AN-1881 Improving Electro-Magnetic Noise Immunity in Serial Communications Systems

ABSTRACT

This application note provides key recommendations for implementing serial communication systems that exceed IEC immunity test standards. To provide an example of highly reliable serial communications system implementation and testing, a Texas Instruments DP83640 Ethernet Physical Layer device was tested for International Electrotechnical Commission (IEC) immunity test compliance. Results from these tests are included for reference.

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1 Introduction

Electronic communications devices that operate in environments with a high level of electromagnetic noise require special consideration and testing to ensure the continuous delivery of uncorrupted data. Communication devices are susceptible to data interruption and corruption in industrial, automotive, telecommunication, medical and test lab environments, to name just a few. Demonstrating compliance with international immunity testing standards helps to ensure robust communications in noisy electromagnetic environments.

The scope of this document is restricted to communication signals; immunity issues related to AC and DC power supply signals are not included in this document.

This document is applicable to the following products:

DP83640	DP83849C	DP83848C
DP83630	DP83849I	DP83848I
DP83620	DP83849ID	DP83848YB
	DP83849IF	DP83848VYB
		DP83848M
		DP83848T
		DP83848H
		DP83848J
		DP83848K
		DP83848Q-Q1

2 Key Recommendations

Texas Instrument's networking and serial communications components are designed to provide robust communications in noisy electromagnetic environments. Some of the features that support robust operation include:

1. Protection against Electro-Static Discharge (ESD) that meets and exceeds industry standards.
2. Robust receive signal common mode noise rejection to reduce susceptibility to external noise on differential communication signals.
3. Robust power supply noise rejection to reduce susceptibility to external noise originating on power and ground signals.

In addition to these designed in advantages, key recommendations for designing robust communications subsystems include:

- Use high quality shielded twisted pair cables to interconnect communications components. For network implementations, use CAT5E or better cable.
- Provide a chassis ground system that is decoupled from the internal PCB ground.
- Use shielded connectors that are connected to the decoupled chassis ground plane.
- Use isolation transformers that include common mode choking devices on both receive and transmit signals.
- Where possible, the use of external transient suppression components like ESD diode, Transient Voltage Suppressor (TVS), or Gas Discharge Tube (GDT) devices on communication signals can increase immunity to high voltage discharge events.
- Use discrete shielded oscillator devices for generating clock signals rather than crystals connected to integrated oscillator pins.
- If possible, use higher voltage digital IO signals (3.3 V rather than 2.5 V or 1.8 V) to increase immunity to noise.

3 Background: Electromagnetic Noise

Three noise sources that can disrupt the operation of electronic communication systems include: direct contact high voltage or current discharges, impulse energy induced by strong instantaneous electromagnetic fields, and strong steady state electric or magnetic fields. All three sources induce common mode noise into systems, which can disrupt the operation of communication devices.

3.1 Discharge and Impulse Noise Sources and Remedies

Discharge events can occur due to Electro-Static Discharge (ESD), lightning or power source induced surges. Strong instantaneous impulse fields can be caused by close proximity to equipment that requires high current during start up (like motors) or by Electro-Magnetic Pulse (EMP) events.

With regard to discharge or impulse noise, communication receivers can experience discrete data corruption or lose synchronization with transmitting devices, which usually results in higher-level protocols requesting that data be re-sent. Under worst-case conditions, communication devices can experience catastrophic failure and cease to function.

In order to improve discharge and impulse immunity in communication systems, using a separate chassis ground in conjunction with a shielded connector and cable is recommended. Also, using an isolation transformer with integrated common mode choking devices on both transmit and receive signals can be beneficial.

Additionally, directly coupling high voltage discharge devices between communication signals and chassis ground can be beneficial. Traditional discharge devices include Trans-Voltage Suppression (TVS) devices, discrete ESD diodes, and Gas Discharge Tube (GDT) devices.

TVS devices have the advantage of operating at high current ratings (~100 A). Unfortunately, TVS devices usually have a load capacitance in the 100 pF - 1000 pF range under normal signal conditions, which can affect the quality, range, and interoperability of communication signals.

