5 MHz phase detector with low residual flicker

C.A. Barnes, A. Hati, C.W. Nelson and D.A. Howe

The measurement of close-to-carrier phase modulation (PM) noise of state-of-the-art oscillators is always challenging. Quite often the residual noise of the phase detector used in these measurements is higher than the noise of the source at Fourier offset frequencies between 5 and 100 Hz. A conventional double balanced mixer using 2N2222A transistors as the nonlinear components of a diode ring was constructed for use as a phase detector. Residual single-sideband PM noise measurements at 5 MHz for this device have shown a low flicker noise floor of L(10 Hz) = −163 dBc/Hz. When this mixer design is implemented in a dual-channel measurement system, a cross-correlated PM noise floor of better than L(10 Hz) = −170 dBc/Hz is expected.

Introduction: The double balanced mixer (DBM) is the most widely used phase detector for high-resolution phase modulation (PM) noise detection at most carrier frequencies. Often, the measurement of PM noise is difficult owing to the high dynamic range that exists between the carrier and the modulated sidebands. In typical measurement systems, a phase detector is used to remove the carrier and down-convert noise sidebands to baseband. For offset frequencies close to the carrier, the residual flicker noise of the DBM is often the limiting factor of a phase noise measurement system. The most difficult range of offset frequencies to measure is between 5 and 100 Hz, where the oscillator noise has a slope of f^{-3}, while the measurement system noise floor follows f^{-1}. The 2N2222A bipolar junction transistor (BJT) has been successfully used in low-flicker PM noise circuits [1, 2] and is chosen as the low noise nonlinear element in a custom-built DBM design. A pair of mixers using this design can be used to construct a cross-correlation PM measurement system to reduce the PM residual noise floor further.

Proposed DBM design: Fig. 1 shows the general topology of the DBM. In this design there are four 2N2222A BJTs used to construct a conventional double balanced diode ring. By shorting the base to the collector these BJTs will operate as diodes. The transformers used for this design are commercial off-the-shelf parts and have a 1:5 impedance ratio. This impedance ratio is chosen so that the input impedances of the reference frequency (RF) and local oscillator (LO) ports are nearly 50 Ω at 5 MHz. The mixer's input impedances are measured using the Smith chart display of a vector network analyser.

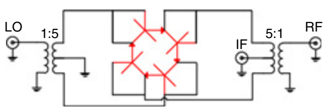

Fig. 1 *Double balanced mixer schematic*

Diode ring in this double balanced mixer is constructed by use of transistors with collector input tied to base

Mixer characterisation: To measure the PM noise of the DBM the nominal operating powers need to be found [3]. To determine the nominal LO power, a 4 MHz sinusoidal signal at −30 dBm is applied to the RF port of the mixer while the power of a 5 MHz signal at the LO port is varied. Conversion loss of the mixer is calculated by taking the power ratio of the 1 MHz beat at the intermediate frequency (IF) port to the RF signal at 5 MHz. A plot of conversion loss against LO power is shown in Fig. 2. By use of this plot, the 1 dB compression point of the LO drive is found to occur at a level of +8 dBm. Operating the LO port in saturation is desired to reduce LO power fluctuation sensitivity. Taking the maximum allowed operating specifications of the transistors and transformers into account, a nominal LO drive of +11 dBm is selected. An additional measurement of conversion loss against RF power at the selected nominal LO was made and is plotted in Fig. 2. The 1 dB compression point of conversion loss, at the RF port, occurs at +5 dBm. All conversion loss tests for the mixer were conducted with a 50 Ω load at the IF port.

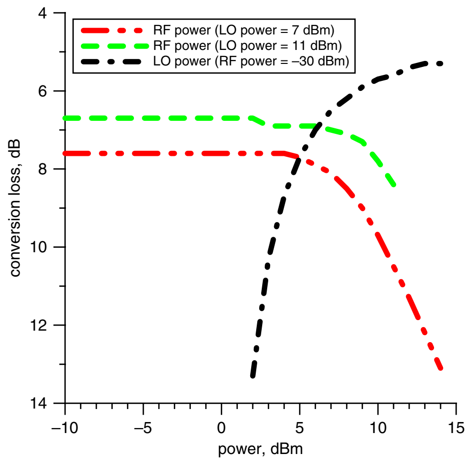

Fig. 2 *Conversion loss against LO power of mixer with a −30 dBm RF power level (RF at 4 MHz, LO at 5 MHz, 50 Ω input impedance to FFT); and conversion loss against RF signal power at constant LO drive powers (LO at 4 MHz, RF at 5 MHz, 50 Ω input impedance to FFT)*

Mixer PM noise measurements: Residual PM noise of the DBM was measured by use of a cross-correlated homodyne measurement system [4]. In phase quadrature, the common mode phase noise of the oscillator and the power amplifier used in this measurement system will cancel out at the mixer. A diplexer terminates the high frequency products of the mixing while still maintaining a high phase-to-voltage conversion at baseband. This diplexer also allows for the baseband signals to be amplified without saturating the IF amplifiers with the 5 and 10 MHz signals from the mixing process. The topology of the diplexer used at the output of the phase detector can play an important role in the mixer's performance [5, 6]. The pair of baseband IF amplifiers raise the residual PM noise of the DBM above the noise floor of the fast Fourier transform (FFT) analyser. The uncorrelated input voltage noise of each IF amplifier can be minimised by the use of cross-correlation, allowing measurement of the thermal residual noise in the mixer.

