SENSITIVITY IMPROVEMENT IN PHASE NOISE MEASUREMENT

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Abstract: An automated microwave phase noise measuring system with improved sensitivity is presented. The system is based on two oscillators measuring method. Improvement of sensitivity can be achieved by increasing the power applied to the RF input of the balanced mixer. However, in classical arrangement of the two oscillators method this is not possible due to already high power contained in the signal carrier. In the proposed measuring system, carrier is suppressed by the resonator. In that way, it is possible to significantly increase RF power from oscillator under test. The sensitivity improvement ranges from 20 to 40 dB.

Keywords: phase noise, measuring sensitivity

1   INTRODUCTION

The commonly used term *phase noise* is really a part of the broader category named *frequency stability* [3]. Frequency stability is a measure that shows in what degree an oscillating source produces same frequency value throughout a specified period of time. Unfortunately, in real world all signal sources exhibit the unwanted amplitude and frequency (or phase) fluctuations. Since frequency and phase are closely related (frequency is the time derivative of phase), these fluctuations can be treated either as unwanted frequency noise or phase noise. A typical spectrum of a microwave oscillator with noise sidebands is shown in Fig. 1.
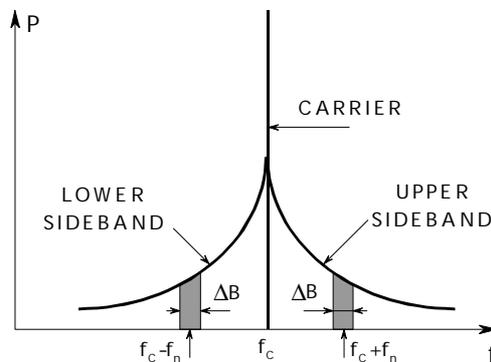

Figure 1. Spectrum of a microwave oscillator.

Several methods exist for the measurement of the phase noise in frequency domain. The most frequently used methods are:

a) Phase discriminator method;

b) Two oscillators method.

In phase discriminator method there is only one oscillator, the oscillator under test [1]. Since this method does not require a reference oscillator (which is usually expensive), the measuring system threshold does not depend on anything else but the quality and design of the measuring system [2]. Phase discriminator method uses phase detector (double balanced mixer) as instability sensor. In this method, the results for the measured phase noise come in form of frequency fluctuations per Hertz bandwidth. The schematic of the measurement system based on this method is shown in Fig. 2.

Two oscillators method uses one oscillator as a phase reference, while the other oscillator is being tested [3]. As the instability sensor, this method uses the phase detector (usually a double balanced mixer), which requires a phase quadrature between mixer ports. To keep this phase quadrature for a time required to make the measurement, method employs the PLL (Phase Locked Loop). In this method, the results for the measured phase noise come in form of phase fluctuations per Hertz bandwidth. Since the frequency is time derivative of phase, both forms of results can be simply

recalculated in any form desired. Fig. 3. shows the schematic of the measurement system based on the two oscillators method. The automation and sensitivity improvement of this approach is the subject of the paper.
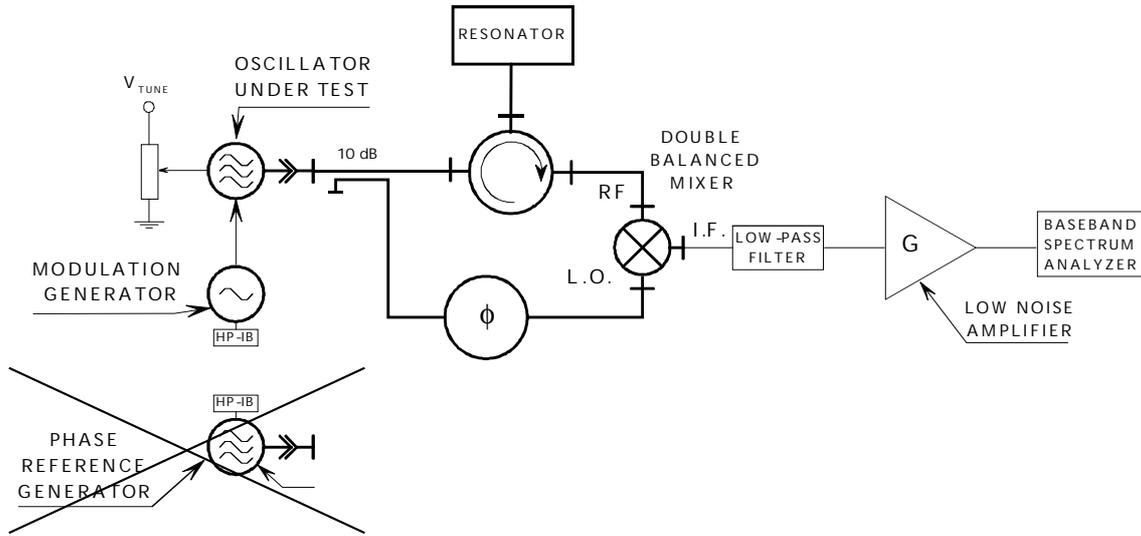

