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Dual Mixers

This article is an introduction to dual mixers and the unique parameters associated with them.

DUAL MIXER DEFINED

A dual mixer is comprised of two mixers and an LO power divider integrated into a single package. This integration yields two channels of frequency conversion, with both using the same LO signal. Figure 1 shows the block diagram of a dual mixer. Note that each channel has independent R and I ports, but shares the LO signal. This integration has many advantages over using discrete components; some of these are: 1) the size and weight of the dual mixer is a fraction of the three components combined; 2) interconnections between components are eliminated, which leads to higher performance by eliminating the reflections associated with them; 3) by having both mixers in the same housing they will track better over temperature; and 4) the price and parts-count of the system are reduced. Since the dual mixer is a two-channel device, some additional parameters, not necessary for single mixers, are required to fully specify its performance; an explanation of these parameters follows.

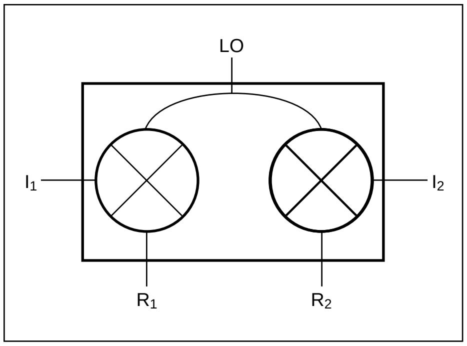

Figure 1. dual mixer block diagram.

AMPLITUDE MATCH

The amplitude match of a dual mixer is the absolute difference in conversion loss between the two channels when both channels have identical inputs. This is normally determined by measuring the conversion loss of each channel independently, using the same input signal, and then comparing the difference (it is usually a good practice to terminate the unused ports when making a measurement on only one channel). Figure 2 shows graphically what is meant by amplitude matching. In this figure the conversion loss-versus-frequency is plotted for both channels. The amplitude match at any given frequency is simply the difference between the two traces. The worst-case amplitude match is 0.6 dB and occurs at a frequency of 14.7 GHz.

PHASE MATCH

Phase matching is completely analogous to amplitude matching, but must be measured indirectly because the phase delay through a mixer is difficult to measure. What is measured is the difference in phase delay between the two channels of the dual mixer. Phase matching is defined as the difference in phase between the two output signals when both channels have identical input signals. Two typical phase-matching measurement techniques are shown in Figures 3 and 4. Figure 3 shows the dual down-conversion method. In this method, both channels of the dual mixer are measured with respect to a third mixer. By taking the difference between these two measurements, the phase matching is determined. This is easily seen mathematically. The phase difference between the reference mixer and channel one of the device under test (DUT) is, $\phi_R - \phi_1$; the difference between the reference and channel two is, $\phi_R - \phi_2$. The difference between these two measurements is, $(\phi_R - \phi_1) - (\phi_R - \phi_2) = \phi_2 - \phi_1$ which is the phase matching. This equation reveals that the mixer in the reference channel is only necessary to provide the reference channel of the network analyzer with a signal of the same frequency as the test channel; the actual phase delay through this mixer is not important. However, from a practical point of view, the mixer should be similar to the DUT because this will allow the equipment to function over a smaller range of phase angles and, hence, be more accurate. The line stretcher in the reference arm is used to remove any differences in line length between the two arms. Again, this is not a necessity, but will enhance accuracy. Finding the difference between the two measurements is easily done by using equipment which can normalize to one measurement, and show the second measurement as the difference between the two, or by using computer-aided testing.

