MIL-STD-1553 is a serial, time-division multiplex data bus that has been used as the primary command and control data interconnect in military aircraft for the past three decades. MIL-STD-1553’s robust performance, high level of interoperability, large installed base, and well established infrastructure of vendors has made it the network of choice for military avionics systems. While MIL-STD-1553’s 1 Mbps data rate is adequate for current avionics applications, there are emerging applications that require higher bandwidth. The challenge facing the military avionics industry is finding cost effective methods of supplementing MIL-STD-1553 with higher bandwidth data communication channels.

Data Device Corporation conducted research aimed at exploring the option of supporting high-bit-rate transmissions over existing MIL-STD-1553 networks. Shannon’s theorem was used as a model in exploring the channel capacity of a MIL-STD-1553 network. Shannon’s theorem states that the capacity of a channel is a function of bandwidth, signal level, and noise level. Each of these elements of capacity was characterized to formulate a theoretical prediction of overall channel capacity.

**Measurements**

The key parameter required to calculate the capacity of a network is the Signal to Noise Ratio (SNR). An analytical prediction of SNR requires a model that quantifies signal and noise levels independently. Figure 1 illustrates a basic communication model for additive noise that shows the relationship between the transmitted signal (ST), the received signal (SR), and noise (N)[1]. The model assumes that a received signal consists of a transmitted signal that is distorted based on the response of the channel through which it travels. Noise is then added to the received signal and presented to the receiver.

DDC conducted a series of measurements on MIL-STD-1553 networks to characterize each of the elements in the SNR model. Electro Magnetic Interference (EMI) tests were conducted to determine the maximum transmit signal level that could be produced by a transmitter and remain compliant to the radiated emissions levels in MIL-STD-461. Insertion loss measurements were conducted to characterize the distortion introduced by a typical 1553 network. Finally, noise environments were researched to characterize the various noise sources, which may be present in a 1553 system.

**Transmit signal level**

A MIL-STD-1553 network was built for test and measurement purposes (refer to Figure 2). This network was tested to RE-102, radiated emission electric field 10 kHz to 18 GHz, defined in MIL-STD-461. The test network is believed to be representative of a worst-case 1553 network consisting of a 300-foot bus with 32 stubs. The couplers were mounted on a copper ground plane.
The 1553 test network was placed in the EMI chamber and covered with grounded foil. Various lengths of cable from different portions of the network, both stub sections and bus sections, were placed on a wooden rack with the specified spacing from the ground plane and the measurement antennae. An arbitrary waveform generator was used to create a number of transmit waveforms with various transmit spectrums.

The results of the emissions tests were used to formulate a transfer function, as a function of frequency, for predicting the radiated electric field strength as a function of the power density of the transmitted waveform on the bus. It is assumed that the emission level will scale linearly with the transmitted waveform power level. This transfer function was then used to calculate the maximum transmit signal level based on a radiated field strength that is less than the limits defined in MIL-STD-461. This calculated signal level represents the transmitted signal level (S_t) in Figure 1.

**Received signal level**

A network analyzer was used to measure the insertion loss of several channels within various MIL-STD-1553 buses. The network analyzer applies a test signal to one end of the channel and measures the response at the other end. The network analyzer sweeps the test signal over a frequency range to generate the response curves. Figure 3 illustrates the magnitude of the channel response as a function of frequency for DDC’s “full test bus” and “half test bus.” The full test bus consists of 32 terminals on a 300-foot bus with a mixture of single- and multi-stub couplers. The half test bus consists of the first 16 terminals of the full test bus. This half test bus is believed to be representative of a typical 1553 bus, while the full test bus is believed to represent a worst-case 1553 bus.

The results of the insertion loss measurements were used to formulate a transfer function for the channels. These transfer functions were then applied to the transmitted signal (S_t) calculated earlier to calculate the received signal level (S_r) for each channel.

**Noise level**

There are numerous types and sources of noise that will be presented to the receiver. These include white noise, EMI ingress, and impulse noise. It is important to formulate a model for an expected noise level that can be used in estimating channel calculations. The real-world noise environment for a MIL-STD-1553 system is ill-defined. MIL-STD-1553B defines a noise rejection requirement based on a relatively large, band-limited Gaussian noise source. The noise level defined in MIL-STD-1553B is intended to be used in running an accelerated noise test and is not representative of the noise level that would be expected in a real system. The noise test is considered a “figure of merit test” used to characterize the relative performance of a 1553 receiver[2].

