HIGH FREQUENCY DIRECT DRIVE GENERATION USING WHITE NOISE SOURCES

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PRESENT DIRECT DRIVE SIGNAL GENERATION METHODS

- DAMPED SINE GENERATORS (DSG)
  - Inherently "narrowband."
  - Insufficient flexibility for complex broadband waveforms.
- ARBITRARY WAVEFORM GENERATORS (AWG)
  - 800 megapoint/s maximum speed.
  - 8 points per cycle required for high fidelity waveform reproduction = 100 MHz maximum frequency.
  - Higher bandwidth would require reducing fidelity (fewer points per cycle) or interleaving outputs of multiple AWGs.
- RANDOM REPETITIVE SQUARE WAVE GENERATORS
  - Provide wideband signals but without fine control of frequency content and pulse envelope shape provided by AWGs.

Damped sinusoid direct drive injection on interconnecting cable bundles between subsystems has long been used as a technique for determining susceptibility to electromagnetic transients in military weapon systems. Questions arise, however, about the adequacy of this method of individually injected, single sinusoids in assuring subsystem strength against broad band threats. This issue has recently been raised in the latest revision of MIL-STD-461 that requires subsystems exhibit no malfunctions when subjected to a repetitive square wave pulse with fast rise and fall time (CS115). An extension to this approach would be to test subsystems using arbitrary waveforms.

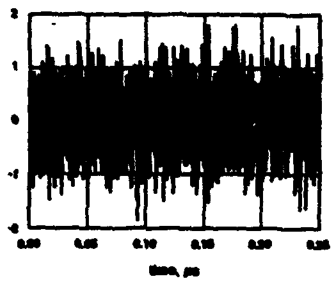
In recent years arbitrary waveform generators (AWGs) have been used to duplicate, with a high degree of fidelity, the waveforms measured on cable bundles in a system illuminated by fields in a system-level EMP simulator. However, the operating speeds of present AWGs do not allow the extension of this approach to meet new threats such as MIL-STD-2169A. A novel alternative approach for generation of the required signals, being developed in a cooperative effort between the Naval Air Warfare Center and Phillips Laboratory, is the use of white noise signals conditioned in such a manner to produce the desired direct drive waveforms.

WHITE NOISE AS ALTERNATIVE SOURCE FOR DIRECT DRIVE

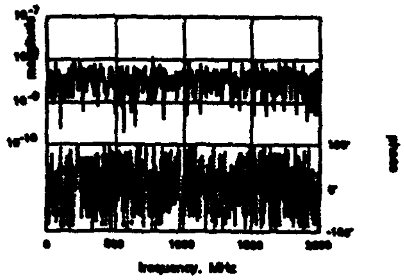
- White noise sources are commercially available. Used primarily in testing and ECM applications.
- Device used is Zener diode biased at breakdown voltage.
- Output is waveform with randomly varying amplitude.
- Frequency components from <1 Hz to >100 GHz are available.
- Products range from bare diodes to integrated programmable noise sources.

Commercial white noise sources, based on semiconductor diodes, are readily available and are commonly used in testing and ECM applications. These sources are available in various bandwidths with frequencies ranging from less than 1 Hz to greater than 100 GHz. Products extend from bare diodes to fully integrated, programmable noise sources.

GAUSSIAN WHITE NOISE



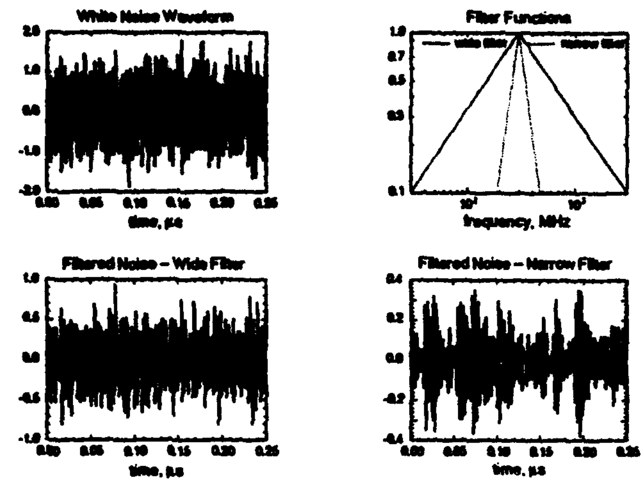
- Amplitude at each time point is uncorrelated with all other times.
- Amplitudes have a Gaussian distribution.



