RFI Suppression Techniques in DP83950 (RIC) Based Systems

National Semiconductor
Application Note 888
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CASE HISTORY—EXCESSIVE RFI FROM 12-PORT REPEATER

All commercial and consumer electronic equipment containing RF generating circuitry or devices must pass compliance tests for RF emissions before the equipment can be sold in the US (and most other countries). The equipment may not be legally marketed without first meeting the requirements of the FCC's rules (or those of the appropriate regulatory agency in the country where the equipment is to be marketed). Compliance testing for FCC requirements may be performed by the manufacturer or by one of many contractors specializing in this type of testing. Manufacturers who elect to self-verify must have the necessary equipment and an open-area test site (OATS) meeting the requirements of ANSI C63.4-1991 and FCC OST 55. In addition, complete verification test records must be maintained by the manufacturer for each device-type being produced. Failure to perform the required testing or marketing of non-compliant equipment can and often does result in severe legal penalties for the offending manufacturer.

Design for RFI suppression and compliance is frequently overlooked or given scant attention by equipment design engineers during the initial stages of product design. The result is often frantic and usually costly last-minute redesigns or modifications. In some cases, significant business and sales opportunities are lost or the product may never be successfully brought to market. It is therefore most important that RFI-proof design techniques be incorporated as an integral part of all engineering design specifications and procedures. These should begin at product concept and continue through to final sale and installation.

This application note is not intended as a comprehensive guide to all aspects of RFI-proof design. The techniques presented in this note resulted from on-site tests and equipment modifications in the example case only. National Semiconductor does not imply that if only the techniques discussed herein are incorporated in any design, that design will be rendered compliant. There are many other RFI-proof design approaches and methods that must be considered and may be found more effective in a particular situation.

Description of the EUT and the Problem

The equipment under test (EUT) in the example system is an expandable, 12-port multiport repeater. The device is designed to operate in a twisted-pair Ethernet environment. Functionality is under the control of National's DP83950 Repeater Interface Controller (RIC). The repeater has 12 twisted-pair ports served via RJ-45 connectors. The input port may be optionally fed via coax or fiber optic cable. The device is designed to be expandable with up to three other units.

Mechanical construction of the unit is conventional. All circuitry is contained on two cards mounted inside of a 2-piece steel enclosure. One large card having the majority of the circuit is permanently mounted. An externally removable plug-in module contains the input interface circuit. Components are primarily surface mounted with some through-board mounted parts such as connectors. A power supply and fan are also mounted in the enclosure.

The inside of the enclosure is coated for increased conductivity. The pieces of the enclosure are joined with screws and all mating surfaces are bare of paint. The input module is inserted through an opening in the chassis and secured with screws. The chassis has other openings which allow mounting of the RJ-45 connector, indicator LED's, air inlet, fan exhaust and AC line power cable socket.

Excessive emission (RFI) relative to FCC Class A limits in the frequency ranges 30 MHz–120 MHz and 200 MHz–260 MHz was the primary problem with the system. Also, emission levels were considered marginal at other frequencies as shown in *Figure 1*. The task was to find the source(s) of the emissions and modify the device to reduce them to at least 6 dB below the specification limits. This was done by isolating the radiation mechanism and identifying the ultimate source of the energy. The process and what was found will be presented first. Next, the causes and cures of the RFI are detailed followed by recommended system design practices. In addition, a list of sources of relevant information is included in the appendix.

Test Facilities

An OATS, *Figure 2*, and all necessary RFI testing equipment was available at the customer's facility. This speeded and eased diagnosis of the RFI problems. Corrections and modifications could be evaluated more readily than might have been possible with a remote or contract facility.

The OATS complied with the requirements of ANSI C63.4-1991 and FCC OST 55. Other facilities included a screen room, antennas and remotely controllable mast, turntable for the EUT, complete and automated instrumentation and capable, experienced EMC engineers to operate the equipment. Most diagnostic and all compliance tests were conducted on the OATS. Test repeatability on the OATS was found to be excellent. Some diagnostic and problem isolation testing were done in the screen room.

TESTING FOR RFI

A number of different tests and techniques were used in the course of tracking down and isolating the RFI problems with this system. These fell into the following general areas of investigation:

- complete RFI scans (30 MHz–1000 MHz)
- shielding effectiveness of the case
- cable and connector shielding and radiation contribution
- internal shielding mechanisms of the case and PCBs
- contribution from peripheral circuits
- signal quality on the PCBs
- power supply and power supply bypassing
- test message traffic and number of ports operating

RFI Scan

An RFI scan is a measurement method used to determine the level versus frequency of RFI emissions being produced

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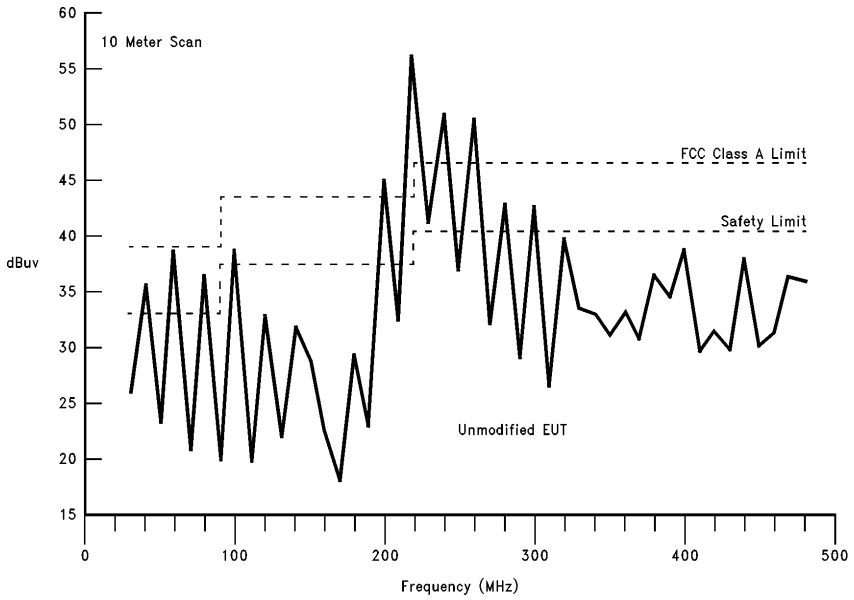