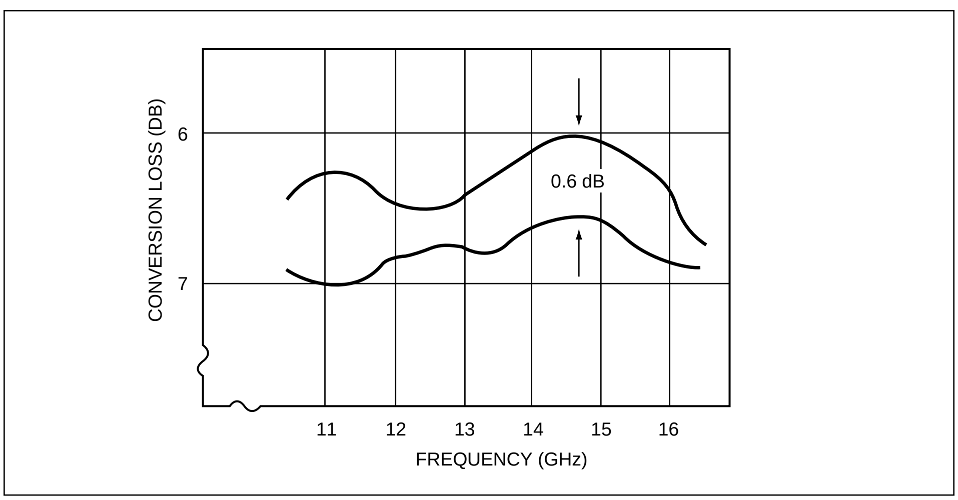

Figure 2. Amplitude matching.

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The second method is shown in Figure 4, and is called the down-up method. In this method, the down-converted IF signal is up-converted back to the original rf frequency (hence, the name). Again, this method provides a measure of the difference in phase delay between the two channels of the DUT rather than a measure of absolute phase delay. The mathematics of this method differ slightly from those of the dual down-conversion method. In this method, the absolute phase delay through the DUT and the reference mixer are added. For channel two of the DUT this measurement is, $\phi_R + \phi_2$, and for channel one it is, $\phi_R + \phi_1$.The difference between these measurements is, $\phi_2 - \phi_1$, which is the phase matching.

The advantages of the dual down-conversion method are: 1) the network analyzer sees a higher power level because only one frequency conversion is taking place and, hence, only one conversion loss is in the test-channel path, and 2) the network analyzer is operating at a lower frequency. The advantage of the down-up method is that a standard automatic network analyzer (ANA) can be used without any modifications except the addition of the LO power source. This leaves the ANA intact and available for other applications.

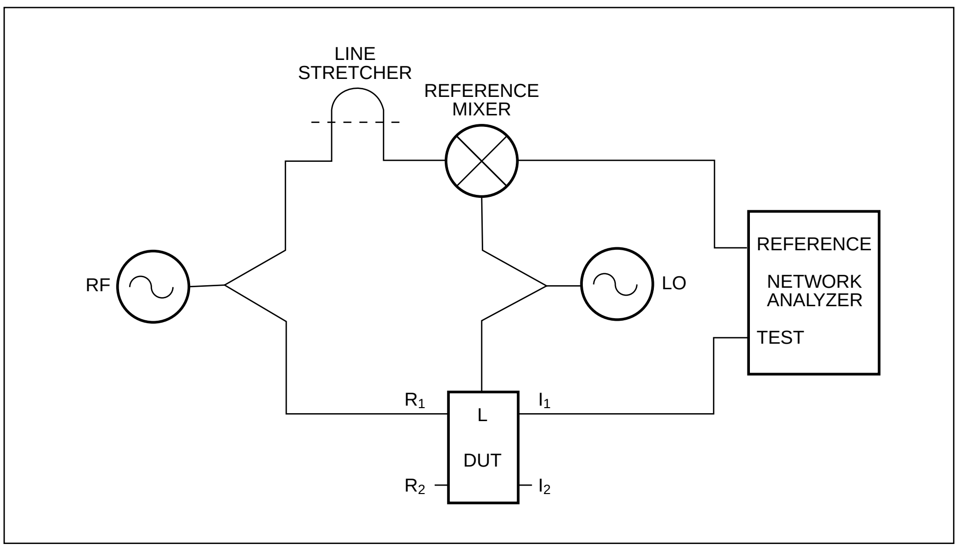

Figure 3. Dual down-conversion method of measuring phase matching.

