NASA Contractor Report 4193

Electrical Noise Reduction Techniques Contributing to Improved Data Quality at the National Transonic Facility

J. R. McPhee
Wyle Laboratories
Hampton, Virginia

Prepared for
Langley Research Center
under Contract NAS1-18304

NASA
National Aeronautics
and Space Administration

Scientific and Technical
Information Division

1988

ELECTRICAL NOISE REDUCTION TECHNIQUES CONTRIBUTING TO IMPROVED DATA QUALITY AT THE NATIONAL TRANSONIC FACILITY

by J.R. McPhee

Summary

An investigation was conducted to determine the cause of excessive noise appearing on the output of the high-speed digital data acquisition systems at the National Transonic Facility (NTF). The work was necessitated due to the detrimental effect of the noise on low-level signal data quality.

It was originally thought that the noise was primarily related to improper cable shield terminations. In pursuing corrective action it became apparent that other, more serious, problems were also present. It therefore also became necessary to evaluate and modify the facility electrical power and grounding, to implement changes in the data acquisition system computer interface, and to eliminate the effects of several sources of electromagnetic and radio frequency interference.

To relate the effects of the various improvements made during the course of this study, the Summary of Results presents actual test data taken before, during and after completion of modifications. Overall, a 5:1 improvement in system performance was realized.

Introduction

The NTF high speed digital data system is an off-the-shelf analog-to-digital converter system available with a variety of input signal conditioner and amplifier cards. A fully expanded system can contain up to 2048 channels. The NTF tunnel system is configured for 192 channels, and the Model Preparation Area (MPA) system for 128 channels. All signal conditioning is external to the systems, no integral manufacturer's signal conditioning is used. The analog-to-digital converters are of the successive approximation type with a resolution of 14 bits plus sign ($\pm$16,384 counts), and a throughput rate of 50,000 samples per second. The NTF computer interface design, however, limits resolution to 13 bits plus sign ($\pm$8,192 counts) and the throughput rate to 40,000 samples per second.

Four basic types of input preamplifier cards are available, two of which are included in the NTF system. These are the Low-Level and High-Level units. In addition to the two basic card types in use, there are two configurations of the Low-Level card. The older cards employ Resistance/Capacitance (RC) filtering at the input to the first preamplifier stage while a newer version uses Inductance/Capacitance (LC) filtering. The newer card also differs in its output switching circuitry. Hence there are effectively three card types in use.

System gain is a combination of the preamplifier gain and the setting of an internal Programmable Gain Amplifier (PGA). In the initial NTF system design, the gain for all low level cards was fixed at x78.125 and for all high level cards at x1.221. This was presumably done to provide an integer input voltage/output counts relationship. Although the data system is capable of measuring input signals of up to ±10.24V, the NTF fixed input gains limits this range to approximately ±8.39V. Table 1 gives an overview of the system measurement capabilities.

TABLE 1. - NTF DATA ACQUISITION SYSTEM MEASUREMENT RANGES

LOW LEVEL (RC Filtered and LC Filtered)

PreAmp Gain	PGA Gain	Full Scale Input	Input Volts/Count
X 78.125	X 32	4.096 mV	.0005 mV
X 78.125	X 16	8.192 mV	.001 mV
X 78.125	X 8	16.384 mV	.002 mV
X 78.125	X 4	32.768 mV	.004 mV
X 78.125	X 2	65.536 mV	.008 mV
X 78.125	X 1	131.072 mV	.016 mV

HIGH LEVEL

X 1.221	X 32	.262 V	.032 mV
X 1.221	X 16	.524 V	.064 mV
X 1.221	X 8	1.048 V	.128 mV
X 1.221	X 4	2.097 V	.256 mV
X 1.221	X 2	4.193 V	.512 mV
X 1.221	X 1	8.387 V	1.024 mV

For purposes of this study, the term "noise range" may be thought of as being interchangable with "data point scatter". Where either term is used it refers to the extremes (in counts or volts) appearing in a set consisting of a pre-determined number of samples. Except where noted, 50 sample sets were used.

At the outset of this investigation, an attempt was made to quantify the then-present system noise. This proved to be difficult since the symptoms varied greatly over time. Because of this, no single set of data could be recorded as being the specific condition of the system. It was concluded, however, that with a shorted preamplifier input, a noise range of 50 microvolts was a conservative measure. This amounts to 1.2% of full scale on the 4 millivolt measurement range. The manufacturer's specification is approximately .03%. This signal/noise relationship was also observed on the other measurement ranges.

Investigation and findings

It was known that the NTF data system input cables were improperly terminated. The system employs a guard-shield type input circuitry requiring termination of the cable shields at the signal source for proper operation. The NTF cable shields were floating at the signal source, and it was initially assumed that this was a significant contributing cause of the system noise. However, in attempting to determine the effect of properly terminated vs. improperly terminated cables, it became clear that other, more serious, problems were also present. In initial testing, it was impossible to differentiate between input signal noise levels as a function of cable shield termination.

A more detailed evaluation was conducted with a short placed across the input terminals of the preamplifier card edge connector, thereby eliminating all external cabling from consideration. It was under these conditions that it was determined that the noise was typically in excess 50 μV on the 4 mV full scale range, apparently as a function of the data system itself. At this point a detailed investigation to determine the true cause(s) was initiated.

The ensuing investigation focused on five main areas. Although there is necessarily overlap between some areas, they are generally described as:

- NTF (Mecca) Grounding
- NTF AC Power
- Data Acquisition System Computer Interface
- Signal Cable/Shielding
- EMI/RFI Sources

NTF (Mecca) Grounding

In the original design of the NTF control room and data systems it was determined that a single-point ground would be employed. In this concept, all system elements are directly connected to the single point ground, which at NTF, is termed the "Mecca" ground. In practice this was implemented by installing an isolated copper plate under the control room floor as a bus. This was then connected through 4/0 welding cable directly to a ground well outside the facility, with no intermediate connections.

During the early stages of the investigation it was determined that the high speed digital data equipment was extremely sensitive to variations in the ground system to which the control chassis is referenced. This ground is typically the instrumentation rack housing the system. At NTF, this was in turn tied to the Mecca ground. Using the facility AC power (non-Mecca) ground as a point of reference, a difference of potential between the two grounds was observed. Rack-to-facility ground readings of 180 mV AC to 200 mV AC were consistently noted. On occasion, these readings reached approximately 600 mV AC on certain racks. The specific reading varied with time at any given location. It seemed that the Mecca "ground" system was in fact not a ground system but was rather a floating AC reference plane to which the instrumentation racks, and hence the data system chassis were connected. The deleterious effect of this was proven by removing the equipment from the instrumentation rack and powering it from standard (non-Mecca referenced) power. Under these conditions, the equipment performed to manufacturer's specifications. The mechanism through which variations in the ground system are reflected in the system output is discussed in a later section.

The cause of the difference in ground potentials was traced to heavy current flow in the Mecca ground system, and inappropriate power/Mecca system interconnections. Rather than acting as a zero (or near-zero) current flow instrumentation ground, current flow of up to 7 amperes (A) was seen in the Mecca system. This ground current flow was caused by the use of the neutral bus in control room power panels as a ground bus. The power ground wires from some of the instrumentation racks were terminated in the power panels at neutral rather than ground. Additionally, inside the power panels, the neutral busses were tied directly to the ground busses. The power panel neutral busses were in turn tied to the NTF motor-generator (MG) neutral which was in turn grounded in the vicinity of the MG set. Neutral current flow in the control room/MG set line was measured at approximately 70A. This current flow, through doubled 4/0 cable produced a voltage drop of approximately 350 mV (70 A X .005Ω = 350 mV). The result was a potential of 350 mV at the power panel ground busses. This was in turn tied to the Mecca system resulting in a Mecca potential nominally of several hundred millivolts, and subject to variation depending upon power neutral current flow.