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FIGURE 1. Unmodified EUT

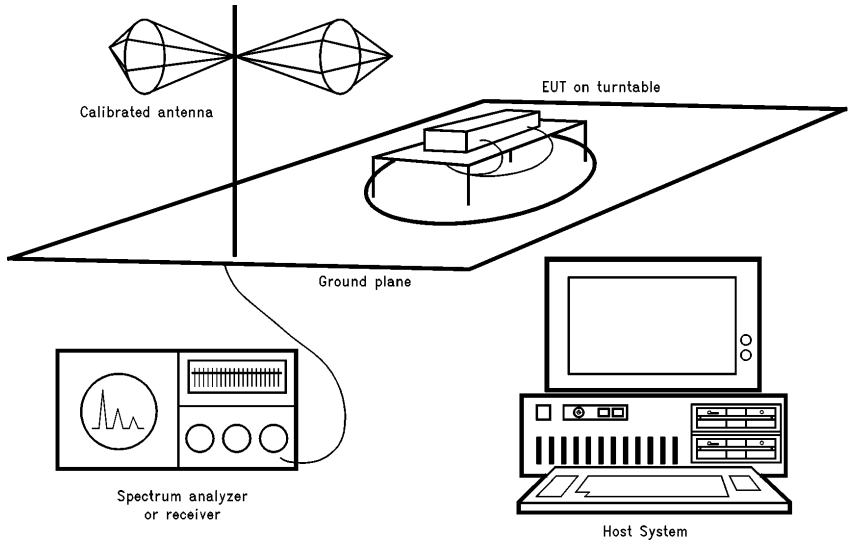

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FIGURE 2. Equipment Configuration

by the EUT. In the test, an operating EUT is positioned on a rotating table 0.80 meters above a ground plane and 10 meters from a receiving antenna. A spectrum analyzer, or calibrated receiver designed for RFI testing, and a calibrated antenna are used to make the level measurements. The turntable azimuth, antenna height and polarization are changed to determine maximum emissions. The turntable is rotated through 360 degrees of azimuth while the receiver's output level is recorded for all frequencies within the specified range (30 MHz–1000 MHz). In combination with azimuthal rotation, the antenna's height is also varied from 1 to 4 meters to determine any elevational variations in emission level. In addition, scans are made with the antenna in both vertically and horizontally polarized modes when linearly-polarized antennas are used. Once a spectral signature is determined for the target device, certain frequencies at specific azimuths will predominate. These could be checked first after modifications are made to quickly assess the effectiveness of the change. This shortens test times appreciably. A complete scan should only be needed when sufficient improvements necessitate a new base-line reading.

RFI scans on the OATS were used to measure EUT RFI performance in the suspected trouble areas to be detailed. Scanning is a time-consuming procedure if done manually. Fortunately, this testing was partially automated in the case presented here.

RFI Versus Port and Activity

RFI qualification tests were eventually conducted with all ports active. But, first it was necessary to determine the contribution that each output made to the overall RFI level. Each port was tested, in turn, transmitting simulated data with an average density of message activity. As testing progressed, it became evident that the level of RFI emissions was a direct function of the port's distance from the RIC device. Later, this was an essential clue to tracking down the RFI generating mechanism.

ENCLOSURE SHIELDING EFFECTIVENESS

It was necessary to determine whether the device's case was an effective shield since openings and joints can leak radiation. The panels of the case can carry induced currents which show up as RFI. Also, the test would reveal if the cables were the radiation source instead.

To carry out the test, the paint was removed around all openings and joints for about 1 cm. All openings and joints were then covered, in turn, with self-adhesive copper foil. This attempted to isolate joints and openings as possible causes of RFI.

The greatest reduction was made when the 12-port, RJ-45 connector was covered over with copper tape (except for the port in use). Similar results were achieved when a ''harmonica shield'', designed for use with the RJ-45 connector, was substituted for the copper tape. After this modification, nothing else was found which greatly affected the radiation from the case. This pointed to the cables as the dominant radiators. But the ultimate RFI source was yet to be isolated.

Another test was carried out to further confirm the cables as the primary radiators. This was done by enclosing the entire unit in a Faraday shield. The unit was first inserted in a heavy, insulating plastic bag. The cables were brought out through small openings in the bag. The insulated unit was then wrapped in heavy aluminum foil with all seams double-folded. A 2.5 cm-wide braided, grounding strap was tightly folded in a seam in the foil along the length of the case. The ground strap was clamped to an earth-ground rod beneath the turntable on which the unit sat. A scan of the unit revealed almost identical radiation levels to the previous measurement without the shield. This further strengthened the view that the cables were the main external radiators.