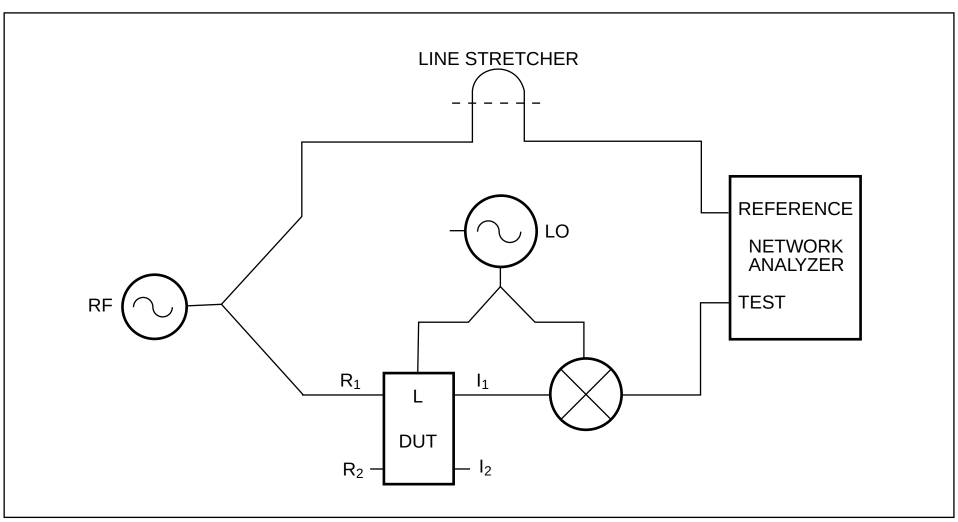

Figure 4. The down-up method of measuring phase matching.

AMPLITUDE TRACKING

Amplitude tracking is a measure of how well the shape of one conversion-loss contour matches another. It differs from amplitude matching in that it is usually specified over narrow intervals and allows for any fixed offsets to be removed. Figure 5 shows graphically what is meant by amplitude tracking. This figure is the same as Figure 2, which shows amplitude matching, except that one of the conversion-loss (CL) curves has been broken down into 1-GHz intervals, and fixed offsets in each interval have been removed. In any given interval, the amplitude tracking is calculated with the following equation[1]:

$$\text{Amplitude Track} = \frac{\Delta_{max} - \Delta_{min}}{2}$$

where,

$\Delta_{max} = (CL_2\text{-}CL_1)_{max}$, and
$\Delta_{min} = (CL_2\text{-}CL_1)_{min}$

before any offsets are removed. In Figure 2, for example, the maximum difference in the interval between 12 and 13 GHz occurs at 12 GHz and is 0.4 dB; the minimum difference is 0.2 dB at 12.7 GHz. Therefore, on this interval, the tracking is 0.1 dB. This equation is derived in Appendix 1.

If the only data points known on the interval are the end points, the tracking equation becomes:

$$\text{Amplitude Track} = \frac{\Delta_{f_1} - \Delta_{f_2}}{2}$$

where, f_1 and f_2 are the end points. From this point of view, it is seen that tracking gives information about the differences in the slopes of the two contours (see Appendix 1). It is also apparent from Figure 5 that the slopes of the curves determine the tracking. Where the slopes of the curves are nearly equal, the tracking is good, and where they are different, the tracking is poor.

Figure 5 and the above equations show that the tracking is always better than or equal to

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the matching. A typical specification for the amplitude matching of a broadband dual mixer is ±1 dB, while the same mixer will track to ±0.1 dB over 400-MHz intervals. Note that when tracking is specified, both an amplitude difference and a frequency interval need to be specified, and as the interval is increased, the amplitude difference will increase.

PHASE TRACKING

Phase tracking is completely analogous to amplitude tracking. However, since phase-tracking measurements measure the difference in phase between the two channels, the data is already in terms of deltas and can be plugged directly into the tracking equations.

CHANNEL-TO-CHANNEL ISOLATION

Ideally, in a dual mixer the input signal on channel 2 does not cause a converted signal to appear at the output of channel 1, and vice versa. In reality, some signal power from channel 2, for example, will show up as a converted signal at the output of channel 1; channel-to-channel isolation specifies how far below the desired output this undesired signal is when both inputs are identical. To measure channel 2-to-channel 1 isolation, an input signal is applied to channel 1, and the output level at channel 1 is noted. Next, the input is moved from channel 1 to channel 2, and the output at channel 1 is noted again. The difference in dB between these two cases is the channel-to-channel isolation. It is important to note that frequency conversion is taking place in channel-to-channel isolation. There are two ways that the undesired signal can cause an output on the opposite channel: the converted signal can leak over to the opposite output, or the input signal can leak over to the opposite channel, and then be converted.

CROSS-CHANNEL ISOLATION

Cross-channel isolation is the term used when input signals on one channel leak to ports on another channel. In cross-channel isolation, no frequency conversion is taking place. There are eight possible cross-channel isolation paths: R_1-R_2, R_1-I_2, I_1-I_2, I_1-R_2, and the reverse of these. Cross-channel isolation is measured in the same manner as normal isolations. For example, R_1-I_2 isolation is measured in the same manner as R_1-I_1 isolation. One important difference, however, is that cross-channel isolations will generally be better than normal isolations and may require more sensitive equipment to make the measurements.

