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PRACTICAL STANDARDS FOR PM AND AM NOISE AT 5, 10, and 100 MHz

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Abstract

This paper describes a practical implementation of secondary standards for phase modulation noise (PM) and amplitude modulation noise (AM) at carrier frequencies of 5 MHz, 10 MHz, and 100 MHz. In each case the standard simultaneously produces output signals at approximately + 15 and + 17 dBm. The PM and AM noise between the two signals can be set to a calibrated level, which is constant to better than 0.2 dB for Fourier frequency offsets from nearly dc to 5% of the carrier, or set to a minimum value. The calibrated level of PM and AM noise is used to evaluate the accuracy versus Fourier frequency. The accuracy of determining the calibrated PM and AM noise in the standards is ± 0.14 dB for both PM and AM noise at carrier frequencies of 5, 10, and 100 MHz. The temperature coefficients of the calibrated PM and AM noise are less than 0.02 dB/K. The minimum differential noise is used to evaluate the noise floor versus Fourier frequency of PM and AM measurement systems. When the different noise is set to a minimum, the PM noise S_ϕ(10 kHz) between the two signals (PM noise floor of the standard) is less than -190 dB relative to 1 rad^2/Hz at 5, 10, and 100 MHz. The noise floor for AM measurements depends on the configuration. Using two AM detectors in a differential configuration, we have calibrated AM noise detectors with a noise floor below -180 dBc/Hz at all the test carrier frequencies. These noise standards can also be used as the calibration standard for determining the conversion sensitivity of the detector and amplifier gains for PM/AM measurements.

1. INTRODUCTION

In the past it has been difficult to evaluate the accuracy and noise floor of phase modulation (PM) and amplitude modulation (AM) noise measurement equipment because no artifact standards were available. Comparisons of measurement systems in different laboratories using commercially available oscillators as transfer standards were typically limited to a repeatability of roughly ± 3 dB due to the temporal variability of the oscillator noise. This paper describes a practical implementation of portable secondary standards and associated measurement techniques for evaluating the noise floor and accuracy versus Fourier frequency of phase modulation (PM) and amplitude modulation (AM) noise measurement systems [1,2]. In each case the standard simultaneously produces output signals at approximately + 15 and + 17 dBm.

The PM and AM noise between the two signals can be set to a calibrated level, which is constant to within ± 0.2 dB for Fourier frequency offsets from 1 Hz to 5 % of the carrier, or set to a minimum value for determining the noise floor. Evaluations of these new PM/AM noise standards at 5, 10, and 100 MHz yield an accuracy of 0.14 dB, a temperature coefficient less than 0.02 dB/K, and a stability better than 0.4 dB over 1 y. The differential PM noise between the two output signals is typically less than -190 dBc/Hz for Fourier offsets of 10 kHz, which is much less than any presently available source. These features make these standards powerful tools for evaluating the performance of PM and AM measurement systems.

These new PM/AM noise standards can also be used to calibrate the conversion sensitivity of the PM/AM detector for PM or AM measurements. This greatly simplifies the measurements since detector sensitivity and amplifier gains versus Fourier frequency are determined simultaneously with an accuracy of better than ± 0.5 dB.

2. DESIGN OF PM/AM NOISE STANDARD

Figure 1 shows a simplified block diagram of the PM/AM noise standard model PMAM 115. A frequency source with very low PM and AM noise is regulated in amplitude and divided into the reference and signal outputs using a passive power splitter or directional coupler. (Active power splitters generally add more PM noise than do passive splitters.) A switch turns the carrier signal "on" and "off." The amplitude and phase of these outputs track one another with great fidelity. The residual differential PM noise between the two outputs is typically much smaller than the resolution of available measurement systems [3-5]. At 10 MHz, for example, the differential phase noise between the two channels, $1/2S_\phi$(10 kHz) is -197 dBc/Hz. This configuration is used for measuring the noise floor of PM measurement systems.

A broadband power combiner is used to add passband-limited Gaussian noise to a carrier (see Fig. 1). The level of added noise is roughly 40 dB above the noise floor of most measurement systems and 60 dB above the residual noise between the two signals. This calibrated noise is typically constant in magnitude to ± 0.2 dB for Fourier frequencies from dc to 5% of the carrier frequency at 5, 10, and 100 MHz. This configuration is used to evaluate the accuracy of PM/AM noise measuring equipment as a function of Fourier frequency. A switch can be used to change the noise level by inserting known attenuators. This results in a spectral density of PM noise, $S_\phi(f)$ given by

$$S_\phi(f) = \frac{PSDV_N(\nu_0 - f) + PSDV_N(\nu_0 + f)}{2V_0^2}, \quad (1)$$

where ν_0 is the carrier frequency, V_0 is the amplitude of the carrier, and $PSDV_N(\nu_0 \pm f) \equiv V_N^2(\nu_0 \pm f)$ per hertz is the power spectral density of voltage noise at frequency $\nu_0 \pm f$. The level of $S_\phi(f)$ is constant from dc to approximately the half-bandwidth of the filter, assuming that the added noise is constant in amplitude from $\nu_0 - f$ to $\nu_0 + f$. A switch connects either a 50 Ω termination or the output of the filtered noise source to the summing device. The summing device linearly adds the noise from either the 50 Ω termination or the filtered noise source with the signal to create a modulated output. Since there is no phase coherence between the signal and the noise, the resulting modulated output has precisely equal AM and PM noise with the condition given by Eq. (2) (assuming negligible amplitude compression in the power summer, which is easily attained) for the same ranges in analysis frequencies about the carrier [3-5]. These noise spectra can be made very nearly constant over a very wide temperature range by stabilizing the carrier and the noise separately using traditional approaches. The level of the added noise is such that

