GETTING A PERSPECTIVE ON NOISE IN AUDIO SYSTEMS

by Philip Giddings, P.Eng.

Philip operates an independent audio system design and project management firm called **Engineering Harmonics Inc.** in Toronto. This article was originally written on July 30, 1991. This version is © Philip Giddings 1995, and was modified last on Feb. 15, 1996.

The complexity of audio systems continues to grow. Consoles get larger with more inputs and outputs, use of signal processing increases, loudspeaker systems grow and use more power, multi-channel wireless microphone use is standard in even the smallest productions, MIDI, PA422, ATR machine control and other control technologies abound. In short there is more and more signal and control interconnection and the subsequent possibility of noise entering systems.

Despite increased system sophistication there exists, at least on some fronts, a vacuum within the industry on how to ensure that systems integrate and function as a system in a reliable and noise free way. When there are ongoing system problems there is generally little consensus on just where things have gone astray. In many cases, operators and users of systems have become so familiar with the inadequacies of the interconnections scheme and the resultant noise and interference that they ignore or work around interface problems without complaining about it. They've concluded that "this is just the way it is". In really unfortunate cases the operators lose confidence in the system and coming to work each day promises them butterflies in their stomachs.

There are a couple of key circumstances at work here.

1. Equipment manufacturers continue to design incredibly sophisticated equipment which suffers from simplistic thinking in the systems design department. Witness unbalanced inserts and other key outputs, such as monitor out, on at least one top of the line console; high impedance unbalanced outputs from leading signal processing manufacturers; unbalanced outputs on multi-channel digital tape recorders - and a host of other glaring examples.
2. System designers and operators contribute by actions such as, lifting the equipment (safety) ground to audio equipment and providing it with either no ground at all or a ground reference through the interconnecting signal cable shield. This strategy, while it may work in some situations, is not the choice solution technically and certainly is not responsible from a life safety standpoint. System grounding solutions like this can result from a simple lack of planning, preparation, knowledge or desire to do it right.

The obstacles in building and maintaining audio systems which are noise free and reliable can be summarized as follows:

1. equipment manufactures are not sensitive to the difficulties of systems interconnection and continue to build EMI sensitive equipment, and user continue to purchase this equipment,
2. many audio systems are built with little or no actual design in the grounding and interconnection department, being simply lashed together or where there is design it is ill-conceived,
3. as a result of the first two items the systems operator may, in an effort to reduce a specific hum problem for example, make changes to the systems wiring (generally ground or shield lifting) with little understanding, or even concern for overall system effects. This resulting lack of consistency within the system can make debugging chronic and other system configurations EMI prone.

There are many reasons for this lack of planning and foresight on the part of equipment manufacturer and system builders and designers. In short it is a statement about the audio industries' inability to standardize on some basic issues. Some time in the future all interconnection will be fibre optic and EMI will be a thing of the past. Until that time system designers and users will be cursed with the inadequacies of our present interconnection systems, be they analog or digital, and time and energy must be spent to get the best performance from our systems.

The remaining portion of this article provides background on where, when and why electromagnetic interference (EMI) noise enters or audio systems. This should be helpful in getting the best performance and value from your audio system.

What is Noise in Audio Systems

Noise is any unwanted signal which gets into the audio signal path and is transmitted though the system. In the case of systems which use electrical signals, as opposed to technologies such as fibre optics, this noise is called electromagnetic interference (EMI). As the name implies it is due to electric or magnetic energy. EMI manifests itself in audio as hums, buzzes, whistles, signal distortion or cross talk, to name a few.

Where it Comes From

EMI can come from anything which uses electricity to operate, as this results in voltages and current and the associated electric and magnetic fields. While all electrical equipment generates EMI, in most case it is too weak or of a nature as not to be detrimental to audio equipment. Typical electrical equipment which can be a problem includes: high power RF transmitters, low power nearby RF transmitters, large motors and other heavy industrial equipment with switched inductive loads, lighting dimmers or other equipment which chops or switches the AC sine wave.

High voltage devices or RF transmitters which are some distance away create electric fields while high current devices create magnetic fields. Magnetic fields only pose a concern when nearby.