External ESD diode devices are available in discrete and multi-device array configurations. These devices present a lower capacitive load (~1 pF) but also have lower current ratings (< 30 A). These devices are suitable for communication signal applications that require extra ESD protection, but are not necessarily suitable for more demanding environments with surge and fast transient protection requirements.

Both TVS and ESD diode devices share the advantage of having low breakdown voltages. This allows the designer to choose a breakdown voltage close to the signal voltage used in the communication system. For example, Ethernet utilizes 5 V differential signals for 10MB/second operation, making the selection of devices with a 7.5 V breakdown voltage applicable.

Alternatively, GDT devices typically present a very low capacitive load (~1 pF) and can service large amounts of current (> 5 kA) making them useful for the more demanding surge standards. GDT devices have the limitation of higher breakdown voltages, starting at 75 V.

In DP83640 demonstration testing, it was found that the use of external suppression devices added value when testing was performed with unshielded cables. With the addition of GDT devices, it was found that ESD testing results improved by +/- 4 kV, and surge testing results improved by +/- 2 kV.

For convenience, Table 1 summarizes the characteristics of ESD diodes, TVS devices, and GDT devices. Figure 1 provides an example circuit diagram utilizing chassis ground and GDT devices.

Table 1. Discharge Device Comparison

Device	Breakdown Voltage	Current Capacity	Capacitive Load
ESD Diodes	No Minimum	< 30 A	~1 pF
TVS Devices	~10 V Min	< 100 A	~1000 pF
GDT Devices	~75 V Min	> 5 kA	~1 pF

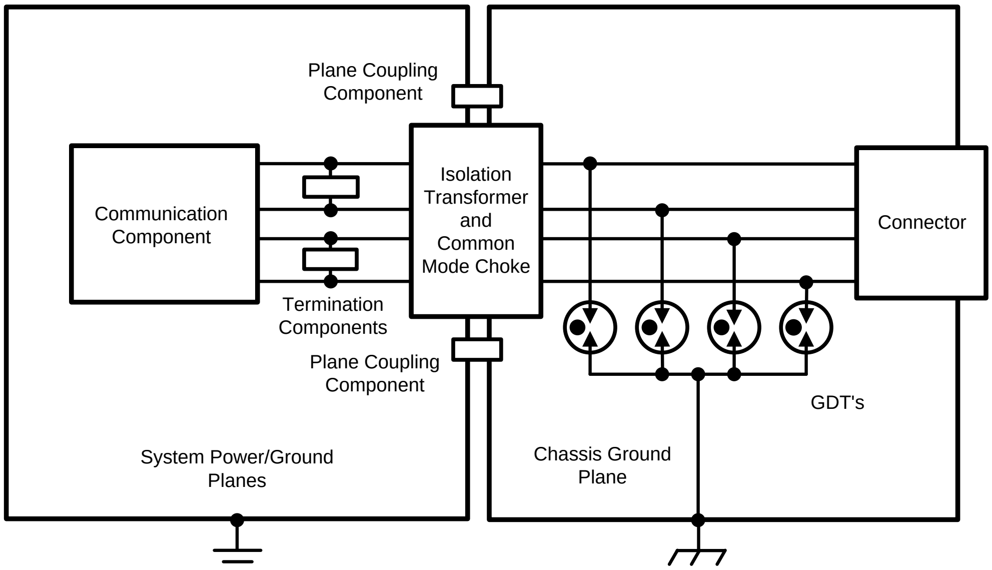

Figure 1. Chassis Ground and GDT Implementation

3.2 Static Electromagnetic Field Noise Sources and Remedies

Strong electromagnetic fields can be caused by close physical proximity to high power transmission equipment and signals or by close proximity to high current power cables. With regard to field-induced noise, common mode signals can interfere with the clocking of internal state machines in devices, which can result in data corruption. Under worst-case conditions, device lockup can occur requiring an intervening reset or power cycle of the device.

As is the case with impulse and discharge noise, strong field noise immunity can be increased using a separate chassis ground in conjunction with shielded connectors and cables. Using isolation transformers with common mode choking devices can also be beneficial.