$$\int_0^\infty S_\phi(f) < 0.01. \quad (2)$$

This ensures that the compression of the measured $S_\phi(f)$ is smaller than 0.04 dB [3-5]. The residual differential PM noise between the two signals when the noise source is off is generally much smaller than the PM noise of the source. The ratio of the differential PM noise to the source PM noise can approach -100 dB at low Fourier frequencies, degrading to approximately -16 dB at $f = \nu_0/10$ [5]. This insensitivity to source noise improves the accuracy of the PM standard, especially at low Fourier frequencies where the PM noise of the source becomes important.

Measuring $PSDV_N$ and V_0^2 separately calibrates $S_\phi(f)$ at the modulation output relative to the reference signal, as specified by Eq. (1). Turning the filtered noise off allows good resolution and accuracy in the measurement of V_0^2 by eliminating or greatly reducing V_N. Turning the noise on and the carrier off optimizes the resolution and dynamic range for measuring $PSDV_N$. Usually the attenuation of the noise signal is set to a minimum for this measurement. The components are chosen to minimize the voltage standing-wave ratio (VSWR) so that changing the state of the various switches does not significantly alter the impedance or phase of the output to the measurement system. The attenuators are calibrated using a source routed through the external port.

Implicit in these discussions is the assumption that the phase detector in the PM noise measurement system under test has sufficient discrimination against AM noise and that the amplitude detector in the AM noise measurement system has sufficient discrimination against PM noise. These assumptions are not excessively restrictive since many devices to be calibrated also have similar PM and AM noise [5]. Discrimination of 15 dB reduces the unwanted effects below 0.14 dB. This discrimination is easily met by virtually all AM and PM noise measurement techniques in use today [4,5] (typical levels of discrimination are 25 dB for PM and even higher for AM measurement systems.)

When the AM noise is measured on a single channel, the differential technique applied to $S_\phi(f)$ does not help to extend the range. The AM noise of the signal contains both the original AM noise of the source after the leveling circuit and the calibrated AM noise. Thus, it might be expected that the spectrum of $S_a(f)$ at the output would rise much faster than the PM noise as f approaches 0. Fortunately, most sources have much lower AM noise than PM noise close to the carrier, so this potential problem is usually eliminated.

When the AM noise is measured using two detectors in a differential mode, the AM noise of the source cancels to a high degree. Using these AM standards with two detectors and a two-channel spectrum analyzer we have verified AM noise floors below -180 dBc/Hz for carrier frequencies of 5, 10, and 100 MHz.

3. CALIBRATION CONSIDERATIONS

3.1 Calibration of PM Noise in PM/AM Noise Standard

If a scanning narrow-band receiver is used to measure the relative value of V_0^2 and $PSDV_N$ on the modulated output, only the equivalent noise bandwidth BW of the receiver, and its accuracy for relative measurements from V_0^2 to $(PSDV_N)BW$ must be calibrated to determine $S_\phi(f)$. The form of Eq. (1) is such that small errors in the alignment of the noise passband filter resulting in odd-order variations of $V_N^2(\nu)$ about ν_0 are averaged away. The only limit in setting $S_\phi(f)$ is that $S_\phi(f)$ should be high enough that it is far above the noise floor of the measurement system and yet small enough to satisfy Eq. (2) (15 dB margin reduces the errors to approximately 0.14 dB). The smaller the bandwidth for $S_\phi(f)$, the higher the noise can be set without violating Eq. (2). Typically $S_\phi(f)$ is constant for $0 < f < \nu_0/10$ and the integrated phase noise is in the range from 10^{-2} to 10^{-4} rad^2. We must also check that all of the amplifiers used in the evaluation are operated in the linear gain region. The error in the calibration for the circuit in Fig. 1 is typically 0.05 dB due to random errors and ± 0.05 dB due to uncertainties in the linearity of the receiver, 0.04 dB due to uncertainties in determining the bandwidth, yielding an overall root-sum-of-squares (RSS) uncertainty of ± 0.14 dB. Errors in a prototype PM/AM noise standard at 10.6 GHz are about ± 0.5 dB for 3 kHz $< f <$ 500 MHz and $<$ 1.5 dB for 500 MHz $< f <$ 1 GHz.

