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A Needle in a Haystack: Optimizing Mixer Selection Using Progressive New Tools

Executive Interview Series

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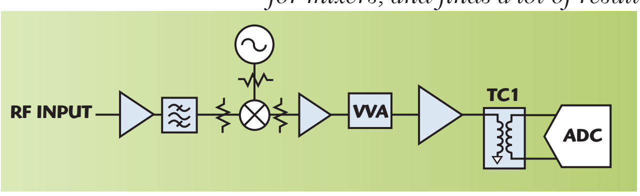
Bob is asked to develop a new radio system design, with some tough goals on RF performance and power consumption. Like many RF engineers, Bob has never really been comfortable with mixers. There is something mysterious about how they convert one frequency to another, and his formal education only covered them briefly; you know, the Taylor series expansion of the diode curve with two sine waves. His design experience and wisdom of his colleagues leads him to a simple rule of thumb: If you need good linearity and IMD performance, use a high LO mixer. But a high LO mixer requires a big LO booster amplifier, and that means more power consumption. Bob's problem is how to distribute the gain and power in his radio design to get the needed linearity and still use the lowest power.

Bob's design (see ***Figure 1****) has goals that include frequency response and IMD performance; his key goal is +22 dBm IP3 at a frequency of 2.5 GHz. He starts with a Web search for mixers, and finds a lot of results, so he picks a few sites and starts looking over spec sheets. He is determined that he can only afford around +7 dBm from his LO drive, but needs good IP3 for his application. He starts to search through data sheets and nothing really meets his needs; all the level 7 mixers have low IP3. What he finds is that he needs high level mixers, +13 dBm or higher, to achieve his IP3 specs, but that is going to require an additional amplifier and he cannot afford the power.*



▲ *Fig. 1 System block diagram of a receiver.*

Let us talk about the skills and knowledge needed to work out a design; the skills required depend upon a wealth of experience in device or components selection, which not all designers possess. For example:

- The ability to predict how components perform given the stimulus of the specific system, understanding that some of the parameters do not change as you may think (this might be particularly troublesome for distortion parameters).
- Even components with similar or the same high level specifications, e.g. "level 7 mixer", or "double balanced mixer", may have very different internal designs, use different in-

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ternal components (diodes, FETs, baluns) so that their behavior vs. RF and especially LO drive may be quite different, even if they show similar behavior at one specified RF or LO drive point.

- Often, performance other than what is contained in a spec sheet is required to understand behavior in a system and therefore data and the ability to characterize components beyond the specified range is a benefit.

Characterization beyond the spec sheet will also allow one to discover how robust a design implementation is with respect to mix-and-match of parts and the performance of parts over time and temperature.

In Bob's search, some of the mixers he found were on the Mini-Circuits website, which also includes a progressive new tool: The Yoni2™ search engine, which searches an extensive database of measured performance of all the mixers in the database. He tries the Yoni2 search engine, puts in an LO power range of 5 to 10 dBm, with his IP3 spec of +22 dBm, and decides he can accept about 9 dB conversion loss if he can get the distortion he needs (see ***Figure 2****). Yoni2 returns the choices (see* ***Figure 3****).*

Bob sees three options, and looks at the data sheet for each. It turns out that the first two options are really the same device—the SIM-722MH+—but the second entry represents the results of a special test of that device. The third choice was a mixer with an integrated amplifier, so it may consume too much power. From here, Bob clicks on the data sheet page (see ***Figure 4****), looks at the measured IP3 data and sees that at his frequency of interest (2500 MHz), the IP3 at lower LO drive (+10) is actually better than at higher LO drive, which is not what he expects. He thought all mixers had better IP3 with higher LO drive, but the data shows that sometimes this commonly held idea is not true, and the normal behavior reverses. Even though this mixer is a level 13 mixer, it looks like it might work in the level 7 design. Although the data directs Bob to a good choice for the right mixer, it does not provide all the information he needs to validate his choice. He needs to see how this mixer behaves at a lower power level.*

A design problem starts with objectives and constraints, e.g. the RF Receiver Chain:

- Objective: Develop a system architecture including the allocation of amplification, filtering and frequency conversion
- Constraints: Power, dynamic range (min and max levels), frequency of operation. To achieve the goals, a designer has a number of tradeoffs available
- Allocation of gain and power stages depends on distribution of noise figure and distortion characteristics

The reality is that tradeoffs may be more complex than what is described in school or conventional data books.

Tradeoffs include: noise floor, noise figure, power consumption, power handling and distortion performance.

One tradeoff not often considered is the power consumed by the LO drive amplifier versus the mixer distortion and gain properties. Can a "starved LO" mixer operate with much lower total power consumption in the converter chain? How should one determine the tradeoffs in mixer LO drive level for different class of mixers?