CABLE AND CONNECTOR SHIELDING

Attention was now focused on cabling as the primary radiator. The contribution from each cable had to be determined and the main culprit identified. To do this, each cable was wrapped, in turn, in an aluminum foil/braided-copper shield along its entire length above the ground plane and grounded to the ground plane. The largest contributor by a substantial margin was the twisted pair followed by the coax and power cables, respectively.

It should be well known that the shielding effectiveness of twisted-pair line decreases with increasing frequency above a few megahertz. For signals above 10 MHz, it must be considered as unshielded line. For this reason, any high frequency signals originating inside the enclosure that managed to couple onto the twisted-pair can easily couple into free space. However, substitution of shielded cables as a fix for this situation was out of the question.

When a shielded power cord was substituted for the normal one, radiation was increased. This larger antenna radiated more efficiently. It also pointed to the grounding wire as the pickup device. The contribution from the power cord was reduced by shortening the length of the safety ground (green wire) connected to the chassis from over 8 cm to about 3 cm.

The coax was found to be leaking some radiation, but the amount was small. It was felt that more could be achieved by concentrating on the twisted-pair cables as the mechanism. And, like the twisted-pair, substitution of another type of coax with a foil/braid shield was not possible. So, efforts were now turned to locating the source of the offending signals within the enclosure.

Internal Case and PCB Shielding Mechanisms

It was generally suspected that RFI produced by the operating logic devices on the PCB was being coupled out of the enclosure. The next job was to isolate and identify the contributors.

The PCB layout divided the board into two main areas: one contained the output driver circuits and filters; the other area contained the RIC, peripheral control, system oscillator and indicator circuits. A clear space across the PCB between these areas allowed a shield to be attached to the case top thus dividing the interior into two cavities. A scan with this arrangement produced lower radiation from the coax and slightly reduced radiation from the twisted-pair. Still, the overall unit was far from meeting FCC limits.

Two other experiments were tried at this time that did reduce the RFI but proved impractical from a manufacturing standpoint. In the first test, a grounded, copper foil shield was placed on the underside of the PCB insulated from the PCB by a thin plastic sheet. Called an ''image plane'', this reduced RFI and pointed to possible deficiencies in the PCB's internal ground plane or its connections to the case. It also indicated that transmission lines from the RIC to an output driver, unshielded by the PCB ground plane, were radiating.

In the second experiment, the size and location of grounding points between the PCB and the chassis was checked as a possible contributor. Larger-area connections were added from the PCB ground plane to the case. Radiation was reduced when the grounding connection at the RJ-45 connector was increased in size.

Results of these experiments pointed to signals associated with the RIC or its output circuits as possible causes of some of the RFI. Further investigations would concentrate on these areas. First, however, other circuitry would be checked for problems.

Power Supply and Fan

The power supply, an open-frame switching type, was checked next. The supply was disconnected from the circuit boards and a dummy load attached to its outputs. A scan revealed no significant RFI from the power supply alone.

The power supply was re-connected to the circuit board and the fan was disconnected. RFI in the frequency range 250 MHz–350 MHz was reduced. The fan was initially bypassed with only a 0.1 μF ceramic capacitor. Evidently, this was not adequate. Addition of a 5 μF/35V tantalum electrolytic capacitor on the PCB at the fan connector reduced radiation by an average of 3 dB over the above range.

Logic Circuitry Power Bypassing

The PCB power distribution system was the next area of investigation. The number, location, type and size of bypass capacitors was examined. This check revealed that the number of capacitors was insufficient and would need to be increased. And, the capacitors would need to be relocated closer to the IC's for better effectiveness.

Noise across the power pins of the high-current consumption devices was checked. In several cases this noise approached a volt or more. In the original design, RF bypass capacitors (0.1 μF ceramics) were placed about 1 to every 4 logic devices. Addition of capacitors across the power pins of the output drivers reduced supply noise by about half. This also reduced RFI in the lower frequency ranges.

Four RF bypass capacitors were located near and intended to serve the RIC device. It was evident from the switching noise in this portion of the PCB that bypassing would need improvement. Additional RF bypasses were added at the RIC's power pins as well as four 5 μF/35V tantalum electrolytics arranged one per side. This improved the supply noise situation and also reduced the RFI below 100 MHz.

The bypassing at the PCB power supply connection point was also checked. The initial design used aluminum electrolytics paralleled with an RF ceramic. These appeared to be performing adequately and were not changed. See Appendix A for helpful bypass capacitor layout hints.

Master Oscillator

All timing and data rate control signals were developed from one 40 MHz crystal oscillator device. RF bypassing at the oscillator appeared to be adequate and tests did not decisively pin point it as the cause of specific interference.

Signal Quality on the PCB

Signal quality was the next area investigated. Signal aberrations like overshoot, crosstalk and ringing contribute appreciably to the RFI problem. Reducing or eliminating these problems correspondingly reduces RFI.

The twisted-pair port drivers were originally FACT devices. But, the twisted-pair Ethernet design does not specifically require either the high current drive or extremely fast rise times of which the FACT devices are capable. So, guided by RFI studies of several logic families made by Violette Associates for National's Digital Logic Division, HCT equivalents were substituted. This reduced RFI above 150 MHz by at least 3 dB, but more improvement was still needed. See Appendix B for additional information sources.

The transmission lines connecting the RIC to the output drivers had been previously identified for closer scrutiny. A look at the signals arriving at the unterminated port driver inputs revealed high levels of over/undershoot. Clearly, some type of termination would be needed to control the quality of these signals. There in, series and diode terminations were tried on the lines exhibiting the worst problem. Of these, the series was the most effective at reducing overshoot. It had the additional advantage of being the easiest modification to incorporate on the prototype PCB.