To further complicate this situation, during an earlier system noise evaluation, not related to this effort, individual ground cables had been connected from each instrumentation and computer system rack directly to the Mecca system. In addition, it was found that the line power neutral was connected directly to the MG set neutral. The overall result was a multiplicity of ground paths contributing in varying degrees to the total detrimental effect.

It should be noted that all power wiring installed at NTF was in conformance with the National Electrical Code and all local codes. That is, the neutral/ground interconnections were in themselves not improper. However, the total design failed to observe the need for a noise free ground as an instrumentation reference.

To correct this situation, the following actions were taken:

1) Corrections were made in the control room power panels to connect all power neutrals to the neutral bus and all grounds to a separate ground bus.

2) The power panel internal ground-to-neutral connections were removed.

3) The ground busses in each of the three power panels were bussed together and tied with one link to the Mecca system.

4) The connection between line power neutral and the MG set neutral was removed.

5) The redundant connections from the instrumentation and computer system racks to the Mecca system were removed from all powered racks. Connections were left in place on unpowered racks for safety considerations.

6) A current transformer and meter were incorporated to monitor current flow in the Mecca system to allow constant verification of its integrity as zero-current flow instrumentation ground.

The result of these actions was the reduction of Mecca ground current from as high as 7A to less than 50 milliamps (mA). Rack-to-Facility ground potential was reduced from several hundred millivolts to approximately 5 mV AC. These figures are considered reasonable and representative of the combined electrical leakage that could be expected with the large quantity of instrumentation and computer equipment in the NTF control room.

NTF AC Power

In normal operation, equipment in the NTF control room is powered from an MG set. The generator is Y (or star) connected and provides three phase, 208 V phase-phase power. The phase-neutral voltage, used by most of the control room equipment, is typically 112 V. The Y centertap (power neutral) is tied directly to the ground grid outside the NTF for a power ground reference. Control room power is manually switchable from MG to line power to allow for MG set maintenance.

At the outset of the investigation, AC power monitoring equipment was used over a period of several weeks to determine the quality of both the line and MG set AC power. It was observed that both sources were free from voltage sag and transients. Both were judged to be basically capable of powering the control room equipment without directly introducing any significant noise into the instrumentation system. Within the control room however, it was determined that the use of certain non-standard techniques and wiring errors did in fact contribute significantly to instrumentation system noise.

Many of the instrumentation racks used in the control room were procured from the computer system manufacturer. Therefore, the AC power distribution boxes within the racks themselves are of the computer manufacturer's design. Several different types of racks and hence power distribution boxes are employed. The difference relates to whether the rack was intended to be used by the computer manufacturer for magnetic tape or for disk equipment. The racks housing the high speed digital data system equipment are of the magnetic tape system type.

The magnetic tape-type power distribution box is circuit breaker protected and provides six standard UL power receptacles and four non-standard small nylon receptacles. The non-standard receptacles are intended to power specific types of computer system equipment rather than for general use. To further complicate the issue, two of the four nonstandard connectors provide "filtered" power, and the other two provide standard line power. In the original configuration, all of the high speed digital system equipment was powered using these non-standard connectors.

Two problems became quickly apparent. The connectors were loose allowing for intermittent power connection. The looseness was such that arcing within the connector could be seen when the connector was moved only slightly. Secondly, although the nature of the filtering on the "filtered" power is unclear, it became obvious that it is incompatible with the data system power requirements. Although no voltage drop or other effects could be seen, the use of this power source produced a substantial increase in the data system noise, when compared to the use of MG unfiltered, or line power.

In the other type (disk system) of power distribution box, several wiring errors were discovered wherein the ground was not properly connected internally. These distribution boxes were associated with racks housing communications equipment and some computer peripherals.

Both types of distribution boxes are provided input power via a large 40A twist lock connector. A rubber boot is provided as part of the connector to protect the otherwise exposed electrical connections. Two problems with this connector were identified.

First, to facilitate original assembly, a lubricant had been used to allow the boot to slide easily over the cable. In some cases, excess lubricant had been allowed to run down the cable and coat the electrical connections. This resulted in poor quality connections, particularly affecting the ground lead. The second of the two connector problems was due to loose screw connections, where the power leads mate with the connector terminals. This was identified clearly on one of the data system racks and in several other locations. The result again was poor quality connections.

Another very subtle but highly significant problem discovered related to the AC power phase differential between adjacent equipment racks. At the outset of the investigation it was assumed that any given contiguous segment of equipment racks within the control room was powered from a common AC phase, i.e., all instrumentation racks on Phase A, all computer mainframes on phase B, etc. This assumption proved to be erroneous.

After working on the system for some time and reaching a plateau in performance improvement, a more detailed analysis of the power wiring within the control room was undertaken. It was found that in the instrumentation system, adjacent equipment racks were wired in sequential phase order, i.e., rack 1 on phase A, rack 2 on phase B, rack 3 on phase C, rack 4 on phase A, etc. This introduced noise from the power line, through the racks into the various equipment chassis. This problem, along with the redundant rack-to-Mecca ground ties proved to be a major contributor to the overall 60 Hz noise problem. The use of mixed phases was subsequently shown to also be a factor in other, non-related, control room instrumentation noise problems.

The last item investigated in the AC power system was phase balancing. The initial readings did indicate a substantial unbalance with a current distribution of 65A, 80A and 95A for the three phases. After final balancing, a distribution of 85A, 89A and 95A was achieved under normal control room operating conditions.

To correct the AC power system problems, the following actions were taken:

1) The use of non-standard AC power connectors was eliminated. This also eliminated the use of the computer equipment rack "filtered" power. All power is now provided via standard three-pin UL power connectors.

2) The twist-lock power connectors feeding the racks were removed, cleaned, connections tightened and replaced. This action was taken for all racks employing this type of connector, including the computer and computer peripheral racks.

3) All equipment rack power distribution boxes that were improperly wired were dismantled and corrected. This included an engineering design change affecting several racks to provide an internal ground where such was omitted in the manufacturers original design.

4) The equipment racks housing the high-speed digital data system, and all adjoining instrumentation equipment racks, were placed on a common power phase. This also provided the opportunity to move certain racks to other phases to facilitate phase balancing.

The result of these actions was a stable instrumentation system free from drift and excessive noise. This was the basic condition necessary before any problems directly associated with the high speed data system, or instrumentation cabling could be addressed.

Figures 1 and 2 show, in simplified form, the NTF power and grounding system as originally configured, and after modification.

