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ELECTROMAGNETIC COMPATIBILITY SURVEY OF FINDINGS ON CABLING, SHIELDING, AND CONNECTORS GAM-87A PROGRAM

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ABSTRACT

This report contains a summary of the findings of the Nortronics EMC group in the fields of power supplies, cabling, shielding, grounding, and connectors. Rules developed during the course of the GAM-87A program are listed, as are important test results. Where applicable, recommendations and conclusions reached are also given.

1. INTRODUCTION

This report is a summarization, from the EMC viewpoint, of the findings and techniques initiated on the GAM-87A program in the fields of shielding, grounding, cabling, and connectors. It covers the philosophies used to determine specifications and test methods, and details analytically and experimentally developed modifications. The report was prepared by the Electromagnetic Compatibility Group of Nortronics, a Division of Northrop Corporation, under authorization of Douglas Aircraft SCCN No. 183.

The electromagnetic compatibility problems encountered and mitigated in the guidance sub-system complex of the GAM-87A (Skybolt) program are directly due to the type of signal transmissions employed. In several sectors, mainly the computer modules, information processing and intercommunication took place in digital form, while the data derived from the optical and inertial systems of the AI (Astroinertial Instrument) was composed in the major part of analog signals. This part of the EMC program was concerned, therefore, with the task of ensuring that these signals could be processed without being adversely affected by other components of the data evaluation and transmission mechanisms, while also being able to function in the external environment in which the system was ultimately destined to become operational.

2. POWER SUPPLY

One of the initial areas of investigation was the matter of the power supply for the guidance sub-system. Ideally, this would have been taken care of by the power supplied from the primary power of the parent aircraft, either the Boeing B-52 or the AVRO Vulcan, and no further modifications would be needed to adapt the weapon system for tactical utilization. Previous experience tended to indicate that the B-52 aircraft electrical power supply was compatible with the guidance sub-system power requirements, but that there existed the possibility that a Motor-Generator set would have to be used. The evidence seemed to indicate the capability of the common power conversion equipment to suppress the transients generated by the Flight Control equipment when the guidance sub-system was also on the power bus.

2.1 Power Requirements of the Guidance Sub-system

An investigation was subsequently launched to determine the power requirements of the various modules, the quality of the primary aircraft power supplied under various load conditions, such as switching over fuel pumps, and the possible methods of curing any problems which might arise due to incompatibility of the two systems. A study was made of the regulated DC power requirement of the AI and PE (Platform Electronics), and the necessity of having a secondary regulated DC power supply evaluated. It was deemed necessary for the PLC (Prelaunch Computer) to have its own power supply, isolated from the B-52's electrical system. This was based on past experience with airborne digital computers and the difficulties with high frequency pulses on electrical systems.

2.2 B-52 Power Quality

A meeting was held to establish test methods, etc., for B-52 interference tests to be conducted at Boeing in order to obtain a better idea of the power available on the aircraft. Transients from 10-100 μ sec duration and of amplitudes up to 10 volts and RF noise of an amplitude of about 4 volts were found along with short duration power dropouts on the 400-cycle power. This short duration power dropout was also noticed on the DC power bus under conditions when various actuators in the aircraft system were turned on or switched over.

2.3 Filters vs. Motor-Generator

At this point a decision had to be made in order to resolve the incompatibility. Two methods were investigated. The method by far the cheaper and easier to implement was to use filters to reduce the noise level on the power line. The disadvantage of this method was the fact that the filters would not be able to store enough energy to compensate for the power-dropouts nor correct for the overvoltages expected to occur during operation on a tactical mission.

The second method was to use a Motor-Generator set for power isolation and regulation. Its disadvantages related to the weight of the unit, the maintainance problem on the rotating parts which would involve inspection and servicing of the bearings every 2000 hours, and poor frequency control due to the fact that the unit was an induction device, and not synchronous, so that its power frequency was partially dependent upon the value of the load it was connected to. The Motor-Generator's advantages included excellent energy storage due to its large inertia; it overrides temporary overvoltages and power dropouts which could cause errors in digital computers. It also has excellent transient attenuation.

The decision to use the Motor-Generator set was consequently based primarily upon the unit's energy storage and regulation capability for overvoltages, since the main problem was the matter of a power dropout or severe overvoltage affecting the computer's operation.

3. CABLING

Another field under consideration involved the selection and specification of the cabling to be employed on critical circuits. After extensive experimental and analytical investigations, a definite line of action gradually evolved.

3.1 General Cabling Concept

The Nortronics cabling concept briefly stated was as follows:

3.1.1 For long cable lengths associated with AC signals, a twisted pair-shielded transmission line with transformer coupling was designated.