Selecting the termination type led to the discovery that the RIC's output signal transition times were in the under 2 ns region. These signals were among the most active and longest signal paths in the system. A look with a spectrum analyzer identified troublesome frequencies as components of these signals. Perhaps here, together with the termination issue, was another root cause of the RFI problem. A small improvement here would likely produce a greater improvement in overall RFI.

Some experimentation showed that low-pass filtering of the RIC's output signals further reduced overshoot at the input of the output driver. Crosstalk with adjacent lines also was reduced. With only the longest transmission path thus filtered, the troublesome RFI frequencies were improved.

Following this test, all outputs were modified to add filtering, 50Ω at the RIC output pin in series with the line and 30 pF from line input to ground. The overall result of modifications can be seen in the scan results plotted in *Figure 3*. When compared to the initial unmodified unit, a significant improvement is evident. The problem remaining was to improve the margin to the specification limit below 150 MHz; but, it was felt that this would require a new layout. The layout needed to incorporate the modifications found thus far together with improvements to power and ground planes, closer placement of the RIC to its output drivers, and grounding improvements. The fullest improvement would be evident only after all of these changes could be tested in concert.

RFI SOURCES AND CAUSES

Now that the layers of the problem had been peeled away, several causes of the RFI problem could be identified. These were:

- excessive noise on RIC-to-driver signals
- excessive transmission line length
- insufficient bypassing with inefficient location
- compromised shielding effectiveness, and
- inefficient PCB layout

Transmission Line Signal Quality and Excessive Length

The noise on the RIC-to-driver lines could be attributed to lack of adequate termination. The transmission lines were relatively high impedance, about 75Ω. The lines also were long, over 10 cm, compared to the RIC output risetime which was in the sub-2 ns region. The lines were unterminated and lightly loaded by just the driver inputs. These conditions permitted excessive over/undershoot. Indeed, the lines over 8 cm in length exhibited 2V to 3V of overshoot and up to 5V of undershoot! Signal level was 12V peak-to-peak or more. Failure to control line length and provide termination contributed significantly to both RFI and crosstalk.

Inadequate and Inefficient Bypassing

Excessive noise was found in the power supply system, as previously mentioned. Despite the use of power planes in

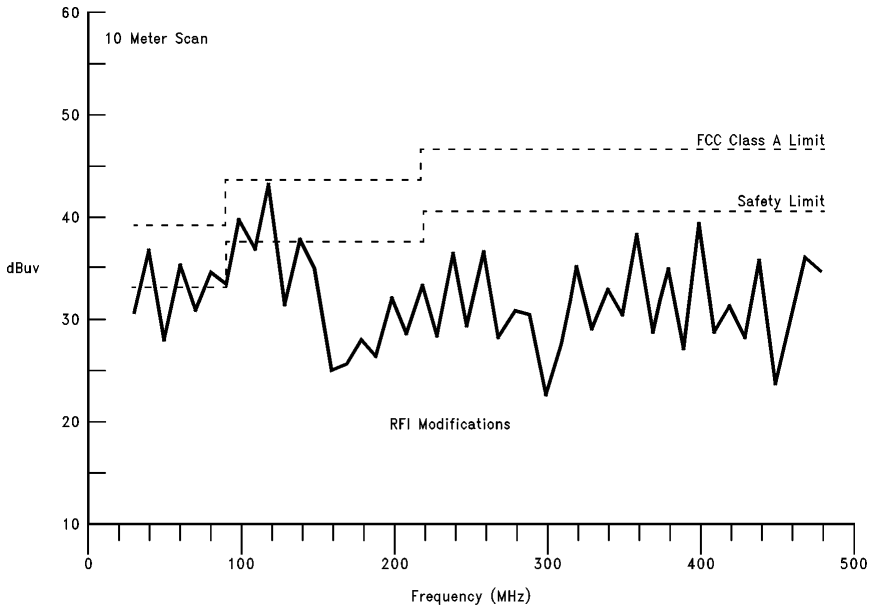

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FIGURE 3. EUT with RFI Modifications

the PCB design, their impedance was excessively high. As such, the power system could not respond to the current demands of the logic devices. Also, the power system was not acting as a good image conductor for the transmission line system.

Several things were done to correct this situation. First, more RF bypass capacitors were added, as previously mentioned. In some cases, multiple capacitors with values of 0.1 μF and 0.01 μF were connected in parallel across the offending device's power pins. This was necessary to adequately control impedance over the operating frequency ranges of the device. Second, LF bypassing in the form of 5 μF tantalum capacitors was added, one to every two high current drivers. Several more were placed at other locations on the PCB, particularly near the RIC. This was done to control low frequency noise and reduce lower frequency RFI emissions.

With these changes mandated, a re-layout was clearly called for. At that time two other problems with bypassing would be corrected. These were the lengths of conductors connecting IC power pins to the planes and the placement of bypass capacitors. Conductor length would have to be shortened and capacitors moved closer to the device requiring the bypass.

Shielding Effectiveness

Experiments indicated the need to improve shielding both on the PCB and in the enclosure. More isolation was needed between the RIC and its peripheral circuits. This could be done with a shield in the case as previously mentioned. Shielding for the RJ-45 connector would be needed together with improved grounding to the case along its length. Ground plane contact area to the case would be increased. And ground plane coverage under transmission lines on the PCB would be extended to twice the minimum line-to-plane spacing for better coverage. All of this was in addition to correcting overall signal quality and bypassing.