3.2 Determining Accuracry and Noise Floor in "2 oscillator" type PM Noise Measurement Systems

Figure 2 shows the preferred method for determining the accuracy and noise floor of the standard "2 oscillator" type PM noise measurement system using the new

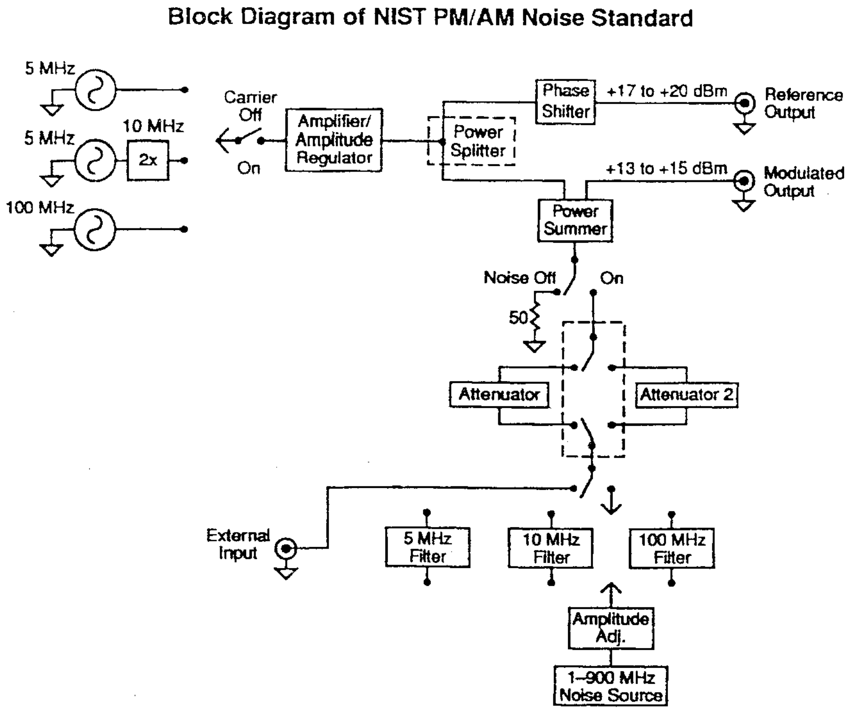


Fig. 1 Block diagram of Calibration Standard PMAM 115 for PM and AM noise.

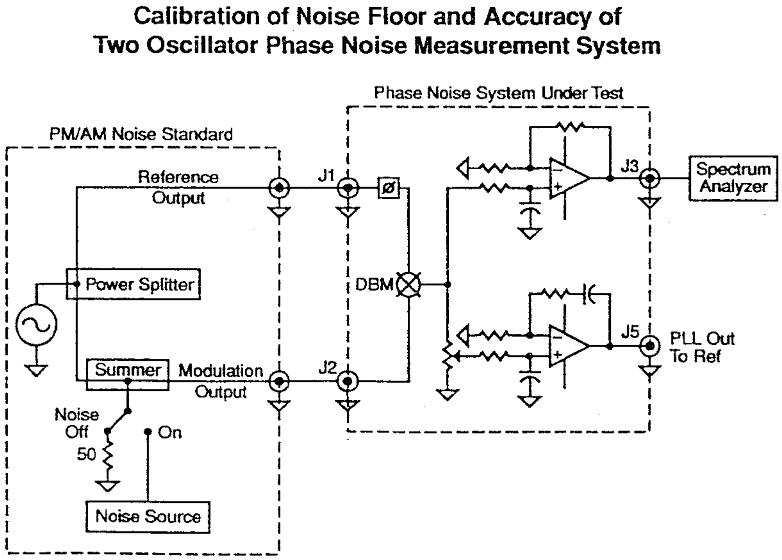


Fig. 2 Preferred calibration method for two oscillator type phase noise measurement systems.

PM/AM noise standard [3-5]. As explained above, the PM noise standard produces signals of about + 15 and +17 dBm. In this configuration there are no phase-lock-loop (PLL) effects to bias the low frequency measurements and the PM noise of the driving source cancels to a very high degree. To implement the. measurements, the phase noise measurement system be able to adjust the phase between the two signals at the mixer to 90° so that the output of the mixer is close to zero V. Not all phase noise measurement systems have this provision, and some may require the use of the phase shifter in the phase noise standard. Once the phase shift has been set to 0, the mixer sensitivity is measured using an external source set to the same output power and impedance as that produced by the signal from one output of the PM standard. It is very important to use the same cable and to terminate the unused signal port with a 50 Ω termination. The beat between the two sources is measured to determine the slope at the zero crossing in V/rad. The cable is removed from the external source and reconnected to the signal port of the PM standard for further measurements.

The noise floor of the measurement system is determined with the noise modulation off and the mixer sensitivity determined above. Since the noise floor between the two signals is typically less than -193 dBc/Hz, the PM noise measured in this configuration is generally due only to the measurement system.

Next the PM noise is measured with the noise modulation on. Differences between the measurement of $S_\phi(f)$ and the calibrated PM noise determined using the method in Section 2 represent errors in the PM noise measurement system under test. The contribution of the noise floor of the PM noise measurement generally needs to be considered only near the carrier, (that is, as f approaches zero Hz) [5]. Errors are usually traceable to differences in rf drive and/or output impedance between the internal source and the external source used to determine k_d. The most common mistake is using a different cable for determining k_d and in measuring PM noise.

