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EMC CHARACTERISTICS OF GROUNDING NETWORKS AND ELECTRICAL INTERFACES

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EMC CHARACTERISTICS OF GROUNDING NETWORKS AND ELECTRICAL INTERFACES

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ABSTRACT

The grounding concept of aircraft installations is addressed by comparing different schemes whose relevant merits are discussed and examined in detail.
The final proposal is to use the Distributed Single Point Grounding (DSPG) system which suits the flexibility and complexity of modern aircraft.
The adoption of the DSPG system puts in evidence the need of suitable I/O equipment interfaces which shall be designed with a high degree of common mode noise rejection and at the same time sufficiently hardened against the RF external environment.
Some design guidelines are also given to improve the EMC equipment design.

INTRODUCTION

In the development of a new aircraft the selection of the grounding philosophy has always represented a matter of concern to EMC engineers, because of the large number of implications which shall be considered.
The grounding concept may have impact to cost and weight, to wiring and equipment installation, to operational performances and even to testing approach.
The wrong choice of the grounding scheme or the lack of control of its implementation may impair the EMC performances of the equipments and, what is even worse, the EMC characteristics of the overall system.
Many conceptual grounding diagrams may be proposed; but their relevant

merits are related to the electromagnetic environment where the equipments/subsystems are installed and the complexity of their electronic/electrical circuits.
Most people are familiar with grounding requirements only because of the need of protecting personnel, equipment and facilities from lightning strokes and for safety reasons.
Signal grounding is still an obscure principle.
Ideally the signal ground should provide:

-- an equipotential reference plane

-- a return path for signal circuits

-- a low impedance network to control stray capacitance.

While the power ground is clearly defined because related to specific waveforms and frequencies, the signal ground in many cases is not easily identified because it is related to the frequency range of the signals under consideration and therefore may extend from DC to microwave frequencies.
The selection of the signal grounding approach depends on the electrical equipment interfaces.
They represent the most critical keypoint in the control of EMC performances of the system and at the same time the major area of trade off..
Electrical interfaces of which the signal ground is a particular case are the preferable paths through which interference enters the equipment creating malfunctions and degradations.
It is essential to select the right components which are less susceptible to both continuous and transient interference.
Studies have been undertaken for several years to determine the RF and microwave power levels which are sufficient to cause interference or damage in integrated circuits.
This information represents the result of thousands of tests of integrated circuits.
Worst case levels of susceptibility in both digital and linear integrated circuits show that digital circuits are 10 to 20 dB less susceptible than linear ones over the frequency range 100 MHz - 10 GHz.

ELECTRICAL GROUNDING

The general lay-out of an electronic/electrical equipment can be sketched as shown in Fig. 1.
In this diagram different types of grounds are indicated: 1 and 1' are the DC and AC power grounds respectively, 2 is the signal reference ground (SRG), 2' is the virtual signal reference ground of balanced receivers which may be isolated from 2, 3 is the equipment structure ground.