LOCAL-OSCILLATOR RELATED PARAMETERS

Many mixer parameters are related to the local-oscillator power level, or use this power level as a figure of merit. For example, in a double-balanced mixer, the third-order input intercept point is typically 3 to 5 dB above the LO drive level. When considering dual-mixer parameters, itis important to remember that the LO power is split between two mixers; therefore, each mixer receives 3 dB less LO drive than the level applied. This means third-order intercept points will be only 0 to 2 dB above the applied LO power level, which appears low when the LO power split is not taken into account. This argument also applies when considering 1-dB compression points and intermodulation products.

APPLICATIONS

The following is an application using a dual mixer. The intent of this application is not to give an exhaustive study of the possible uses for dual mixers, but to give an example of how the parameters discussed above are related to system performance.

IMAGE-REJECT MIXERS

When a double-balanced mixer is used to down-convert a band of frequencies to an IF baseband, a problem known as imaging can exist. For any given LO frequency, there are two frequencies which can mix with this LO to give the same IF. If one of these signals is the desired signal, the other is known as the

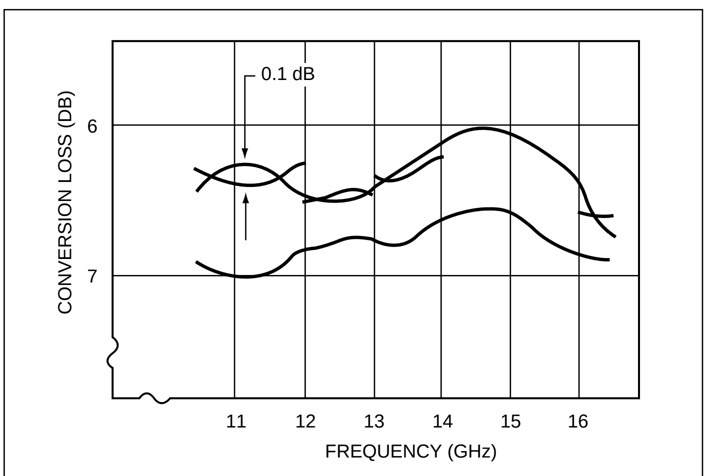

Figure 5. Amplitude tracking.

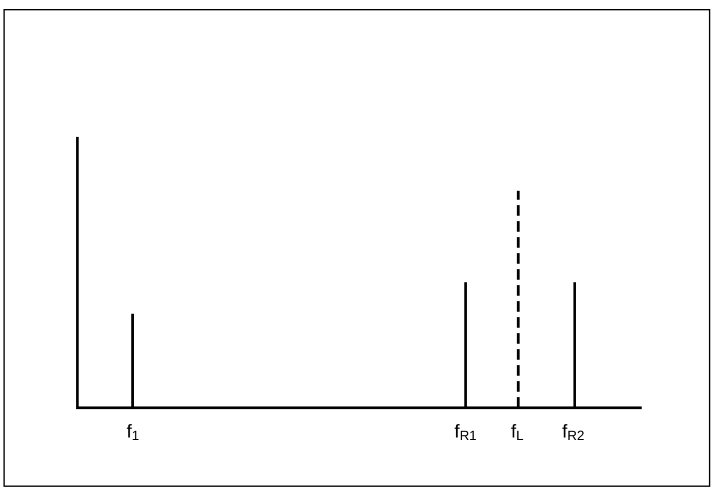

Figure 6. Frequency spectrum showing two signals which convert to the same IF.

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image frequency. Mathematically, this can be shown by the two equations:

$f_I = f_L - f_{R1}$ or $f_I = f_{R2} - f_L$

One signal is above f_L and the other is below fL; both are separated from f_L by the IF frequency. Figure 6 is a graphical representation of this situation. Since signal processing at the IF frequency cannot determine which of these signals has been received, an ambiguity exists.

One solution to this problem is the use of image-reject mixers (IRMs). An IRM canalizes these two signals to separate outputs. Figure 7 shows the block diagram of an IRM. Notice that this circuit can be made with a dual mixer and two quadrature hybrids. The operation of the IRM is most readily seen by considering the high-side and low-side LO cases separately. (High-side LO) means that the LO frequency is above the signal frequency, as with f_{R1} in Figure 6.)

