The Dynamic Range Tester: A Multipurpose "Real-World" Signal Simulator for Correlator Testing and Other Applications

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***Abstract*— The dynamic range tester (DRT) is a patented prototype system that functions as a dual-channel, precision signal-to-noise ratio (SNR) generator [1]. It was designed for testing high-speed acoustooptic correlators, and can be used for many applications requiring "real-world" test signals. The DRT is a convenient tool for generating two highly isolated, noisy test signals from a single signal source, to simulate two antennas receiving the same signals. By splitting a user-supplied signal into two copies and adding wideband, random noise to each portion, the DRT generates two noisy test signals, one in each channel. The noise generated in one channel of the DRT is uncorrelated and isolated from the noise generated in the other channel by approximately 90 dB. The correlated (signal) and uncorrelated (noise) parts of the test signals are each variable over a wide dynamic range. The DRT is useful for a variety of testing and demonstration purposes: generally, for evaluating a system's tolerance to noisy inputs and specifically, for making measurements of dynamic range, processing gain, and frequency resolution of a correlator, spectrum analyzer, or other signal processing system. The DRT can also use two signal sources, one in each noisy channel, to simulate two antennas receiving different signals. This configuration of the DRT may be useful for performing interference and bandwidth testing of signal processing hardware. The patented design is extendible to all frequency ranges, perhaps for producing useful instrumentation in such fields as telecommunications, telemetry, biomedical engineering, etc.**

***Index Terms*—Acoustooptic correlators, antennas, correlators, interference, spread spectrum communications, test equipment, white noise.**

I. Introduction

THE dynamic range tester (DRT) is a versatile laboratory instrument for generating two highly isolated "real-world" signals, each with variable signal-to-noise ratio (SNR) over a wide dynamic range. A prototype of the DRT has an operating range from 30 MHz to 400 MHz (see Fig. 1). The DRT can be operated in three related configurations, selectable by switches on the front panel (see Fig. 2). The user-supplied signals processed by the DRT may be narrowband or wideband, for instance, a spread-spectrum or frequency-hopping signal. An unlimited number of frequency ranges for the generated signals may be chosen by selecting from a bank of filters or connecting a filter at the designated ports in each of the two noisy channels of the DRT. Precision attenuators, also accessible on the front panel of the DRT, control the signal and excess noise power through the DRT.

Fig. 1. Photograph of the prototype DRT.

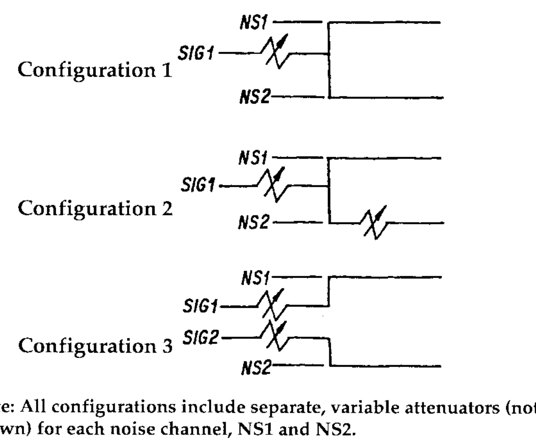

Fig. 2. Three related configurations of the DRT.

II. Background

Thermal noise, present in all electrical systems and caused by the thermal agitation of electrons, limits the processing of low-level electrical signals [2]. A measure of the relative level of signal power to noise power in any given electrical signal is the SNR. The decibel (dB) [3] is a logarithmic unit of measure

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for expressing the ratio of two power signals, defined as

$$\text{Number of dB} = 10 \log P_2/P_1. \tag{1}$$

When power measurements are expressed in absolute terms by replacing the denominator in (1) with a reference power level, P_0, the power measurement is defined as

$$\text{Number of dB (absolute)} = 10 \log P/P_0. \tag{2}$$

Commonly, in the field of RF signal processing, a reference power of 1 mW is used, and (2) becomes

$$\text{Number of dBm} = 10 \log P/1 \text{ mW}. \tag{3}$$

The ratio of two power measurements with both numerator and denominator expressed in units of dBm, such as SNR, is then quite readily calculated as a difference, since the following is a property of logarithms:

$$\log A/B = \log A - \log B. \tag{4}$$

Throughout this paper and in experiments using the DRT, signal and noise power are measured in dBm, so that SNR's can be easily calculated as the difference between the signal and noise power.