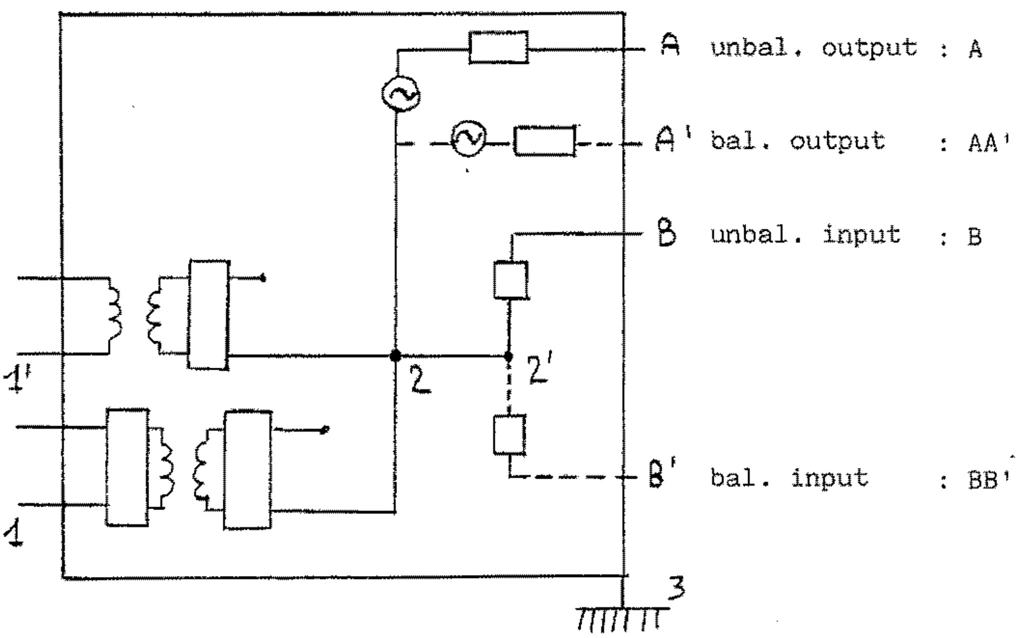


FIG. 1 Grounding diagram

In the past all grounds used to be connected together.
This grounding concept while adequate for simple aircrafts where few electrical equipments were installed is not suitable to meet the performances of sophisticated electrical and electronic equipments installed on board of modern aircrafts especially now that metal structures are substituted by composite materials.

In addition to severe interference problems that solution is in contrast with safety regulations because poses definite personnel hazard if the metal housing of the equipment happens to become electrically energized.
The main concern of signal grounding is related to minimize the potential difference of one part of the system with respect to another part of the system.
Examine the electrical connection between equipment A and equipment B shown in Fig. 2.

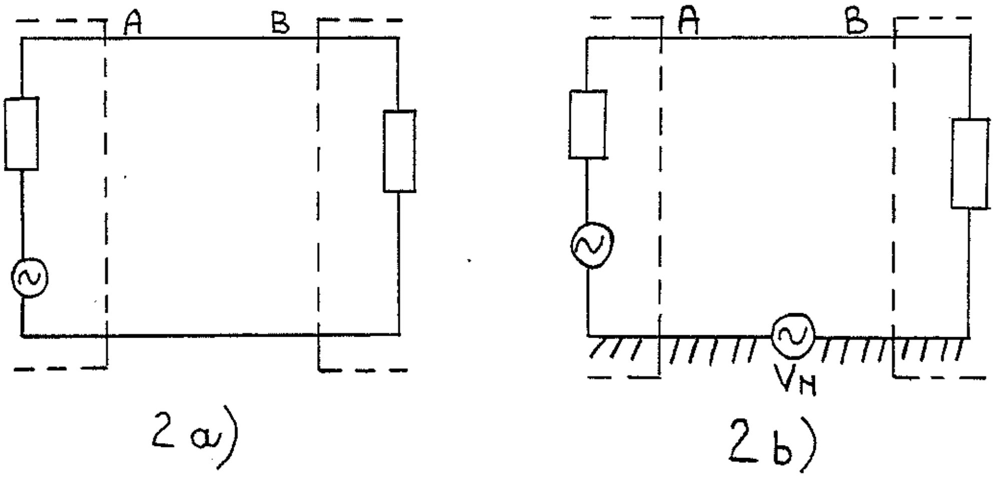


FIG. 2 Electrical connection between two equipments

In Fig. 2a there is the ideal situation where the energy from equipment A is transferred to equipment B in an interference free manner if there is no extraneous voltage induced by capacitive or inductive coupling.
In Fig. 2b the situation is electrically equivalent to the one of Fig. 2a but now the return path 1-2 is through the aircraft structure. This solution offers the advantage of reducing the number of conductors with the remarkable benefit of saving weight; but unfortunately the EMC situation has worsened:

-- the aircraft structure does not represent an ideal good conductor because of joints, bonded junctions, deterioration effects due to aging, use of composite material, corrosion;

-- if all the equipments have their returns through the structure the voltage drop between points 1 and 2 may increase because of common mode noise generated by the return currents and by the stray induced currents due to external sources such as lightning strokes, external and on board transmitters.