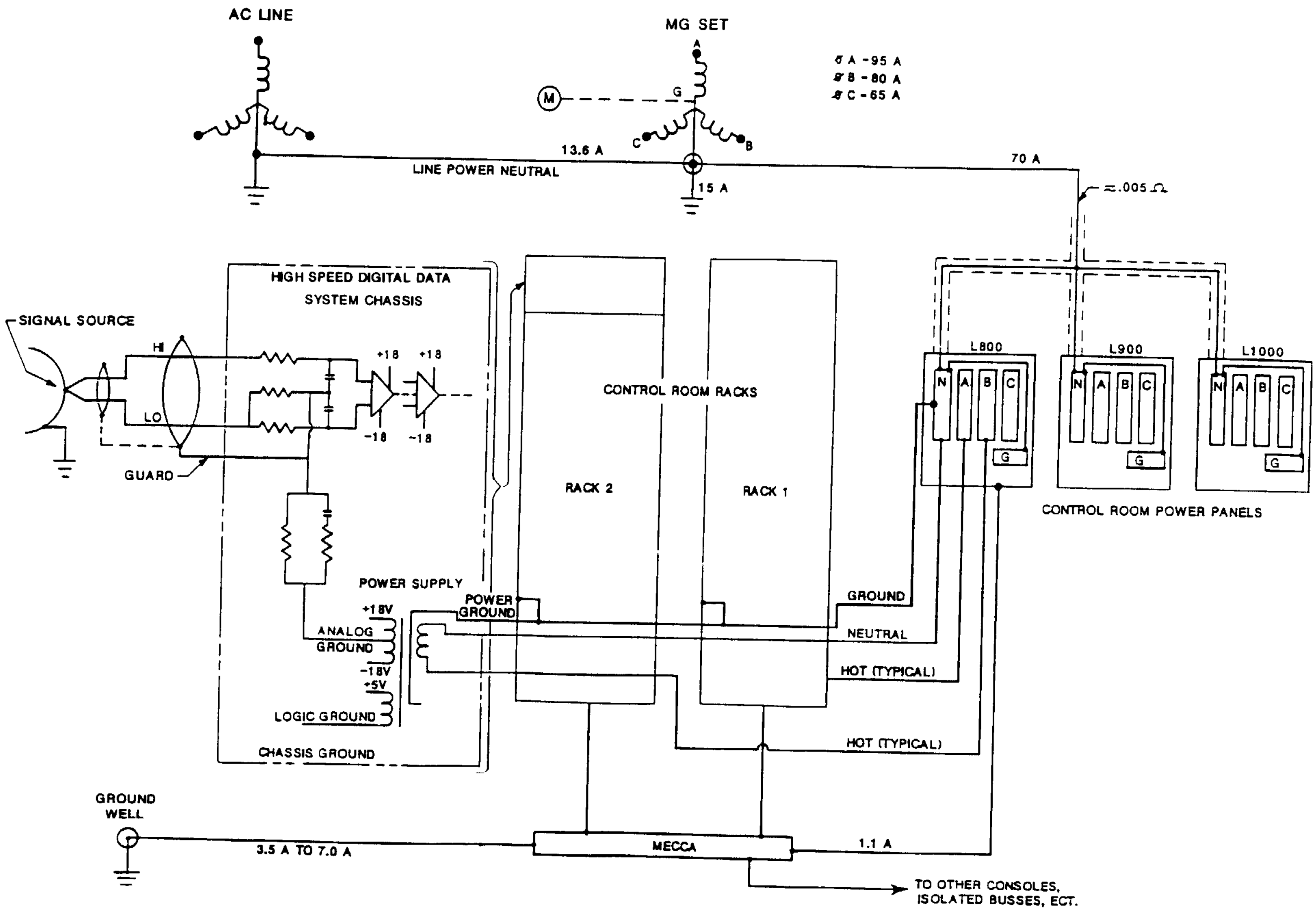

FIGURE 1, NTF POWER AND GROUNDING – ORIGINAL CONFIGURATION

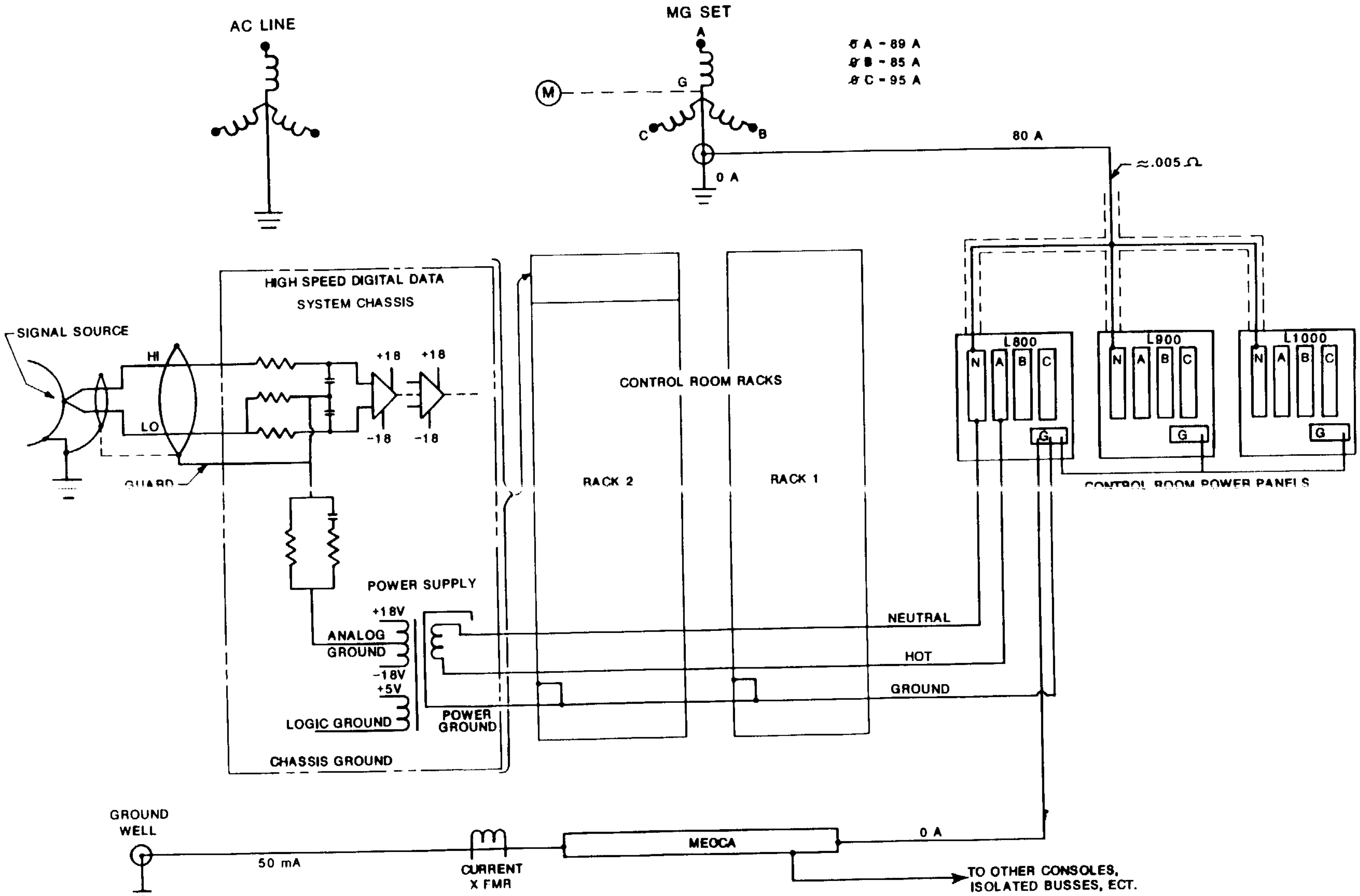

FIGURE 2, NTF POWER AND GROUNDING – AFTER MODIFICATION

Data Acquisition System/Computer Interface

Initially, it was thought that the data system equipment itself was a primary contributor to the system noise problem. However, this investigation proved quite the opposite. With the exception of specific component failures during the course of the investigation, the equipment proved capable of meeting manufacturers specifications when used in a suitable electrical power/grounding environment. The equipment did display a distinct need for correct grounding, and exhibited wide ranging variations in output when the proper grounding conditions were not met. Although specific detail of the equipment internal grounding system is beyond the scope of this report, a general overview follows.