The presence of a strong AC field with a frequency that is near a harmonic of the operating frequency of the communication device can interfere with the internal operation of the device. For example, if a communication device operates using a 25 MHz oscillator, strong fields with frequencies of 25 MHz, 75 MHz, 125 MHz, and so on, have the potential to interfere with the operation of the device. The interference can be due to the stimulating field coupling into device I/O signals, including external clock sources. To help avoid issues due to strong electric fields, it is recommended that external shielded, or canned, oscillators be used to generate clocks, rather than relying on integrated oscillators utilizing external crystals. It is also recommended that higher voltage signaling be used for I/O signals, that is, 3 V rather than 2.5 V or 1.8 V, as higher voltage signals increase noise immunity.

4 IEC Test Descriptions

The International Electrotechnical Commission (IEC) provides standards to ensure robust operation of electronic devices under discharge and strong field conditions. These standards are organized hierarchically, such that high-level generic standards (IEC61000–6) specify the use of more detailed individual test standards (IEC61000–4). The high-level generic standards also specify stimulus level and result requirements for groups of individual test standards.

In addition to IEC standards, various other standards exist for specific applications. For example, the International Telecommunications Union (ITU) has its own set of immunity standards. Similarly, standards exist for military, security, and other application spaces. For the purpose of this application note, the IEC standards are referenced because they provide a relatively concise focus that is similar to susceptibility tests defined in other application based standards.

The IEC61000-6-1 specification defines test performance requirements for operating in commercial and light industrial environments, while the IEC61000-6-2 specification defines test performance requirements for operating in industrial environments. For the purpose of this document, IEC61000-6-2 industrial performance standards will be discussed.

All IEC tests provide a common method for evaluating and reporting test results, categorized in four ways:

A. The network device continues to operate without data corruption.

B. The network device continues to operate, but some data corruption is experienced during testing.

C. The network device ceases to operate, but can be restarted with operator intervention.

D. The network device ceases to operate and cannot be restarted.

In addition, all IEC tests describe different levels of test stimuli, usually in terms of applied signal voltage or field strength.

Table 2 provides a brief summary of the test requirements described in the IEC EN61000-6-2 general industrial immunity standard. For more details, please refer directly to the individual IEC documents.

There are two methods described in these tests for coupling stimuli into equipment: through non-intrusive coupling, and through a fixture that directly couples stimuli to network signals. Non-intrusive coupling includes external cable clamping devices and antennae; direct coupling includes Coupling / Decoupling Network (CDN) devices. The method used depends on the cable type tested as part of the system; unshielded communications cables may require direct CDN coupling while shielded cables may not.

All of the individual tests enumerated in Table 2 are briefly described below.

Table 2. Immunity Test Description Summary

Test	Description	Stimulus Level	Passing Criteria
IEC61000-4-2	Electrostatic Discharge	+/- 4 kV direct contact	B
IEC61000-4-3	Electric Field Test	10 V/m @ 80 MHz to 6 GHz	A
IEC61000-4-4	Fast Transient Noise	+/- 1 kV	B
IEC61000-4-5	Surge Induced Noise	+/- 1 kV	B
IEC61000-4-6	Conducted RF noise	10 V rms @ 150 kHz to 80 MHz	A
IEC61000-4-8	Magnetic Field Test	30 A/m @ 30, 50, or 60 Hz	A

4.1 IEC61000-4-2

This standard specifies a system’s ability to withstand ESD events.

Conditions are described under which direct or air discharge testing should be performed. For the purpose of this application note, metallic chassis grounded network connectors were utilized, so the direct coupling method was required. Applications utilizing all plastic chassis and connectors require air discharge testing.

Specifications are provided for rise time, current, and impedance control of the voltage applied in the testing. For the purpose of this application note, the procedures that apply to an ungrounded, battery operated device are utilized, including bleed resistors used to couple the chassis to ground to prevent charge from accumulating between tests.

Texas Instrument's serial communications devices are designed and tested to withstand ESD energy on a component level as specified in individual device datasheets. IEC testing is defined for system level testing, which complements Texas Instrument's component testing.

4.2 IEC61000-4-3

This standard specifies a system’s ability to operate in environments where strong electric field energy is present. The frequency spectrum applicable for this test ranges from 80 MHz to 6 GHz. Tests above 1 GHz are limited to specific frequencies at which mobile telephone and radio equipment may be operated.