Fig. 3 shows the results of the residual PM noise of this DBM design used as a phase detector. From this data it can be seen that the flicker noise of this device is L(10 Hz) = −161 dBc/Hz (L = single-sideband PM noise) when the DBM is operated at LO = +11 dBm and RF = +5 dBm. In deep saturation (LO = RF = +11 dBm) the 10 Hz noise is improved to L(10 Hz) = −163 dBc/Hz. Both these measurements show that this DBM has very low flicker noise as a phase detector.

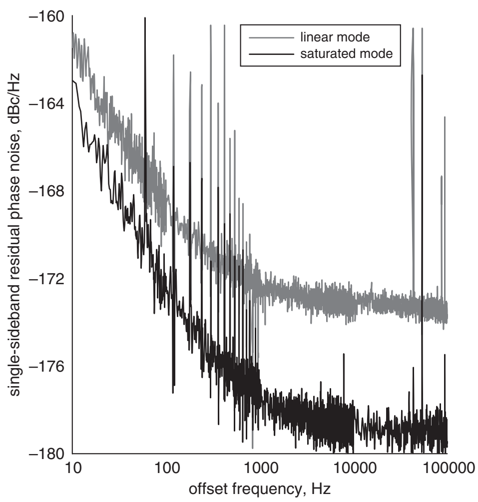

Fig. 3 *Cross-correlated residual PM noise floor of 2N2222A based mixer in linear and saturated operation*

Conclusions: A DBM mixer design using diode-connected 2N2222A BJT transistors is presented. The phase detector design in this Letter has shown a residual PM flicker noise floor at levels of L(10 Hz) = −163 dBc/Hz. As compared to many commercially available DBMs used for phase detection at 5 MHz, this design performs among the best. Furthermore, this phase detector will be useful for the measurement of state-of-the-art oscillators where the phase noise at 10 Hz offset can be difficult to measure with currently available detectors. In the future we will use this detector design in a cross-correlation measurement system and expect the residual noise levels to reach $L(10\ \mathrm{Hz}) = -170\ \mathrm{dBc/Hz}$ or better.

Acknowledgments: The authors thank J. Searle for the idea of constructing their own mixers; E. Rubiola for an IF amplifier design used in the noise floor measurements described in this Letter [7]; and J. DeSalvo for theoretical discussion regarding measurement systems.

15 June 2011
doi: 10.1049/el.2011.1863
One or more of the Figures in this Letter are available in colour online.

C.A. Barnes, A. Hati, C.W. Nelson and D.A. Howe (*Department of Commerce, National Institute of Standards and Technology, Time and Frequency Metrology, 325 Broadway, Mailcode 847.30, Boulder, CO 80305-3337, USA*)

E-mail: corey.barnes@nist.gov

References

1 Nelson, C.W., Walls, F.L., Sicarrdi, M., and De Marchi, A.: 'A new 5 and 10 MHz high isolation distribution amplifier'. Proc. IEEE 48th Annual Symp. on Frequency Control, Boston, MA, USA, pp. 567–571
2 Walls, F.L., Ferre-Pikal, E.S., and Jefferts, S.R.: 'Origin of 1/f PM and AM noise in bipolar junction transistor amplifiers', *IEEE Trans. Ultrason. Ferroelectr. Freq. Control*, 1997, **44**, (2), pp. 326–334
3 Kurtz, S.R.: 'Mixers as phase detectors', *Watkins-Johnson Tech-Notes*, 1978, **5**, (1)
4 Wall, F.L., and Ferre-Pikal, E.: 'Measurement of frequency, phase noise and amplitude noise' *in* 'Wiley Encyclopedia of Electrical and Electronics Engineering' (Wiley-Interscience, 1999, Vol. 12, 1st edn) pp. 459–473
5 Walls, F.L., and Stein, S.R.: 'Accurate measurements of spectral density of phase noise in devices'. Proc. 3lst Annual Frequency Control Symp., Atlantic City, NJ, USA, 1977, pp. 335–343
6 Rubiola, E.: 'Tutorial on the double balanced mixer', physics/0608211, Aug. 2006
7 Rubiola, E., and Lardet-Vieudrin, F.: 'Low flicker-noise amplifier for 50 Ω sources', *Rev. Sci. Instrum.*, 2004, **75**, (5), p. 1323