The high speed digital data equipment functions with four distinct internal grounds. These are identified as Analog Ground, Logic Ground, Chassis Ground and Power Ground. It should be noted that the term "ground" here may more appropriately be considered "reference" rather than ground. The use of the term "ground" would seem to imply a commonality between the four references, which is not the case. These "grounds" are kept separated within the equipment and are brought out a terminal strip on the rear of each chassis. Analog Ground is the center tap, or reference, for the ±18V power supply used to power the analog circuitry; Logic Ground is the low side of the +5V logic power supply; Chassis Ground is the chassis itself; Power Ground is the third (ground) pin of the AC input power and, in this equipment, is connected to the guard shield of the power supply input transformer. Although, as in any system, these grounds ultimately become comingled, it is important that this occur at the appropriate point.

Through experimentation it was determined that the Analog Ground could have a profound effect on system operation. For minimal noise, this ground is connected to an external (real) ground. Since the analog ground is the centertap of the $\pm 18V$ power supply used for amplification and filtering stages prior to the digitization process, it forms the reference for analog voltage measurement for all stages following the initial differential input. Any changes in this reference are therefore exhibited as variations in the voltage ultimately appearing at the input to the analog-to-digital converter. Therefore, relatively minor variations appearing on the real ground to which the Analog Ground is attached are coupled directly into the system and appear at the output. This, along with noise coupled directly through the chassis due to AC potential on the equipment racks, and ineffective use of the power supply transformer guard shield due to power system neutral/ground interconnection, represented the mechanisms by which AC power and grounding problems were reflected in the system output.

The manufacturer's literature recommends a specific interconnection of the data system grounds to an external ground. At the outset of this investigation the system power and grounding problems were such that modifications in these connections had no positive effect. After the NTF power and ground system modifications, it was possible to clearly see the effect of different ground configurations. It was also found that a deviation from the manufacturers recommended configuration provided improved system operation. This modified configuration is now included in both the MPA and tunnel systems.

After AC power and grounding modifications, it was then possible to identify other problems. One group of problems was associated with the interface between the high speed data system and the computer system.

It could now be seen that there were intermittent excursions in the system output which were sometimes as brief in duration as one data sample. Two contributing problems were identified as being in the interface digital logic circuitry. As corrective action, a D type flip flop was added to latch the I/O request, and capacitors were added to the I/O line optoisolators. A third interface problem resulted from the use of switching power supplies.

In the complement of NTF instrumentation there are three high speed digital data acquisition systems (with independent computer interfaces), and three separate interfaces used for digital data input. Each of these six units contained switching power supplies.

Prior to correction of the AC power/grounding induced noise, the transient noise contribution of the switching supplies was not identifiable. At this point in the study however the switching power supply transients could clearly be correlated with the output data. The switching supplies were replaced with linear supplies resulting in an additional significant performance improvement.

Another problem was traced to the output switching of the preamplifier cards. The data system equipment configuration uses four preamplifiers per card with sixteen cards per rack module. The output of an individual channel is connected through a series of solid state switches to the programmable gain amplifier and analog-to-digital converter. The card select and channel select switches are located on the preamplifier cards. As mentioned earlier, two versions of low-level cards are used in the system. In the newer versions of these cards, the switch drive circuitry was improved resulting in a faster switching time. When used at high switching rates, the older configuration exhibited a zero shift of nearly 100 μV (when compared to the same card at low switching rates or a newer card at any switching rate). Discussions with the manufacturer indicated that an Engineering Change Order had been issued to modify the switching of the older cards to the newer configuration. All affected NTF cards were subsequently modified on-site, thereby eliminating this problem.

Signal Cable/Shielding

As noted earlier, the NTF high speed digital data acquisition system employs a guard shield front-end concept. In a system of this type the signal cable shield serves not only the obvious "shielding" function, but is also an integral part of the common mode rejection circuitry of each preamplifier. Properly configured, the shield ties to the guard input at the amplifier and to the low side of the signal and ground at the signal source. Figure 3 shows a simplified proper configuration.

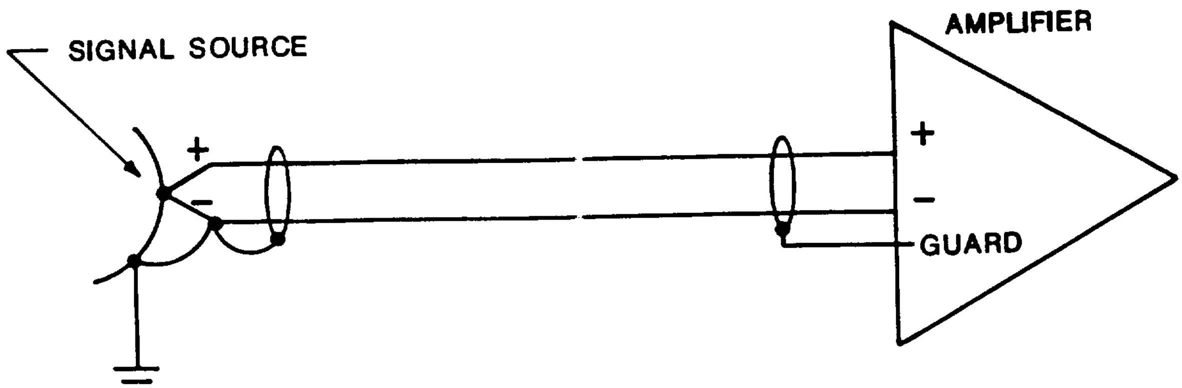

FIGURE 3, SIMPLIFIED GUARDING CONFIGURATION

Although certain variations are employed, the critical point is that the shield must tie once, and only once, to the source of the common mode voltage. Further, the shield must be continuous with no breaks from end-to-end. This is particularly important when signals are passed through intermediate signal conditioning devices such as thermocouple reference junctions, and with externally excited devices such as strain gage bridges.

The proper termination and continuity of the guard system ensures that the common mode rejection circuitry within the amplifier will function based upon the actual common mode voltage superimposed on the data signal at the signal source. Failure to properly complete this guard system can seriously affect the data quality. Simply put, the amplifier common mode rejection circuitry cannot remove an unwanted common mode signal that it does not know exists. Although an in-depth discussion of guarding and grounding in instrumentation systems is beyond the scope of this report, suffice it to say than an improper guard configuration in a system of this type may result in errors in the output data.

In the design of a system of this type the power supply used for externally excited devices must also be considered. To be consistant with the guarding concept, the supply must also be guarded. This is essentially a floating-output supply, the low side of which is not grounded at the output of the supply itself. A further consideration is that the supply be enclosed in a guard shield isolated from the chassis. This guard shield is the point to which the shield of tranducer excitation cable is connected.

The shield of the excitation cable is then grounded to the common mode source along with the power supply low and the data system input cable shield. The entire system is thus referenced to the common mode source and the preamplifier circuitry can effectively remove the unwanted common mode voltage. Figure 4 shows a simplified proper configuration for a four-arm bridge type transducer.