- Magnitude is essentially constant.
- Phase is random.

The output from one of thesenoise sources is a continuous signal with time domain amplitudes varying randomly according to a Gaussian distribution. These characteristics lead to a nearly constant frequency domain magnitude (over the bandwidth of the source) and a randomly varying phase.

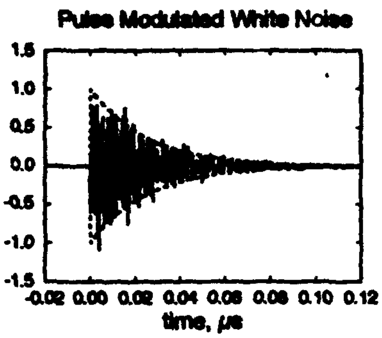
EFFECTS OF FILTERS ON WHITE NOISE

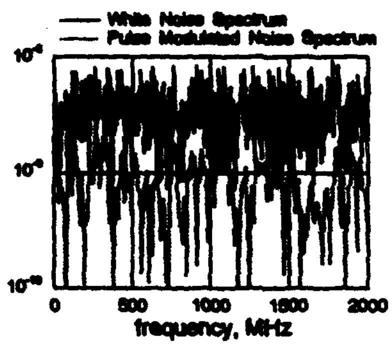


Calculations were performed using numerical methods to investigate generation of direct drive waveforms starting from a white noise signal. It was found that waveforms with any desired characteristics could be generated by (frequency varying) filtering of the white noise spectrum followed by (time varying) pulse modulation of the continuous filtered noise signal.

The effect of application of a frequency domain filter to white noise signals is illustrated above. Plot 1 shows a numerically generated white noise waveform with frequency content up to 2 GHz. The two filters shown in Plot 2 were applied to this signal. Both filters have a center frequency at 300 MHz. The wide filter rolls off from this peak at 20 dB/decade while the narrow filter roll off is 100 dB/decade. The white noise signal after passing through the wide filter is shown in Plot 3. Some change in the frequency content is evident, but the general appearance of the filtered noise is similar to that of the unfiltered signal in Plot 1. The waveform resulting from use of the narrow filter is given in Plot 4. The appearance in this case is that of a carrier frequency at 300 MHz and an amplitude modulation with a period inversely proportional to the bandwidth of the filter. These results indicate that so long as the applied filter is sufficiently broadband, the filtering does not disturb the quasi-CW characteristic of the noise waveform. Under these circumstances pulse modulation can be applied as an independent step; i.e., a pulse modulation envelope applied to any portion of the waveform in Plot 3 will result in nearly identical pulse waveforms in terms of norm quantities. This is not the case with the output from the narrow filter; placing a modulation envelope at different points along the time axis in Plot 4 would produce widely varying pulse waveforms. It should be pointed that a filter function with a series of sharp spikes spaced over a broad band of frequencies will produce results more like Plot 3 than like 4. Thus, the coupling spectra for most subsystems satisfy the criterion of "sufficiently broadband."

