# Development of a bulk current injection direct-drive system to test system level components with stress waveforms that are encountered during full threat indirect effects lightning

1994

Sam Frazier
Kurt Sebacher
Naval Air Warfare Center Aircraft Division
Patuxent River, Maryland, USA



## 1. Introduction

The Naval Air Warfare Center Aircraft Division (Patuxent River) is the lead DoD facility used for testing military aircraft to indirect effects lightning. Despite housing some of the largest lightning simulators available, reaching amplitude levels of 200 kA and beyond has been unattainable and impractical on full-scale aircraft. To qualify aircraft to the desired test level of 200 kA and beyond, which is demanded in several new aircraft's lightning compliance specifications, the Navy uses a bulk current injection (BCI) direct-drive system.

Lightning tests performed at the Naval Air Warfare Center Aircraft Division are divided into two phases. The first phase involves stimulating the aircraft with the lightning simulator. During this phase the aircraft is an a coaxial return array. Different entry and exit configurations are used; Nose-to-Tail, Nose-to-Wing and Wing-to-Wing. While in these different configurations stress response data is measured throughout the aircraft. The stress response measurements are taken on specific bulk cables or individual wires using current probes. These test points usually involve flight controls, or other mission essential equipments.

The second phase of testing involves BCI direct driving the appropriate stress response waveform onto the test point cable in which it was measured during Phase I. The appropriate test point BCI direct drive waveform is either the largest amplitude measured during the different entry/exit configurations or a combination of the waveforms measured in the different configurations. This BCI direct drive waveform is then extrapolated to the desired corresponding threat and threat plus margin level and injected onto the cable of the system under test. During this injection the component under test is monitored for deficiencies. This idea though simple in concept has been difficult in execution. Exact waveform replication along with frequency and amplitude limitations have hindered the effectiveness of this test technique. This paper covers the Navy's BCI direct drive test methodology and some recent findings that have allowed the Navy to use the BCI direct drive test technique as an effective test tool.

## 2. Direct-Drive Concept

The Navy uses BCI direct drive as a test method to determine, characterize, or develop subsystem strength as part of a system level test. Strength is defined as the level at which a system upsets. Figure 1 illustrates the process of BCI direct drive. Stress is measured during the Phase I stimulation process using current probes and high speed transient digitizers. Compliance and test requirements are reviewed to determine the BCI direct drive test levels. The signal is reproduced, amplified and inductively coupled onto the aircraft cable/test point. Levels are increased until upset occurs or a predetermined margin level is meet. This level is the subsystems strength. The margin of survivability equals strength divided by stress. This process is used for many E3 disciplines beside lightning . MIL-STD-461/462, EMP, and EMR just to name a few.

Historically, BCI direct drive testing was performed using damped sinusoidal waveforms. Large margins were required to bound a multitude of uncertainties. The emergence of high speed transient digitizers for capturing the data, powerful computers for advanced signal processing, and arbitrary waveform generators for exact digital waveform replication has allowed BCI direct drive to advance beyond narrow band technology. Wide band composite waveforms that replicate the exact waveform measured can be accurately reproduced and direct driven.