Figure 2. The schematic of the phase noise measurement system based on phase discriminator method.
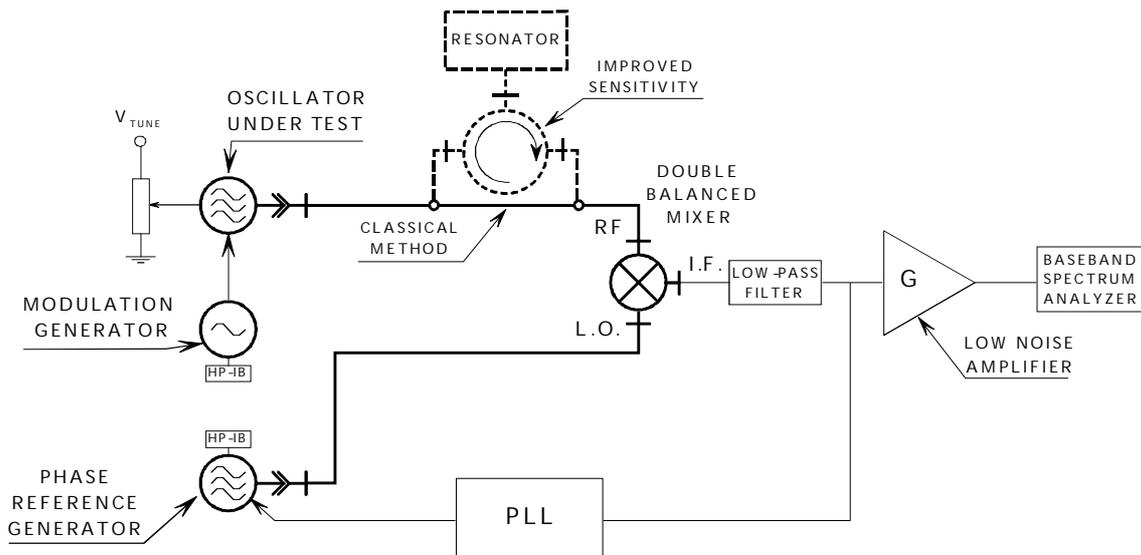

Figure 3. The schematic of the phase noise measurement system based on two oscillators method (sensitivity improvement addition shown in dotted line).

2   MEASUREMENT SYSTEM

2.1   Outline

Although the previous described methods look different, they have many similarities. The basic differences are the origin of the local oscillator signal and form in which the results of a measurement are presented.

In phase discriminator method, local oscillator signal is derived from the oscillator under test (Fig. 2.), while in two oscillators method the phase reference generator is used for this purpose (Fig. 3.). From this point forward, principle of operation is pretty much the same. Phase discriminator method uses resonator for carrier suppression. This results in numerous effects that are beyond the scope of this paper. However, one of the effects that can be used in two oscivators method is the possibility of increasing power applied to the RF port of the double balanced mixer. Namely, the signal that need to be measured (phase noise) is located in the sidebands of the signal (Fig. 1). Since most of the modern oscillators have low phase noise, the sidebands are very close to the system threshold. Increasing of