In the high-side LO case,

$I_1' = (1/\sqrt{2})[A_1V_R \cos(\omega_L t - \omega_R t + \phi_1)]$

and

$I_2' = (1/\sqrt{2})[A_2V_R \cos(\omega_L t - \omega_R t - 90 + \phi_2)]$,

where the $1/\sqrt{2}$ terms represent the power split through the quadrature coupler, A_1 and A_2 are the voltage losses through channel 1 and channel 2 of the dual mixer, and (1 and (2 are the phase delays through the dual mixer. To express voltage losses in terms of conversion losses use the equation CL = 20LogA. Recall that $\phi_2 - \phi_1$ equals the phase matching and $CL_2 - CL_1$ equals the amplitude matching. When the signals are recombined through the IF hybrid;

$$I_1 = 1/2\,[A_1V_R \cos(\omega_L t - \omega_R t + \phi_1)] + 1/2\,[A_2V_R \cos(\omega_L t - \omega_R t + \phi_2)] \quad (1)$$

$$I_2 = 1/2\,[A_1V_R \cos(\omega_L t - \omega_R t + 90 + \phi_1)] + 1/2\,[A_2V_R \cos(\omega_L t - \omega_R t - 90 + \phi_2)]. \quad (2)$$

If $A_1 = A_2$ (i.e., $CL_1 = CL_2$) and $\phi_1 = \phi_2$, then, $I_1 = A_1V_R \cos(\omega_L t - \omega_R t + \phi_1)$ and $I_2 = 0$.

For the low-side LO case;

$I_1' = (1/\sqrt{2})[A_1V_R \cos(\omega_R t - \omega_L t + \phi_1)]$

and

$I_2' = (1/\sqrt{2})[A_2V_R \cos(\omega_R t - \omega_L t + 90 + \phi_2)]$,

This yields output signals of:

$$I_1 = 1/2\,[A_1V_R \cos(\omega_R t - \omega_L t + \phi_1)] + 1/2\,[A_2V_R \cos(\omega_R t - \omega_L t + 180 + \phi_2)]$$

$$I_2 = 1/2\,[A_1V_R \cos(\omega_L t - \omega_R t + 90 + \phi_1)] + 1/2\,[A_2V_R \cos(\omega_L t - \omega_R t + 90 + \phi_2)].$$

If $A_1 = A_2$ and $\phi_1 = \phi_2$; then,

$I_1 = 0$, and

$I_2 = A_1V_R \cos(\omega_R t - \omega_L t + 90 + \phi_1)$.

This analysis has assumed perfect quadrature hybrids, and does not consider VSWR effects. However, it does lead to an analysis of what effects the amplitude and phase matching of the dual mixer have on the image suppression of the IRM. This is easily seen by considering these effects separately.

If $A_1 = A_2 = A$, then for the high-side LO case, using equations (1) and (2);

$$I_1 = 1/2\,\{A_1V_R[\cos(\omega_L t - \omega_R t + \phi_2) + \cos(\omega_L t - \omega_R t + \phi_1)]\}$$

$$= AV_R \cos[(\phi_2 - \phi_1)/2] \cos(\omega_L - \omega_R)t \quad (3)$$

and

$$I_2 = 1/2\,\{A_1V_R[\cos(\omega_L t - \omega_R t - 90 + \phi_2) + \cos(\omega_L t - \omega_R t + 90 + \phi_1)]\}$$

$$= AV_R[\cos 1/2(\phi_2 - \phi_1 - 180)] \cos(\omega_L t - \omega_R t)$$

$$= AV_R \sin[(\phi_2 - \phi_1)/2] \cos(\omega_L - \omega_R)t \quad (4)$$

By dividing (3) by (4) and taking the Log to convert to dB;

$$\text{Suppression (dB)} = -20\,\text{Log}\left|\frac{\cos\left(\frac{\phi_2-\phi_1}{2}\right)}{\sin\left(\frac{\phi_2-\phi_1}{2}\right)}\right|$$

$$= -20\,\log \cot\left(\frac{\phi_2-\phi_1}{2}\right) \quad (5)$$

This equation gives the image rejection of the IRM as a function of the phase matching of the dual mixer, when the amplitude matching is perfect.

To find the suppression when the phase matching is perfect and the amplitude matching is allowed to vary, return to equations (1) and (2).