Layout Problems

Since another layout would be done, several other things contributing to the RFI problem could be corrected. Grouping of the circuits would be improved. In particular, the distance from the RIC to its farthest output port drivers was as much as 25 cm. The objective would be to reduce these transmission line lengths by half. Peripheral circuitry on the PCB might need to be moved to do this. However, the power supply, connectors, mounting points and similar items could not be relocated for manufacturing reasons.

Other Problem Areas

Strong 30 MHz, 50 MHz, 70 MHz and 90 MHz signals from the area of the RIC, 40 MHz from the oscillator and components from the fan were noted as potential problems, but it was thought that changes to bypassing, layout and shielding would correct these.

RFI Radiation Mechanisms

Several mechanisms were finally identified by which RFI was being radiated. The primary mechanism was radiation and crosstalk from the RIC-to-driver lines and thereby to the output twisted pairs. A secondary mechanism was through the power supply system due to inadequate bypassing. This was allowing excess noise on the grounding system for all signals. The third component was through reduced shielding provided by the internal power and ground layers of the PCB. This should have provided suppression of radiation and interraction of signals on the PCB. Other mechanisms included inadequate shielding and isolation between sensitive parts of the system and noise sources, fan bypassing and direct radiation from the RJ-45 port.

CORRECTIVE ACTION SUMMARY

The encouraging results from the modified system made it practical to proceed with a full revision of the unit. It was anticipated with a high degree of confidence that the result would be a production-worthy and fully FCC-compliant system. In summary, the changes made to the unit were:

- changed peripheral logic from FAST and FACT to LS, ALS and HCT
- added series termination and filtering to RIC outputs
- revised and improved power/ground plane layout and coverage
- improved PCB grounding to case
- improved layout of differential lines from RIC to drivers (See Appendix A for details)
- tightened-up layout between RIC, output drivers and RJ-45 connector
- added shielding to RJ-45 connector
- added and improved RF bypassing for high-current-demand IC's and RIC
- added tantalum bypass capacitors (LF bypassing)
- improved fan bypassing and
- improved placement of peripheral circuits and indicators.

RESULTING PERFORMANCE IMPROVEMENTS

The performance improvements in the production unit as the result of the above revisions can be seen in the new scan, see *Figure 4*. These are the corresponding measurements under FCC Class A test conditions to those in *Figures 1* and *3*. (For ease of comparison, all are plotted in *Figure 5* .) The EUT has been brought into compliance and with a healthy safety margin. It should be emphasized that these tests were carried out with all 12 ports operating and with the same traffic and messages. Later tests of a multi-unit system yielded results similar to the single unit system. All variations tested thus far have been fully compliant.

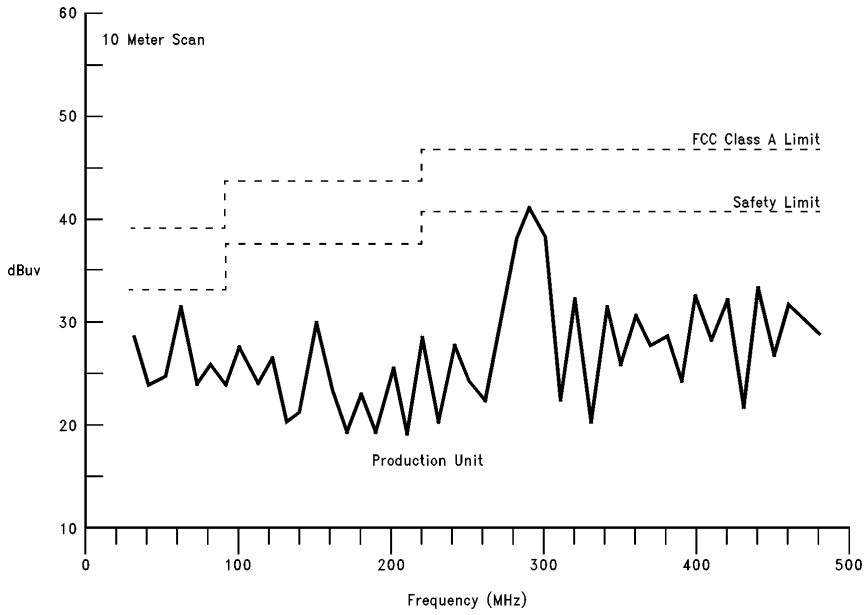

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FIGURE 4. Production Unit

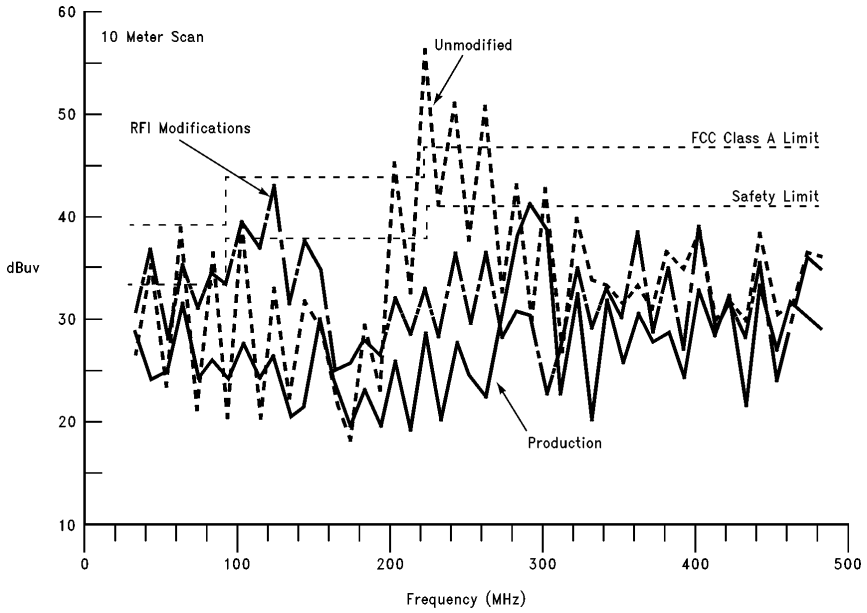

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FIGURE 5. Comparison All EUT Types

From these tests and the relayout, it is clear that RFI is a design issue that cannot be ignored until after the product is ready for market. It must be an integral part of the product's specifications and design from the beginning. Failure to do so can be extremely costly.

