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Online Resources for Understanding Noise and its Measurement

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Noise is a key concept in electronics, and has many online references and informational resources available at various commercial, educational and government web sites

Noise—it's part of all electronic circuits and systems. Noise is a limiting factor in performance, but it is also a valuable tool for measuring performance. For our tutorial coverage, we have chosen to direct interested readers to some of the excellent material available online at the web sites of companies and institutions.

The Fundamentals

For someone new to this subject, we recommend that the first stop should be the Noise Com site: www.noisecom.com. In the "Application Library" section there are several application notes. Start by downloading *Noise Basics: What is Noise?* and study it. This concise two-page note has been around for nearly 20 years and has started the learning process for many engineers.

Noise Basics starts with the classic thermal noise power equation: $N = kTB$, where N is the total noise power, $k = 1.380\times10^{-23}$ Joules/Kelvin (Boltzmann's constant), T is the temperature, and B is the noise bandwidth. Additional fundamental data includes definitions of Gaussian noise, excess noise and power relationships. The principles of noise figure measurement are also covered.

The next step is to get more in-depth instruction. There is a vast amount of information at the National Institute of Science and Technology (NIST) web site. First, try the Radio-Frequency Technology Division site: www.boulder.nist.gov/div813/. Click on the "noise" subject area, then on "Presentations" at the bottom of the next page. Download the presentation "Thermal Noise Measurements" for your study. These are the slides to a tutorial on noise that is a perfect follow-up to the Noise Com application note.

Getting more specific, fundamental data on phase noise is also available from NIST. The Time and Frequency Metrology Group has the world's top experts on this subject, and information can be found at: www.boulder.nist.gov/timefreq/phase/. This page has many links, but start with "Tutorial" under "Metrology" in the left-side column.

By now, you're beginning to understand how much information is available online! These are just a few of the good places to begin your study of noise fundamentals.

Noise Figure Measurement

Next, we will look at some specific applications of noise in performance measurements. First, noise figure (NF) is a classic measurement for amplifiers and other circuit elements, a means for quantifying the degradation (however small) they contribute to the noise floor of the system.

Agilent Technologies' Application Note AN57-1, *Fundamentals of RF and Microwave Noise Figure Measurements* is good place to start learning about this subject. Download the note from: http://cp.literature.agilent.com/litweb/pdf/5952-8255E.pdf, or you can search from the main www.agilent.com page.

This 33-page application note is quite comprehensive, including both background theory and measurement techniques. Although measurement data features Agilent instruments, the information in not brand-specific.

Additional noise figure measurement

information is available from companies the make device test products. Application note 5C-042 from Maury Microwave (www.maurymw. com) provides a useful introduction to these measurements. Similarly, Application Note 31 from Focus Microwaves (www.focus-microwaves. com) also reviews this topic.

Phase Noise Measurement

Designers of oscillators and frequency synthesizers need to understand and measure phase noise. Fortunately, there is a lot of excellent information available online. Go back to the NIST Time and Frequency Metrology Group web site and explore some of the other papers and presentation material beyond the Tutorial noted earlier.

Additional detailed information on noise characteristics of oscillators can be found in several tutorials on basic oscillator performance, archived on the IEEE Ultrasonics, Ferroelectronics and Frequency Control Society (UFFC). Go to: www.ieee-uffc.org/fcmain.asp and click on "Tutorials" in the left-hand column. A number of the papers and tutorials listed include sections that summarize the key elements of oscillator noise that correspond to various physical behaviors within electronic devices.

You will eventually want practical data on how to make phase noise measurements, and reduce phase noise in your own designs. Be sure to review the online notes and data offered by Wenzel Associates at www.wenzel.com. This company is well-known for making some of the lowest noise crystal oscillators available, and they willing give away a few "trade secrets" in the "Library" section of their web site. Of special note are several articles listed under "Time and Frequency Circuits and Articles." Several articles include practical design techniques and circuit suggestions: "Low Cost Phase Noise Measurement," Low Phase Noise Systems – Hints and Tips," and "Finesse Regulator Noise."

Most of the semiconductor companies that manufacture PLL integrated circuits have background information on phase noise. Product data sheets often include phase noise fundamentals in the sections describing loop filter design. Analog Devices (www.analog.com) also offers the technical notes, "Shielding and Guarding," and "Ground Rules for High Speed Circuits," which provide practical guidance on implementing PLL and direct digital synthesis (DDS) circuits. Other companies with PLL applications data include National Semiconductor (www.national.com), Philips Semiconductors (www.semiconductors.philips.com) and Maxim Integrated Products (www.maxim-ic.com).

Companies the offer phase noise measurement equipment also have useful application notes. Examine the application note sections of the web sites for Agilent Technologies (www.agilent.com), Rohde & Schwarz (www.rohde-schwarz.com), Aeroflex (www.aeroflex.com) and Poseidon Scientific Instruments (www.psi.com.au). The operating manuals for phase noise measuring instruments also contain tutorial information, so be sure to examine them, if they are available online.

Signal-to-Noise, E_b/N_o and Related Measurements

Noise as a measurement tool for digital communication systems has increased rapidly in importance over the past decade. Again, Noise Com's application notes should be reviewed, since that company makes equipment specifically for this task. Another company in this business is Micronetics (www.micronetics.com), which has several notes available, as well as product data.

The Communications Research Center Canada (CRC) has an extensive library of technical notes on communications quality and reliability, many of which contain significant background and measurements based on signal-to-noise and data error rates relative to E_b/N_o. Canada is a large country that relies on satellite and terrestrial radio for communications more than most other developed nations. Significant research at CRC is targeted toward these systems. Review the "CRC Library" and "CRC Publications" sections of their web site: www.crc.ca.

Formal Online Courses

There are formal education opportunities online, as well. A few of the institutions best known in this industry include Besser Associates (www.besser.com and www.besser-net.com), Georgia Tech (www.gatech.edu) and UCLA Extension (www.ucla.edu).

It was not possible to catalogue them for this report, so we recommend that you use a search engine with combinations of the search parameters: "noise," "noise figure," "phase noise," "education," "class" and "course." Additional educational opportunities that include noise topics are certain to be located.

Additional Resources

Although this report emphasized online resources, there are numerous textbooks that include excellent materials on all the specific noise topics mentioned here. Books are often noted on the above web sites, and there are some web sites that serve this industry by offering collections of data, including books and useful web links. Two sites to look at are RF Cafe (www.rfcafe.com) and New Wave Instruments (www.newwaveinstruments.com/resources/).

Finally, remember that all these online resources were written by someone. The best sources of information on this (or any) topic are those experts. Engineers and educators are nearly always willing to suggest the best resources, or even to provide a one-on-one tutorial themselves.