Figure 3 shows another method in which a second oscillator is used to determine the accuracy of PM measurement systems. The effects of the PLL on the measurements for small f can be important in this configuration. The PM noise of both oscillators and the calibrated PM noise are detected in the measurement. This approach can also lead to accurate evaluations of the measurement system errors versus Fourier frequency if the oscillator PM noise is small enough [5]. Our PM/AM noise standards accommodate this approach by providing oscillators with very low residual AM and PM noise and the ability to turn the calibrated PM noise off to check the noise floor of the measurement. As above, k_d is measured by allowing the two oscillators to beat. The noise floor of the entire setup is measured with the calibrated PM noise off and then with the calibrated PM noise on. From these two measurements we can determine the contributions of the uncancelled PM noise of the oscillators and the measurement system and their contribution to the measurement of the PM noise standard. Unlike the measurement technique outlined in Fig. 2, it is not generally possible to verify the noise floor of the measurement system because the phase noise of the reference oscillators always contributes to the measured noise. Also the accuracy cannot be carried out at small values of f since the PM noise of the reference oscillators dominates over the added noise. This problem can be alleviated somewhat by increasing the added noise and decreasing the bandwidth to satisfy Eq. (2). The accuracy of determining k_d is typically better than in the configuration of Fig. 2 because no substitution oscillator is required.

3.3 Determining Accuracry and Noise Floor of "Single Oscillator" Type PM Noise Measurement Systems

The PM/AM noise standard can also calibrate the accuracy of single-oscillator (frequency discriminator) phase noise measurement systems by the configuration shown in Fig. 4. The PM noise of both the oscillator and the single-oscillator measurement system is detected in the measurement. This approach can lead to accurate measurements if the oscillator PM noise is small enough [5]. The procedure is to measure the residual PM noise in the measurement with the calibrated PM noise off and then to measure the PM noise with the calibrated PM noise on. Unlike the technique of Fig. 2, it is not generally possible to verify the noise floor of the measurement system for these calibration methods because the phase noise of the reference oscillator always contributes to the measured noise. Another limitation is that the measurement cannot be carried out at low values of f since the PM noise of the reference oscillator generally dominates the added noise. This problem can be alleviated somewhat by increasing the added noise and decreasing the bandwidth to satisfy Eq. (2). There are no PLL effects to bias the measurements at low values of f. The noise floor of single oscillator systems is generally inferior to that of 2 oscillator systems [4].

3.4 Measuring PM Noise Added by Amplifiers, Frequency Multiplier, and other Components.

The phase noise added by amplifiers frequency multipliers and various components can be determined using a configuration similar to Fig. 2. The element to be tested is inserted in one or both of the signal paths from the PM/AM noise standard to the PM measuring system. PM measurements with the calibrated noise modulation on are used to calibrate the system sensitivity for converting phase fluctuations to voltage fluctuations versus Fourier frequency. PM measurements with the noise modulation off yield the PM noise (noise floor of the system plus the added noise of the element under test) relative to the calibrated PM noise. With this approach there is no need to measure k_d. Errors due the gain variations with frequency in the amplifiers and/or the spectrum analyzer cancel to a high degree. Accuracy is very good for this method since there is no change in sources or cables and there are no PLL effects to take into account.

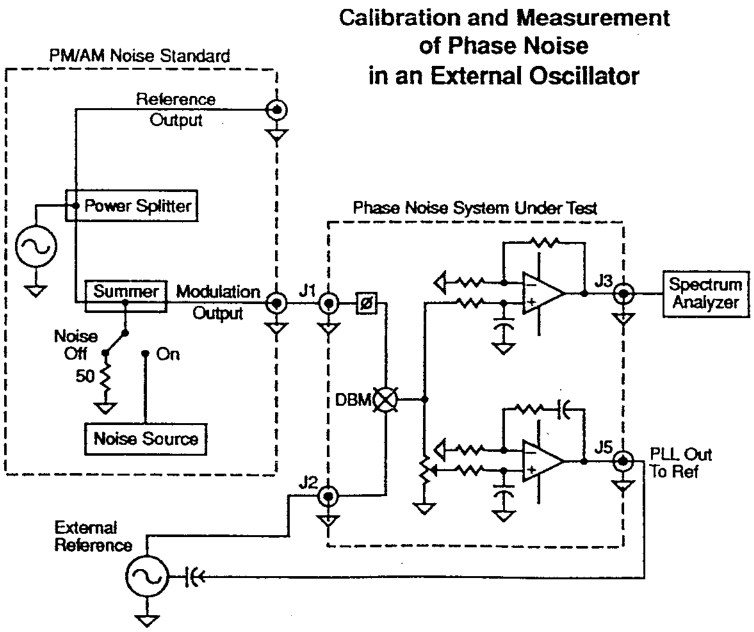


Fig. 3 Calibration method for two oscillator phase noise measurement systems.