RECOMMENDED SYSTEM DESIGN PRACTICES

System designs using the RIC can benefit from careful attention to the design practices discussed in the topics which follow. Such practices can greatly reduce problems associated with RFI testing and qualification. Their adoption as a part of existing design standards is highly recommended.

System Design Hierarchy

Design for RFI compliance must be high on the list of system design requirements. This is especially true for devices which broadcast pulse signals over wire. Meeting regulatory requirements is made easier if a systematic approach is used in the design process. It is also a fact that systems designed for minimum EMI/RFI are more resistant to ESD and are subject to fewer signal-related problems.

The main elements of a good system design approach are, in order of importance:

- system specification including regulatory requirements and RFI
- signal quality standards and RFI-proof design practices
- testing methodology and requirements
- manufacturability considerations
- power system, supply and bypassing requirements
- transmission line system and terminations
- system mechanical, thermal and environmental requirements
- logic system design and functionality (initially, logic-technology independent)
- choice of appropriate logic technologies and other components
- layout and organization of PCBs, enclosures, cabling, etc.
- prototype evaluation and rigorous testing, and compliance testing.

Bypassing

The importance of good power system bypassing cannot be over-emphasized. Bypassing is the key ingredient allowing maximum system and component performance. The correct choice and application of bypass capacitors should be based on measured electrical performance and not on ''rules-of-thumb'' or unsubstantiated recommendation.

Bypass capacitors should be characterized for attenuation versus frequency. All capacitors are not created equal. Moreover, one size cannot necessarily perform best in all situations. The correct combination of capacitors is one which achieves adequate suppression of RFI-contributing power system noise.

In RIC-based designs, the following bypassing is recommended:

- Locate bypass components close to the RIC's V_{CC}/GND pins.
- Use no less than two, 0.1 μF ceramic caps on each side of the RIC.
- Use one, 5 μF to 10 μF tantalum capacitor per side.
- Use one, 0.1 μF per O/P driver; one, 5 μF to 10 μF per 2 O/P drivers.
- Use one, 0.1 μF per octal driver; one, 5 μF to 10 μF per 2 octal drivers.
- Use one, 0.1 μF per 2 SSI logic devices; one for each synchronous device.
- Use one, 5 μF to 10 μF per 4 SSI logic devices; one for every 2 synchronous devices.
- At PCB power entrance points use a 0.1 μF and a 10 μF per supply voltage.
- For DC fans (if used) use a 0.1 μF and a 10 μF.
- Use a Pi-filter (or longitudinal choke) for oscillator V_{CC} power.

Note: All ceramic capacitors are RF-rated types, leadless-monolithic preferred. Electrolytic capacitors are solid-electrolyte, tantalum types. Tantalum capacitor voltage rating should be a minimum of 5X the power supply voltage.

Layout Recommendations

A disorganized component layout can contribute to both signal and RFI problems. When laying-out a RIC-based design, observe these precautions and recommendations.

- Use a multi-layer PCB with dedicated power/ground planes.
- Keep layout compact with RIC close to output drivers.
- Locate less critical peripheral and indicator circuits farther away.
- Locate output connector and filters close to RIC output drivers.
- Layout to minimize transmission line lengths from RIC to drivers.
- Provide frequent and generously sized grounding pads for case ground points.
- Design in extra locations for bypasses. Omit the capacitors if tests show them to be unnecessary.

Note: It is easier to remove unnecessary components from a PCB than it is to add needed ones after the board is built. This is especially true for surface-mount PCB's.

Transmission Lines

An efficient layout also must consider the transmission lines. Particular attention should be paid to the following recommendations:

- Keep lines short and direct.
- Extend ground plane under all transmission lines.
- Use fully shielded lines (stripline) for high-level signals.
- Terminate all lines exhibiting over/undershoot or crosstalk noise.
- Observe pairing of differential lines from RIC outputs (*Figure A3*) (Appendix A).
- Maintain at least twice the transmission line's width between pairs of differential lines.
- Terminate RIC O/P's to reduce reflections, overshoot and noise. Series terminations with a value of $Z_O - 10\Omega$ are recommended.
- LP filter RIC outputs, if necessary, to reduce noise associated with fast output transitions. The capacitor value should be chosen for a 5 ns time constant in conjunction with the series termination resistor's value.

Recommended Logic Device Types

In any logic system design it is wise not to employ devices with performance characteristics exceeding those required to adequately handle the system's frequencies or signals. Higher performance devices (usually taken to mean frequency handling and rise times) normally produce increased amounts of RFI over a broad spectrum. To save RFI difficulties, do not put in more performance than the design needs. The following device types have been tested and found to work well and reduce RFI in RIC-based designs:

- HC or HCT for differential line driver circuits
- LS, ALS or HC for peripheral circuits, interfaces and LED drivers.

Oscillator Recommendations

Though often overlooked, the choice and use of oscillator components can greatly affect system RFI performance. The following are the recommended design practices for RIC-based systems. (These apply equally well to any logic system).