If $\phi_2 = \phi_1 = 0$;

$$I_1 = 1/2\,[A_1V_R \cos(\omega_L t - \omega_R t)] + 1/2\,[A_2V_R \cos(\omega_L t - \omega_R t)]$$

$$= 1/2\,V_R(A_1 + A_2)\cos(\omega_L t - \omega_R t)$$

$$I_2 = 1/2\,[A_1V_R \cos(\omega_L t - \omega_R t + 90)] + 1/2\,[A_2V_R \cos(\omega_L t - \omega_R t - 90)]$$

$$= 1/2\,V_R(A_1 - A_2)\cos(\omega_L t - \omega_R t)$$

By dividing the magnitude of I_2 by the magnitude of I_1 and converting to dB;

$$\text{Suppression (dB)} = -20\,\text{Log}\left|\left(\frac{A_2-A_1}{A_2+A_1}\right)\right| \quad (6)$$

A graph of the general case where both phase and amplitude matching are allowed to vary is shown in Figure 8.

This analysis has been simplified by removing all non-ideal effects except amplitude and phase matching to show how these parame-

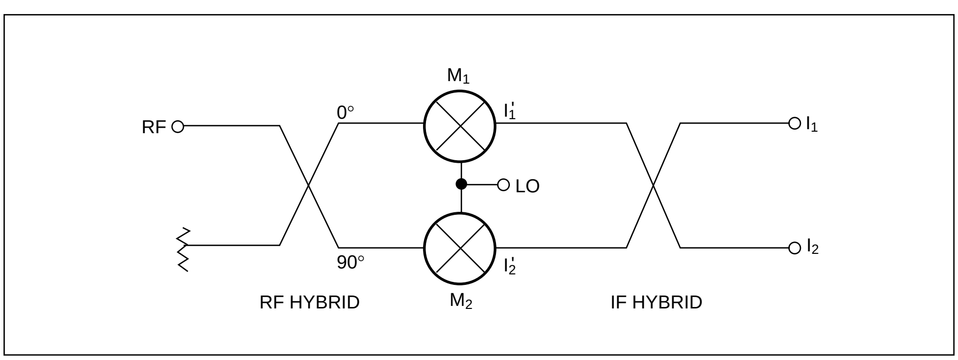

Figure 7. Block diagram of an image-reject mixer.

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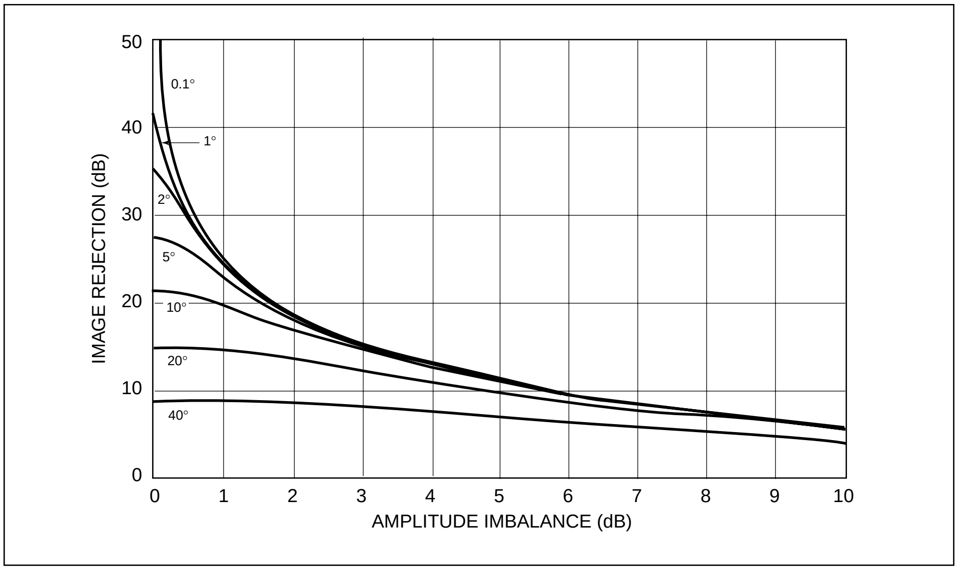

Figure 8. IR-vs-amplitude and phase imbalance.

ters effect the performance of the IRM.