3.1.2 For short cable lengths where pulses are involved and direct coupling is employed, a typical low-capacity coaxial cable was designated.

3.1.3 For long lines where mechanical switching (isolated contacts) was involved, coaxial cable was designated.

3.2 Cable Selection

Category 3.1.1 comprised the major problem area, as initial considerations and circuit designs were based upon the use of 160-ohm No. 22 AWG cable. This cable met the electrical and environmental requirements, but could not fit properly in the cabling area available at the PLC connector shelf. A subsequent comparison of No. 22 and No. 26 gauge Twinex samples prepared and submitted by Nortronics resulted in full agreement that the diameter of the No. 26 cable was preferred. However, No. 26 wire was rejected because of several features that were unacceptable. They were:

3.2.1 The No. 26 wire had inadequate physical strength. While tests (tensile as well as flexure) of No. 26 steel copper clad wire showed it to be superior to conventional No. 22 copper wire, questions arose as to the confidence level which could be assigned to controlled laboratory tests insofar as they represented the full severity of the environment expected to be encountered in the wing.

3.2.2 The cable bundle did not lend itself readily to modifications due to its construction of alternate layers of reverse twisted wire.

3.2.3 An AF specification restricted the use of No. 26 gauge conductor in aircraft wiring, and provisions would also have had to be made to develop and stock a special No. 26 crimping tool.

3.3 Comparison of Alternative Cabling

3.3.1 In an effort to reduce the weight of the cabling, the use of standard aircraft shielded twisted-pair wiring was investigated. This selection was rejected for the following reasons:

3.3.1.1 The capacity of the cable was too high and its compacitance variation too wide for it to be suitable for the transmission of the critical signals involved.

3.3.1.2 The voltage drop in the cable was too high.

3.3.1.3 The cable had the wrong impedance.

3.3.2 The final selection fell upon No. 24 gauge 135-ohm annealed copper Twinex. The decision was based upon the following data:

3.3.2.1 The cable cross-sectional areas were reduced to the point where they were useable at the PLC connector shelf.

3.3.2.2 Modifications of critically affected circuits to employ the new 135-ohm cable was feasible without a major redesign effort.

3.3.2.3 Interference rejection of the new cable was high and good isolation was obtainable with transformer coupling.

3.4 Critical Cabling Information

In order to keep track of the various cables and signal lines employed, a periodically revised document (NORT 10601550) was issued which contained wire functions with approximate voltages and current amplitudes. EMC personnel assisted in these periodic revisions, partly as a task concurrent to the test efforts, and partly to establish an analytical basis, based on worst case analysis, to which these circuits should be tested and their performance evaluated.

3.5 Cable Routing

Whenever possible, cable routings were investigated from an EMC standpoint, especially at interfaces, where the placement of appropriate pin connections could reduce cross-coupling appreciably.

4. SHIELDING

The purpose of shielding of the signal wires was twofold. In one case it was necessary to protect signal lines from externally generated interference, and in the other it was found useful to shield certain high level lines, especially pulse signals and square wave power lines. This reduced the radiated interference which might upset other signal lines.

4.1 Shielding to Lessen Radiated Susceptibility

In order to obtain data upon which to base a realistic shielding requirement, it was found that more information was required about the environment in which the system was destined to function.

4.1.1 Environmental Measurements

To obtain the above mentioned data, a series of tests were run to determine the highest field intensity levels expected to be encountered by the equipment in tactical configurations of the B-52 and Vulcan aircrafts. On the B-52, for example, measurements were made in up to five locations while the AN/ARC-58, AN/ARC-34, AN/ALT 6B ECM, AN/ASG-15 radar, and AN/APN-69 beacon were keyed to various CW channel frequencies; at the same time, audio frequency magnetic fields were also measured.

4.1.2 Method Used to Determine Shielding Specifications

The method employed to determine shielding requirements was based upon the data obtained in tests such as the foregoing. A spectrum chart was prepared showing the highest expected environmental levels, and the radiated susceptibility levels of the specification to which the unit was to be tested. The difference between the two curves, converted to db, was an indication of the necessary additional level of shielding to be provided.

Concurrently with this program, data also had to be obtained on the various degrees of shielding obtainable by different enclosures, wiring arrangements, and cable shields. Extensive tests were made on module enclosures, Twinex cabling, and several shielding methods. Whenever there existed the possibility of parallel routings of wires and shields, measurements were usually made to obtain data on the levels of crosstalk to be expected. All this entered into the final specifications for shielding.