the power applied on the RF input of the mixer may result in mixer diode burnout, since practically all power is concentrated in the carrier. The proposed modification of the two oscillators measuring method suppresses the carrier by a resonator. In that way, the carrier power is reduced and the power in sidebands remains the same (in practice, this power is also reduced due to finite Q factor of the resonator). This modified signal can be amplified up to the mixer peak power prior entering the mixer RF port. This will result in rather significant improvement of measuring sensitivity. Described process is shown in Fig. 4.
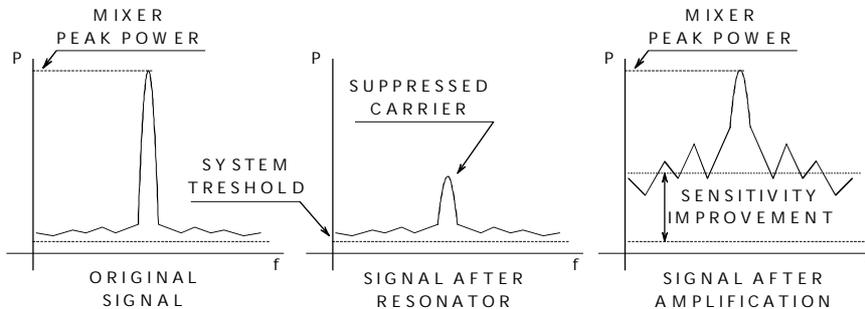

Figure 4. Proposed modifications of the signal.

The additional effect of introduced resonator is the change in form of the measurement results. As already mentioned, basic two oscillators method gives results in form of phase fluctuations per Hertz bandwidth. Due to the resonator's phase characteristic, the resonator acts as a frequency-to-phase converter. Since the mixer is sensitive to phase fluctuations at the output of the resonator, the whole system at the output gives the value that shows frequency fluctuations (not phase fluctuations) of the oscillator under test. In that point, this system is more similar to phase discriminator method, although it is based on two oscillators method.

2.2   System schematic

Fig. 5. shows the complete block diagram of the measurement system. The system is based on two oscillators method.
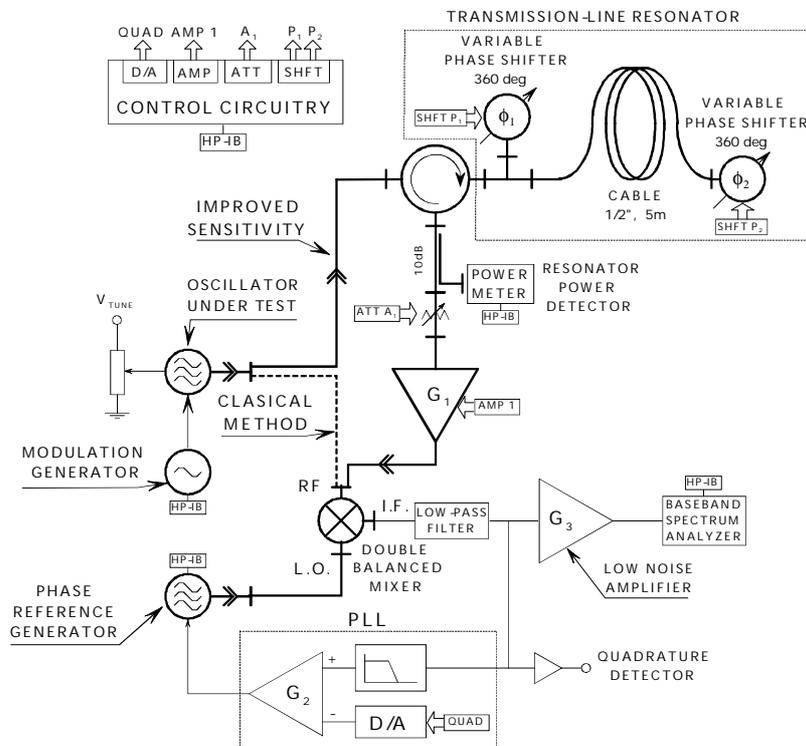

Figure 5. Complete block diagram of the phase noise measuring system.

The signal from oscillator under test is modified by transmission-line resonator [4] and the broadband amplifier, as described earlier. One of the additional demands on the system was the ability

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of the system to perform measurement automatically. Because of that, a whole set of electronically tuned components is developed. In classical phase-noise measurement systems, tuning of the resonator was achieved manually, or in some cases, by servo system. This type of tuning has the advantage of being precise, but the major disadvantage is the complexity of the tuning system. Furthermore, this type of tuning shows rather slow response and requires well-trained operator. The resonator proposed in this paper uses long transmission line and the pair of reflection-type phase shifters. This type of resonator has somewhat lower Q-factor (compared to cavity resonators) but in return, its tuning is very simple. The structure resembles the one stub tuning circuit, but in this case, the narrowest possible frequency bandwidth is desirable (this corresponds to higher Q-factor).