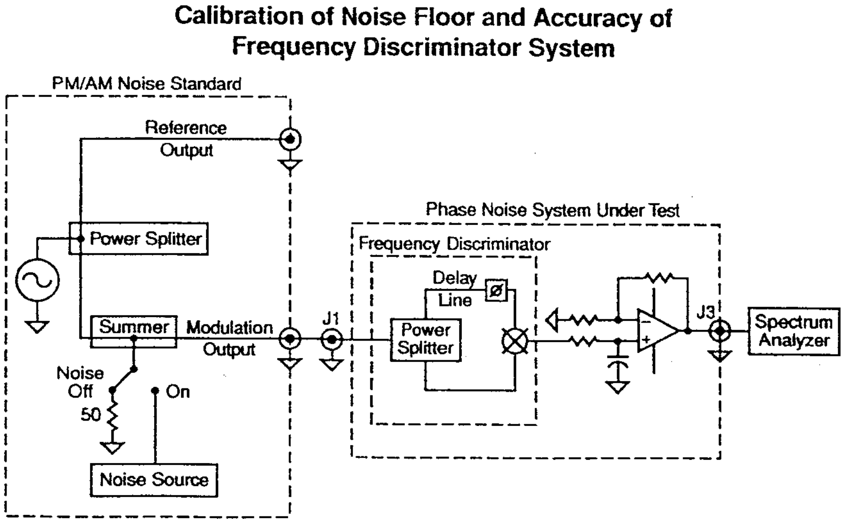


Fig. 4 Single oscillator phase noise calibration method using a frequency discriminator (see [3,4]).

3.5 Measuring PM noise in Oscillators

The configuration of Fig. 3 can be used to measure the phase noise of an external oscillator. PM measurements with the calibrated noise modulation on are used to calibrate the system sensitivity for converting phase fluctuations to voltage fluctuations versus Fourier frequency. PM measurements with the noise modulation off yield the PM noise (noise floor of the system plus the added noise of the oscillator under test) relative to the calibrated PM noise. Unbiased estimates of the PM of individual sources can be obtained using 3 oscillators in the 3 different pair comparisons [5]. Cross correlation which eliminate many of the problems with this type of measurement is discussed in [6,7].

3.5 Calibration of AM Noise in PM/AM Noise Standard

The AM noise in the standard is determined using the procedure described in section 3.1 and Eq. (1), since in the PM/AM noise standard,

$$S_a(f) = S_\phi(f) = \frac{PSDV_N(\nu_0-f) + PSDV_N(\nu_0+f)}{2V_0^2}. \qquad (3)$$

3.6 Determining Accuracry and Noise Floor of AM Noise Measurement Equipment

Amplitude noise can be measured by several different methods. Each method is characterized by a detector that converts the amplitude of the rf carrier signal to a dc voltage. A working definition of $S_a(f)$ is

$$S_a(f) = \frac{\delta V^2(f)}{V_o^2}\,\frac{1}{BW}, \qquad (4)$$

where $\delta V^2(f)$ is the mean squared fluctuation of the carrier rf amplitude measured at Fourier frequency f from the average frequency of the carrier in a noise bandwidth BW, and V_0 is the average amplitude of the carrier [3]. The most uncertain part of the process is determining the sensitivity of the detector $k_a(f)$ for converting the fractional changes in the carrier amplitude to a dc voltage fluctuation, since $k_a(f)$ is a function of V_0, f, and the carrier frequency ν_0, and in determining the variations of amplifier gain G(f) with Fourier frequency.

3.6.1 Calibration of Simple AM Noise Measurement Systems

The signal input of the AM noise measurement system to be measured is connected to the modulated output of the PM/AM noise standard as shown in Fig. 5. The spectral density of AM noise is calculated as

$$S_a(f) = \frac{V_n^2(f)}{BW}\left(\frac{1}{((k_a(f)G(f))^2}\right), \qquad (5)$$

where $V_n^2(f)/BW$ is the PSD of voltage noise measured by the spectrum analyzer.

When the noise modulation is on, the measured noise computed with the aid of Eq. (5) should agree with the results of the calibrated level as given by Eq. (3). The differences between the measured results and that determined from Eq. (4) yield the error of the AM measurement system under test as a function of Fourier frequency. This measurement can also be used to determine $k_a(f)G(f)$ except at very low values of f where the AM noise of the source might mask the added noise. This problem can be alleviated somewhat by increasing the level of the added noise and decreasing the bandwidth to satisfy Eq. (2). The variation of $k_a(f)G(f)$ with f is extremely difficult to determine by traditional methods since few sources can be accurately amplitude-modulated over a broad frequency range. This issue becomes even more serious as the carrier frequency and the offset frequency from the carrier increase. One method for determining k_a is shown in Fig. 6.