Separate returns for AC and DC power grounds are commonly implemented for most equipments; however some problems still exist in case of DC power ground because the separation of the return from the equipment structure can only be achieved by means of DC-DC converters: this solution may be expensive and complex for some simple equipments such as electronic switches or termistor bridges.
The area of major uncertainty is represented by the manner of treating the SRG 2: it may be isolated or connected to the equipment structure ground.
In the former case some problems exist as illustrated in Fig. 3.

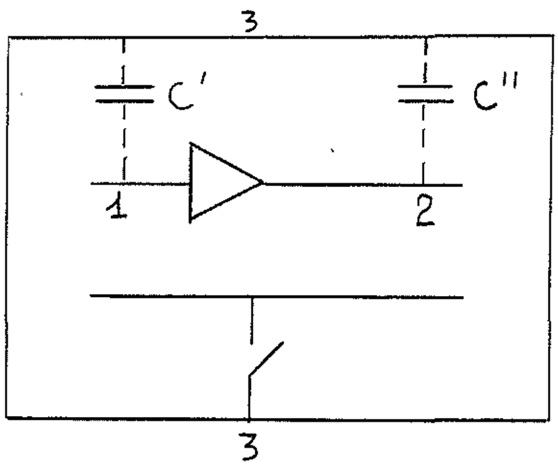


FIG. 3 Possible connection of SRG

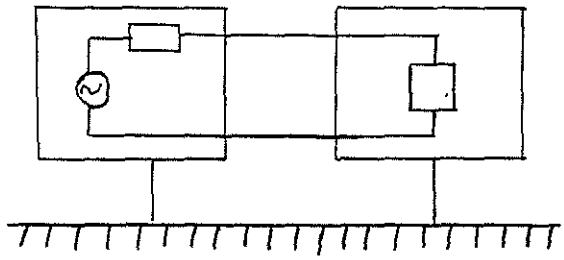
In case the SRG is isolated from the equipment structure the amplifier is bypassed because the signal at the input 1 of the amplifier is connected to the output 2 through the stray capacitance path 1-3-2. By short circuiting 3 to Ø the stray capacitances C' and C" are now in parallel to the input and output terminals of the amplifier and therefore can be compensated out: obviously this problem is frequency dependent and is particularly severe at high frequency.
It appears that the connection of the SRG to the equipment structure ground is essential to minimize unwanted coupling between circuits.
In RF equipments the SRG is connected to the structure ground: in coaxial cables the outer conductor shall always be electrically connected to the equipment case.
The isolation of SRG in the low frequency section of RF equipment can only be achieved by decoupling the audio frequency section from the RF one; in some cases this may be difficult.
In the interconnection of the equipments of a system there are four fundamental ways shown in Fig. 4.
One method is to isolate the SRG from the equipment case at the source and at the load providing the necessary shielding and filtering to avoid unwanted coupling via other means (Fig. 4a).
This is the Floating Grounding (FG) system.
The equipments derive their power from the external source and therefore must have their cases grounded to the fuselage structure to provide adequate fault protection.
The FG system suffers from a number of practical disadvantages:

-- static charge build up on the equipment case may pose shock and spark hazard to the internal circuitry;

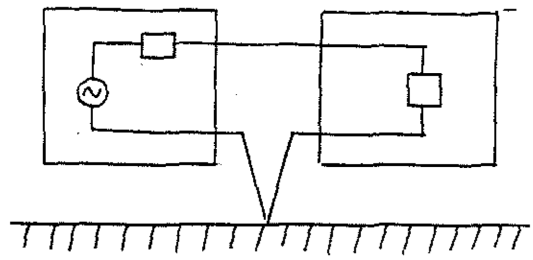
-- it is possible to have the threat of flash over between the equipment case and the internal circuitry in the event of a lightning stroke to the aircraft;

-- a fault in the signal system may rise the equipment case to a hazardous voltage level.