Most electrical systems work on signals defined by positive SNR's, where the signal power is greater than the noise power. If the signal power falls below the noise power, the SNR becomes negative and the signal is said to be "buried in the noise." High-speed correlators are designed to detect signals that are defined by negative SNR's, by performing a mathematical correlation of two signals and thus "pulling the signals out of the noise." This is possible if the noise is uncorrelated between each of the two signals being processed in the correlator, or if the resulting signal correlation is stronger than the noise correlation.

Acoustooptic (AO) correlators and spectrum analyzers are used to perform very wideband processing in real time [5]. AO correlators may be characterized by processing gain, which can be thought of as the depth from which a correlator can extract signals from below noise level. This parameter can be experimentally verified with two independently noisy and variable test signals. Recall that dynamic range is generally defined as the difference between the highest and lowest signal, in terms of power, that any system can process simultaneously [4]. Processing gain can be thought of as dynamic range, where the high signal is the noise, and the low signal is the "clean" or information-carrying signal.

The DRT was specifically designed to test the AO correlators and spectrum analyzers developed at the Army Research Laboratory, which are both space- and time-integrating processors [5]. These AO signal processing systems use piezoelectric transducers to convert RF signals to acoustic signals that interact with laser light. As the acoustic signals propagate through a medium, they cause a periodic variation in its index of refraction. This sets up a diffraction grating that then modulates a coherent light beam as it passes through. Correlation is realized using two modulated light beams, or one light beam twice modulated and a reference beam. The interference pattern of the two beams on a photodetector array is recorded as a matrix of electrical voltages for further processing and/or display. AO correlators will detect signals with common frequencies in their two RF inputs and will reject dissimilar signals, such as independent, random noise. The AO spectrum analyzer operates similarly. It maps the electrical voltages from the photodectector array to produce a frequency versus amplitude display of a single RF input.

During the development and testing of AO correlators and spectrum analyzers, it is useful to generate test signals in the laboratory in order to quantify system parameters such as dynamic range, correlator-processing gain, or frequency resolution. Further, it is convenient to have two test signals that are calibrated and easily variable over a range of SNR's, where the noise in each test signal is uncorrelated from the other. Because there are no commercially available instruments available to satisfy these and other requirements, the DRT is designed as an inexpensive test instrument and constructed using off-the-shelf components. The DRT is used to demonstrate the response of an AO or RF system to simulated real-world signals in the laboratory. It is used for a wide range of testing and demonstration purposes, and is especially intended for devices processing two inputs, such as correlators or dual-channel receivers. The design and uses of the DRT are the subject of this paper.

III. Design of the DRT Signal-Plus-Noise Channels

The DRT was designed for a maximum noise power of 1 W for a 20 MHz bandwidth out of each channel. Since noise power varies linearly with bandwidth, more noise power is processed through the DRT when larger bandwidth filters are used [2]. The use of larger bandwidth filters is allowed with the additional requirement for user-tuned attenuation via the front panel of the DRT. This user-tuned attenuation limits the excess noise power that is contained in the larger bandwidth, so that the maximum noise power at each output remains 1 W. Filter bandwidths smaller than 20 MHz may be used, but the maximum power available in the outputs will be proportionally smaller than 1 W.

The DRT creates real-world signals by combining internally generated, Gaussian-distributed, wideband noise and user-supplied signals into two highly isolated channels. An artificial noise floor is created in each channel of the DRT using a wideband (1 GHz) diode noise source, user-selectable filtering, and amplification to raise the level of the DRT noise floor in the frequency range of interest. The ratio of noise power out of a diode noise source to the noise floor is known as the excess noise ratio (ENR) and is specific to the individual device. In the DRT, noise sources having ENR $= 33$ dB are used. Each noise source is enclosed in a copper box and powered by its own battery pack. Separate voltage regulator circuits and electromagnetic interference (EMI) filters are used with each noise source. The generated noise is amplified to a maximum of 1 W in each output of the DRT. This power level is available for bandwidths from a minimum 20 MHz up to the system bandwidth of approximately 400 MHz, with the requirement for user-tuned attenuation to be set in each noise channel, accordingly (see Table I).