The previous analysis shows what effect matching has on the image rejection of an IRM. The same analysis can be used to illustrate how tracking is related to system performance. Recall that over a given interval, tracking is the same as matching except that any fixed offsets are removed. If the IRM circuit has the provisions for removing these offsets, then the image rejection over

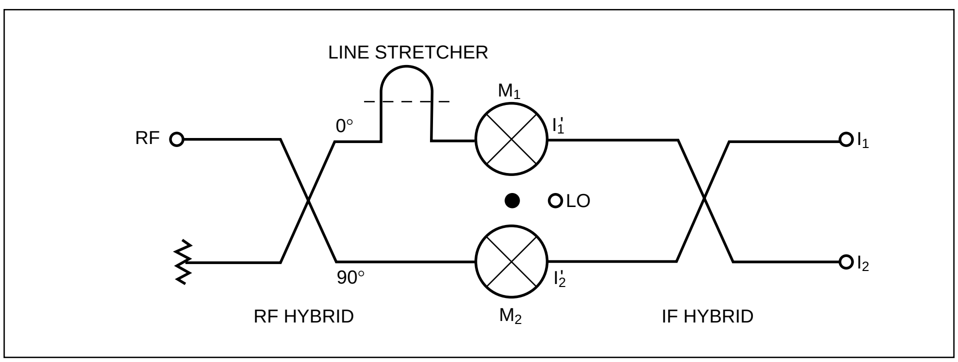

Figure 9. Image-reject mixer with phase-correction capability.

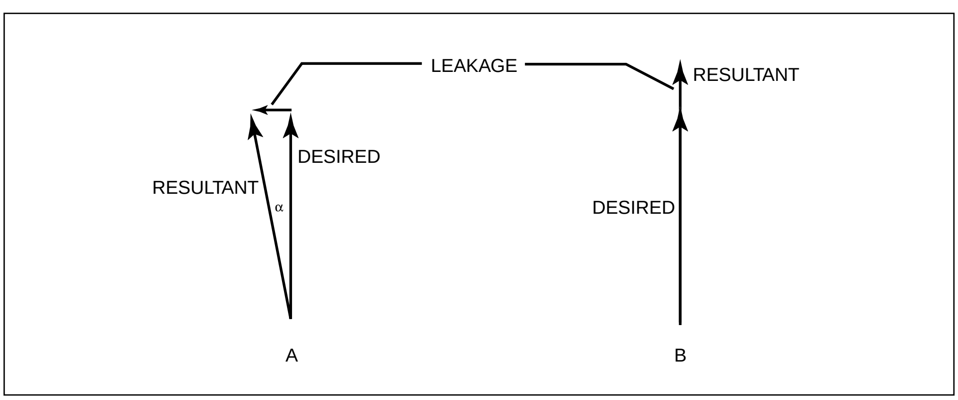

Figure 10. IF signals resulting from channel-to-channel leakage..

this interval can be improved. The improvement in image rejection is determined by comparing the results of equations 5 and 6 when tracking-vs-matching numbers are used. Figure 9 shows the previous IRM circuit with the addition of a variable phase delay in the I1' path. When this phase delay is set for the optimum offset, then the worst-case image rejection on the interval is determined from the phase tracking. Note that this offset will only be correct for one frequency interval and must be changed as the frequency of operation is changed between intervals. With shorter intervals, the tracking is better and the image rejection is improved, but more intervals are needed to cover the same frequency range. It can, therefore, be seen that tracking becomes an important parameter when the system has error-correcting or calibration capability[2].

To show how channel-to-channel isolation can affect the image rejection, consider what happens if signals leak from channel 2 to channel 1, but not from 1 to 2. This leakage will add vectorially to the desired signal at I2' and cause the resulting IF signal to have an incorrect magnitude and phase. The worst-case phase error will happen if the signal is 90 or 270 degrees out of phase with the desired IF. This will result in a phase error of,

$$\alpha = \mathrm{Tan}^{-1}\left[10^{-\left(\frac{Iso.}{20}\right)}\right],$$

where the isolation is in dB. This case is shown in Figure 10A. An isolation of 30 dB results in a phase error of 1.8 degrees, giving an image rejection of 36 dB. The worst-case amplitude error will occur if the signal is at 0 or 180 degrees with respect to the desired signal. This will cause an amplitude error of,

$$\alpha = 10^{-\left(\frac{Iso.}{20}\right)}.$$

This case is shown in Figure 10B and an isolation of 30 dB gives an amplitude error of 0.032, which yields an image rejection of 30.27 dB. The actual case will probably be at some intermediate angle, but this analysis gives an idea of how channel-to-channel isolation can affect system performance.