Tuning of the resonator is achieved with two reflection-type phase shifters. Control circuitry generates the appropriate signals to setup the shifters. Resonator is exactly tuned on the oscillator frequency when the minimum carrier power is obtained. As the reference, automatic tuning circuit uses signal obtained from the resonator power detector as shown in Fig. 5. Carrier can be suppressed even to the 90 dB (see Fig. 6.). Transmission-line resonator has the multiple responses. Their spacing depends on the length of a cable, but this might be important only when measurement far from the carrier frequency must be made. Measured Q-factor of the resonator is 300 at 1.7 GHz.
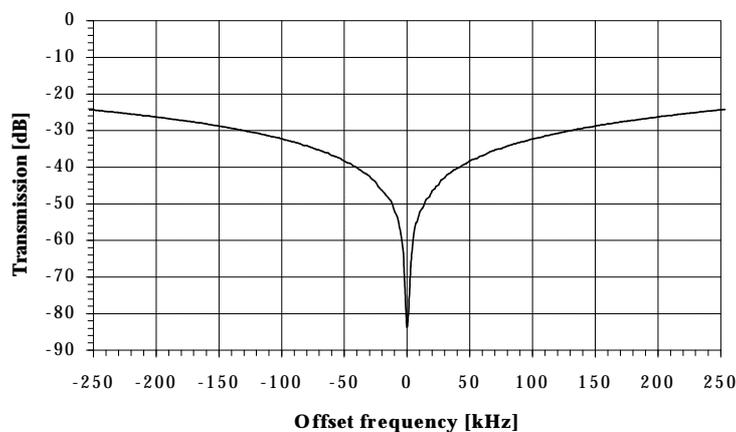

Figure 6. Measured response of the transmission-line resonator.

The measurement system uses two reflection-type phase shifters for tuning the transmission-line resonator. Phase shifters are designed to use the variable capacitance diodes. Since one diode can produce phase shift of only 140°, combination with switched line technique was necessary to get phase shift of 360°. Namely, switching line technique introduces additional fixed phase shift in front of the variable capacitance diodes (see Fig. 7.). In that way the areas of variable phase shift achievable by each varactor diode can be evenly distributed around the full circle (e.g. 360°). Lines switched in front of the varactor diodes need to have only half of the wanted fixed phase shift since the signal travels in both ways. Switching is achieved with three "Beam Lead" PIN diodes phase shifter. The layout schematic of the phase shifter is shown in Fig. 8. Design of phase shifters is also unconventional, mainly because classical arrangements have larger losses. That was not acceptable, since the Q factor depends on losses in the resonator. Phase shifters are designed and optimized to operate from 1.5 GHz through 1.9 GHz. Additional improvement of phase shifters can increase operating bandwidth to one octave at least.

Broadband low-noise amplifier with adjustable gain (G_1 in Fig. 5.) is used to amplify the signal emerging from the output of the resonator. The signal is amplified to the operating level of the double balanced mixer. The needed amplification depends on the output power of the oscillator under test, as well as obtainable suppression of the carrier. Both demands are easily met with adjustable gain amplifier. Gain of the amplifier is set by control circuitry.

The PLL circuit is used for maintaining the phase quadrature between two oscillators. The exact quadrature ensures that the mixer operates in linear region.

Figure 7. The phase shifter principle of operation.

The entire system is controlled by the microcontroller and the PC. The system performs automatic calibration, which must be done every time before the measurement of an oscillator whose parameters (oscillating frequency and output power) are unknown. Calibration is performed by external RF source on the same frequency and power level (because nonlinear elements operating in the mixer).

The system can perform measurements automatically, but since it does not have massive memory storage device, it is convenient to transfer measured data to PC, where data can be further analyzed and manipulated.

Figure 8. Phase shifter schematic.