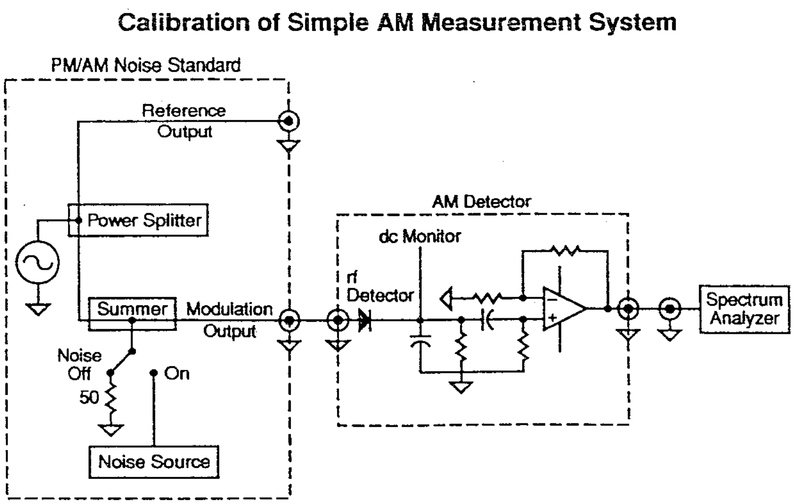
3.6.2 Determining the Noise Floor of an AM Noise Measuring Systems

The noise floor for AM measurements can be estimated by turning the noise modulation off, measuring $V_n(f)$, and computing $S_a(f)$ using Eq. (5). The noise floor determined in this manner includes the true noise floor of the AM noise measurement system being calibrated plus the AM noise of the internal source in the PM/AM noise standard. In most cases, the noise floor of the PM/AM noise standard is lower than the detectors being tested.

A differential measurement technique, shown in Fig. 7, can be used to evaluate AM noise in detectors even below that of the source. The dc outputs of the two detectors are preferably adjusted to be the same within approximately 1% using attenuators on the input of the detectors. The gain following the detectors may also be adjusted; however, the cancellation of the residual AM noise in the source may not be as complete as when input attenuators are used. The outputs are then subtracted in a conventional device such as a differential amplifier (see Fig. 7). Some spectrum analyzers also can process the difference between the two input signals. With either of these methods, the AM noise of the internal source is substantially reduced, perhaps as much as 20-40 dB. (At very high Fourier frequencies it may be necessary to adjust the phase slightly on the incoming signal to one of the AM detectors to optimize the cancellation.) The noise floor measured in this manner is that of both detectors (and their associated amplifiers). If they were identical, we would subtract 3 dB from the measured result to obtain the noise floor of a single unit. [4,5,8]

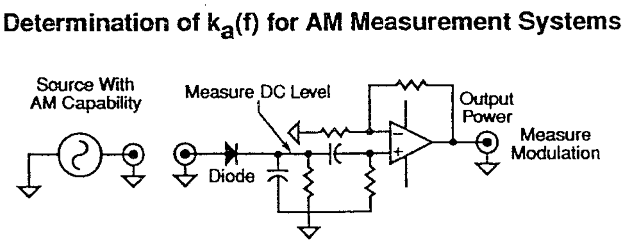
5. RESULTS

The first PM/AM noise standards operate at 5, 10, and 100 MHz. The noise source is flat within ± 0.2 dB over the bandwidth equal to 5 % of the carrier frequency and stable with temperature to 0.02 dB/K. The differential noise added to the carrier ν_0 is exceptionally flat due to



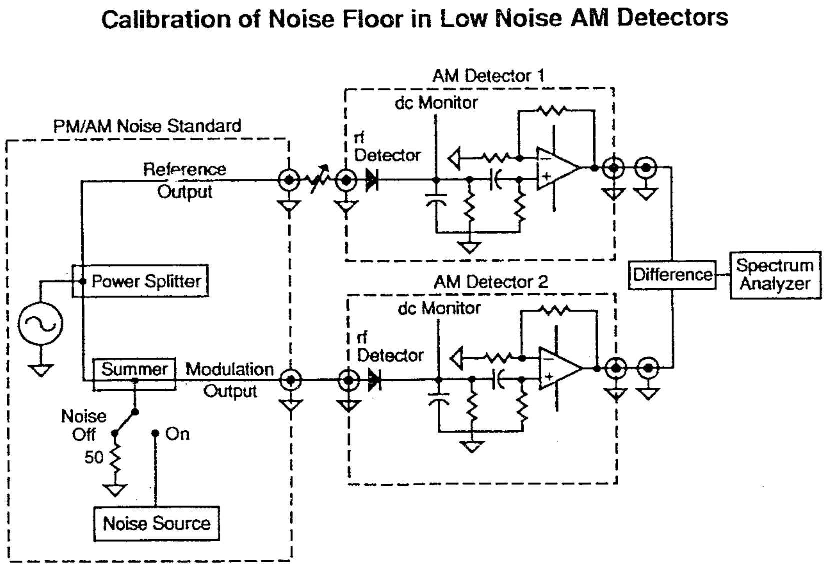
Calibration of Simple AM Measurement System

Fig. 5 Simple calibration method for AM noise measurement systems.



Determination of $k_a(f)$ for AM Measurement Systems

Fig. 6 One method of determining the sensitivity for converting small changes in amplitude to small changes in voltage.



Calibration of Noise Floor in Low Noise AM Detectors

Fig. 7 Differential AM calibration method to determine the noise floor of AM detectors and measurement systems.

the symmetry of Eq. (1). The results obtained at 100 MHz are shown in Fig. 8.