- Metal can, grounded-case oscillator modules are preferred. In general, plastic-case types have inadequate shielding and are not recommended.
- Supply oscillator power through a Pi-section filter or longitudinal choke.
- Observe proper supply bypassing.
- Locate oscillator close to the RIC.
- Keep transmission lines short and well shielded.

APPENDIX A—CIRCUIT AND LAYOUT DETAILS

Bypass Layout

Poor layout will seriously handicap even the best bypass components. Bypass components must be placed in close proximity to the point where impedance control is needed. Any excess inductance between the capacitor and the signal source (usually an IC) increases the effective impedance of the network. This decreases the effectiveness of the bypassing. Bypassing is often called impedance compensation. The extremely fast energy demand impulses produced by high-speed IC's, especially CMOS, require an equally fast response from the power system supplying them.

Figure A1 shows how to locate bypass capacitors for good performance in an SOIC layout. *Figure A2* shows the layout for PCC device packaging. Of course, differences in the power/ground pin organization of the device may necessitate a different placement of bypass components.

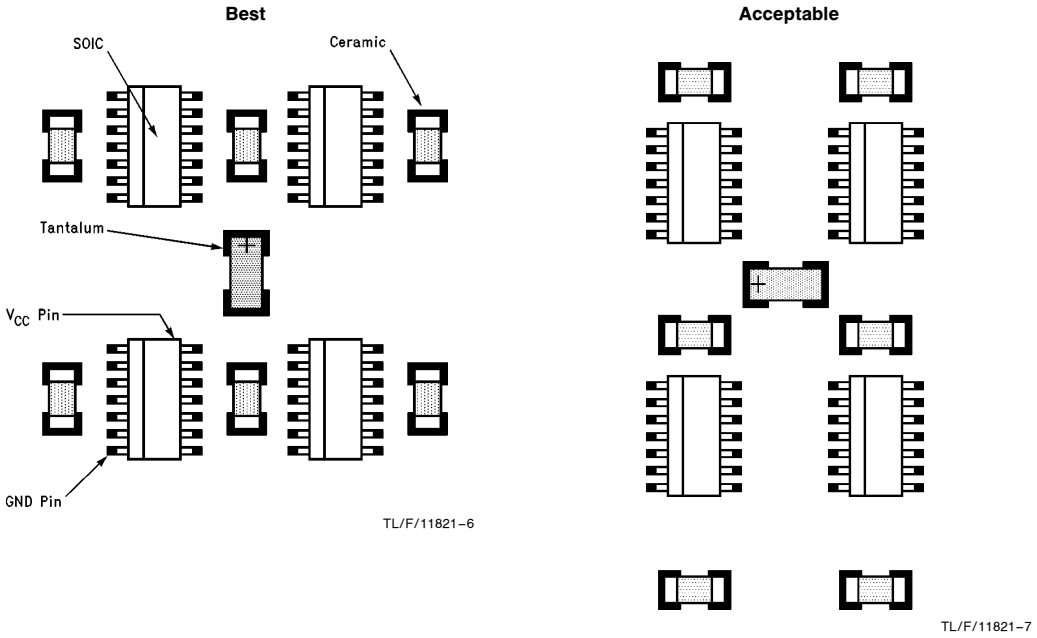

FIGURE A1. SOIC Bypass Capacitor Placement

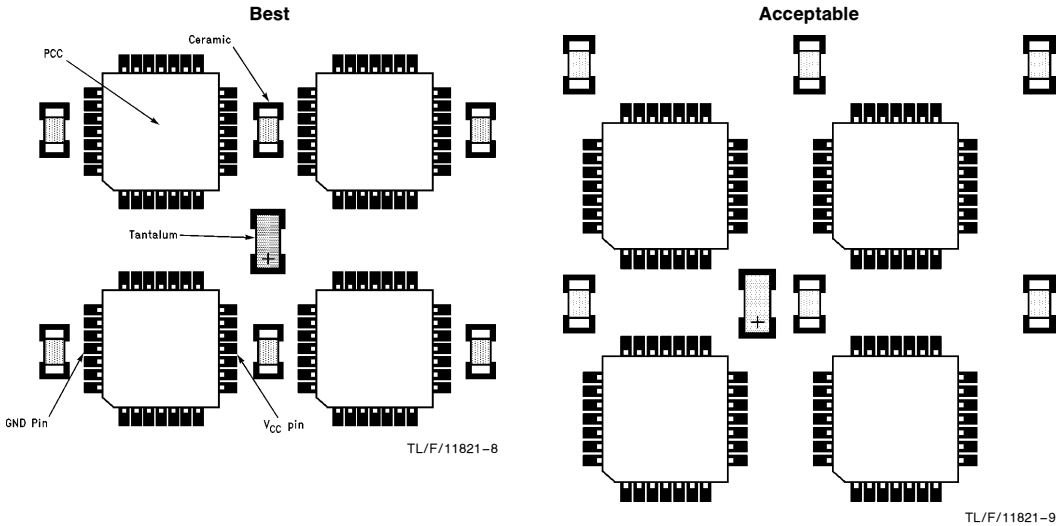

FIGURE A2. PCC Bypass Capacitor Placement (Typical)

Differential Line Layout

Differential transmission lines require additional care in layout if they are to function correctly. *Figure A3* illustrates both correct and incorrect ways of differential line layout. The spacing of differential lines affects their even or odd-mode characteristic impedance. It also affects coupling to adjacent lines. Since crosstalk is a function of line spacing, a good rule to observe is to allow at least twice the spacing of the differential pair between pairs.

