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NOISE MODEL FOR FREQUENCY TRANSLATORS AND TRANSPOSED-GAIN AMPLIFIERS[#]

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Abstract.- This paper reports phase modulation (PM) noise measurements of mixers used as frequency translators and of mixers used in homodyne systems. The relationship of the PM noise of a mixer used in a frequency translator (heterodyne system) to that in a homodyne system is not well known. The purpose of this paper is to investigate this relationship (if any). We found that the PM noise of mixers used in heterodyne systems consists of a 1/f portion decreasing to a thermal noise floor characterized by the temperature and conversion loss. The 1/f PM noise is typically 4-7 dB lower than in a heterodyne system for the same mixer used.

Introduction

The purpose of this paper is to investigate the relationship of the phase modulation (PM) noise of a mixer used in a frequency translator to the PM noise in a homodyne system. The PM noise of mixers in homodyne systems is well known and consists of a 1/f portion decreasing to a thermal noise floor characterized by the temperature and conversion loss [1]. To our knowledge, the PM noise of mixers used as frequency translators has not been investigated. This paper reports PM noise measurements of mixers used as frequency translators, and mixers used in homodyne systems. We measured the 1/f PM noise for mixer pairs in homodyne and heterodyne configurations. Three different types of mixers were tested.

Homodyne Measurement System

Figure 1 shows the system used to measure the PM noise of mixers in the homodyne configuration, at carrier frequencies of 10 and 100 MHz. In this measurement system the source signal is split and each channel is fed into a mixer. A phase shifter is placed in one of the channels and is adjusted so that the two inputs to the mixer are in quadrature. The lowpass filter eliminates the high frequency components at the mixer's output. The signal is then amplified and measured in a Fast Fourier Transform (FFT) signal analyzer.

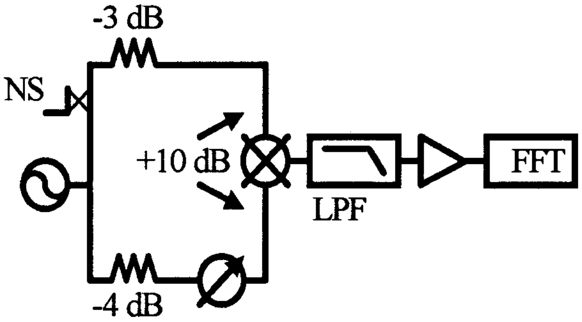

Figure 1. Measurement system used for the homodyne system at 10 and 100 MHz, where NS is the PM noise standard.

For homodyne measurements at a carrier frequency of 50 MHz, we used the configuration shown in Fig. 2. To make the measurement, A was connected to C, and the power spectral density (PSD) of the output voltage noise (V_n) was measured with a FFT analyzer. The PM noise of the 100 MHz source and the divider cancel and the noise of the phase detector, dominated by the mixer noise, is measured. To calibrate the measurement, B was connected to C, A was connected to a 50 Ω resistance to ground, and a calibrated noise source was added to one of the channels. The gain of the system was then obtained by measuring the PSD of the output voltage noise and subtracting the value of the added noise from it. The same input power to the mixer and

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the same cables were used for both the measurement and the calibration.

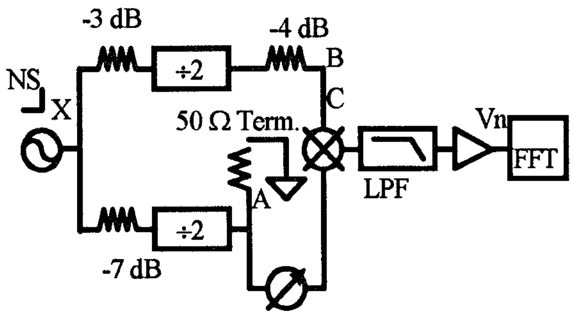

Figure 2. PM measurement system for homodyne system at 50 MHz. This figure shows the connection for calibration (B connected to C) and for PM noise measurement (A connected to C).