EFFECTS OF PULSE MODULATION ON WHITE NOISE

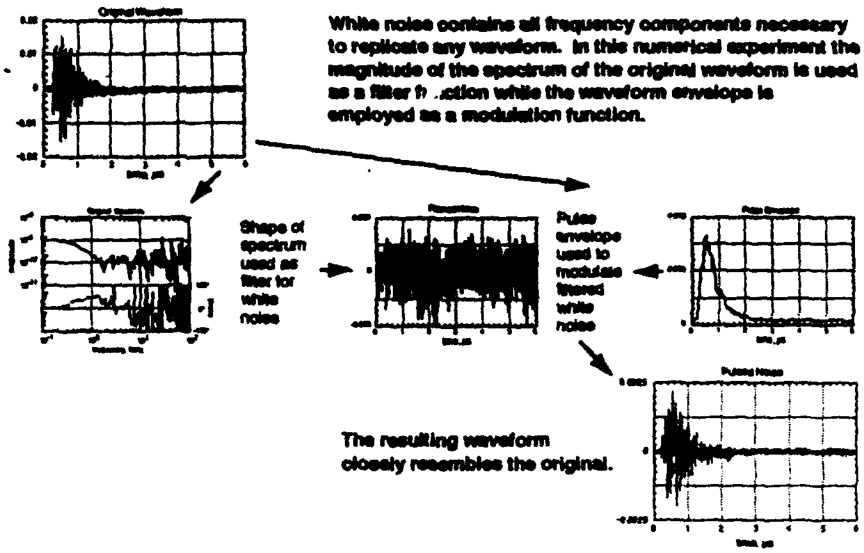




The effect of pulse modulation on the white noise signal is shown above. In Plot 1 the noise waveform is multiplied by an exponentially decaying pulse envelope. Plot 2 shows the magnitudes of the spectra of the continuous noise waveform and the pulse modulated noise. The average amplitude of the spectrum is reduced by the pulse modulation since the total energy in the waveform is decreased, but the spectrum is still essentially constant across the entire frequency range. The width of the features, i.e., peaks and valleys, are broadened in the pulse modulated spectrum as compared to the spectrum for the continuous noise. The degree of broadening is inversely proportional to the pulse width of the modulation envelope. These results indicate that pulse modulation does not appreciably alter the frequency domain characteristics of the white noise signal as long as the pulse length is not too short. This again indicates that filtering and pulse modulation can be treated as independent processing steps for white noise waveforms.

The above discussion applies only to the magnitude of the noise spectrum. The white noise signal contains no phase information in the sense that the phase is completely random. This is still true after the white noise passes through a filter; even if the filter has a phase function, the phase of the output is still random. It is the pulse modulation step that attaches a non random phase function to the signal.

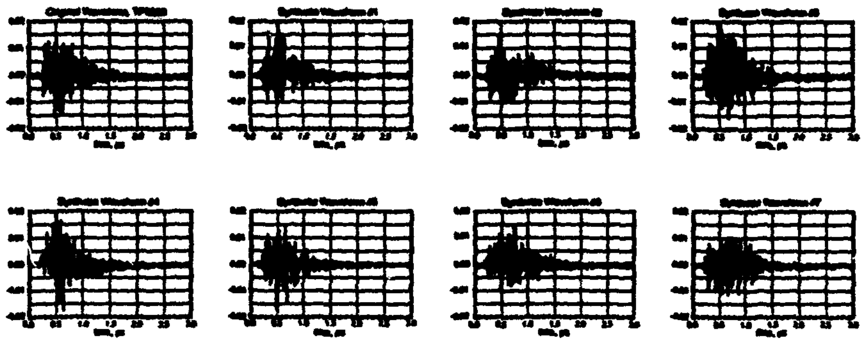
SYNTHETIC WAVEFORM CONSTRUCTION



Additional numerical experiments were performed in which attempts were made to replicate coupled waveforms measured on cables in the EMPTAC aircraft. The process used is illustrated above. The starting point is an EMPTAC waveform shown at the top of the viewgraph. The magnitude of the spectrum of this waveform was used as a filter by multiplying it with the spectrum (magnitude and phase) of a numerically generated white noise signal. (The phase of the EMPTAC spectrum was discarded. Whether this phase is used or not is immaterial since multiplication with the white noise spectrum results in a random phase in either case.) The product spectrum was inverse Fourier transformed to produce the filtered noise waveformc. The pulse envelope of the EMPTAC waveform was extracted by rms averaging over a moving time window. This envelope was then multiplied times the filtered noise and appropriately scaled to produce the pulse waveform shown at the bottom. This synthetic waveform appears to be a quite satisfactory replication of the original measurement and probably differs from it no more than the shot-to-shot variation observed in a typical test series.