How It Travels

EMI travels in one of two ways: through the air or through conductive wires. In many cases a combination of these two means exist. For example, dimmer lighting circuits run in a building containing chopped sine waves may radiate energy which is picked up through the air by a guitar pick-up or cable.

EMI can travel as electric or magnetic fields or a combination of both.

Electric fields create voltages in the circuits they strike. In fact the coupling between an electric field source and a victim circuit can be modeled as a capacitor between two wires: the coupling improves as the wires get close together, have greater common area and as the exciting frequency goes up.

Magnetic fields create current in the circuits they strike. In order for the current to flow there must be a loop for this circulating current. The magnetic field may strike the loop in only one place, such as a ground conductor or one conductor of a balanced line. (In this latter case the loop consists of the source output, one of the balanced conductors, the driven input and the other balanced conductor.) The coupling between a magnetic field source and a victim circuit can be modeled as the mutual inductance between loops of wire: the coupling improves as the wires get closer together, have more turns of wire or a greater loop area, or as the exciting frequency goes up.

As both electric and magnetic coupling increases with frequency, chopped sine wave AC power, which contains frequencies much higher then 60 Hz, will be a greater EMI threat.

How It Enters Audio Equipment and What Its Effects Are

While it is possible for EMI to enter a piece of equipment through the air and be picked up by the circuits within the equipment, this is rare. (This could occur with a walkie-talkie being used beside a console, for example) It more commonly enters the equipment via the AC power cord or the interconnecting signal or control wire connected to it. In other words, EMI on the power or ground lines may travel down the line and into the equipment power supply or airborne EMI picked up in signal or control wiring may enter the equipment through the inputs and outputs.

The input and output impedance of the interconnecting circuitry will influence its EMI immunity. Circuits which are below 600 ohms tend to be affected by magnetic fields while those above 10,000 ohms tend to be affected by electric fields. Those in between these two impedances may be affected by either.

The electric signals which are transmitted between two pieces of equipment are referenced to the ground of the output circuitry. EMI, which is present everywhere in a facility, may create current and voltages on the ground reference system. If the input circuitry is not referenced to the same ground potential this creates a noise voltage at the input. If the system is balanced it will be able to reject this common mode ground reference noise up to a frequency where the input is well balanced (Note that common mode rejection ratios fall off with rising frequency).

If an interconnect is not well balanced it is also possible to have common-mode to differential- mode conversion. This occurs when the impedance to ground of both sides of the balanced line are not exactly equal and the signal on one side is partially shorted to ground or impeded and hence a differential exists. A common-mode signal is thus converted to some extent to a differential-mode and passes through the balanced input.

Unbalanced interconnects having no ability to reject common mode noise are vastly inferior in their EMI immunity.

Once in the equipment the EMI creates voltages or current which mix with the audio or control signals and become noise.

It is also possible for EMI signals which are well above the audio band (20 kHz) to be inadvertently demodulated down in frequency, in a manner similar to a radio receiver, and hence become a problem in the audio band. Also, out-of-band EMI signals can be so strong as to overdrive inputs and result in distortion of the in-band audio signal.

The Basic Means of Controlling EMI

There are only three ways of controlling EMI: reduce or eliminate it at the source; remove or reduce the effectiveness of the path over which it travels; make the victim more immune to the EMI. There are only a limited number of ways of realizing each of these. Choosing the most appropriate means or combination of means and the optimal location for these may make the difference between a short term fix and one which withstands the test of time.

Controlling the Different Types of EMI

Reading the text books on Electromagnetic Interference reveals that there are only a few well known ways of controlling EMI. These are:

- Shielding
- Grounding and Bonding
- Balancing and Twisting
- Separation and Routing
- Isolation.

These are all means which are under the control, to some extent, of the system designer. Other EMI controls such as circuit impedance and configuration, and internal RF filtering, are the province of electronic equipment design and are only under the control of the system designer to the extent that s/he may choose or not choose to use certain equipment. (Most equipment however is often chosen on the basis of operational facilities, not on the basis of EMI immunity.)

Shielding

Shielding is placing a conductor in the path of an impinging EMI field.