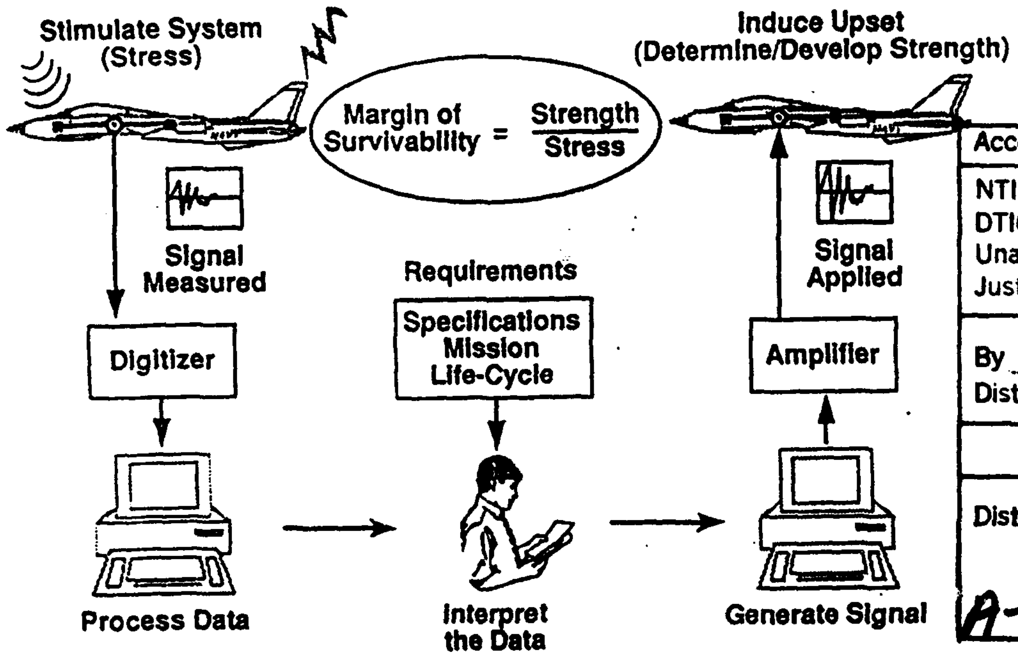




Figure 1: Direct Drive Concept

## 3. Direct-Drive System

### 3.1 Arbitrary Waveform Generator

The emergence of high speed arbitrary waveform generators that digitally reproduce the BCI direct drive waveform has allowed wide band composite waveforms to be used for BCI direct drive testing. Waveforms measured with Lecroy 6880 or 8828 digitizers are processed and then downloaded via computer to the arbitrary waveform generator. The Naval Air Warfare Center aircraft division currently uses two different Arbitrary Waveform Generators. They include the Lecroy 9100 and the Analogic 2040. The Lecroy 9100 samples at 5 ns allowing a useable bandwidth up to 50 MHz. The Analogic 2040 samples at 1.25 ns allowing a useable bandwidth up to 200 MHz. A block diagram of the BCI direct drive system is shown in Figure 2.

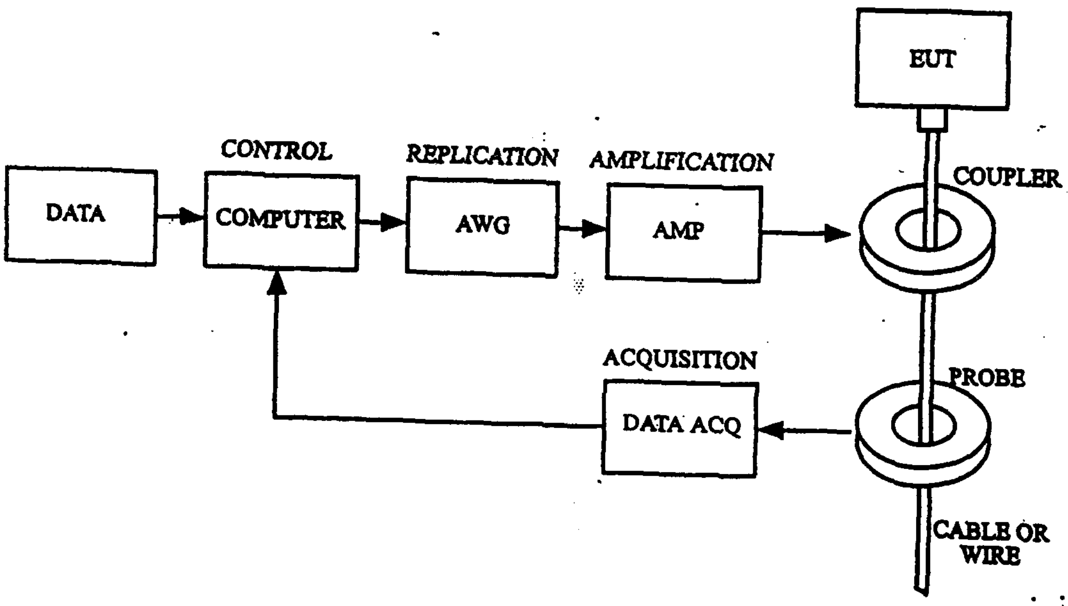


Figure 2: Direct Drive Setup

### 3.2 Amplifier

The Navy uses pulsed amplifiers to increase the BCI direct drive signal. The Naval Air Warfare Center uses a 11.25 kW Instruments for Industry (IFI) amplifier that contains a frequency range from 10 kHz - 100 MHz. Other companies such as Amplifier Research (AR) build comparable amplifiers. The proper use of the amp[illegible] is straight forward. However, to ensure maximum performance, proper charac[illegible]ion of the amplifier should occur. The minimum and maximum allowable signal amplitude that can be put into the amplifier input should be found. It is also good practice to adjust the gating pulse used to turn on the amplifier for each appropriate waveform.