The PM noise of the 100 MHz reference oscillator of the PM/AM standard is shown in curve A of Fig. 9. The added differential PM/AM noise between the reference and modulated outputs at 100 MHz is shown in curve B. The noise floor of the PM/AM standard at 100 MHz using the method of Fig. 2 with the noise modulation off is shown in curve C. The cancellation of the 100 MHz reference oscillator phase noise by using the method of Fig. 2 (the difference between curves A and B) reaches approximately 85 dB at 1 Hz. The large suppression of the reference oscillator PM noise makes it possible to use the PM/AM noise standard over a much larger range of Fourier frequencies about the carrier than any technique that is sensitive to the PM noise of the reference such as that shown in Figs. 3 and 4. At 100 MHz, the difference is having an accurate PM standard for Fourier frequency offsets from 1 Hz to 10 MHz versus 300 Hz to 10 MHz. The peaks at 60, 120, and 180 Hz in curve B are due to spurious signals originating from the power lines.

Curve A of Fig. 10 shows the PM noise in the PM/AM noise standard at 100 MHz determined using a high-dynamic-range scanning receiver in the calibration mode described in Section 2 above. The noise is constant to ± 0.05 dB for Fourier frequencies from dc to 5 MHz and gradually decreases 0.3 dB from 5 to 10 MHz. Curve B of Fig. 10 shows the measurement of the PM noise level using a separate and independently calibrated phase noise measurement system PNMS [4,5,9]. Curve C of Fig. 10 shows the AM noise determined using the simple measurement technique of section 3.6. The divergence of curve C from curves A and B for Fourier frequencies below 100 Hz is easily shown, by the AM noise floor measurements, to be due to noise in the diode detector used for these measurements. The fluctuations in curve B of Fig. 10 versus frequency are primarily due to the finite number of samples taken to estimate the spectral density [10]. The differences between curves A and B of Fig. 10 are consistent with the estimated errors in the internal phase modulator used in the calibration of the PNMS. Table 1 summarizes the PM/AM calibrated noise and noise floor at 5, 10, and 100 MHz. The independent data from the PNMS confirm the calibration of the PM/AM standard to ± 0.5 dB.

6. CONCLUSION

A series of new portable PM/AM noise standards has been developed, tested, and used to evaluate the noise floor and accuracy of PM and AM noise ($S_\phi(f)$ and $S_a(f)$) measurement equipment. The differential PM noise in the PM noise standard used to test the noise floor is typically much less than the noise floor of present measurement systems. The PM noise in the standard was evaluated for Fourier frequencies from 1 Hz up to 10% of the carrier frequency to an accuracy of ± 0.14 dB at 5, 10, and 100 MHz. The temperature coefficient of the PM and AM noise is less than 0.02 dB/K. These calibrations were independently verified for all frequencies to ± 0.5 dB using the Phase Noise Measurement System [4,5,9]. The design of the standard is such that the fractional amplitude noise $S_a(f)$ is equal to $S_\phi(f)$ over a very wide range of Fourier frequencies. The new secondary standard has maintained the same level of PM and AM noise to within ± 0.4 dB over the past year [1,2].

These PM/AM noise standards can also be used as the calibration aid for both PM and AM measurements of sources, amplifiers, frequency multipliers and other devices. Their use greatly simplify the measurement process because the sensitivity of the detector and the relative gain of the post amplifier versus Fourier frequency are determined simultaneously.

7. ACKNOWLEDGEMENTS

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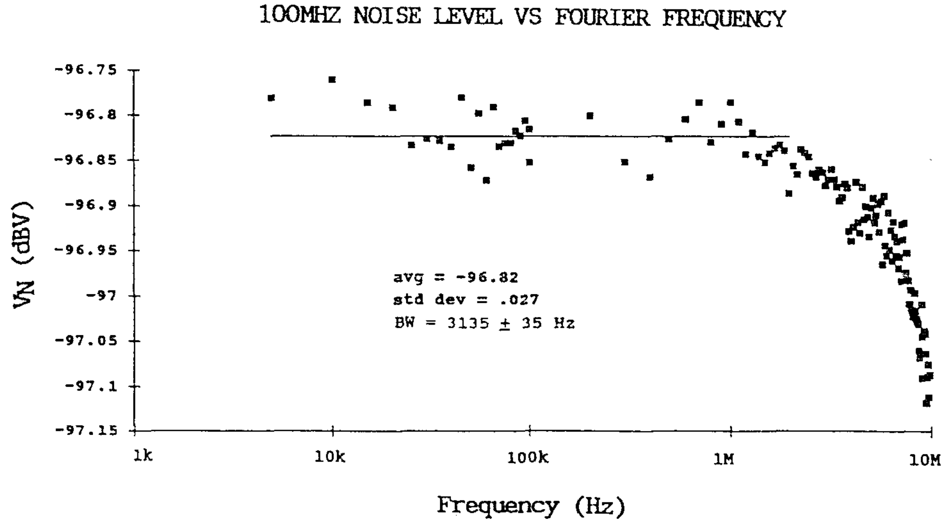

Fig. 8 Calibration of V_N added to the carrier V_0 versus Fourier frequency f at 100 MHz.