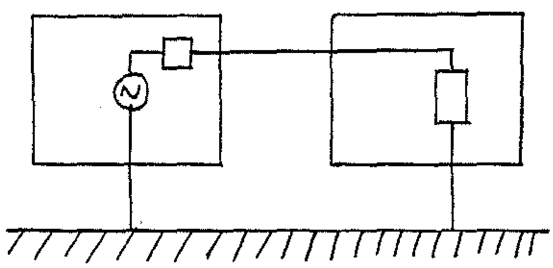
Another grounding scheme is the Single Point Grounding (SPG) system where the SRG of all the equipments is connected to a Central Signal Point Ground (Fig. 4b).



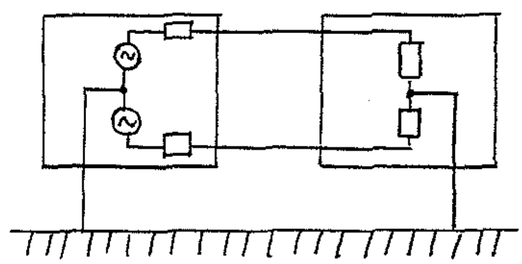
a) Floating Grounding (FG)



b) Single Point Grounding (SPG)



c) Multiple Point Grounding (MPG)



d) Distributed Single Point Grounding (DSPG)

FIG. 4 Grounding Diagram

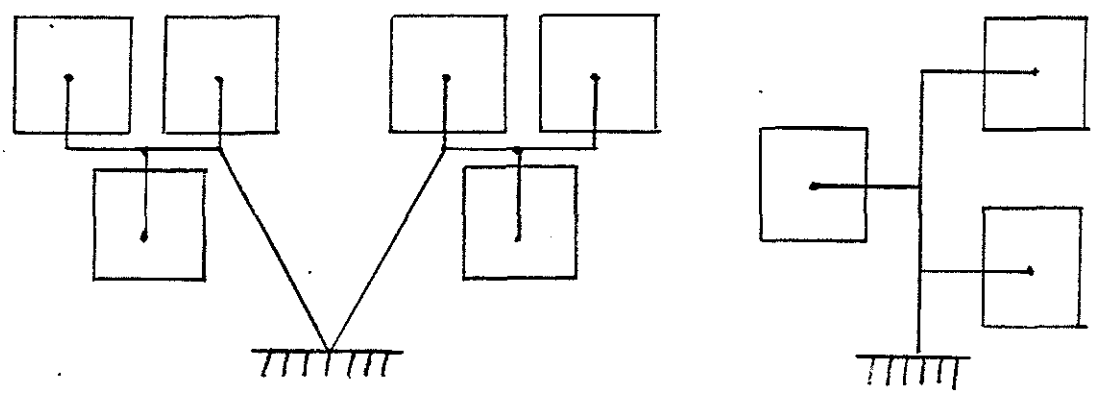
In this manner there is no problem of common mode interference. This type of ground system requires a very large number of conductors and therefore is not feasible mainly because of weight implications. This ideal configuration is not practical and therefore is approximated by two different schemes (Fig. 5): star system and tree system. In the former configuration principal single point grounds are identified within different subsystems and are then connected to the main Single Point Ground.
In the latter configuration the ground network assumes the form of a tree to which the various equipment SRG's are connected.

The main drawbacks of the SPG grounding scheme are:

-- the difficulty of implementing the isolation between the SRG and the case within RF equipments in conjunction with the increase of stray capacitance coupling;

-- the reduction of the shielding effectiveness of equipment cases due to the grounding wire penetrating the equipment structure and therefore violating the metallic barrier. This is particularly detrimental for systems where the EMP protection is required.