### 3.3 Coupler

Early in the development stages of building the Navy's lightning BCI direct drive system, it became apparent the coupler was an extremely important part of the system. It is important for the coupler's response to be flat in the frequency region of interest while minimizing the i[illegible] loss. Ferrite and iron cores were purchased from many vendors such as Fisc[illegible], E[illegible]&G, Ferrox-Cubed, and Solar. These cores were configured with the number of [illegible]indings ranging from 1 to 12 using solid 12 gauge wire. The frequency characteristic sweeps were measured with a network analyzer. A program was written on the computer that multiplied the frequency domain of the test point measurement with the frequency sweep of each coupler. An inverse FFT was applied to the resultant frequency domain file in order to convert into the time domain. The engineer could then determine the coupler that would most effectively drive the waveform. The engineer must decide between peak amplitude or better waveform replication. Through these series of tests it was determined that the EG&G cores worked most effectively. However the size of these cores made it difficult to instrument in tight areas. For tighter instrumentation requirements the Fischer cores worked most effectively. The EG&G core exhibited the highest non-saturation level. Through this investigation the Navy has couplers which can be used from 1 kHz - 1 GHz.

## 4. Waveform Preparation

To ensure a better replication of the BCI direct drive waveform certain processing is performed. Raw frequency domain of Phase I data is corrected for the instrumentation effects used to measure the stress response waveform. A Wiener filter is then applied to eliminate unwanted noise. The leading and trailing time domain baselines of the digitized waveform is then removed to eliminate any chance of introducing spurious low frequency components. Once this processing is complete the waveform is extrapolated to the desired margin. The above mentioned processes allow for a greater Signal to Noise ratio.

## 5. Waveform Normalization

A software process developed at the Naval Air Warfare Center called Waveform Normalization has allowed the BCI direct drive system to increase it's effective bandwidth and better replicate the original stress waveform. During this process, shown in Figure 3, the output of the first BCI direct drive attempt is used to adjust the original BCI direct drive waveform for the effects of the BCI direct drive system, any non-linearities, and the test point load impedance. Succeeding BCI direct drive testing then uses the adjusted BCI direct drive waveform. The adjustment process to the BCI direct drive waveform is shown in Equation 1. All adjustment processing is performed in the frequency domain. When dividing measurements in the frequency domain, the domains of each measurement should be compatible in terms of number of data points and data point spacing. If they are not compatible an interpolation process can be used.