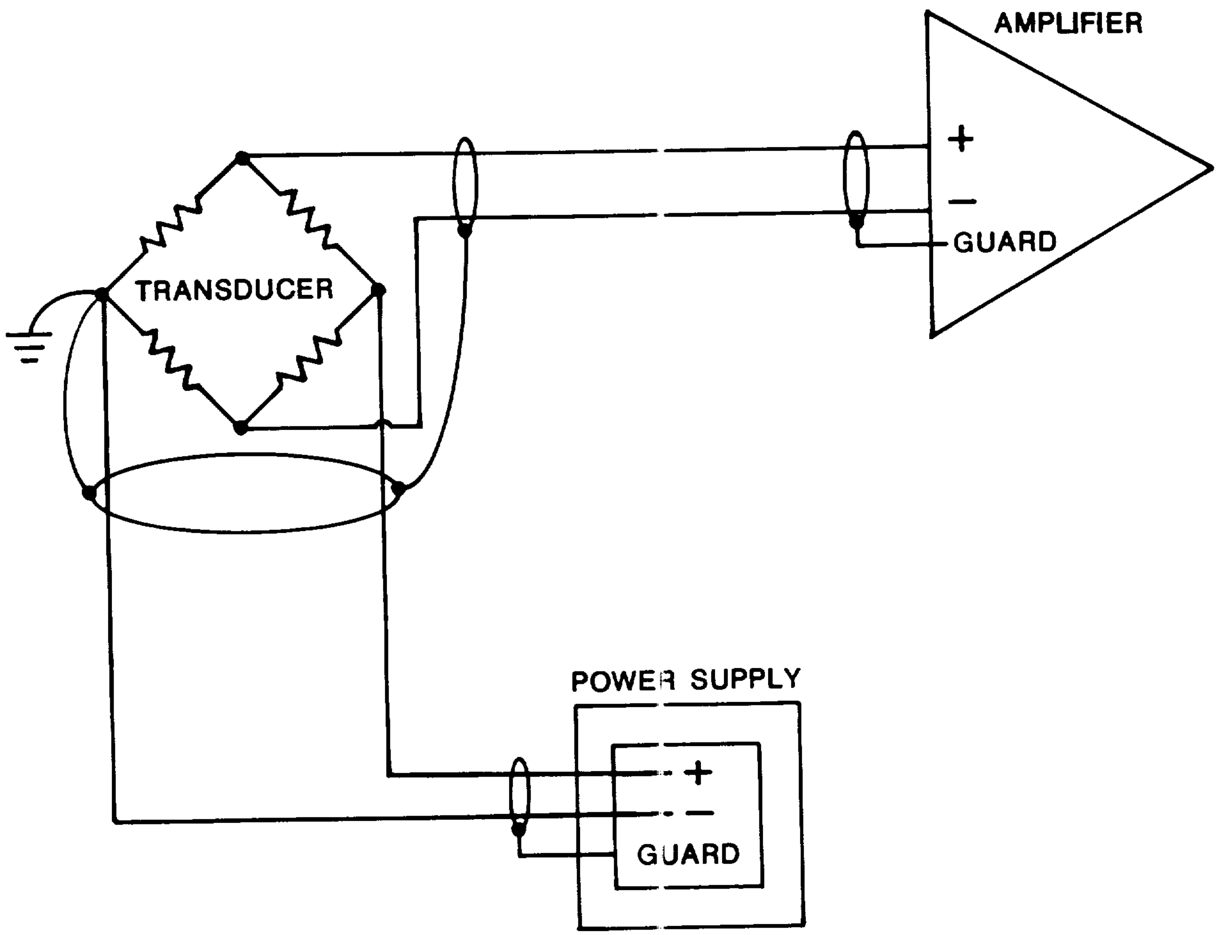

FIGURE 4, GUARDING CONFIGURATION FOR EXTERNALLY EXCITED DEVICE

For reasons that are not clear, the original design of the NTF cabling and transducer excitation systems was inconsistent with the above stated concepts. The signal cables, though tied to the guard input at the data system were left unterminated (floating) in both the MPA and tunnel areas. The excitation power supplies used were not guarded, but rather were laboratory type supplies configured with the low side grounded at the power supply output. In addition, the excitation cable shields were grounded at the power supply and floating at the transducer. The result was a system where the data system common mode rejection capability was rendered inoperative, or in certain cases could actually contribute to the common mode error.

Since unwanted signals may be superimposed upon data via inductive, resistive or capacitive coupling (or various combinations thereof), and since various factors such as cable length, cable resistance, line unbalance, etc. are also important, it is virtually impossible to accurately analytically determine the specific detrimental effect of the improperly configured NTF cabling/power supply system.

Corrective action taken included; grounding of the cable shields at the signal source; grounding the low side of the data system input signal (or where used, the low side of bridge transducer excitation power supplies) at the signal source; and, removing the excitation low and shield ground at the excitation power supplies. The power supplies themselves were not replaced and the excitation cable shields were left floating at this point. The supplies were retained due to their very good noise and drift characteristics. Although not in complete conformance with the desired configuration, the greater part of the total possible benefit has been realized. If guarded supplies with correspondingly good noise and drift characteristics could be identified, consideration would be given to replacing the original supplies.

At the beginning of this project an attempt was made to assess any improvement that could be made using properly terminated cables vs. the then current NTF cabling system. At that time, due to the overwhelming noise from other causes, the comparison showed inconclusive results. After system improvements, changes in data signal guarding could clearly be correlated with noise in the system output.

EMI/RFI Sources

At the outset of this investigation it was assumed that all instrumentation system noise was induced by, or otherwise related to, the 60 Hz AC power and grounding system. The investigation therefore focused on defining and correcting such problems. After making the various corrections and improvements described previously, an additional, unexpected factor surfaced. It was noted that there was now a slight difference in the baseline noise level between an older (RC filter input) low level preamplifier channel and a newer (LC filter input) preamplifier.

This difference was traced to the existence of a low level distorted sinusoidal signal at approximately 55 KHz appearing as a common mode voltage on the data input lines and on the cable shields. Although the system baseline noise was at this point improved by a factor of approximately 4:1, it was felt that elimination of the EMI could yield additional significant benefits.

Support was solicited from the Langley Research Center Flight Electronics Division in conducting a search for sources radiating EMI/RFI. With a spectrum analyzer, it was ascertained that the approximately 55 KHz noise signal was in fact real, rather than an erronous artifact of the previously used detection process. Tunnel testing activity however prevented further in-depth investigation with spectral analysis equipment at this time.

At a later point, a less sophisticated system consisting of an oscilloscope, counter and bandpass filter was used to survey the entire NTF Facility. Using this equipment, three independent EMI sources, at approximately 48 KHz, 55 KHz and 57 KHz, were identified. It was further shown that the sources produced both conducted and radiated EMI, to varying degrees. One difficulty that emerged in the identification of the three sources was the fact that, at the data system input, the three EMI signals were of approximately equal amplitude. Being rather close in both frequency and amplitude tended to result in a distorted single interference signal rather than three independent signals. It was only when the search was spread throughout the control room and beyond that the three distinct signals emerged.

1) The 48 KHz noise was traced to color CRT terminals used in the control room. There are eight such terminals involved, four rack mounted and four on work tables. All units were shown to impose 48 KHz sinusoidal noise on the power and ground systems to which they were connected. Since they were tied to MG power and the Mecca ground system, the noise was then conducted to the data system. In addition to this direct conductivity, the four rack mounted units were also sources of radiated EMI.

Apparently due to space considerations, the covers of the rack mounted units had been removed. This was done even though the CRT chassis were clearly marked with a notice stating that: "This equipment has not been tested to show compliance with FCC Rules (47CFR Part 15)... and is likely to cause unacceptable interference to radio communications requiring the operator to take whatever steps are necessary to correct the interference". In this case, the data system equipment served to replace the radio communications equipment that could be (and was) interfered with. With the table top units, no significant radiated EMI could be detected. However, with the covers removed, the rack mounted units were shown to be strong sources of radiated EMI. This was then conducted through the racks and associated cabling to the Mecca ground system and hence to the instrumentation. There was some evidence of earlier attempts to minimize this noise source by isolating the CRT chassis from the equipment rack. In two of the four cases however, the isolation was only partially effective resulting in additional EMI conductivity paths.

To correct this problem, EMI filters were placed in the CRT power leads to prevent the units from contaminating the MG power and Mecca ground system. This proved only partially successful. Since there was no need to maintain a common ground between the CRTs and the remainder of system, they were then removed from the MG/Mecca system and placed on line power. This completely eliminated the EMI conducted through the power system. New covers were fabricated and installed on the rack mounted units, eliminating the remainder of the CRT induced EMI.