The third grounding scheme is the Multiple Point Grounding (MPG) system where the SRG is directly connected to the equipment structure ground (Fig. 4c).
The common mode noise represents the greatest problem; the reduction of this type of interference is obtained by striving for a zero impedance reference plane.
If a truly zero impedance ground plane could be built, it could be used as the return path for all currents (power, signal and RF). Unfortunately the aircraft fuselage structure is far away from an ideal zero impedance plane.
The most conventional approach is to utilize a network of dedicated aircraft structural parts (longerous, bars and so on) interconnected to provide several paths between any two points within the system.



a) Star system b) Tree system

FIG. 5 Different schemes of PSG

The advantages of the MPG system are:

-- to make the RF equipment design easier because within the equipment the case offers a ground plane better than any wire and to avoid complex decoupling systems;

-- to improve the shielding effectiveness of the equipment because the metallic barrier of the case is not violated;

-- to eliminate spurious capacitive coupling.

Despite the equipment design simplification the MPG system is critical from the system point of view because it may be strongly affected by common mode noise: stray currents in the fault protection system when the equipment operating frequency range extends down into the low frequency range.
The last grounding scheme is the Distributed Single Point Grounding (DSPG) system where the SRG is connected to the equipment structure ground but the input and output interfaces are differential balanced circuits with high levels of Common Mode Rejection Radio (CMRR) (Fig. 4d).
This grounding method is probably the best one because it combines the advantes of SPG and MPG systems.
In order to have a high CMRR it is necessary to have a true balanced system at the source, at the load and along the connecting line: the impedances along the two wires of the transmission path shall be perfectly equal.
Sometimes because of specific circuital reasons the balanced transmitter cannot be used; in this case a single ended source is acceptable as long as the receiver is balanced with a high input impedance (pseudo balanced system).
The interface wires shall be twisted and shielded to prevent magnetic and electric couplings.
Twisting reduces the cross sectional area of the loop formed by the conductors and therefore reduces the inductive coupling; shielding reduces the capacitive coupling.
The balanced interfaces required by the DSPG system increase the number of wires and the circuit complexity; on the other hand modern

transmisssion systems such as those specified by MIL-STD-1553B and ARINC 429 which are currently used on modern aircrafts are already in line with this interfacing philosophy.
In the development of a new aircraft it may happen that some equipments have different grounding systems because either of old design or procured under a separate contract which specifies a different type of grounding network.
The EMC engineer is faced with such a complex situation that it may be difficult to establish a proper common grounding philosophy. The hybrid approach shall be adopted which consists in a compromise between old design equipment and the new equipments which shall be designed to fit the different grounding schemes.
In this case which represents the majority of the situations the DSPG system represents the most suitable approach because it can be connected to the other grounding networks without too many detrimental effects (assuming that there is a certain freedom in the installation of the equipments).

ELECTRICAL INTERFACES

As it has been stated in the previous paragraph the DSPG system is mainly based upon suitable interfaces between the equipments: the basic components are the isolation amplifier and the differential amplifier.
The isolation amplifier is a device which provides ohmic isolation between the input and the output.
It is characterized in terms of isolation impedance between the input and output common terminals.
It has an input circuit that is galvanically isolated from the power supply and output circuit.
Isolators are particularly suitable for applications requiring safe accurate measurement of DC and low frequency voltage in the presence of high common mode voltage (thousands of volts).
It may be necessary to use a dual isolated DC/DC converter which provides two ground connections.
One ground is isolated from the equipment case, the other is connected to SRG which in turn is connected to the equipment structure ground.
Proper shielding of input leads is necessary to the ground isolated

