2:1 at all phase angles, with temperature as a parameter. For an antenna load such that VSWR ≤2:1 at any phase angle at 25°C, the PA will be presented with an impedance anywhere in the green circle. The same is true at 85°C (red circle) and –55°C (blue circle). As can be seen, these three circles, containing all possible values of S11 as a function of temperature and antenna impedance ($|\Gamma| \leq 0.333$), cover a lot of the Smith chart and a wide range of PA efficiency and ACPR contours. For example, efficiency could vary by 25 percent as temperature ranges from

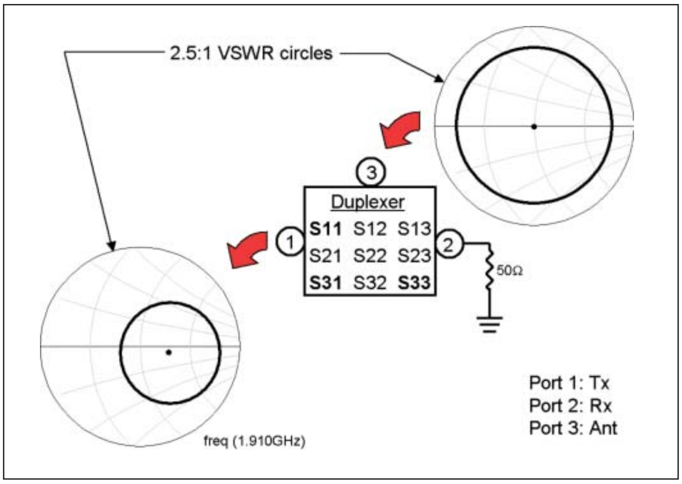

Figure 5 · How a variable antenna load changes S11.

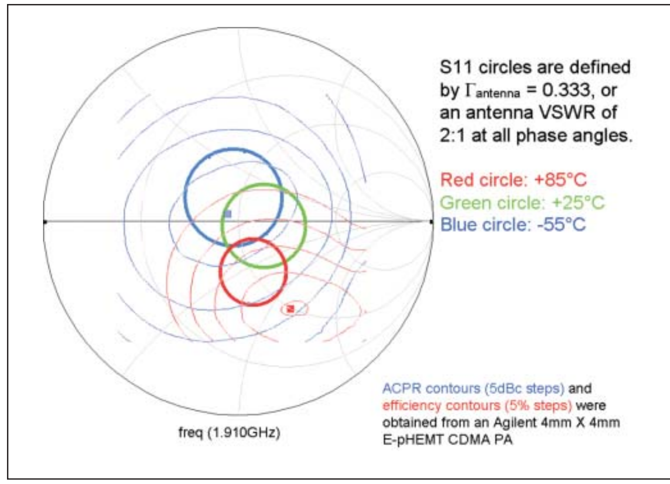

Figure 6 · Loci of all possible S11 at 1910 MHz.

85°C to –55°C, depending upon the antenna impedance presented to port 3 of the duplexer.

There is little that can be done to control these external influences on Tx chain performance. In the real world, temperature varies widely (as it does in FCC certification tests). There is no way in which the antenna's environment can be controlled—I think that a maximum VSWR of 2:1 is optimistic. All that the designer can do is to select a duplexer and PA such that the impact of these variables is minimized, and perform simulations with S-parameter and contour data over temperature.

Conclusion

When selecting a components and designing the transmit chain of a handset, the designer must obtain S-parameter S3P files at +85°C, +25°C and –30°C from the duplexer manufacturer. Room temperature data is not enough. Further, simulations must be performed on the power chain using these S3P files to conduct sensitivity analyses over temperature and antenna impedance variations before committing a handset design to production.

Acknowledgments

I would like to thank Asrul Sani Abdullah for his careful measurements of duplexer S-parameters over temperature and Mitchell Bramlett for the power amplifier contour data. I am particularly mindful of the insightful advice provided by Dave Wu and Marshall Maple, without which this note would have been very much different.

Reference

1. Agilent Technologies' Advanced Design System (ADS); information at www.agilent.com

Author Information

Ray Waugh is Applications Engineer for the Agilent Technologies line of FBAR duplexers. He has a BSE from the University of Michigan, a MS from UCLA and has more than 40 years experience in RF and microwave engineering. He can be contacted by e-mail at: ray_waugh@agilent.com