WAVEFORM VARIABILITY

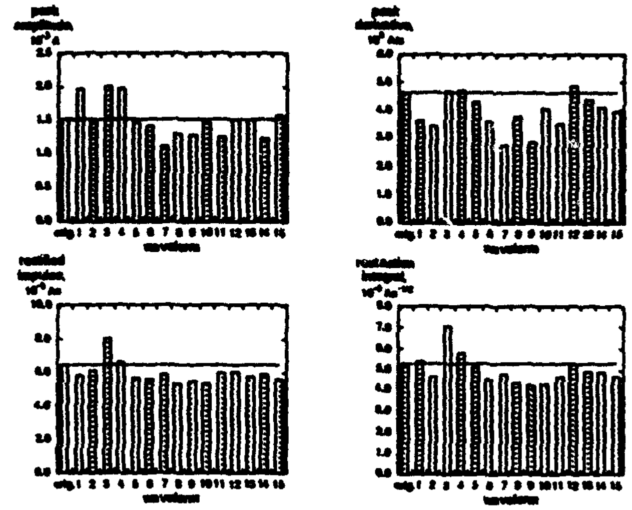
The process described on the previous slide produces shot-to-shot variations in the details of the wave shape. The original waveform and seven synthetic waveforms derived from it are shown below.



The process described above was repeated several times using different random seeds for the white noise waveform. Several examples are shown above.

WAVEFORM NORMS COMPARISON

Although the wave shapes show considerable variation, the values of waveform norms are relatively constant. All waveforms can be considered equivalent.

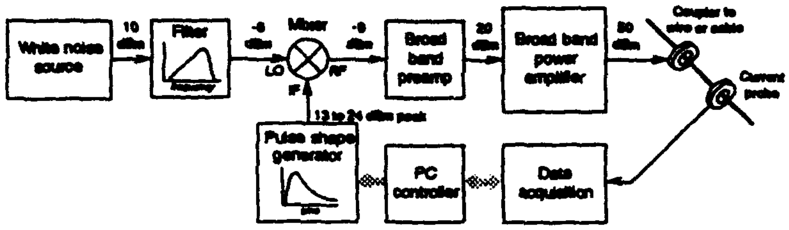


Norm quantities were calculated for the original and synthetic waveforms and were found to be satisfactorily constant. Some results are shown above for the peak amplitude, peak derivative, and root action integral. The first bar in each plot represents the value of the norm for the original waveform, and the remaining bars are the values for fifteen synthetic waveforms. (The same scaling factor was used for all the synthetic waveforms.) The maximum variations seen are ±30%. Similar results were found for the rectified impulse; the peak impulse was not calculated. This process was used on other EMPTAC data having different characteristics with equally satisfactory results. Although these EMPTAC data only extend in frequency to about 90 MHz, the principles of this process apply to any frequency range.

PROTOTYPE NOISE SOURCE DIRECT DRIVE SYSTEM

Below is a block diagram of a noise source waveform generator constructed as a proof-of-principle demonstration and will also be used to perform subsystem testing.

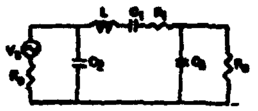
The pulse shape generator in the prototype is a square wave generator with a pulse forming filter. An arbitrary waveform generator can also be used to produce a more complicated pulse envelope. An example of a filter design for shaping the noise spectrum is shown on the next viewgraph.

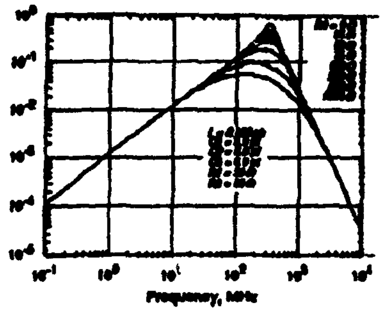


A prototype white noise source generator has been constructed for evaluation in direct drive applications; a block diagram of this system is shown above. The source is a Noise Com NC 6110, which has an white noise output flat to ±2.5% from 100 Hz to 1.5 GHz and a total output power of 10 dBm. The filter is any one of a number of simple filters constructed in the laboratory using copper-plated PC board as a substrate. These filters have center frequencies ≥100 MHz and roll off above and below the peak at 20, 40, or 60 dB/decade. The choice of filter depends on the general shape of the coupling spectrum to be simulated. The pulse source is a square wave generator and a pulse-forming filter that provides a suitable double exponential waveform. These two inputs are fed into the LO and IF ports, respectively, of a double balanced mixer with rf bandwidth of 10 MHz to 1.5 GHz. The pulse modulated noise signal appears at the RF port of the mixer. This signal is then amplified to the desired level. Various output amplifiers have been used: e.g., Amplifier Research models 10W1000M7 or 100W1000M7. Both of these units have bandwidth on the order of 1 GHz. This output is then fed into a broadband (>1 GHz) inductive coupler (previously developed by Phillips Laboratory) for injection onto a test article cable. The approximate power levels at each stage in this process are indicated in the diagram.