Bob knows that making IP3 versus LO power measurements can be pretty daunting, but he needs to know the details of this curve to ensure that if his LO drive to the mixer varies due to battery voltage or temperature it will still perform. Traditional methods to test this include using a signal generator to get the two tones, another one to get the LO drive, and a spectrum analyzer to read the results, but then he has to write some code to control everything, calibrate everything and plot the curves. Fortunately for Bob, he has a newer VNA, with integrated sources, and integrated applications, such as IMDX, which allows direct measurement of mixer IP3 characteristics: The PNA-X. Bob sets up a swept-frequency, IMD-X measurement of the SIM-722MH+ mixer, and makes measurements to confirm the Yoni2 data, and see how conversion loss behaves versus LO drive level. (see swept frequency input IP3 in ***Figure 5****).*

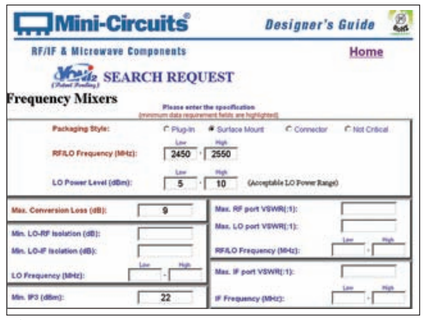
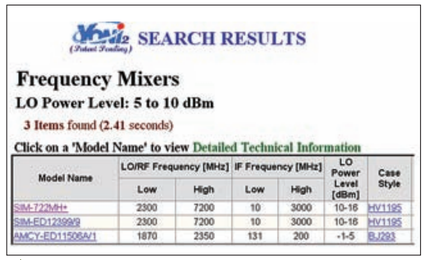


Fig. 2 Yoni2 search request page.



SEARCH RESULTS

Frequency Mixers

LO Power Level: 5 to 10 dBm

3 Items found (2.41 seconds)

Click on a 'Model Name' to view Detailed Technical Information

Model Name	LO/RF Frequency [MHz]		IF Frequency [MHz]		LO Power Level [dBm]	Case Style
	Low	High	Low	High		
SIM-722MH+	2300	7200	10	3000	10-16	HV1195
SIM-ED12399/9	2300	7200	10	3000	10-16	HV1195
AMCY-ED11506A/1	1870	2350	131	200	-1-5	BJ293

Fig. 3 Yoni2 search results.

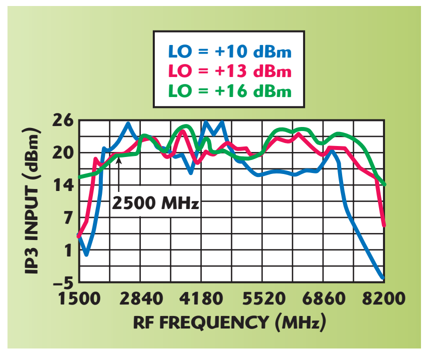


Fig. 4 Data Sheet from the Yoni2 search.

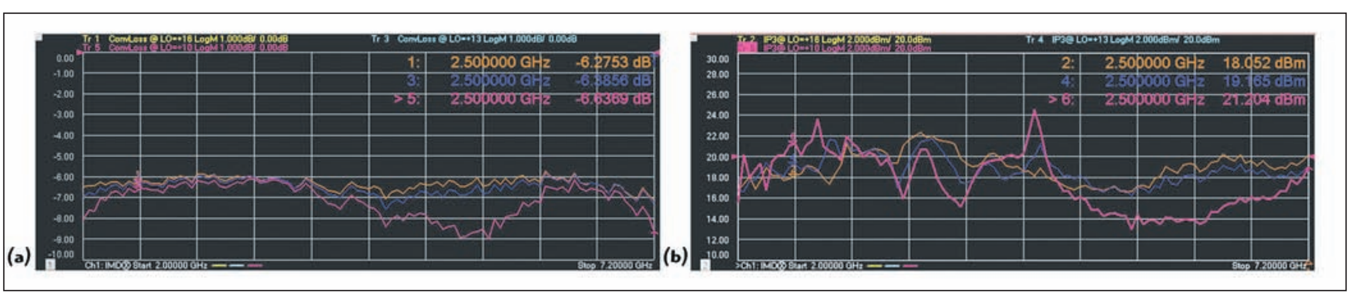
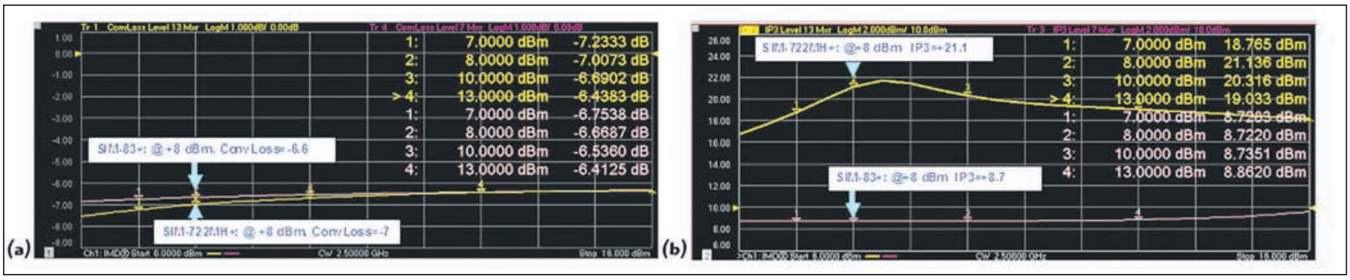


Fig. 5 Measurements of a real SIM-722MH+ mixer, at +10, +13 and +16 dBm LO drive for conversion loss (a) and IP3 (b).