4.2 Shielding to Lessen Radiated Interference

The data necessary to determine the level of shielding in modules around pulse circuits and square wave power supplies was somewhat easier to obtain. For one, the approximate amplitude levels were known, as was the waveform to be employed. On the basis of Fourier analysis calculations, giving the amplitude-frequency characteristics of the radiated interference, and specification limits, it was therefore possible to obtain the necessary shielding requirements by the decibel difference between the two. Some of the signals analyzed were the 1.6 Kc square wave power supply, signals in the BC (Ballistic Computer), on subcontract to G.E., and signals employed in the PLC.

4.3 <u>Shielding to Prevent Cross-Coupling</u>

The primary reason for shielding, especially in the matter of sheathing over interconnecting cabling, was to reduce the coupling of external interference onto the cabling and thereby directly into the guidance circuitry.

An especially sensitive area in this respect was the AI. All wiring within the instrument that could be coupled to the external field admitted through the guidance window had to be checked to ascertain that it was either shielded, filtered, or both, to prevent this interference energy from being coupled into <u>other</u> missile or carrier guidance modules.

Whenever there existed an absolute necessity for a break in external shielding, these following requirements were set forth:

4.3.1 Shield discontinuities should be less than 1" for the sheath and triax (102.4 Kc clock).

4.3.2 Shield discontinuities should be less than 3" for other shields at any break.

4.4 <u>Shielding Against Magnetic Fields</u>

Due to the relatively low power-frequencies employed, magnetic shielding created quite a problem. The best remedy was in most cases a thorough study of the cabling arrangement, and if possible, a rerouting of sensitive cables away from power carrying lines. If the level of interference was reasonably low, all that was necessary was the use of shielded cable along with modifications of the transmission mechanization, such as use of balanced lines.

5. GROUNDING

The lessons learned and implemented in the grounding methods used in the guidance sub-system can be divided into four main categories: signal grounds, power grounds, chassis grounds, and shield grounds. Rules to cover these items were initially based on previous experience and were subsequently continuously updated during the course of the GAM-87A program. Following is a listing of the design practices used in grounding, as recommended from an EMC standpoint.

5.1 Signal Ground

These were zero volt reference and signal returns within sub-units, units, and modules. Each was isolated from all other grounds except where tied to the single point reference.

5.1.1 Missile Signal Ground

5.1.1.1 The signal reference ground from each module was initially to be isolated from all other grounds and brought out of each module to the missile structure single point ground. This was later changed for the Ballistic Computer and Platform Electronics by tying signal ground to chassis ground to reduce interference pickup on long signal ground wires.

5.1.1.2 Isolation between signal grounds within modules was maintained where the signal currents would interfere with other signal levels of a lower value.

5.1.1.3 Missile DC coupled telemetry used the missile single point ground reference for signal returns. For example, only the high side of the DDL information was transmitted directly from the Ballistic Computer to the telemetry.

5.1.2 Carrier Signal Ground

5.1.2.1 Signal ground of carrier modules was originally isolated and brought out to a common-point structure ground. This point was not to exceed seven feet from the modules used in a two missile system. Excessive interference pickup on these ground wires led to a tying of signal ground to chassis ground within the Prelaunch Computer and Astro Tracker Control.

5.1.2.2 Signal grounds for tracking circuits were isolated in the Astroinertial Instrument and returned to secondary power supplies of the Astro Tracker Control. Signal grounds for these circuits were the carrier signal ground.

5.1.2.3 DC coupled carrier telemetry used the carrier single point ground reference for signal returns with the exception of the Digital Data Line. This output was transformer-coupled with both lines isolated from all grounds.

5.1.2.4 All inputs to the Prelaunch Computer from the Bomb/Nav tie-in were referenced to guidance carrier single point ground and were isolated from the Bomb/Nav signal grounding system.

5.1.2.5 Transformer coupling was employed in all signal communications between PLC and BC. Among other advantages, this maintained ground isolation between carrier and missile modules.

5.2 Power Grounds

These were grounds related to primary power on either the missile or the carrier aircraft.

5.2.1 Missile Power Ground

5.2.1.1 All primary 28 volt DC power returns to missile guidance system modules were returned by isolated wires to the missile single point ground.

5.2.1.2 The neutral wire of the 400 cycle 3-phase power was isolated in the missile and carried through the umbilical and pylon to airframe ground. All modules using single phase and three phase power in the missile were isolated from this neutral return.

5.2.2 Carrier Power Ground

5.2.2.1 Carrier equipment using 3-phase 400-cycle had power ground (AC neutral) brought out to a common structure ground point not exceeding seven feet from connectors on the modules.