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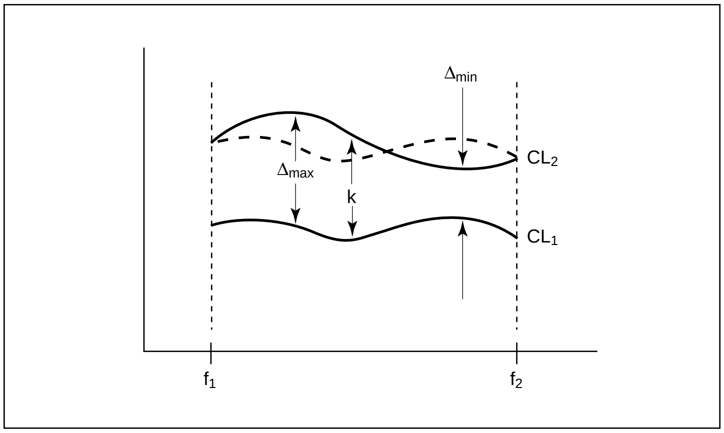

Figure A-1. Graphical representation of tracking.

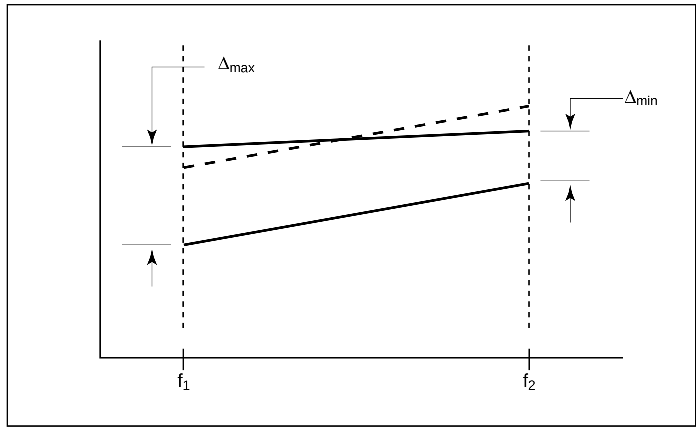

Figure A-2. Graphical representation of tracking.

SUMMARY

Matched sets of mixers are becoming widely used in microwave systems. A logical extension of the matched set of mixers is to combine the mixers and their LO power splitter into one unit; the dual mixer. This article has defined the dual mixer and the specifications which are unique to dual mixers. The main area of confusion in dual mixer specifications is the difference between matching and tracking. It is hoped that this article will help clear up this confusion. An application has been discussed with the intent of showing how the dual-mixer parameters relate to system performance. The advantages of size, weight, and performance make the dual mixer a valuable tool for the microwave system designer, and this article is intended to aid in the specification and use of dual mixers.

APPENDIX 1

DERIVATION OF TRACKING EQUATIONS

Tracking specifies how well one conversion loss or phase delay contour matches another over a given interval when a fixed offset is removed. Figure A-1 shows a plot of two conversion loss contours over a given frequency range. One of the contours has been offset by an amount, k, to give the best possible match over this interval. To determine the optimum offset, k, it is important to note that for any value of k the worst-case match will always be at the frequency of, Δ_{max} or Δ_{min}. If CL_1 is moved down (i.e., k is negative) then Δ_{max}-k will increase in magnitude and always remain the largest difference. If CL_1 is moved up (k positive), then at some point the magnitude, Δ_{min}-k, will be equal to the magnitude of Δ_{max}-k. Until this condition is reached, Δ_{max}-k will be the largest difference, and after this point, Δmin -k will be the largest difference. Therefore, the worst-case track is either

$\Delta_{max}-k$ or $\Delta_{min}-k$.

The optimum k is when these two are equal in magnitude and opposite in sign. From the above argument, any other value of k will make one of these larger in magnitude. It follows that for optimum k:

$$\Delta_{max}-k = -(\Delta_{min}-k)$$

or

$$k = \frac{\Delta_{max} + \Delta_{min}}{2}$$

Plugging this result back into the worst-case condition yields:

$$\text{Worst-Case Track} = \Delta_{max} - \frac{\Delta_{max} + \Delta_{min}}{2}$$

$$= \frac{\Delta_{max} + \Delta_{min}}{2}$$

When the only data points known on the interval are the end points, then these points are the Δ_{max} and Δ_{min} points. The tracking equation then becomes:

$$\text{Amplitude Track} = \frac{\Delta_{f_1}-\Delta_{f_2}}{2}$$

This case is shown in Figure A-2.

Notes:

1 There are other mathematical definitions for tracking. Some use a running average to determine the offset (see Appendix 1), but the common factor is that a fixed offset is removed over a given interval.

2 These error-correcting schemes are not common in image-reject mixers, but are quite common in direction-finding systems such as monopulse radars.

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