from the equipment case.
The differential amplifier is a device which responds only to the difference voltage between inputs and produces no output for a common mode voltage.
Both components are characterised in terms of the Common Mode Rejection Radio (CMRR) which is defined as the signal attenuation between the shorted input and the shorted output when the input is measured between the shorted input and a ground reference and the output is measured between the shorted output and the same ground reference.
Operational amplifiers are susceptible to RF energy conducted into either of the input terminals.
When stimulated in this manner the interference effect is an offset voltage at the particular input terminal entered by the RF: this offset voltage may be either a DC level or an undesired low frequency response due to demodulation effects.
The magnitude of the offset voltage depends on such factors as the power level,frequency equivalent RF source impedance and the op. amplifier input circuit.
Demodulation RFI effects are greated in operational amplifiers with bipolar input transistors (741 and LM10) than they are in operational amplifiers with MOSFET input transistors (CA081) and with JFET input transistors (LF355).
At RF frequencies above 10 MHz demodulation RFI effects in the 741 op amplifier are significantly greater than in the LM10 op, amplifier. This is possibly a result of the cutoff frequency of the npn bipolar input transistors in the 741 op.amplifier being higher than the cutoff frequency of the less conventional (pnp substrate) bipolar input transistors in the LM10 op.amplifier.
Improvement in operational amplifier performances with regard to rejection of RFI demodulation effects can be obtained by means of suppression capacitors in the feedback path.
An example is shown in Fig. 6.
Curve I represents the DC shift as a function of frequency of the original circuit ($C_1 = C_2 = 0$).
The suppression capacitor C_2 is chosen so that the circuit bandwidth is limited by R_2C_2; C_1 is chosen with the condition $R_1C_1= R_2C_2$ in order to ensure circuit stability.

Line receivers are significantly more susceptible than line drivers (7dB or more): susceptibility is defined in terms of changes in the input voltage threshold which determines the receiver switch point.
A problem created by the threshold variation is a percent jitter change of the signal at the receiver output.
However this difficulty does really exist for the data bus rates and line lenghts involved in aircraft installations.
The data bus specified by MIL-STD-1553B is well characterized from the EMC point of view.

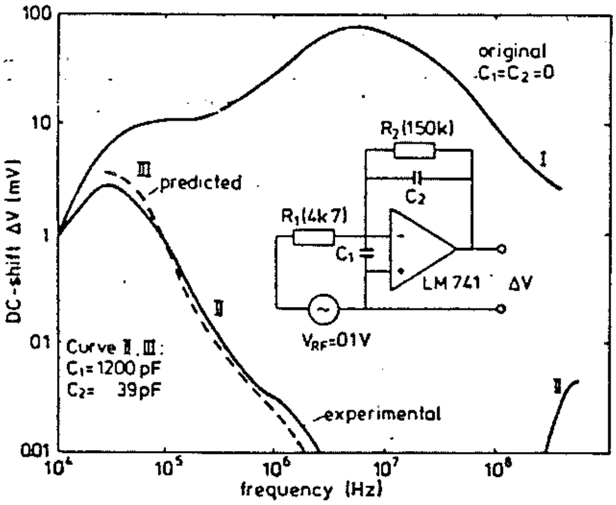


FIG. 6 DC shift as a function of frequency

The transformer coupling solution (Fig. 7) represents the best approach because the coupling transformer improves the common mode rejection of the overall transmission system.
The CMR of the coupling transformer is required to be greater than 45dB: it can be improved by minimizing the interwinding capacitance and the core to winding capacitance.
Interwinding and core to winding capacitance may be reduced by reducing the total number of turns on the core.
This requires the use of a high permeability material.
From tests performed on a 1553B data bus it appears that the ground connection of the coupling transformer center tap may be critical: it shall be connected to the equipment structure only at the transceiver end as shown in Fig. 7.
The susceptibility level of the data bus system is specified as additive Gaussian noise distributed over a bandwidth 1.0 KHz to 4.0 MHz at an RMS value of 140 mV injected at point A of Fig. 7.
The frequency range should be extended at least up to 1 GHz.
Differential receivers are available with a minimum CMR of 40 dB up to 2 MHz.
The ARINC 429 data link (Fig. 8) is not well characterized as MIL-STD-1553B data bus from the EMC point of view.