Coincidentally at this point a group of temperature channels was added to a similar but separate high speed digital data system in the control room. It was observed that this equipment experienced a 5:1 reduction in noise on these channels after implementation of the CRT system corrections. The effect on the research data system equipment is shown in the Summary and Conclusions section.

2) The 57 KHz noise source was found to originate with microprocessor equipment both within, and external to the control room. This equipment is used to sample a large number of discrete variables (switch closures, etc.) throughout the facility. Three such systems are employed to monitor a total of approximately 2100 inputs. Each system monitors a number of input/output tracks, each of which may contain up to 16 individual input/output modules. Each of the input/output tracks contains its own DC power supply for its complement of modules. Several EMI problems associated with this equipment were identified.

The first problem was that the microcomputer systems themselves are sources of radiated EMI. The CPU portion produces a signal in the 50 KHz range, while cabling at the rear of the equipment radiates at frequencies over 1 MHz. The second, and most significant problem was that the input/output track power supplies are sources of both radiated and conducted EMI at approximately 57 KHz. There are eighty-two such supplies in the NTF control room and eighty-five located in remote field boxes distributed throughout the tunnel area.

Since the EMI seemed to be a function of system design rather than component failure, the manufacturer was contacted regarding any engineering changes developed to minimize the noise. It was thus determined that no equipment design changes were offered. The manufacturer indicated that the equipment was normally used in industrial environments where other devices (motors, relays, etc.) could produce significant EMI/RFI. As such, the system was designed with a high level of EMI/RFI immunity without specific consideration being given to its becoming a source of such noise. Although the system chassis is not labeled as such, it was stated that it does not conform to FCC specifications and has been operating under a deviation, due to its intended purpose.

Even though the equipment was a significant EMI source, it was primarily the way in which it was interconnected to the NTF power and ground systems that caused the interference with the low-level instrumentation.

In an apparent attempt to be consistent with the concept of a single-point facility ground, the individual grounds from all of the input/output tracks including those in the remote field boxes, had been connected to the Mecca system. This deviated from the manufacturers recommendations for maintaining maximum system noise immunity. Two key elements of the manufacturers recomendations were violated; 1) local earth grounds were not provided for the remotely located input/output tracks and 2), a number of the remote field box grounds were daisey chained together in their interconnection to the control room Mecca system. This provided a direct path for EMI to reach the Mecca system and in addition, placed unshielded ground cables as EMI radiators in the instrumentation cable trays and conduits. Even though the input/output tracks in the control room were also connected to the Mecca bus, observance of manufacturer's recommendations for the remote equipment could have minimized the total EMI noise effect considerably.

To correct the problem, individual local earth grounds were provided for the input/output tracks in the remote field boxes, and the connections to the Mecca bus were removed.

In the control room, an independent ground bus was established as the Process Ground. This was a copper bus, mounted alongside, but insulated from the Mecca bus. A 4/0 cable was run from this bus to the facility earth ground. All of the process (or non-research) equipment was tied to this, rather than the Mecca bus. This parallel ground arrangement prevents process system ground disturbances from effecting the research data acquisition systems. This ground configuration is shown in Figure 1.

3) The 55 KHz noise was found to be associated with a rack of servo amplifiers in the control room. This system is used to control the movement of the test section walls, model support walls, reentry flaps and the model roll drive.

The servo amplifier channels are connected to three-phase silicon controlled rectifiers (SCRs) located remotely from the control room. It was clearly noted on the manufacturer's drawings that the shield of the SCR control signal cable, in this case from the servo amplifier system, should be grounded at either end. The choice of grounds was apparently left to the user depending upon local circumstances. At the NTF, no shield ground had been provided. This resulted in a path for the SCR generated EMI to infiltrate the servo amplifier system, equipment rack, and ultimately the data systems. There was evidence within the servo amplifier equipment rack that an earlier attempt had been made at reducing noise. However, this work had not proven successful. To correct the problem, the cable shields were tied to the new Process Ground at the control room end.

Summary of Results

The effort described, which began as a specifically focused investigation into high speed digital data acquisition system cable-induced noise problems, quickly and necessarily expanded to include many additional factors pertinent to the proper operation of the NTF instrumentation systems. The original motivation came about due to an indirectly related problem; the data acquisition software execution time was too slow. This was determined to be at least partially due to the need to average 50 samples of each data channel to establish a single data point. The 50 sample average had been in turn chosen at least partially due to excessive noise and random variation in the data system output. Hence, the need to investigate the cause of the apparent data system noise.

Since the investigation was conducted using the tunnel data acquisition system on an as-available basis, a specific comparison of the before and after effects for all channels and all ranges is not possible. However, just prior to and during the period of this investigation, a particular model, Pathfinder I, a generic wide body transport, was tested several times. Using software developed during the course of this investigation it is possible to use actual test data from four separate Pathfinder I tests as a yardstick for measuring system performance improvement. To cover all types of data typically acquired, a comparison was made for balance (4 arm strain gage bridge), grounded thermocouple, and ungrounded thermocouple data.

Since the performance of the system is most meaningful in terms of the overall context of the data acquisition process, this is the manner in which the sample data is presented. For thermocouple data this includes the thermocouple itself, the reference junction, and all cabling, connecting and patching in route to the control room. For balance data, the additional effect of the balance power supply, excitation cabling and sense cabling is also included. Average cable length for the channels evaluated is approximately 150 ft.

In each of the following graphs, wind-off zero data is presented for each of four tests. Tests represent data taken prior to any corrections being made (Test 14); following the implementation of the power and grounding system changes (Test 17); after completion of improvements in shielding and guarding (Test 23); and after elimination of EMI/RFI noise (Test 27). The contribution of the major noise sources and effect of corrective measures can clearly be seen.

Figure 5 shows the improvement, in terms of microvolts of noise, for the six balance components. Figure 6 shows the equivalent data for grounded and ungrounded thermocouples. Figures 7 and 8 compare the improvement in terms of standard deviation. The data in Figure 5 through 8 represent fifty-sample averages.

Figure 9 shows, in engineering units, the 95% confidence limits for 5, 10, and 50 sample averages for the balance components prior to system modifications. Figure 10 shows the same data following completion of all modifications. In a comparison of figures 9 and 10 the extent of the improvement in performance becomes very apparent; the 95% confidence limits for five sample averaging after modifications are significantly better than that achievable with 50 sample averaging at the outset.