Heterodyne Measurement

One of the methods used to investigate mixer PM noise when used as a translator was to build a transposed-gain amplifier with a pair of mixers and measure its PM noise. In the amplifier shown in Fig. 3, the input signal is translated to a lower carrier frequency by a local oscillator (LO), amplified by a low 1/f PM noise amplifier, and then translated back to the original frequency [2,3]. The PM noise of this configuration includes noise from the pair of mixers plus the noise of the amplifier. If the noise of the mixers is only thermal, then the use of an amplifier with low 1/f PM noise, such as those developed by Ferre-Pikal et al. [4], could produce transposed-gain amplifiers with virtually no 1/f PM noise for Fourier frequencies above 1 Hz. If the noise is due to a true 1/f PM modulation of the phase, then the translated 1/f PM noise should be roughly the same as the homodyne 1/f PM noise.

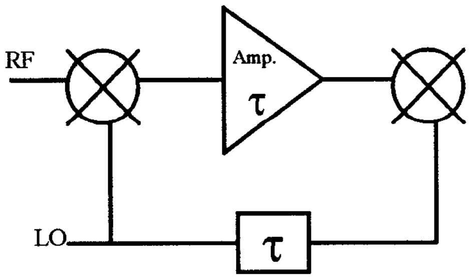

Figure 3. Block diagram of a transposed gain amplifier.

Figure 4 shows the PM noise measurement system used to measure the noise of the transposed-gain amplifiers. We found that the delays of the two paths (in the transposed-gain amplifier) have to be exactly the same, so that the local oscillator noise in the two paths is correlated and canceled out at the mixer. If the delay is not matched, then extra noise due to the local oscillator is observed. In our measurements we were not able to match the delay of the two channels, thus we were not able to see the noise of the mixers and the amplifier.

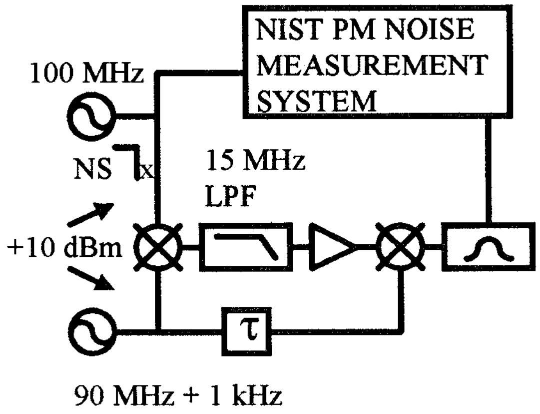

Figure 4. Measurement system for PM noise in transposed-gain amplifier.

Another method used to investigated the 1/f PM noise of the mixers in a heterodyne configuration was to build a regenerative divide-by-two circuit and measure its noise. The block diagram of a regenerative divide-by-two circuit is shown in Fig. 5. If a very low 1/f PM noise amplifier is used in the dividers, the divider noise is limited by the mixer noise. Figure 6 shows the three-cornered-hat measurement system used to measured the PM noise of the 100 MHz to 50 MHz dividers. The PM noise of divider 1 is common to both channels but the PM noise of dividers 2 and 3 is not. Therefore the power spectral density (PSD) of (Vn1 x Vn2) includes only PM noise of divider 1 [5].

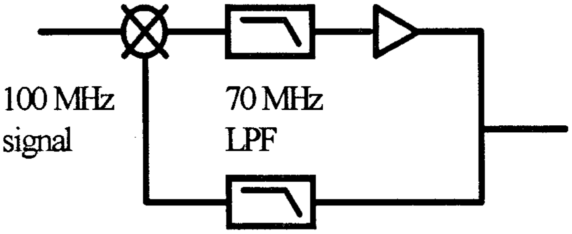

Figure 5. Divider configuration used for measured PM noise in the mixer (heterodyne)

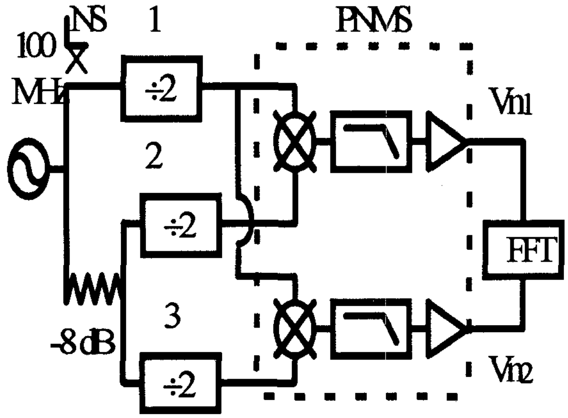

Figure 6. Three-cornered-hat measurement system used to measured the PM noise of 100 MHz to 50 MHz divider, where NS is the NIST PM noise Standard and PNMS is NIST PM noise Measurement System.