The IEC Specification describes a non-intrusive configuration for the test environment, including an antenna-based source for stimulus energy.

Electric field energy is experienced as common mode energy by serial communication devices. TI's physical layer network devices are designed and tested to withstand common mode energy as specified in the Ethernet IEEE 802.3 specifications

4.3 IEC61000-4-4

This standard specifies a system’s ability to withstand fast transient bursts of energy. Energy bursts of this type occur due to local environmental factors, such as large current relay switching in close proximity to the device being tested.

Test characteristics such as burst frequency and repetition, as well as voltage from the burst generator under 50 ohm and 1000 ohm load conditions are described in the standard.

Because this application note focuses on communication interface rather than power supply oriented susceptibility, the sections of the test that focus on I/O standards are applicable. When unshielded interface cables are utilized, testing is performed using a capacitively coupled clamping device. When shielded interface cables are used, testing is performed using a capacitively coupled direct connection to the cable shield.

4.4 IEC61000-4-5

This standard specifies a system’s ability to withstand power surges due to nearby lightning strike induced transients.

The signal generator used for this test has a source impedance specified at 40 ohms and 2 ohms, and is designed to meet open and short circuit conditions up to 6 kV and 3000 Amperes.

With regard to communications equipment, testing varies depending on whether unshielded or shielded cables are used. When using unshielded cables, a transformer coupled CDN fixture is required for directly injecting surge current into the communication signals. When using shielded cables, the surge is induced across the cable shield.

4.5 IEC61000-4-6

This standard specifies a system’s ability to operate in environments where EMI energy is present. The frequency spectrum applicable for this test is from 150 kHz to 80 MHz.

This is a conducted test, which means that direct stimulation of cables through a Couple / Decoupling Network device (CDN) is required for testing unshielded cables. For shielded cables, a capacitive clamping device is used to stimulate the cable.

4.6 IEC61000-4-8

This standard specifies a system’s ability to operate in environments where magnetic field energy is present. The test specifies that 30 Amp / meter magnetic energy be applied at frequencies of 30, 50, or 60 Hz, depending on the intended operating environment of the device. The field is applied using a magnetic loop antenna.

5 Test Demonstration

For demonstration purposes, the tests described above were performed using a Texas Instruments DP83640 Precision PHYTER based test system. Tests were performed by AHD LLC, a National Voluntary Lab Accreditation Program (NVLAP) certified test lab. All tests were performed to the industrial levels and passing criteria indicated in the IEC61000-6-2 industrial standard.

5.1 Test System

The test system consisted of an aluminum enclosure that housed a DP83640 physical layer component based PCB, and a Programmable Logic Device (PLD) based packet generator PCB. Tests were performed using both shielded and unshielded CAT5 cables. 100 MB per second data was generated in standard MII mode by the PLD, and looped back through the PHY device and the cable back to the PLD, fully exercising the PHY component MDI and MII transmit and receive signals (see Figure 2).

The PLD was designed to identify the reception of corrupted packet data. When a corrupted packet was received, the PLD stopped transmitting for 10 seconds, and the activity LED signal from of the physical layer device indicated that corrupted packets had been received. Thus, a test passing level A compliance would operate without interruption, a test passing level B would temporarily halt packet data and resume, and a test passing level C would require a system reset to resume operation.