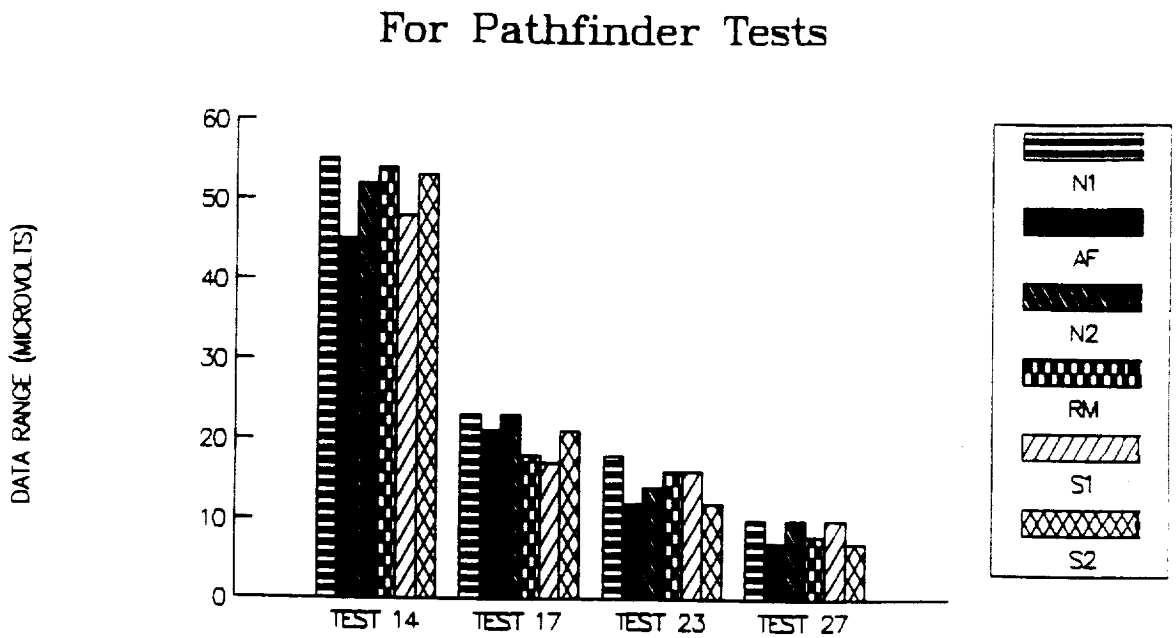

FIGURE 5, BALANCE CHANNEL DATA SCATTER

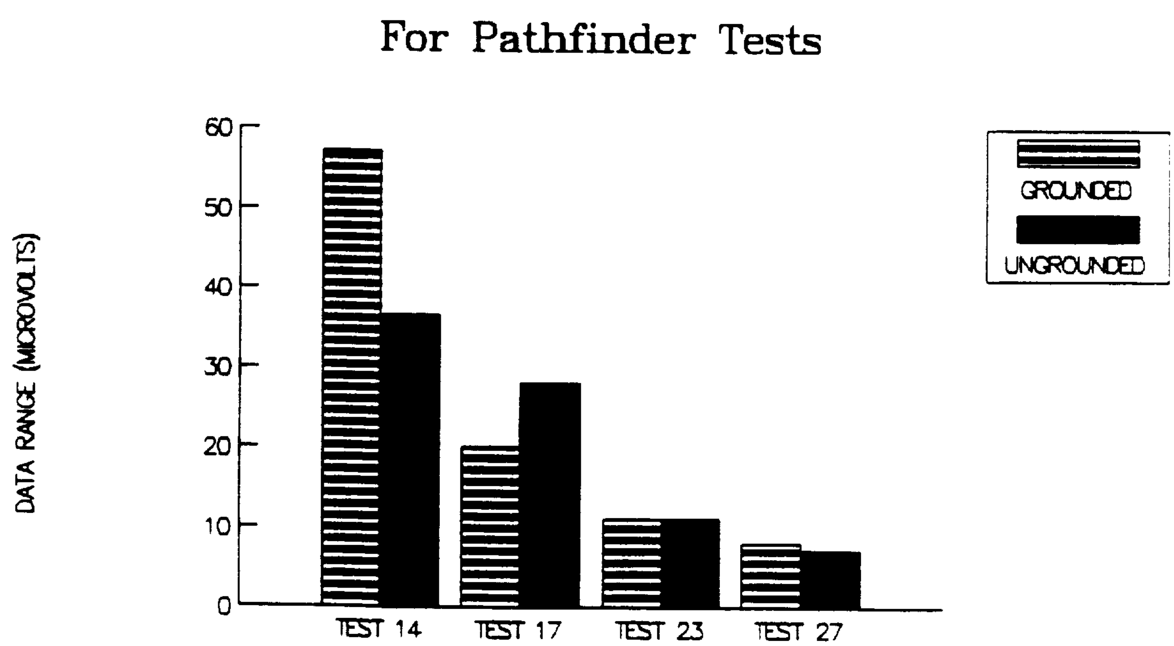

FIGURE 6, THERMOCOUPLE DATA SCATTER

ORIGINAL PAGE IS
OF POOR QUALITY

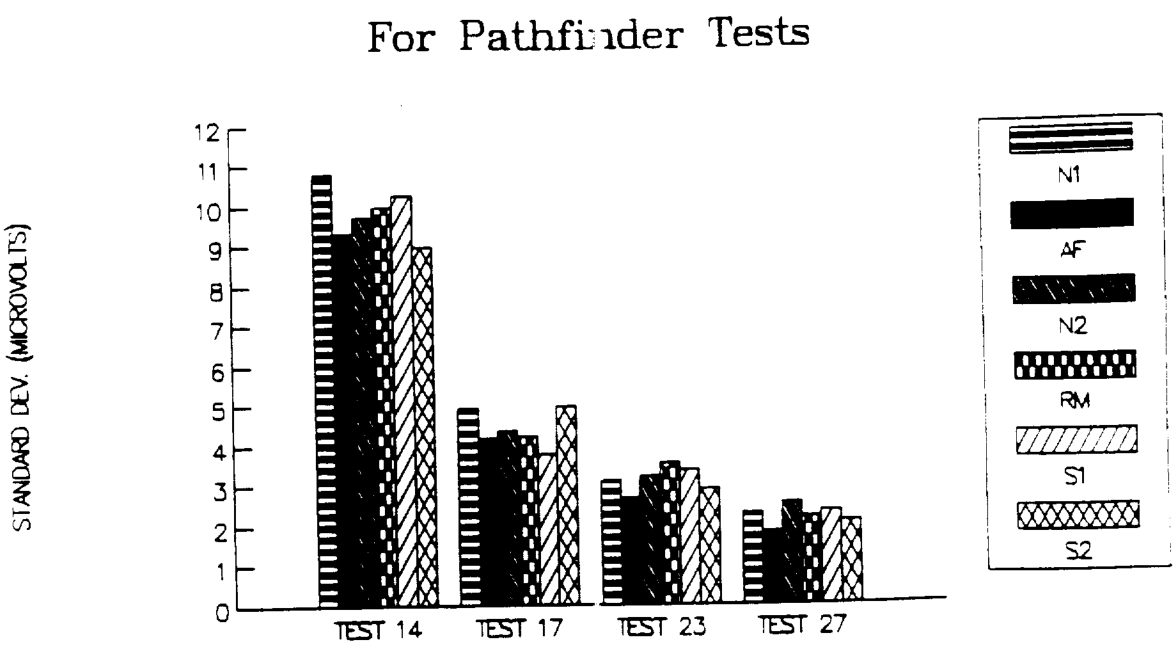

FIGURE 7, BALANCE CHANNEL STANDARD DEVIATION

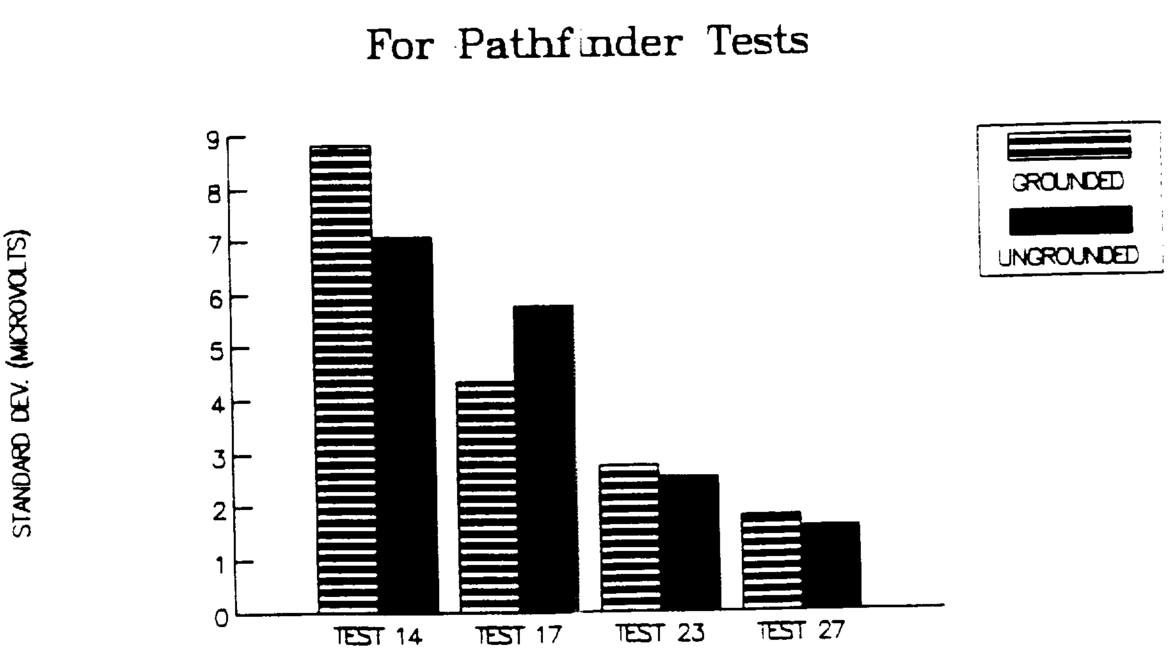

FIGURE 8, THERMOCOUPLE STANDARD DEVIATION

Test 14 Balance Forces

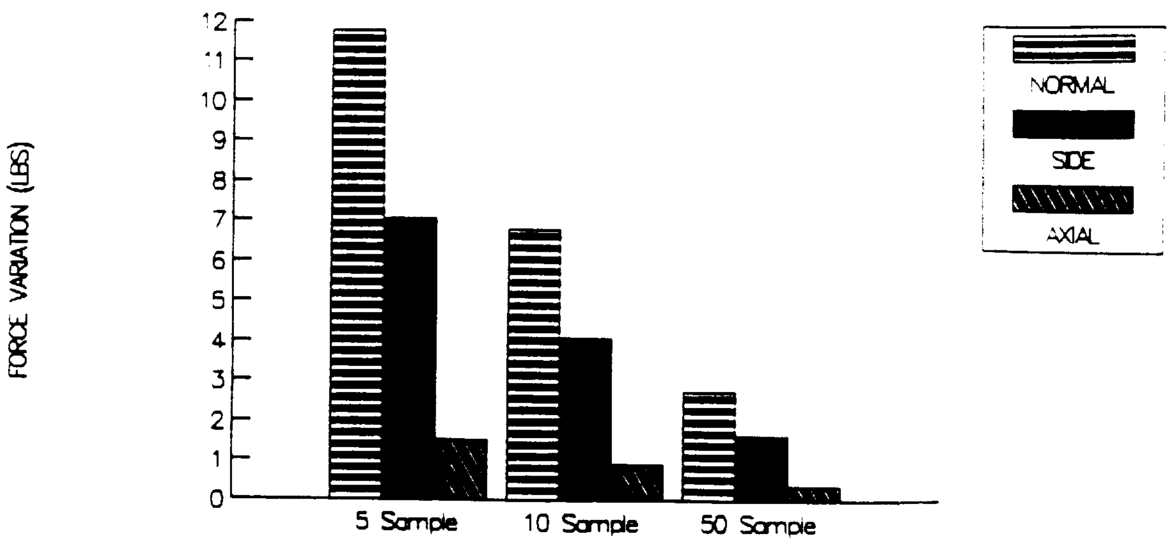

FIGURE 9, 95% CONFIDENCE INTERVALS

Test 27 Balance Forces

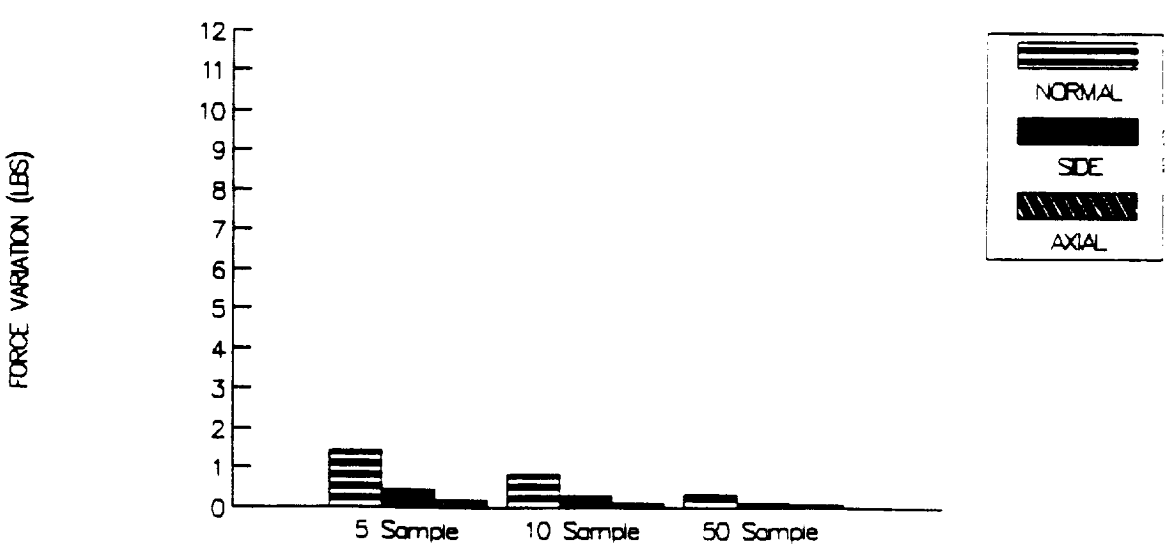

FIGURE 10, 95% CONFIDENCE INTERVALS

Tests were also made to evaluate long term drift. After modifications, this was found to be from two to four microvolts over a 72 hour period, with no interim correction. Due to the extent of the noise at the outset, no meaningful data is available for comparison.

The initially established goals were achieved through the reduction or elimination of EMI and 60 Hz noise. Since major changes were made, systems other than the high speed digital data acquisition system can also be expected to benefit. Problems not yet clearly identified in other systems may have also been eliminated.

NASA
National Aeronautics and Space Administration

Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR-4193		

4. Title and Subtitle	5. Report Date
Electrical Noise Reduction Techniques Contributing to Improved Data Quality at the National Transonic Facility	November 1988
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
J. R. McPhee	
	10. Work Unit No. 505-61-01-01
9. Performing Organization Name and Address Wyle Laboratories 3200 Magruder Blvd. Hampton, VA 23666-1498	11. Contract or Grant No. NAS1-18304
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Langley Research Center Hampton, VA 23665-5225	13. Type of Report and Period Covered Contractor Report
	14. Sponsoring Agency Code

15. Supplementary Notes

Langley Technical Monitor: W. E. Bruce, Jr.

16. Abstract

In initial use, the high-speed digital data acquisition systems at Langley Research Center's National Transonic Facility produced data containing unacceptably high noise levels. This report describes a process wherby the contributing noise sources were identified and eliminated. The effects of 60 Hz power, system grounding, EMI/RFI, and other problems are discussed and the corrective action taken is outlined. The overall effort resulted in an improvement of greater than 5:1 in system performance. Although the report describes a system specifically used for wind tunnel data acquisition, the corrective techniques employed are generally applicable to large scale high-speed data systems where signal resolution in the low microvolts range is important.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
electrical noise guarding/grounding EMI/RFI	Unclassified - Unlimited Subject Category 35

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	40	A03

NASA FORM 1626 OCT 86

NASA-Langley, 1988

For sale by the National Technical Information Service, Springfield, Virginia 22161-2171