Experimental Results

We measured two mixers each of three different types. Due to limitations in space, we show only the results of one mixer of each type. Figure 7 shows the PM noise of mixer 1A when used in homodyne and heterodyne (divider) configurations at a carrier frequency of 50 MHz.

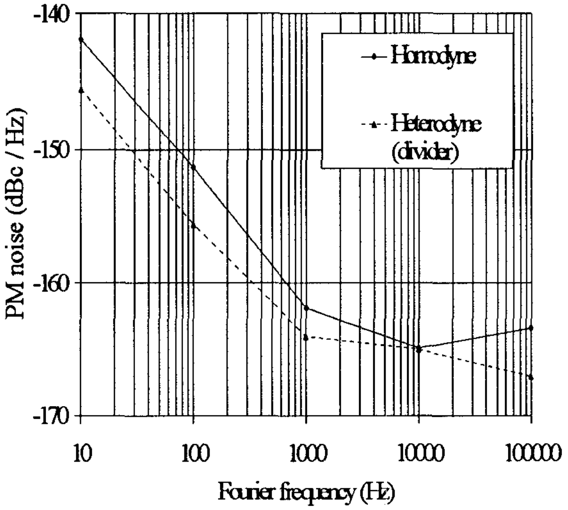

Figure 7. PM noise in dB below the carrier in a 1 Hz bandwidth (dBc/Hz) for mixer 1A at 50 MHz.

The heterodyne mixer noise was obtained assuming that the PM noise contribution of divider components is 6 dB lower than the open loop PM noise of the components [6-8], and that the mixer noise dominated the noise of the divider. The flicker noise of mixer 1A in the heterodyne configuration is approximately 4 dB lower than the PM noise of the mixer in the homodyne configuration. Similar results were obtained for mixer 2A (see Fig. 8). For this mixer the heterodyne (from divider) PM noise was 6 dB lower than the homodyne PM noise.

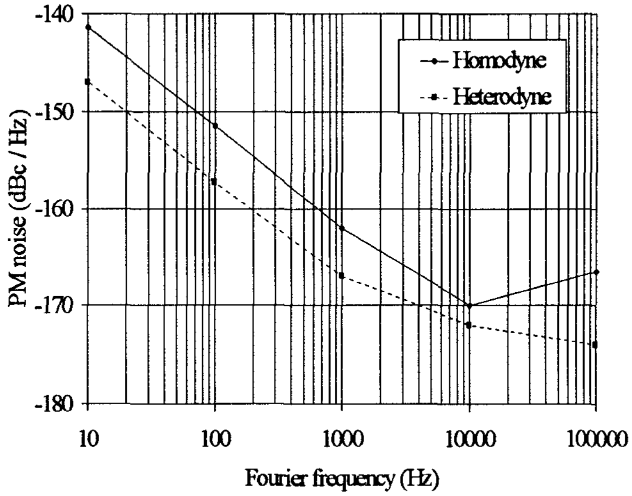

Figure 8. PM noise for mixer 2A at 50 MHz.

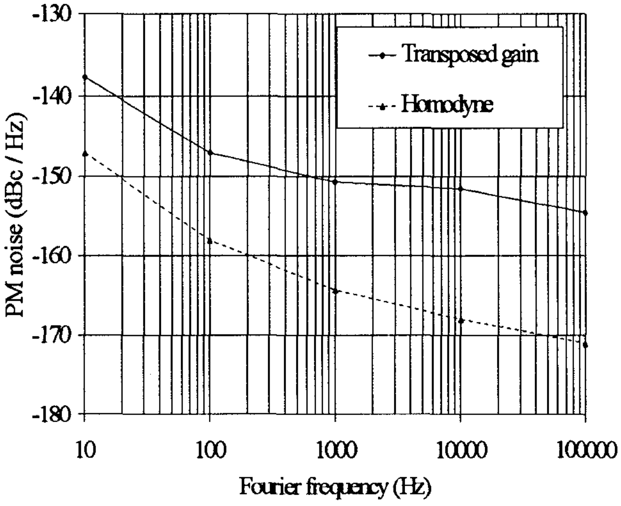

Figure 9. PM noise for mixer 2A at 10 MHz.