FILTER DESIGN FOR GENERIC WAVEFORM GENERATOR

An example of a filter circuit for use with the noise source generator is shown below along with performance curves for specific component values.





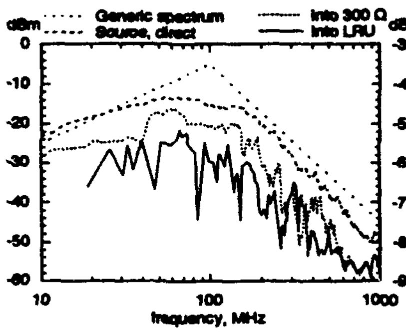
The shapes of these curves approximate the envelopes of coupling spectra in the vicinity of system aperture resonances with the peak corresponding to the aperture resonance frequency.

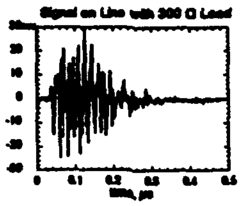
Several filters with this or similar circuits have been constructed with peak frequencies from 100 MHz to 1 GHz.

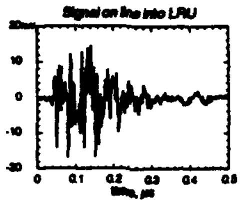
SUBSYSTEM DIRECT DRIVE EXAMPLE

A subsystem was tested to a simulated ultrawideband (UWB) environment using the generic spectrum shown below and a double exponential pulse envelope. The output spectrum of the noise source generator fed directly into the recording instrumentation is shown immediately below the desired generic spectrum.

The signal inductively coupled on to an individual wire in a cable is shown in the frequency and time domains with the wire terminated with a matched load and connected to the unit under test.







Evaluation of this prototype is underway at Phillips Laboratory, where it is being used to conduct a direct drive test on an aircraft subsystem. The upper dotted line in Plot 1 represents the generic coupling spectrum to the subsystem with the aircraft illuminated by a specific ultrawideband (UWB) source. This spectrum peaks at 100 MHz and rolls off at 20 and 40 dB/decade, respectively, below and above the peak. The dashed curve immediately below the generic spectrum is the output of the noise source waveform generator fed directly into the recording instrument (a Tektronix 602 Digitizing Signal Analyzer). The output of the generator was then inductively coupled to the subsystem cable, and the signal on a single wire in the bundle was monitored with a Tektronix CT-1 current probe and the 602 DSA. Measurements were made with the cable connected to the subsystem LRU and disconnected with the monitored wire terminated with 300 Ω. The spectra for these measurements are also shown in the figure. Time domain waveforms for these two test configurations are shown in Plots 2 and 3. These data were generated using a 10 W power amplifier; plans for testing the subsystem include replacing this with a 200 W amplifier.

VARIABILITY OF PULSE PEAK AMPLITUDE

The noise source direct drive system was repetitively pulsed, and the recording instrument (a Tektronix 602 Digitizing Signal Analyzer) was used to record the statistics of the pulse characteristics, both directly from the generator and inductively coupled to the unit under test at varying drive levels. Results for the peak amplitude are shown below and those for the rms value (proportional to the root action integral) are shown on the next viewgraph.

measurement	pulses	max.	min.	μ	σ	σ/μ	$(\max-\mu)/\sigma$	$(\mu-\min)/\sigma$
source, direct	100	3.92	2.00	2.91	0.434	0.149	2.33	2.10
source, direct	100	4.08	2.00	2.87	0.429	0.149	2.03	2.62
into LRU no pad	32	0.1780	0.0960	0.1277	0.0203	0.160	2.47	1.56
into LRU 10 dB pad	32	0.0584	0.0288	0.0402	0.0076	0.189	1.50	2.41
into LRU 20 dB pad	32	0.0244	0.0084	0.0128	0.0029	0.225	1.63	4.33

In order to investigate waveform variability, the generator was repetitively pulsed and data collected with the 602 DSA. Some resulting statistics are shown above for the peak amplitude and on the next viewgraph for the rms value (related to the root action integral). Values generated by the 602 internal diagnostics were the maximum and minimum values found in the sample, the mean, μ, and the sample standard deviation, s. For the measurement directly from the source, statistics were collected for two groups of 100 waveforms with the test setup unchanged. The statistics for the two samples are very similar; the standard deviation is 15% of the mean for the peak amplitude and 8% for the rms value. The maximum and minimum values are between about two to three standard devintions from the mean, a value consistent for a sample of this size for a Gaussian distribution. For injection into the LRU, varying amounts of attenuation were inserted between the generator and the coupler to look for effects of nonlinearity on the variability. The data indicate a small increase in variability with decreasing waveform amplitude.

