# Audio Noise Sources for Generating Phase Noise

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System designers occasionally need an adjustable level of phase noise from an oscillator to determine the required oscillator noise specifications. Audio noise sources are often employed to modulate the phase of frequency sources to simulate a specific level of phase noise. The desired spectral density usually includes white and flicker phase noise and may include white and flicker frequency noise. The audio noise may be applied to a phase shifter or to the electrical tuning of the oscillator to achieve the desired modulation. White and flicker noise applied to the phase modulator will yield white and flicker phase noise and white and flicker noise applied to the oscillator's electrical tuning will yield white and flicker frequency noise. The bandwidths of the electrical tuning input and the phase modulator input must be sufficiently high to include the desired frequency range.

A number of simple phase shift circuits including a simple low-Q series tank may be used to construct a simple phase modulator. A varactor diode is added to the circuit to slightly modulate the phase shift in response to the audio input. The sensitivity of the phase modulator may be determined by applying a known-amplitude sinewave and measuring the resultant phase modulation with a phase noise measurement setup. (Making sure that the analyzer is not measuring power spectral density since the sinewave is not a random signal.) Changing the setup between calibration and measurement may change the loading of the phase modulator and, consequently, its modulation index. Load-insensitive phase shifters may be constructed by placing buffer amplifiers at the input and output.

An excellent way to generate white and flicker frequency noise is to modulate the electrical tuning of an oscillator. The sensitivity of the electrical tuning at the operating point can be precisely determined with a frequency counter and as long as the tuning is reasonably linear this sensitivity will be quite predictable. Since the modulation is not in the RF path, loading changes will not change the sensitivity of the modulation. Obviously, the electrical tuning bandwidth must be above the frequencies of interest. Calculating the amount of phase noise which results from a particular level of modulation is relatively easy:

First, the fractional frequency noise, Y(t), which results from the audio noise is calculated by multiplying the audio spectral density numbers by the fractional frequency tuning sensitivity.

Example: Assume a 10 MHz oscillator with a tuning sensitivity of 5 Hz per volt is to be modulated with white noise at a level of 100 nV per root Hz.

$$\frac{5\text{Hz}}{10\text{MHz}} = 5 \bullet 10^{-7}$$

$$Y(t) = (5 \bullet 10^{-7})(100 \bullet 10^{-9})$$

$$Y(t) = 5 \bullet 10^{-14}$$

$$Y(t)^2 = 25 \bullet 10^{-28}$$

The "power" of the frequency noise is obtained by squaring Y(t). The resulting number is the power that a noise voltage of Y(t) would generate in a one ohm resistor. Since the example uses white noise , the power spectral density is the same for any offset frequency:

$$S_y(f_0) = 25 \bullet 10^{-28}$$

Converting to phase noise spectral density is accomplished by multiplying by the carrier frequency and dividing by the offset frequency:

$$S_\phi(f) = S_y(f) \bullet \frac{\upsilon^2}{f_0^{\,2}}$$

$$S_\phi(100) = (25 \bullet 10^{-28})\left(\frac{10\text{MHz}^2}{100\text{Hz}^2}\right) = 2.5 \bullet 10^{-17}$$

$$S_\phi(100)_{\text{dB}} = 10\log(2.5 \bullet 10^{-17}) = -166\text{dBc}$$

The numbers chosen for this example illustrate that a fairly noisy tuning voltage will not significantly degrade most precision crystal oscillators with small electrical tuning ranges. For effective modulation of typical crystal oscillators, higher noise levels will be required.

White noise sources may be purchased as modules or easily constructed from fast, low noise op-amps. A 150k ohm resistor exhibits about 50 nV per hertz at room temperature and many low noise op-amps are suitable for amplifying this noise to usable levels.

Flicker noise may be obtained from many three-terminal voltage regulators and band-gap voltage references but a suitable device must be hand selected. A more predictable approach is to approximate the flicker noise slope by filtering a predictable white noise source. The circuit shown in fig. 1 is an implementation of a flicker noise generator described in NBS technical note #604, “Efficient Numerical and Analog Modeling of Flicker Noise Processes” by J.A. Barnes and Stephen Jarvis, Jr. The circuit employs a TLC2272 op-amp although other low noise op-amps will work. The amplifier must have low noise current since a high value resistor is used to generate the 50 nV white noise. The white noise generator may be left out when using a spectrum analyzer with a built-in noise generator. The capacitor values vary slightly from the calculated values in the referenced paper to simplify construction and the circuit includes bias to allow the use of polarized electrolytic capacitors. The electrolytic capacitors should be selected carefully since many aluminum electrolytics have poor tolerances. The values shown will give a 1/f noise slope from below one hertz to over four kilohertz.

Summing amplifiers could be added to the circuit in fig. 1 to combine the white noise and flicker noise. Two summing amplifiers would allow independent control of the white and flicker noise level applied to a phase shifter and to the electrical tuning. The complete system would allow the experimenter to independently adjust the phase noise terms from $f^0$ to $f^{-3}$.

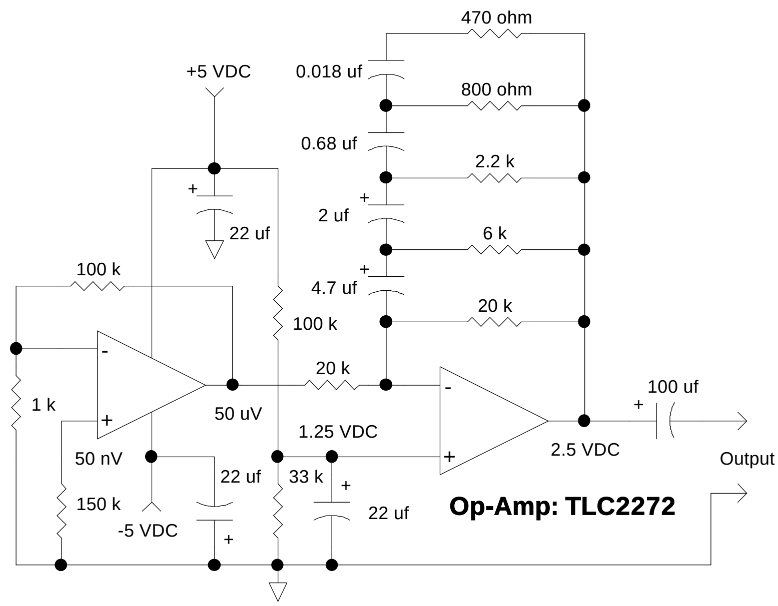


**Figure 1: Flicker noise generator.**