TABLE I
FILTER BANKS IN THE PROTOTYPE DRT AND NOISE CHANNEL ATTENUATION SETTINGS

Filter number	Center frequency (MHz)	Bandwidth (MHz)	Noise channel attenuation setting (dB)
1	45	30	2
2	175	60	5
3	180	60	5
4	200	400	13
5	300	100	6
6	External connection	External connection	10 log(B/20 MHz)

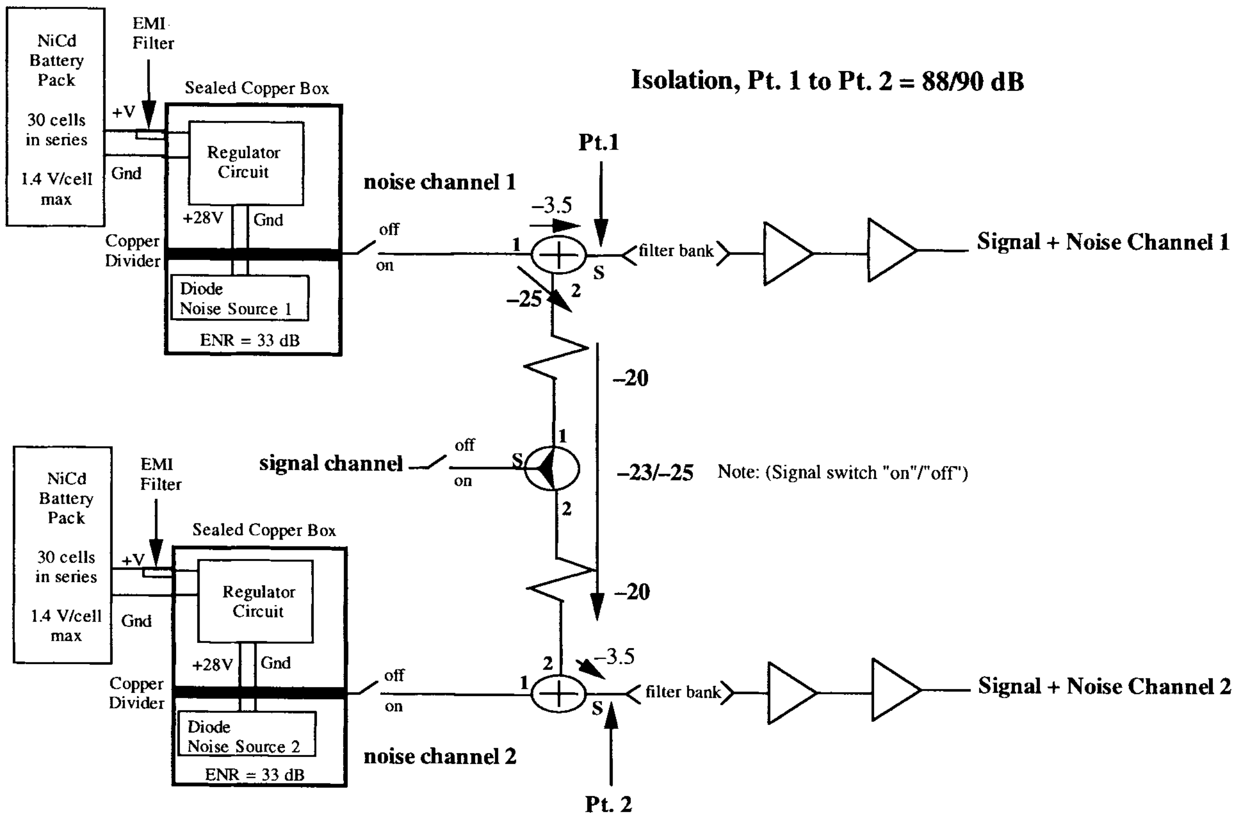

Fig. 3. Creating the isolated signal plus noise channels.

The means of injecting a common signal into these two channels uses three power splitters/combiners (see Fig. 3). Isolation of the two channels is vital to preserving the independently random noise that each contains. Since the power splitters/combiners do not provide perfect isolation, channel 1 noise will leak into channel 2 and vice versa. To suppress this interference, attenuation is inserted into the path that the noise leakage will follow. Although this leakage still occurs, the power level is negligible upon reaching the opposite channel. The inserted attenuation value is large enough to provide sufficient noise isolation, yet small enough to permit the user-supplied signal to pass through to both channels, following its original split. The exact attenuation value is determined by taking into account other system requirements.