Maintain equal lengths for both conductors by avoiding crossover and layer-change situations. If a crossover or direction change is made in routing the lines, then an opposite change should be made elsewhere in the lines to compensate the resulting length difference. Mitering corners also aids in preserving signal quality and impedance uniformity.

Oscillator Supply Isolation

Oscillators and other frequency generating devices operating above a few megahertz should be isolated from the power supply system. This is done to prevent their becoming the dominant interference signal both on the PCB as well as in free space. Two convenient methods are shown in *Figure A4*. Both have the same component count; the only difference is the way in which the inductor is used. The pi-filter uses a simple ferrite-loaded inductor as part of a broadband filter. The longitudinal choke uses a ferrite-loaded transformer as a bucking choke. It is, in effect, a form of pi-filter in which the effects of opposing AC currents are made to cancel. Ferrite inductors like those illustrated are available from several sources: Siemens, Fair-Rite, Ferroxcube and Arnold.

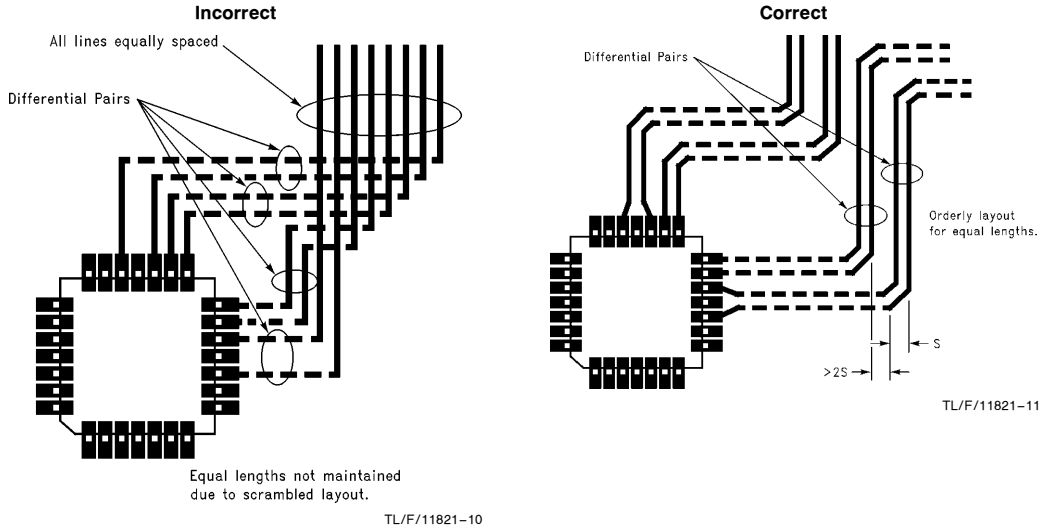

FIGURE A3. Differential Line Layout

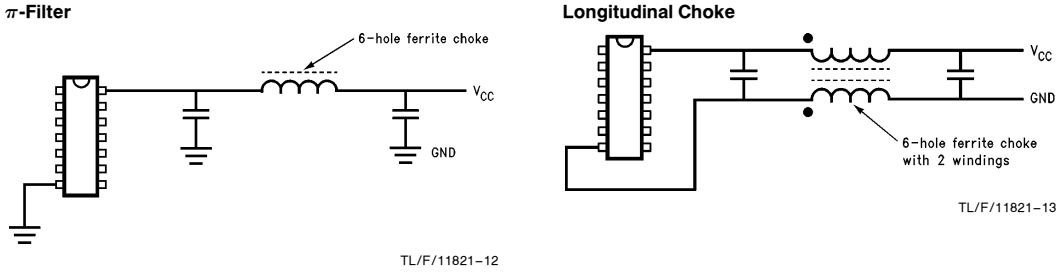

FIGURE A4. Oscillator Isolation Techniques

APPENDIX B—ADDITIONAL INFORMATION

National's application note library contains more information pertaining to the design of high-performance and RFI-proof systems. Some of these are listed below.

Application Notes

AN817—''Taking Advantage of ECL Min-Skew Clock Drivers''

AN467—''Surface Mount: From Design to Delivery''

AN393—''Transmission-Line Effects Influence High-Speed CMOS''

AN389—''Follow PC-Board Design Guidelines for Lowest CMOS EMI Radiation''

Databooks

400028—F100K ECL Logic Databook and Design Guide

Bibliography

''Antennas''; J.D. Kraus, Ph.D.; McGraw-Hill; 1950 (THE seminal work on antennas and radiation)

''Communication Systems: An Introduction to Signals and Noise in Electrical Communications''; A. Bruce Carlson; McGraw-Hill; 1968

''Grounding and Shielding Techniques in Instrumentation, 2nd Ed.''; Ralph Morrison; John Wiley & Sons; 1977

''Code of Federal Regulations 47 (CFR 47) FCC Part 15—Radio Frequency Devices''

CFR 47 Part 2—''Frequency Allocations and Treaty Matters: General Rules and Regulations; Sub-part I, Marketing of Radio Frequency Devices; sub-part J, Equipment Authorization Procedure''

89-336 EEC—''EMC Directive of the European Economic Community''

EN55022 (CISPR 22)—''Radiated and Conducted Emission Limits (CENELEC)''

FCC OST 55—''Characteristics of open-field test sites (Aug. 1982)''

ANSI C63.4-1991—''Methods of measurement of radio noise emissions from low voltage electrical and electronic equipment in the range of 9 kHz to 40 GHz.''

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