Analysis of the Effects of LO Amplifier Noise on the Overall Noise Figure of a Downconverting Mixer and IF Amplifier

Introduction

WJ Communications has developed a line of dual-branch converters designed for mobile infrastructure applications (CV210-1, CV210-2, CV210-3, CV210-3, CV211-1, CV211-2, CV211-3, collectively referred to as CV2xx). The dual-branch converters provide two separate mixer and IF amplifier elements driven by a common LO amplifier (Figure 1) and are intended to serve as the primary and diversity receive chain downconverters in single or multi-carrier transceiver cards. The mixer is a high-dynamic-range mixer that is driven by 17 dBm of LO power. In pre-production, the noise figure of the down-converter was measured to be higher than predicted. This increase in noise figure is due to the noise power contribution of the LO amplifier. This note outlines a method to determine the noise figure contribution of the LO amplifier and compare it to measured data. A CV211-1 downconverter was used in the analysis for this note, but the same concepts can be applied to all of the dual-branch downconverters.

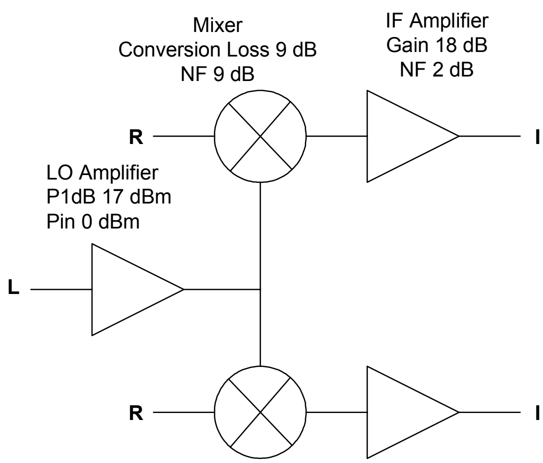

Figure 1. Downconverter Block Diagram

Mixer Characterization

The mixer was examined to determine the cause of increased noise figure. The mixer was characterized by coupling a Radio Frequency (RF), Image (IM) and Intermediate Frequency (IF) signal into the Local Oscillator (LO) and measuring the isolation at the RF, IM and IF frequencies. A high-directivity coupler was used to combine the LO signal and sideband signal at the output of the LO amplifier. The sideband signal level was –20 dBm and the LO signal level was 17 dBm. The measured isolation results for a PCS mixer are shown in Table 1.

Figure 2 illustrates the paths used to compute the leakage noise power at the R port of the mixer. The main contributors are the L-R and L-I isolation at the Image and RF frequencies. The leakage IF noise power is referenced to the R port by the conversion loss of the mixer. Table 1 gives the isolation of all the leakage paths in Figure 1 and a calculation of the noise power contribution of a LO amplifier with an output noise power of –150 dBm/Hz in the three bands. The conversion loss of the mixer was 9 dB. For a LO noise power of –150 dBm/Hz, the effective noise power at the R port is approximately –170 dBm/Hz.

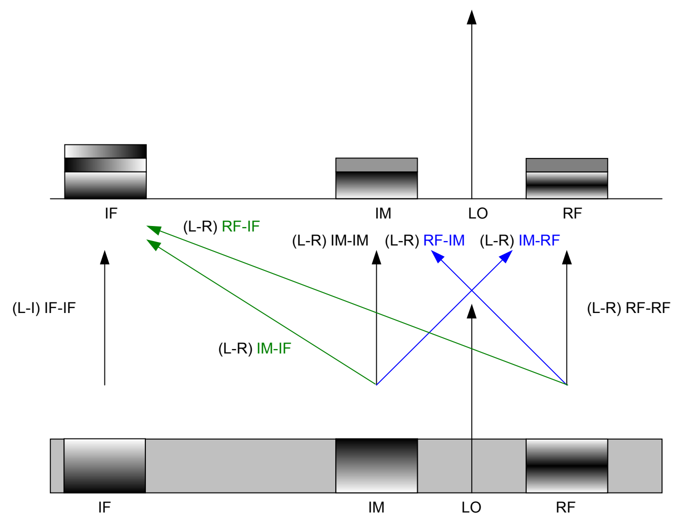

Figure 2. Components of leakage noise from LO in a mixer.

Table 1. Noise power contribution of LO amplifier with –150 dBm/Hz noise power. Mixer conversion loss is 9 dB. All noise powers are referenced to the RF port.