5.2.2.2 A separate transformer-rectifier unit in the carrier was used to supply prelaunch power to the guidance equipment in each missile. The input power to the T/R unit was at carrier power ground, and isolated from the power output ground. The power output ground was isolated from carrier ground and routed through the umbilical and grounded at the missile single point ground.

5.2.2.3 Where more than one primary power ground was required in a single item of equipment, they were maintained separately within the equipment and brought out on separate connector pins.

5.3 Chassis Ground

The chassis or main structure of each module was brought to a pin of a plug for test purposes when the module was not mounted in airframe. When mounted in the airframe structure, each module was bonded with one or more bond straps from module chassis to the missile or carrier main structure. Resistance of bond connections was not to exceed 10 milli-ohms when measured with a Kelvin bridge.

5.4 Shield Grounds

Shields around the individual conductors to a module were brought through a pin on the module connector and tied to chassis ground as close as possible to the connector.

A general rule of grounding all shields on the receiving end only was adhered to. However, individual consideration was required in some cases where the shield was broken several times before reaching the destination of the shielded line. In these cases, either segment grounding at one end or carrying individual isolated shields through each break was required for satisfactory operation.

However, there were several interesting configurations for which additional rules had to be developed.

5.4.1 Digital lines had multi-point grounding for reduction of radiated interference and excessive pickup.

5.4.2 Critical analogue lines had double shielding with the inner shield grounded at one end, the outer one at both ends.

These cable sheaths were grounded to chassis ground. Tying shields to signal reference internally would have reduced the effects of signals coupled unto the reference line, but would have negated the shield's effectiveness for RF purposes unless the signal reference line were at the same impedance level as the chassis at all frequencies.

5.4.3 Grounds for the sheath and Triax had to be less than 4" and composed of a minimum of 20% strand combout.

5.4.4 Grounds on digital lines had to be less than 6" total from shield to aircraft, and 1/8" braided copper had to be used. Any hardware used for grounding had to be a minimum of AWG No. 20.

6. CONNECTORS

The EMI investigation of various connector configurations had the following major objective: to arrive at an optimal design which would allow for grounding of gross GAM cable sheaths and shields under static and dynamic environmental conditions. The tests were concerned in the large part with measurements of the bonding resistance under conditions of vibration, humidity, and salt spray. What was desired was a good DC and RF connector bond under all conditions expected to be encountered on the operational missile system through which sheaths and shields could be connected to chassis ground. Two methods of grounding were investigated. One method utilized the external shells of both connector and receptacle. The second method involved carrying the shield through a connector pin and bonding to the module receptacle shell internally.

6.1 External Shell Grounding

On April 23, 1962, a test program was initiated to determine the feasibility of carrying a gross cable sheath or shield through cable connector and module receptacle shells for the purpose of R. F. bonding the shield to module ground. This test involved the measurement of the D. C. grounding effectiveness of a gross cable shield under combined vibration and temperature tests. A System Integration test cable consisting of a Bendix Pygmy bayonet cable connector with a Glenair Adapter was mated to a Bendix hermetic module receptacle. The module receptacle was torqued to an aluminum vibration fixture. Prior to, during, and after vibration runs, D. C. bonding resistance measurements were made through the following series resistive interfaces:

6.1.1 Connector Cable Clamp

6.1.2 Connector Shell

6.1.3 Connector Bayonet Engagement Ring

6.1.4 Connector Bayonet Engagement Ring Back-up Wave Spring

6.1.5 Receptacle Bayonet Pins

6.1.6 Receptacle Shell

6.1.7 Aluminum Vibration Fixture.

The results of this test revealed that an initial reference resistance of 14 milli-ohms increased to approximately 1000 milli-ohms at one-tenth of the highest vibration levels, ($0.2g^2$/cps) to be encountered on the missile. Upon completion of the vibration run it was found that the reference did not return to its original static value, but remained at a high level. (650 milli-ohms) In addition, the low and high temperature level (+150°F, -65°F) vibration tests gave the same results. This test revealed an overall non-linear increase in bonding resistance.vs. vibration level for this method of shield to module bonding.

Since the standard bayonet type connector depends on three small bayonet pins to furnish any shell continuity for this type of connection, a special beryllium-copper, spring-finger contactor was fabricated by Applied Mechanics. This contactor was clamped to the receptacle outer shell and served to engage and contact the outer surface of the connector bayonet engagement ring to obviate the reliance on the bayonet pins. Ambient temperature vibration tests that were conducted with this advice soon gave the same results as stated above.