▲ *Fig. 6 Conversion loss (a) and IP3 (b) for the SIM-722MH+ and SIM-83+ vs. LO power drive.*

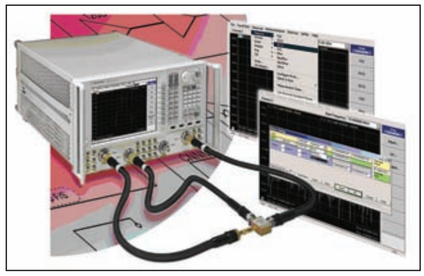
STANDARD CHARACTERIZATION VERSUS EXTENDED CHARACTERIZATION

New characterization tools and techniques can efficiently provide the wealth of data the engineer can use to optimize his/her component selection and system architecture. A new instrument, the PNA-X with the new mixer IMD measurement application (IMD-X), provides for the first time an integrated calibration and measurement suite that simplifies these complex measurements. As shown in Figure 5, the conversion loss and IP3 results for a particular SIM-722MH+ mixer closely match the results of the data sheet, but the PNA-X has the capability to extend the measurements beyond the data sheet to match the requirements of a design. In this case, it is clear that for the frequency of interest, 2.5 GHz, the conversion loss does not change much with LO drive, but the IP3 appears to change significantly. This change versus LO drive power can be displayed directly in a LO power sweep.

These results show that at level +10 dBm, the mixer has better IP3 than at +13 dBm, and might be very suitable for the design. But he still needs to see how the mixer behaves versus LO drive power. Fortunately, with the PNA-X, he can simply change the sweep type to power sweep, and with a couple of keystrokes, set the LO start and stop powers, to plot the IP3 versus LO drive power. To make it even easier, the automatic calibration he did for the swept frequency IP3 measurement can be used for this measurement as well. ***Figure 6*** *shows what Bob saw, that the IP3 for the mixer does have a peak value with lower LO drive power, and is pretty well controlled around his desired power range. He can also see the behavior of the conversion loss versus LO drive level. Just to be thorough, Bob tests a level 7 version of the same family, a SIM-83+. This mixer has the same pin-out, but a lower drive level. Yoni2 did not select it, but Bob was curious. The plot shows the results of the SIM-83+ versus power level, and he sees that it is very well controlled, and has slightly better conversion loss, but just does not have enough IP3, confirming the recommendations from the Yoni2 selection tool.*

With these results, Bob can continue his design with a new understanding of the tradeoffs available to him when it comes to mixer performance. In this case, it is clear that 8.5 dBm is the optimum drive, but the IP3 is reasonably controlled at a lower power level, and the conversion loss is also reasonably controlled. Bob can now make intelligent tradeoffs between LO drive, IP3 and conversion loss with data that was previously insufficient or just too difficult to obtain. This understanding might allow him to completely eliminate an LO gain stage, saving power and cost. The realization of using components beyond their data sheet values, and the willingness of part manufacturers to provide a database of characteristics, provides insights into design options that were not possible to see in the past.

The results of Figure 6 provide compelling evidence that many aspects of mixer design contribute to the overall performance, especially in the nonlinear domain. To many engineers, it would be unexpected that a high drive (level 13) mixer might perform better at lower drive than a lower drive mixer (level 7), but the data from Figure 6 shows this is true. In addition, the conversion loss versus LO drive level data provides very useful information on system design tradeoffs. Without this data, "common wisdom" would say that one would risk getting poor nonlinear performance if one used too low a LO drive, a conclusion that is in fact wrong for this mixer type.



▲ *Fig. 7 Agilent PNA-X configured for mixer measurements.*

This article points to a new direction in the component specification and circuit design. Current practice limits a designer to sorting through physical or virtual (web-based) data sheets to infer from them the parts that might be usable in a design task. Unfortunately, most data sheets are not sufficiently detailed, and even if they were, sorting through tens or hundreds of pages of data sheets to find the one "needle-in-the-haystack" component is just not feasible.

However, there are new progressive data mining tools like Yoni2, which through access to new dimensions in selecting off-the-shelf components, enable designers to select a part that conventional search engines or websites cannot locate. When coupled with progressive measurement and analysis tools like the PNA-X (see ***Figure 7***), which can characterize components in multiple dimensions to support these search tools, it enables designers to validate this data, and support the designers' ability to meet more challenging system requirements in a fast, repeatable method that is beyond the normal "rule-of-thumb" design wisdom that might limit innovation. This ensures the operational attributes are fully understood and the optimum operating point is clear for the designer to use. ■