Figure 9 shows the PM noise for the same mixer (2A) at 10 MHz in homodyne and transposed-gain. Figure 10 shows the PM noise results for mixer 3A. The homodyne and heterodyne (divider) measurements are very similar. Possibly the divider noise was limited by the amplifier noise. The PM noise of the transposed-gain amplifier was approximately 15 dB higher than for the divider and homodyne measurements. Because of our inability to match the delay properly, this was in part due to the very high delay in the intermediate frequency (IF) filters needed to separate the signal from the spurs.

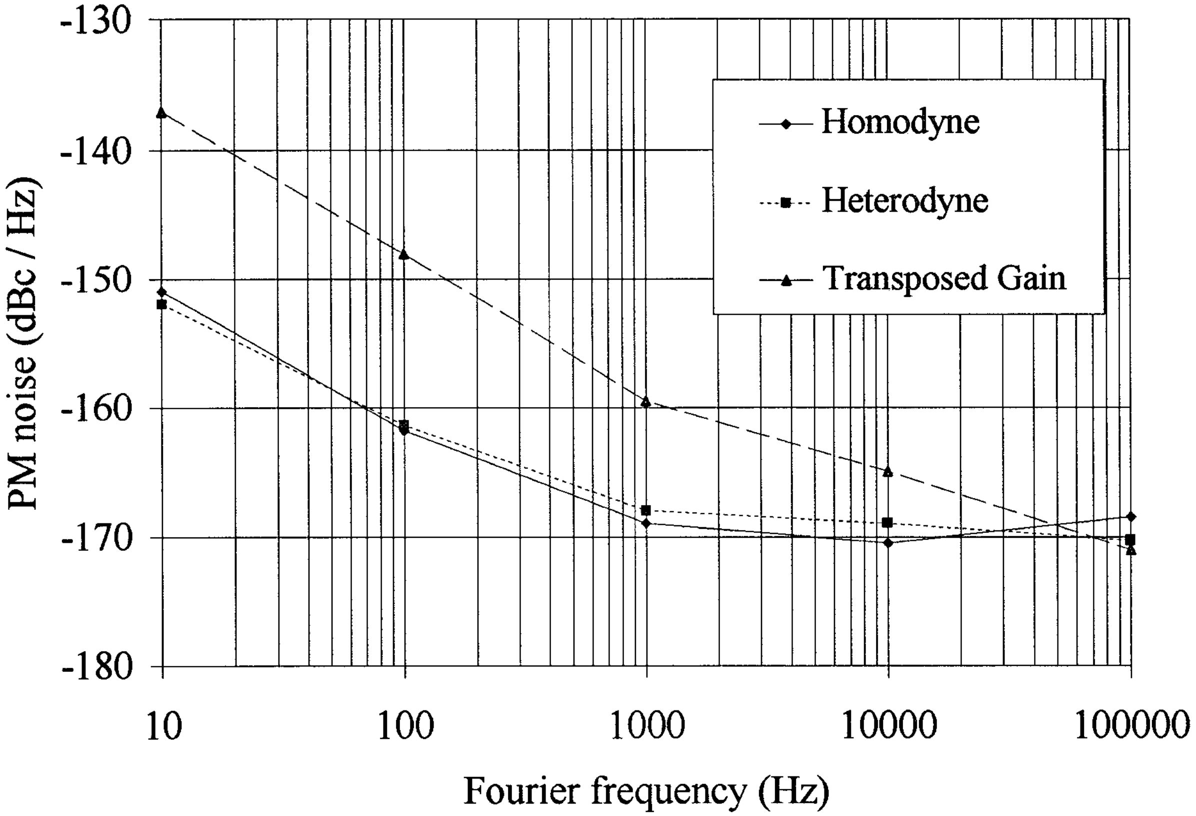

Figure 10. PM noise for mixer 3A in homodyne, heterodyne and transposed-gain amplifier at frequency of 50 MHz.

Conclusion

The PM noise in the mixers is 4 to 7 dB lower when used in a heterodyne configuration than when used in a homodyne system operating at the same frequency and the same power. In the one case where the noise was similar between the two cases, we believe that the PM noise in the heterodyne configuration was limited by amplifier PM noise. In the transposed-gain amplifier we saw that the noise floor is determined by how closely you match the delay. The frequency offset oscillator has to be chosen such that the intermodulation spurs produced within the mixer do not interfere with the intermediate frequency; this also requires selection of IF filters with stable phase delays.

References

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