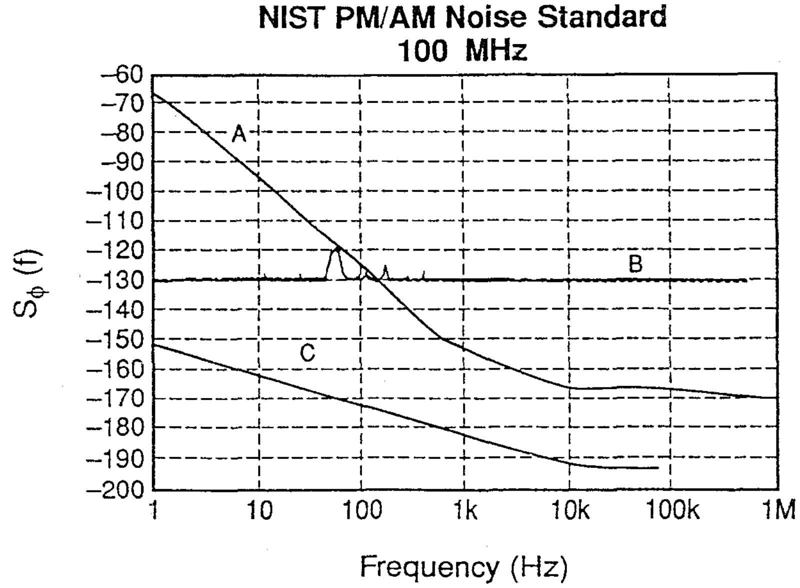

Fig. 9 Measurement results for PM/AM Standard model PMAM 115 at a carrier frequency of 100 MHz. Curve A shows the PM noise of the 100 MHz reference oscillator. Curve B shows the calibrated level of PM and AM noise. Curve C shows the typical noise floor for PM noise in the PM/AM Noise Standard at 100 MHz. Somewhat better results are obtained at 5 and 10 MHz.

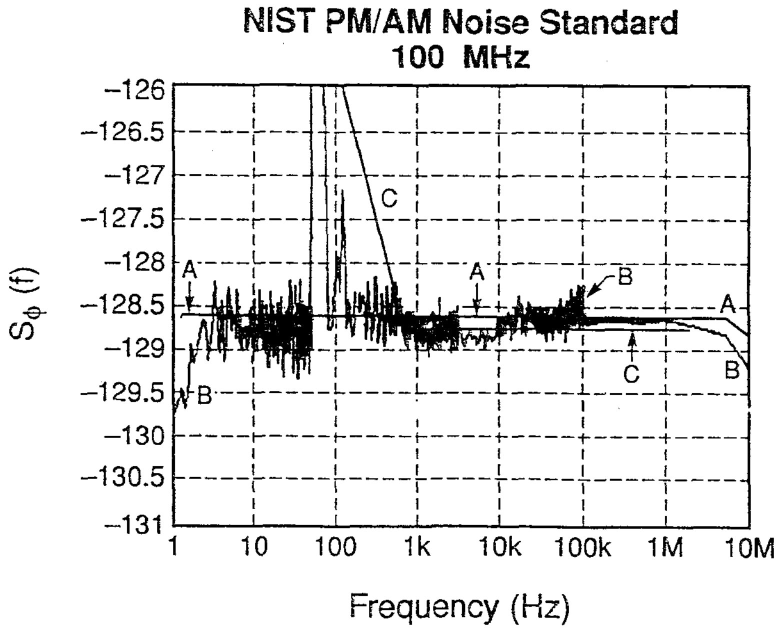

Fig. 10 Measurement results for PM/AM Standard model PMAM 115 at a carrier frequency of 100 MHz. Curve A shows the PM noise level of the standard determined using the technique of Section 3. Curve B shows the measurements of PM noise using the totally independent NIST Phase Noise Measurement System (see [4,5,9]). Curve C shows the level of AM noise of the standard at 100 MHz using the method shown in Fig. 5. The peaks at 60 and 120 Hz are due to the power line. Similar results are obtained at 5 and 10 MHz.

TABLE 1. SYSTEM NOISE FLOOR AND PHASE NOISE OF SOURCES

SOURCE FREQUENCY	FOURIER FREQUENCY							
	NOMINAL SOURCE PM NOISE/CHANNEL (dBc/Hz)							
	1 Hz	10 Hz	100 Hz	1 kHz	10 kHz	100 kHz	1 MHz	10 MHz
5 MHz	-121	-151	-163	-171	-174	-174	-174	
10 MHz	-115	-145	-157	-165	-168	-168	-168	
100 MHz	-70	-100	-130	-156	-170	-170	-173	-173
MAXIMUM RESIDUAL PM NOISE BETWEEN CHANNELS (dBc/Hz)								
5 MHz	-162	-172	-182	-190	-194	≤-175	≤-175	
10 MHz	-161	-176	-183	-191	-197	≤-175	≤-175	
100 MHz	-152	-162	-172	-182	-193	≤-175	≤-175	≤-175
DIFFERENTIAL PM/AM NOISE LEVEL (dBc/Hz)								
5 MHz	-128.3	-128.3	-128.3	-128.3	-128.3	-128.3		
10 MHz	-129.1	-129.1	-129.1	-129.1	-129.1	-129.1	-129.2	
100 MHz	-128.9	-128.9	-128.9	-128.9	-128.9	-128.9	-128.9	-129.2