Isolation Path	Mixer Isolation (dB)	Noise Power (dBm/Hz)
(L-R) RF- RF	25	-175
(L-R) IM - IM	35	-185
(L-R) RF- IM	50	-200
(L-R) IM - RF	35	-185.
(L-I) RF - IF →R	26	-176
(L-I) IM - IF →R	31	-181
(L-I) IF - IF →R	51	-201
Total leaked LO noise power at the R port		-171
Total leaked LO noise power at the R port + kTB		-170

Simulation of Noise Figure

The noise power seen at the R port of the mixer is –174 dBm/Hz but the leakage noise power from the LO amplifier increases the mixer input noise power and the corresponding overall down-converter noise figure. Given the mixer isolation information from Table 1, an Excel spreadsheet was constructed to determine the affect of LO output noise power on the overall input noise power seen at the R port of the mixer. This information was then used to calculate the overall noise figure of the down-converter chain using WJ Communications' WINCAP software

The total noise power seen at the R port is a function of LO output noise power (Figure 3). At LO output noise powers below –160 dBm/Hz the noise power is dominated by thermal noise but as the LO output noise power rises, the LO noise quickly contributes to the overall noise power. This information was fed into the WINCAP analysis program (Figure 4). In the chain analysis simulation, the mixer conversion loss was 9 dB and the IF amplifier had 18 dB of gain and a noise figure of 2 dB. The chain noise figure rose 0.5 dB from 11.0 to 11.5 dB when the leakage noise was added to the analysis (-170 dBm/Hz input noise power at the R port versus –174 dBm/Hz). The sensitivity of simulated chain noise figure to input noise power at the R port is plotted in Figure 5 for the mixer alone and the mixer and the IF amplifier combination.

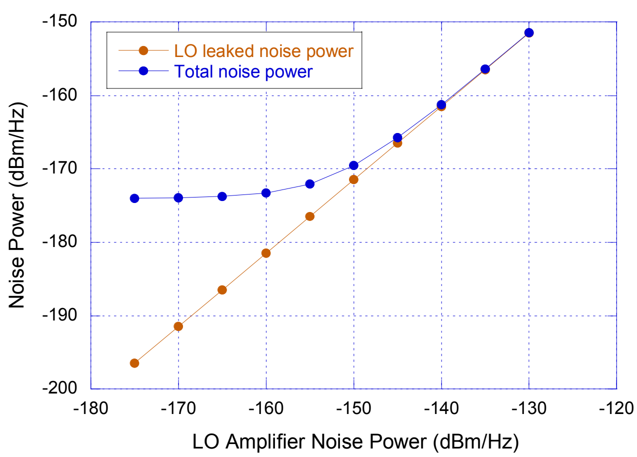

Figure 3. Total noise power seen at the R port as a function of LO noise power.

Stage	Desc.	Gain (dB)	Noise Figure (dB)	Cum. Linear Gain (dB)	Cum. Noise Figure (dB)	Cum. Noise Power (dBm)	Cum. Carrier -Noise Signal Ratio (dB)
1		.0	4.0	.0	4.0	-170.0	170.0
2	Mixer	-9.0	9.0	-9.0	9.8	-173.2	164.2
3	IF Amp	18.0	2.0	9.0	11.5	-153.5	162.5

Figure 4. Chain analysis of down-converter with an input noise power of –170 dBm/Hz.

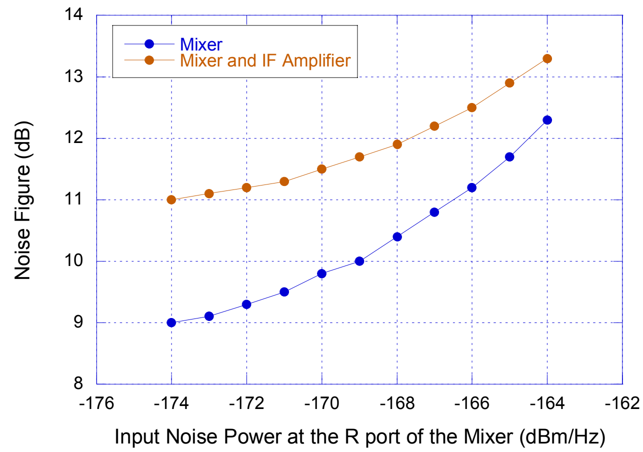

Figure 5. Chain analysis of the Mixer and Mixer/IF amplifier noise figure. Noise power is referenced to the R port of the mixer.