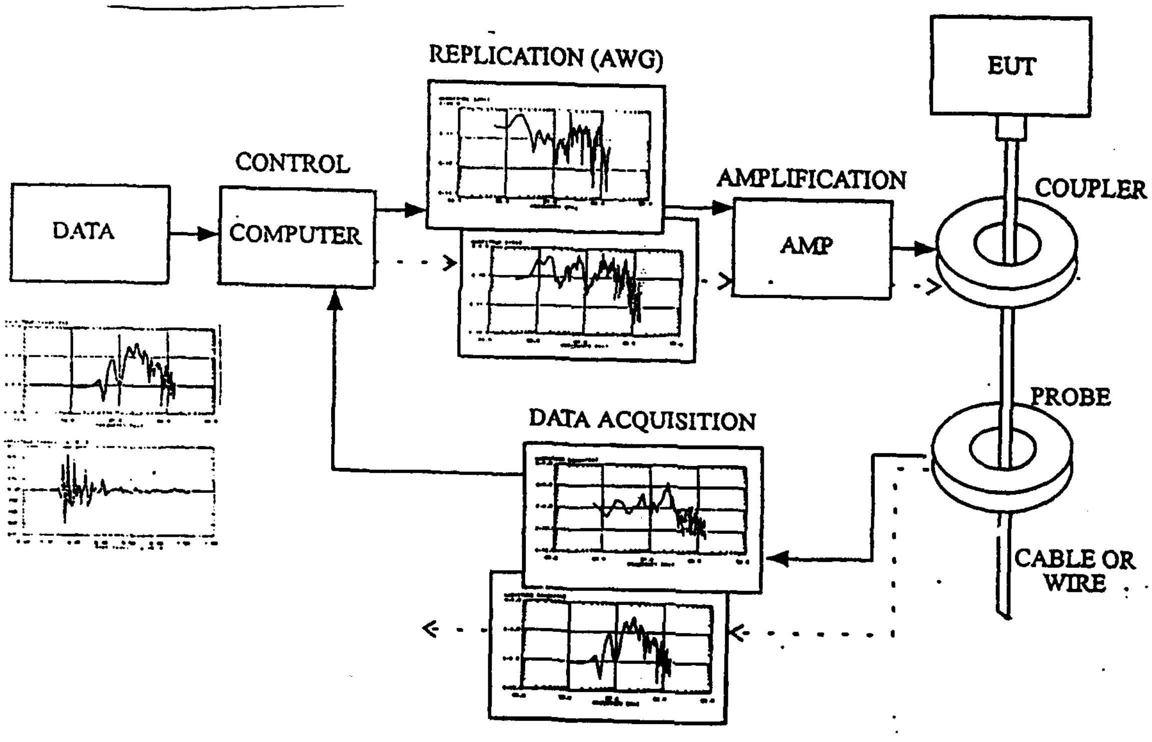


**Figure 3: Waveform Normalization Process**

$$\text{NORMALIZED WAVEFORM} = \text{DESIRED WAVEFORM} \times \frac{\text{DESIRED WAVEFORM}}{\text{MEASURED WAVEFORM}}$$

**Equation 1: Waveform Normalization Equation**

### 6. Impedance Normalization

Another method used to adjust the BCI direct drive waveform to compensate for load impedances involves network analyzer measurements. As shown in Figure 4, the coupler and the current probe on the test point cable, a network analyzer is used to stimulate the coupler. The current probe measurement is placed on channel A. The network analyzer source is split between the coupler and Reference. An A/R plot will display the true characterization of the test point cable. This plot defines the cables load impedance, once the characteristics of the coupler and current probe are processed out. This load impedance can be processed into the initial BCI direct drive waveform in order to compensate for test point load impedance.

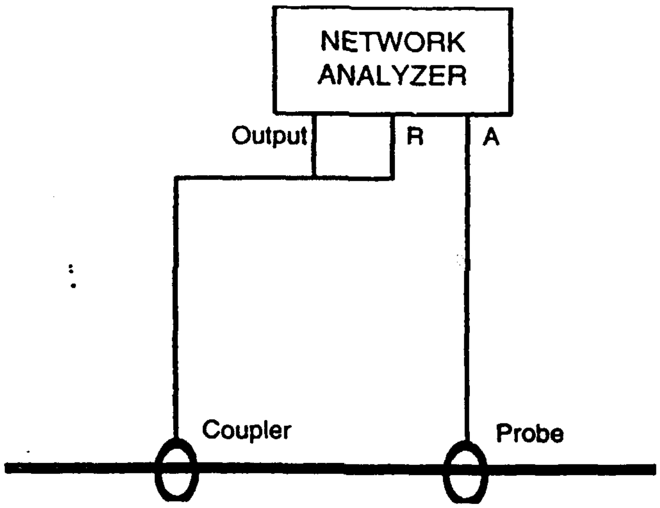


Figure 4: Impedance Normalization Setup

### 7. Direct-Drive Capabilities

The present lightning BCI direct drive system has the capability to inject any composite waveform having frequency content between 10 kHz - 200 MHz onto a test cable. Using the normalization techniques mentioned above, a near perfect replication of these waveforms can be reproduced. The ability to inject levels that reach 6 dB above the test point amplitudes measured with a theoretical 200 kA stimulus has been achieved. Drive levels up to 170 amperes on test cables have been reached.

## 8. Conclusions

The NAWCAD has developed an effective lightning BCI direct drive system that can be used to inject indirect effects waveforms onto test point cables. The amplitudes and shapes of these waveforms correspond to what would be seen caused by indirect effect lightning with a 6 dB margin. The waveform normalization and the load impedance normalization processes mentioned in the text have allowed near exact replication of waveforms. This BCI direct drive ability has allowed the Navy to test aircraft to indirect effects lightning and define strength levels well above the 200 kA threat.