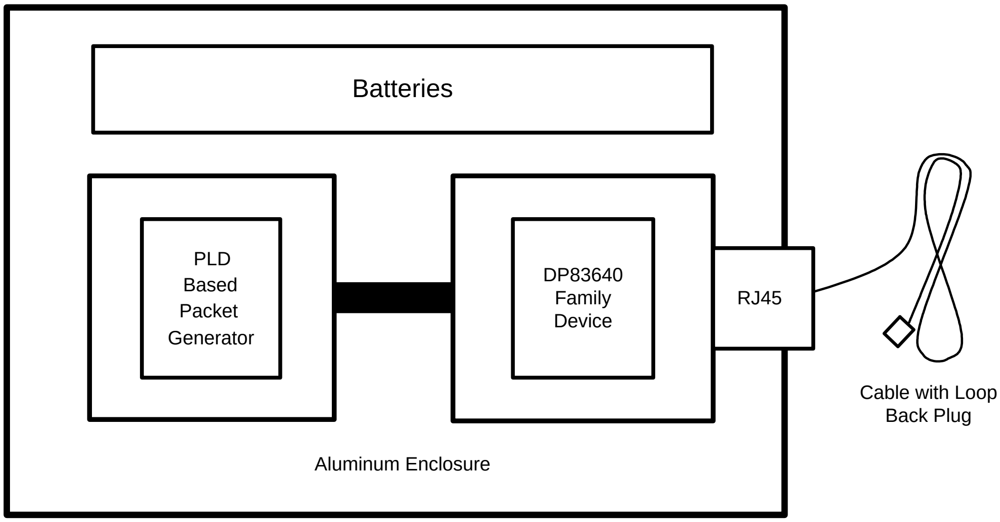

Figure 2. Test System Configuration

5.2 Test Results

The results from testing the DP83640 demonstration system are included below. The system met and exceeded all IEC61000-6-2 passing criteria when tested with shielded cable.

The system had mixed results when tested with unshielded cable. Consequently, the tests that failed while using unshielded cable were later investigated in conjunction with board modifications. It was found that the addition of GDT devices improved unshielded cable discharge test performance by as much as +/- 4 kV overall, and surge test performance by as much as +/- 2 kV.

With regard to strong electromagnetic field oriented testing using unshielded cable, worst case performance was recorded at 175 MHz. This result was later replicated using direct 175 MHz noise injection onto the receive signal. It was determined that the strong common mode signal disrupted the very small (< 1 V) input signal levels used for operating the crystal based integrated device oscillator. By replacing the external crystal with a shielded external 3.3 V oscillator device, the data corruption issues at 175 MHz were resolved.

Table 3. Results Summary

Test	Test Description	EN61000-6-2 Pass Criteria	Shielded Results	Unshielded Results
IEC61000-4-2	System level ESD test	Test +/- 4 kV to Level B, recoverable data errors	Exceeded pass criteria, Passed Level A to +/- 8 kV, no data corruption	Met pass criteria, Level B to +/- 4 kV levels.
IEC61000-4-3	Radiated Immunity test, swept from 80 MHz to 1 GHz	Test at 10 V/m signal levels to Level A, no data corruption	Met pass criteria, Level A, no data corruption across frequency range	Failed at 10 V/m signal levels, worst case recorded at 175 MHz
IEC61000-4-4	Fast Transient Burst Test	Test +/- 1 kV to Level B, recoverable data errors	Exceeded pass criteria, Passed Level A to +/-1 kV, Level B to +/-2 kV	Did not meet pass criteria, Passed Level A to +/- 500 V
IEC61000-4-5	Transient Surge Test	Test +/- 1 kV to Level B, recoverable data errors	Exceeded pass criteria, Passed Level A to +/- 2 kV	Exceeded pass criteria, Passed Level B +/- 2 kV, Passed Level A +/- 1 kV
IEC61000-4-6	Conducted susceptibility test using 10 V signals from 150 kHz to 80 MHz	Test 10 V signal levels to Level A, no data corruption	Met pass criteria, Passed Level A at 10 V signal levels, no data corruption	Did not meet pass criteria, but did pass Level A at 3 V signal levels
IEC61000-4-8	Radiated susceptibility tested with 50 Hz magnetic field	Test 30 A/m field to Level A, no data corruption	Met pass criteria, Level A, no data corruption	Met pass criteria, Level A, no data corruption

6 Summary

This application note provided key recommendations for implementing serial communication systems that exceed IEC immunity test standards. IEC standards were described that test for immunity to electromagnetic noise, produced through discharge and surge events, and through strong electromagnetic fields.

To provide an example of highly reliable serial communications system implementation and testing, results from tests utilizing a Texas Instruments DP83640 Ethernet Physical Layer device were provided. This testing showed that while using shielded cable helps communication systems to meet and exceed immunity standards, other options are available for improving the immunity of systems using unshielded cable. These options include the use of Gas Discharge Tube devices on communication signals to improve discharge immunity and the use of shielded oscillator devices as clock sources for communication devices.

7 References

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