Finally, all of the analysis is pulled together and results in the graph of chain noise figure as a function of LO output noise power (Figure 6). With this information the affect of LO output noise power on the overall downconverter can be determined. Figure 6 illustrates the sensitivity of noise figure to LO noise power for the mixer inside the dual branch converter. Given the isolation of the PCS mixer, LO output noise powers greater than –155 dBm/Hz start to degrade noise figure.

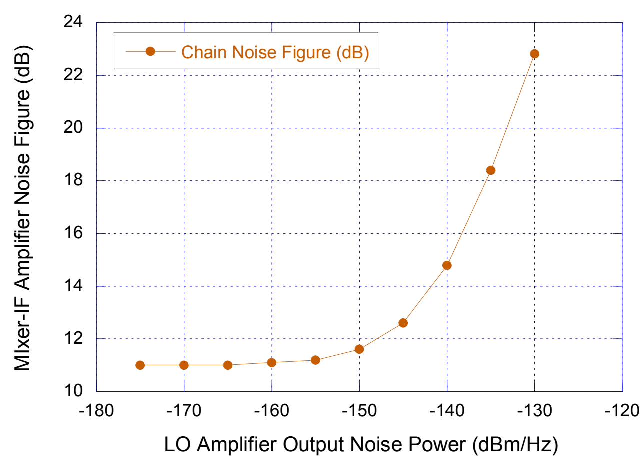

Figure 6. Chain noise figure as a function of LO output noise power.

Mixer Measured Data

To validate the simulations, the noise figure of a PCS FM12C mixer was measured as a function of LO noise power. The results are given in Table 2. The measurements are in good agreement with the simulations based upon the LO leakage noise.

Table 2. Calculated and measured noise figure for a WJ FM12C mixer.

LO Noise Power (dBm/Hz)	Measured Noise Figure (dB)	Calculated Noise Figure (dB)
-139	14.7	15.1
-136	17.8	17.4
-133	20.3	20.0

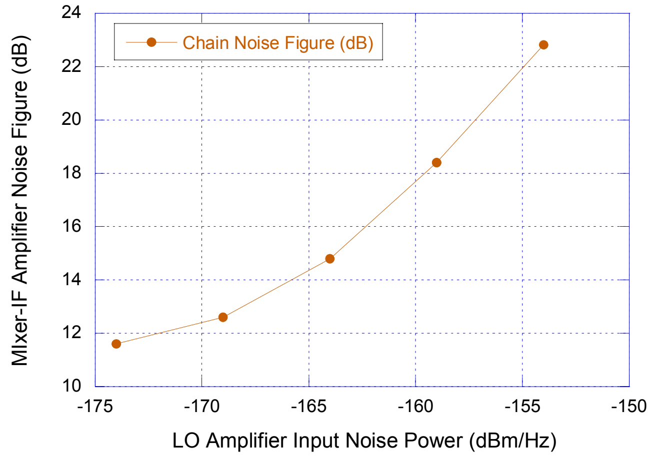

Figure 7. Chain noise figure as a function of LO input noise power to the CV211-1.

LO Amp Noise Power Characterization

The LO amplifier noise power was measured. During the test the LO amplifier was compressed and a band-pass filter was used to isolate the noise power at the RF and Image frequencies. A preamplifier with 30 dB of gain and a noise figure of 1 dB was used to overcome the noise figure of the spectrum analyzer.

A LO amplifier inside the CV211-1 dual branch converter was measured to have –153 dBm/Hz and –148 dBm/Hz of output noise power at the RF and IM frequencies respectively. The input power of the amplifier was 0 dBm and the compression point was 17.5 dBm. The corresponding Gain + Noise power of the WJ LO amplifier is approximately 24 dB. The calculated input noise power at the R port of the mixer under this condition was –170.4 dBm/Hz. This input noise power corresponds to a predicted noise figure of 11.5 dB. This agreed with measure noise figure for the down-converter.

Figure 7 is a modification of Figure 6 with noise power referenced to the input to the LO amplifier**. If the broadband LO input noise power is not at the thermal noise floor or if the isolation is not increased with a LO filter at the RF and Image frequencies, adverse effects on noise figure will result**. For example, a LO input noise power of –160 dBm/Hz will result in a down-converter noise figure of 17.5 dB. A noise figure of 11 dB is measured when a LO band-pass filter is used.

Conclusion

A method of determining the affect of LO noise power on overall down-converter noise figure has been performed. This note can be used to ascertain the overall noise figure of the down-converter given the input noise power of the LO. The noise figure of the down-converter is very sensitive to LO noise power.