A complete block diagram of the DRT is shown in Fig. 4. The DRT provides 50 dB signal gain to a maximum of 1 W (+30 dBm) in each of the two outputs simultaneously, requiring a nominal signal input of −20 dBm. The total maximum output level, at each output is 2 W, and is composed of equal parts signal and noise. The power level of the input signal and added noise components in each of the two outputs of the DRT are independently variable via user controls, so that a range of SNR's may be generated in each output. Highly calibrated attenuators, ranging from 0 dB to 110 dB in steps of 1 dB, operate on the signal and noise in each channel. The signal or excess noise in each channel may also be independently turned off using front panel switches. With the system noise floor of the DRT being approximately −50 dBm in a 20-MHz bandwidth, the signal power may be varied over a 80-dB range in each output, when using a 20-MHz bandwidth filter in each channel.

The DRT is designed to allow a range of bandwidths to be used for the generated signals. Table I details the contents of the two identical filter banks, which are accessed separately

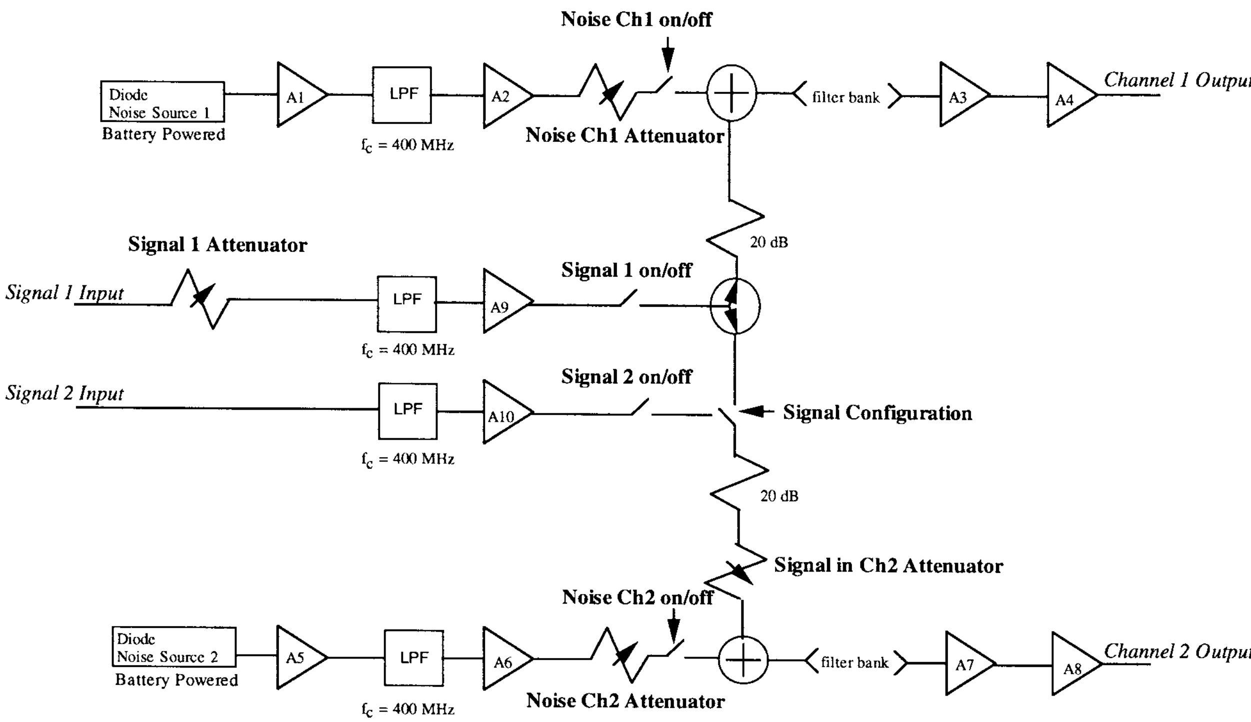

Fig. 4. Complete block diagram of the DRT.

on the front panel of the DRT. These filters match the specific systems that the DRT was designed to test. Noise power is proportional to the bandwidth of the selected filter in each channel. Selected noise bandwidths greater than the designed minimum of 20 MHz require that the precision attenuator in the respective noise channel be set accordingly to limit the excess noise power through the DRT, which still provides the maximum 1 W noise power in each output. Use of filters with bandwidths less than the designed minimum of 20 MHz will equate to maximum power in the outputs proportionally smaller than 1 W.