A third test in this series was performed. A Bendix Pygmy cable connector <u>without</u> Glenair adapter was fabricated with a short simulated harness of wires including a braided shield. This braided shield was coaxially terminated by soldering to the inside surface of a gold plated flared adapter which is caused to contact the connector shell by a threaded connector cable clamp. In addition, the bayonet engagement ring and back-up washer of the connector were gold plated. This is the method of shield termination that G. E. is using in their test cables in the G. E. depot and that are furnished with the BCTS.

Ambient temperature vibration tests on this "G. E. method" at one-tenth maximum vibration showed a 6DB increase above D. C. bonding reference with no return to reference after vibration removal.

It must be concluded at this point that carrying a shield thru a bayonet connector-receptacle combination is not recommended due to unreliability of the small contact areas of the bayonet pins under vibration.

6.2 Internal Grounding

At this point in the time-history of the investigation, direction was given by DAC in TWX A808 - 1398 to perform shield grounding by going through one of the pins on the module receptacle and grounding internally in close proximity.

Various approaches and possibilities were discussed in meetings coordinated by R. Dillon. The easiest and most economical method appears that of soldering a wire to a module receptacle pin and bonding directly to the back surface of the receptacle shell. These wires then would have a free length in the range of 3/8 to 3/4 inch.

Measurements were made on 20 ga. wires (solid and stranded) that were soldered, spot welded, and conductive cemented to the back surface of the receptacle. The combined series resistance values measured from the connector female insert, thru the receptacle pin, grounding wire, and shell, ranged from 4.3 milli-ohms for the spot welded wires to 5.4 milli-ohms for the conductive cement bond. These values indicate that at least 90% of the resistance appears at the pin contact. To check the effectiveness of the bonding interface of the sealing surface of the module and the interface of the torqued outer nut to the outside module surface, tests were made on several connectors of available production modules. (AI, ATC, BC, IPC, and PLC.) The combined interface resistances ranged from 0.5 to 0.9 milli-ohms as measured from the exposed shell of each receptacle to the closest, convenient, housing point.

A closer examination eliminated the spot welded and conductive cemented ground methods because of fabrication, sealant or process problems. Soldering appeared to be the most promising, provided the heat did not affect the sealant properties of the molded butyl gasket and that the small ground wire was not affected by vibration. Next, a Deutsch receptacle (DTK-07H-2255PY) identical to production, but with the sealant gasket removed, was drilled at a 45° angle (0.045 "D") at the inner diameter of the shell at 4 points 90° apart. The holes were designed to anchor a solid or stranded 20 ga. wire from the pin solder pot, and to remove the point of heat application as far as practicable from the area of the molded gasket.

Tests were performed to evaluate the proper soldering technique to minimize the maximum temperature that the gasket could tolerate (200°F). It was determined that by applying the 3/8" tip of a 100W. iron to one side of the wire contact area for not longer than 5 seconds, allowing the heat to dissipate for 10-20 seconds, and repeating a 5 second solder process to the other side of the wire contact area, a satisfactory solder bond is obtained, and the maximum temperature measured at the nearest gasket area does not exceed 165°F. Bonding tests thru the pin-socket interface, the wire, and the solder joint to the back of the receptacle shell measured thru the range of 5.5 to 6.5 milli-ohms. These values agree with those obtained on the previous receptacle. The next test involved establishing that these short, soldered, solid and stranded ground wires would survive vibration tests. The vibration tests performed on this receptacle showed excellent results; the variations from static to dynamic resistance under vibration, did not vary more than 10%.

The final investigation in this group was a test performed on a complete production Deutsch receptacle. The receptacle was initially tested for leakage, drilled for ground wires in the same manner as the previous receptacle and then soldered with the same technique described previously. This test item was then re-tested for leakage to ascertain that the sealant properties of the molded gasket were not affected by the solder process. The re-test showed that the seal was unaffected. Bonding measurements made on this receptacle gave the same values as did the previous two receptacles.

The tests demonstrate the feasibility of carrying the shield ground through the pins of a connector receptacle combination. The thru-the-pins resistance of 4 to 6 milli-ohms agree with the vendors published ratings of 25 millivolts at 7.5 amps. test current which is equivalent to 3.3 milli-ohms. Since the Shallcross Bonding Meter 670A uses low currents for measurement the higher values can be considered dry circuitry effects. Assuming a high value (10MA) of

R. F. shield current, 50 microvolts would be developed on the shield for 5 milli-ohms D. C. bonding resistance to structure. Adjacent pickup on sensitive shielded single and twisted pair lines in the calbe should be reduced by a factor of 60DB or better.

It is recommended that on the basis of ease of method, reduced internal lead length, least conflict with environmental problems and effectivity, the method of drilling and soldering a ground wire to the module receptacle shall be adopted.