3   MEASUREMENT WITH THE SYSTEM

3.1   Actual measurement of the phase-noise

After the system is calibrated, two sets of data must be collected. First, it is necessary to establish system noise threshold. Second measurement collects actual noise data. If the noise data is closer to the threshold than 10 dB, correction must be made. After that, calibration constants are applied to the corrected data. The result of an actual phase noise measurement is shown in Fig. 9. The oscillator under test was PLL synthesised generator. The sensitivity of the tested measurement system based on classical two oscillator method is around −70 dBrad/Hz BW. However, with the proposed additional circuitry, the sensitivity of the system can be extended up to −100 dBrad/Hz BW.

3.2   Frequency coverage

The measurement system consists of many components. Most of them are frequency dependent. Because of this, system has the limited frequency band in which it can operate as designed. Circulators and phase shifters used in the system have narrowest frequency band. The prototype of the system uses two circulators that cover the frequencies from 1500 MHz to 1900 MHz. Phase shifters are designed to match that frequency band. By use of the different components, system can be easily modified to any frequency range of interest. In order to increase operating frequency bandwidth,

it is necessary to employ broadband circulators and modify the phase shifters. Because of the relatively low Q-factor of transmission-line resonators, it is not recommendable to design this type of measuring system at frequencies higher than 5GHz. In order to make a phase noise measurements of an oscillator that operates in higher frequency band than that of designed measuring system, before applying oscillator signal at the input, signal should be down converted.
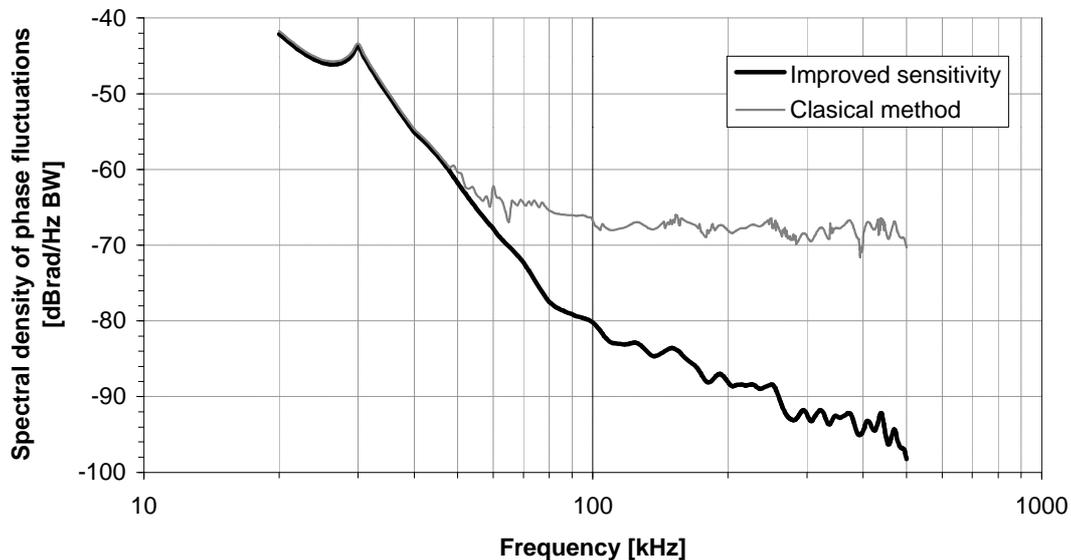

Figure 9. Measurement results of the system with sensitivity improvement compared with results of the classical system.

4   CONCLUSION

An automated microwave phase noise measuring system with improved sensitivity is presented. The system is based on two oscillators measuring method. It is shown that the improved sensitivity can be achieved by increasing the power applied at the RF input of the double balanced mixer. The problem with high power concentrated in the carrier (which can cause mixer diode burnout) is solved by suppression of the carrier. This suppression is achieved by the transmission-line resonator. Such resonator is chosen because it can be tuned electronically with relatively simple control circuitry. The sensitivity improvement ranges from 20 to 40 dB. So far designed prototype of the measurement system covers frequency band from 1500 MHz to 1900 MHz, but it can easily be modified to any frequency range of interest. With proposed changes, it is possible to extend operating frequency bandwidth to at least one octave.

The system uses additional components that already exist in RF lab so it can be made as inexpensive addition to the lab equipment. It is easy to use and can perform the measurement very fast, which is important especially to modern communication equipment industry.

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