FURTHER DEVELOPMENTS

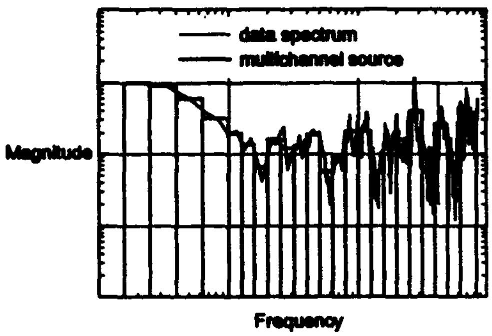
- A second noise source direct drive system has been built with the following enhancements:
  - Computer-controlled selection from a suite of generic spectrum envelope filters with peaks at 100, 200, 300, 400, 600, and 1000 MHz.
  - Computerized level control.
  - Pulse shape generation by AWG.
- Integration of high frequency noise source direct drive system with low frequency AWG-based system is planned.
- Improvements to amplifiers and couplers are being considered.
- Single noise source plus filter will be replaced by multichannel noise with individual channel amplitude control as shown on next viewgraph.

Additional noise source direct drive systems will be constructed in the near future for use in test programs at NAWC and PL. Planned improvements on the prototype system include a wider choice of filter shapes, computer-controlled switching for level control and filter choice, and the use of an arbitrary waveform generator to produce the pulse modulation envelope. (Note that even though an AWG is not fast enough to generate a complete high frequency waveform, it can generate its envelope.) The NAWC system will be integrated with an existing low frequency, AWG-base direct drive system that provides frequency components below 100 MHz. The existing NAWC system incorporates a feature called "real-time normalization" in which the waveform actually coupled to the test article is measured and adaptive feedback applied to correct the drive waveform. A similar function, using statistical measures of the drive and coupled waveforms, will have to be developed for the noise source system.

Long term plans include the development of a high power, broadband pulse amplifier. NAWC has developed a 5 kW, 100 MHz pulse amplifier, and this design can be pushed higher in frequency, possibly as high as 1 GHz. Another long term goal is the development of a more flexible control of the spectrum of the drive waveform.

MULTICHANNEL NOISE SOURCE

One approach to frequency domain shaping of white noise might be a multichannel noise source. The amplitude of individual frequency bands would be adjusted to provide a complicated "filter function" shape closely approximating the spectrum of the desired waveform.



Filters cannot provide the kind of precise shaping of the spectrum performed in the numerical experiments. Such control could be obtained with an approach shown in a conceptual form above. A multichannel noise source is used: each channel would consist of an individual noise source covering a narrow frequency band and a level control. The level of each channel would be adjusted to match the average amplitude of the desired spectrum within the frequency band covered by that channel, and outputs from all the channels would be combined. The plot above shows an example data spectrum and the match that could be achieved with 23 channels spread over three decades of frequency. Such a system would allow replication of any desired waveform (in a statistical sense) and would be amenable to computer control and adaptive feedback.

CONCLUSION

- White noise signals can be conditioned to provide the frequency content and pulse envelope to represent any arbitrary direct drive waveform.
- Noise source direct drive has been demonstrated and successfully employed to test electronic subsytems.
- Basic components for noise source direct drive (white noise source, filter, mixer) are inexpensive.
- Noise source technique can be extended beyond 1 GHz. Bandwidth is limited mainly by amplifiers and couplers.
- Random character of noise source waveforms may be an advantage.
  - Drive waveform is difficult to specify at high frequencies due to random nature of coupling.
  - Repetitively pulsed noise source direct drive generator applies many variant pulse waveforms to unit under test, with nearly constant waveform norms for all pulses.