In researching other well defined noise environments, it was determined that the Digital Subscriber Line (DSL) industry’s definition for background noise on outside telephone cable plants would be a good starting point in establishing a reference noise model. The outside telephone plant was very well defined as part of the development of the various DSL technologies. A noise power density of -140 dBm/Hz was applied to the Very high-speed Digital Subscriber Line (VDSL) standard noise model[3]. DSL’s standard noise power density may be used to represent the noise component (N) in Figure 1 and can be used in calculating the SNR of the system.

**Capacity estimate**

Shannon’s capacity theorem, as illustrated in Equation 1, can now be used to calculate the theoretical capacity of the various channels that were measured[4]. S represents the signal level at the receiver. N represents the noise added to the signal as measured at the receiver. BW is the bandwidth of the signal. C is the theoretical maximum capacity, in bits-per-second, of the channel.

\[
C = BW \times \log_2 \left(1 + \frac{S}{N}\right)
\]

*Equation 1*

S was calculated using the transmitted power spectrum of the maximum signal level for a given bandwidth that still meets the MIL-STD-461 emissions limits. This maximum transmit signal is calculated using the emissions transfer function that was derived from the MIL-STD-461 EMI testing. The transfer function of the channel, based on the network analyzer measurements, was then applied to the transmit power spectrum to determine the power spectrum of the received signal. The noise power density was assumed to -140 dBm/Hz. The resulting SNRs were applied to Shannon’s equation to calculate the theoretical capacities. Table 1 summarizes these capacities for various bus networks and bandwidths. The “simple bus” configuration consists of two couplers and 200 feet of 1553 cable. The full test bus configuration consists of the 300-foot bus with 32 stubs as described previously. The half test bus configuration consists of the first 16 stub connections in the full test bus.

**Big question: Faster 1553?**

These measurements and analyses demonstrate that there is excess capacity within legacy MIL-STD-1553 networks that theoreti-
cally could be used to transmit higher data rates than currently supported by MIL-STD-1553. The amount of excess capacity is heavily dependent on the topology of the network, including length, types of couplers, number of couplers, and lengths of stub connections. In addition, the high frequency response of the network is also very dependent on the performance of the couplers beyond the frequency band for which they were designed and tested to work in.

The true noise environment of the MIL-STD-1553 networks on various platforms needs to be evaluated. Further testing and characterization of actual aircraft is required to formulate a noise model that is truly representative of a real-world network. Noise is a primary impairment to the performance of a higher data-rate signal, especially given the lossy nature of the network. The results of the MIL-STD-461 EMI emissions testing have provided a baseline for determining the maximum signal level that may be transmitted in the network.

A framework for predicting the theoretical capacity of a MIL-STD-1553 network has been presented. Additional studies and research are required to evaluate modulation and coding schemes to determine how closely they can approach the theoretical capacity limits. Shannon’s theorem describes the theoretical capacity limit but does not address methods to achieve those rates. The best method of analyzing the achievable data rates on these networks is through a combination of simulation and actual working hardware.

Michael Hegarty is a principal marketing engineer at Data Device Corporation. Michael has a leading role in defining future products and technologies for DDC’s high-speed networking product line. Michael has more than fifteen years’ experience with avionics networking technology. He has a patent pending for network access technology and has authored several papers and articles on avionics and related technologies. Michael holds BSEE, MSEE, and MBA degrees.

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References

**Editor’s Note:** This article is an excerpt of a much larger and more exhaustive white paper. For the full article, visit www.mil-embedded.com and search for “DDC”.

<table>
<thead>
<tr>
<th>Bus Configuration</th>
<th>Bandwidth</th>
<th>Average Received SNR</th>
<th>Shannon Capacity (estimated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full test bus</td>
<td>20 MHz</td>
<td>50 dB</td>
<td>332 Mbps</td>
</tr>
<tr>
<td>Half test bus</td>
<td>20 MHz</td>
<td>61 dB</td>
<td>405 Mbps</td>
</tr>
<tr>
<td>Simple bus</td>
<td>20 MHz</td>
<td>66 dB</td>
<td>438 Mbps</td>
</tr>
<tr>
<td>Full test bus</td>
<td>40 MHz</td>
<td>44 dB</td>
<td>585 Mbps</td>
</tr>
<tr>
<td>Half test bus</td>
<td>40 MHz</td>
<td>56 dB</td>
<td>744 Mbps</td>
</tr>
<tr>
<td>Simple bus</td>
<td>40 MHz</td>
<td>61 dB</td>
<td>811 Mbps</td>
</tr>
</tbody>
</table>

Table 1