The DRT uses four variable attenuators, mounted on the front panel of the prototype DRT, to alter the signal and noise power in the DRT outputs. The DRT may be used in three related ways. In all three instances, the user may decrease the amount of noise added to the user-supplied (clean) signal in *each channel independently*, using two of the four attenuators. The other two attenuators affect the clean signals in the DRT as follows (see Fig. 2). First, a single signal is split into two separate signals and each is combined with the band-limited white noise to form two independent channels; the power level of the clean signals is *attenuated equally in both channels* using one attenuator. Second, the clean signal of the second output is *further attenuated independently* using the second attenuator. Third, the DRT creates two unrelated signals by combining white noise with two separate user-supplied signals. The clean signal component in each of these is *independently attenuated* using the two attenuators.

IV. Signal and Noise Power Measurements

Normally, in the measurement of SNR, a true measurement of "signal only" cannot be made directly because some thermal noise is always present. Therefore, SNR is calculated as follows:

$$\text{SNR dB} = 10 \times \log\left\{\frac{(\text{S}+\text{N})-\text{N}}{\text{N}}\right\}(\text{W}). \quad (5)$$

This superposition of signal and noise in the output is a valid assumption, since thermal noise has Gaussian-distributed randomness and is therefore independent of the signal. This theoretical calculation would be used if the signal and true noise floor level were on the same order, since there would be no way to turn the noise off. The DRT design, however, is based on having an artificial noise floor in each of its outputs which may, in fact, be turned off and on using front panel switches. This artificial noise floor may be set to various power levels, many well above the system noise floor. This excess noise power and the signal power in the DRT outputs must be set to high levels, so that direct measurement of "noise only" and "signal only" can be made by using front-panel switches to cutoff signal or noise power, respectively. The maximum excess noise levels and signal levels, $\sim$+30 dBm, are much larger than the actual DRT noise floor, $\sim$−50 dBm in a 20 MHz bandwidth. Therefore, when signal and noise power levels are well above the noise floor, direct measurement of signal only and excess noise only can be made, ignoring the addition of the DRT noise floor, which becomes negligible. All noise power measurements are based on average power and may be verified with a high-quality power meter with the use of a thermocouple sensor. Reducing the SNR of the output signals then relies upon the calibrated attenuators of the DRT. Signal power may be measured as peak power or average power, depending on the signal type supplied and the power sensor used.

The function of the DRT is to generate test signals having variable SNR, both positive and negative, for use in testing AO correlators as well as other systems. In order to do so accurately, test signals with a particular SNR are initially generated using signal and excess noise power levels that are well above the noise floor of the DRT. These signals are individually measured in the DRT outputs directly using the front-panel cutoff switches. Signal only (in dBm) in the output may be measured as peak power or average power, depending upon the user's interest. A thermocouple power sensor will detect the average power of noise only (in dBm) in the output. "SNR" (in decibels) is simply the difference of these measurements. It should be noted whether peak ("SNR_{peak}") or average ("SNR_{avg}") power measurement is used for the signal.

Subsequently, the DRT's high-quality, calibrated attenuators give accurate and independent control to the user in lowering signal and excess noise power levels in the outputs. Initial SNR is set using relatively high power levels of signal and excess noise. SNR's made up of lower power levels or negative SNR's are generated by simply setting calibrated attenuators to the required values and subtracting from the initial power levels.

The use of the DRT is limited by the real noise floor. As the signal level approaches the real system noise floor, its power can be calculated by subtracting the thermocouple sensor measurement of N from $(S+N)$ in (5). When these measurements register the same value, the signal power contribution is zero. The DRT is designed for reliable use above this region, where signal power approaches the real noise floor.

V. Conclusion

The DRT is a prototyped, patented, analog instrument, operating in the RF range of 30 MHz to 400 MHz. It generates "real-world" signals by combining wideband noise and user supplied signals into two highly isolated channels. It was designed as an application-specific test instrument for determining high-speed correlator processing gain. However, the DRT has extended usage as a useful laboratory instrument for generating real-world or noisy RF signals for many applications. It can be used for a variety of testing purposes and is a versatile demonstration tool. The design of the DRT can be extended to other frequency ranges to produce useful instrumentation for telecommunications, telemetry, biomedical applications, etc.

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