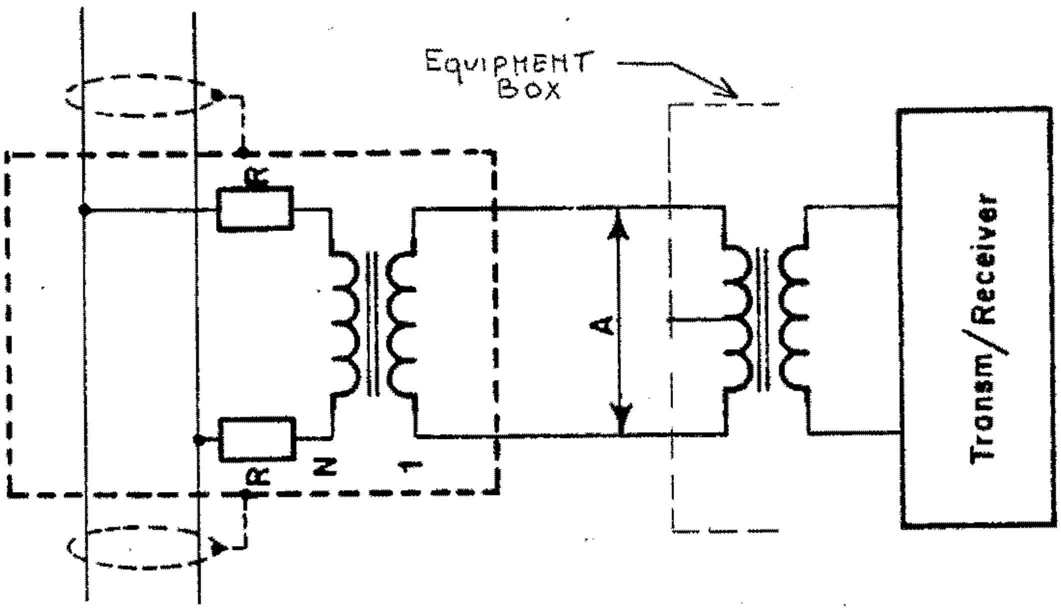


FIG. 7 MIL-STD-1553B interface (transformer coupling)

It is not a data bus but it is a point to point connection; therefore it may present fewer problems.
The transmission shall be fully balanced especially at the transmitter end; no current return on the wire screen is permitted.
Differential receivers are available with a minimum CMR of 60 dB up to 1 MHz.

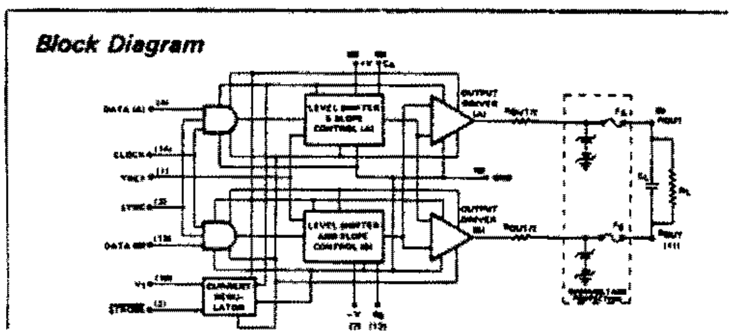


FIG. 8 ARINC 429 Transmission System

The DSPG system requires the balanced transmission for each interface which means to have two wires at each input and output of the equipment; some problems may come out because of the large number of wires which are necessary to meet this requirement.
Obviously a compromise shall be achieved in order to avoid weight and space implications.
It is up to the EMC engineer to decide where the DSPG system philosophy shall be tightly followed and where concessions can be granted: for example in case of discrete signals of low priority or importance one may grant to have a common return for many signal wires.

CONCLUSION

Different approaches to grounding philosophy for aircraft installation have been examined.
The conclusion is that the DSPG system appears to be the most flexible and suitable to meet both the hybrid solution and the specifications of new data transmission systems.
The electrical components of the I/O interfaces shall be chosen in such a manner to reduce the RFI threat of the external environment.

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