Stated simply, shielding controls electric fields. In general, when an electric field strikes a shield which is grounded the voltage which the field tries to create is drained away to ground and does not affect the conductors on the protected side of the shield. Shielding can be done anywhere, but is normally done close to the source of the noise or the device affected by the noise.

Shielding has little or no effect on magnetic fields except where the shield is very thick (2 mm) or made of high permittivity material such as Mu-metal.

In order for a shield to be effective it must be a good conductor, be well grounded, and have no discontinuities, such as openings or slots, in its surface.

For these reasons foil shields are generally the best, with some foil shielded cables being better then others depending on the details of how it is made and the conductivity (thickness) of the aluminum foil.

Grounding and Bonding

In audio, technical grounding is connecting a circuit or a shield to the earth using a dedicated conductor. Bonding is connecting various elements of a system together, using low impedance conductors so that they are at the same electrical reference voltage - it is a reference common.

Grounding allows shields to work by draining away potentials. Grounding and bonding means that any equipment which is referenced to it is at a similar and likely stable, reference. Thus ground reference noise will not enter the system.

In order for grounding and bonding to work well it must connect all equipment in a system together with a low noise and low impedance ground network which ultimate terminates to the earth. The connection to the earth should also be of low impedance. In order for the system to be low noise it is normally made of insulated conductors so that it is not shorted to other noise containing ground systems. In order for it to be low impedance heavy gauge conductors are used. They should be as short and straight as possible to minimize impedance. In critical designs braid or foil are used as ground conductors, as these have lower impedance at high frequencies.

Balancing and Twisting

Balanced interconnecting wiring is an in-polarity and an out-of-polarity voltage pair which form a differential signal. This distinguishes them from unbalanced (single-ended) circuits which do not have an out-of-polarity signal. Balanced inputs and outputs can be active electronics or transformers. Twisting is applied to a pair of wires which carry a differential signal. If these wires are twisted the input/wiring/output circuit will be better balanced and less prone to EMI.

Most electric noise picked up on twisted pair - be it shielded or not - is common-mode. As common-mode signals do not pass through while balanced (differential) input and differential mode signals do, this is a very powerful means of controlling EMI.

Magnetic pick-up does not occur on twisted pair wire because the current created in each successive loop (twist of wire) are in the opposite direction and cancel. Another way to visualize this is that the loop area of a twisted wire is zero and so there is no loop to pick-up the magnetic field. Consequently twisting balanced lines is the most effective and efficient way to control magnetic EMI.

Note that magnetic EMI sources (such as high power wiring and transformers) must, in most cases, be within a few meters of the victim receiver to be a threat, whereas electric EMI can be many miles away, such as the case of high power RF transmitters.

Separation and Routing

This method of EMI control consists of locating and running sensitive wiring and equipment in a way which maximizes the distance to EMI sources.

As mentioned earlier, EMI field strength diminishes with distance. Generally, the field will be reduced by about 6 dB for each doubling in separation. The importance of the initial separation (the first 10 cm) cannot be overstated.

In most cases it costs nothing to obtain good separation and routing, only good planning and implementation.

Isolation

Isolation is the use of some intermediate interconnection device, such as an optical isolator or transformer, which eliminates a hard wired connection between the output and the input. This will eliminate the possibility of any and all ground related noise inputs. For this reason, transformers are indispensable when it comes to EMI immunity in harsh environments.

Using this Information

In considering how to best use this information, review your interconnect hardware based on the following table and adjust your design appropriately. This table has been assembled in an attempt to quantify the information contained in this article and the references.

Your probability for success based on the score are as follows:

- 10 or more — excellent
- 5 or more — good
- 0 — questionable
- -5 — poor
- -10 or less — futile

1. Does the system have a dedicated technical ground system?

- yes — 3 points
- no — -3 points

2. Does the system have a dedicated technical power system or a source of clean power?

- yes — 2 points
- no — -2 points

3. Is the interconnect balanced?

- yes actively — 3 points
- yes with a transformer — 6 points
- no — -6 points

4. Is the interconnect low impedance?

- yes — 2 points
- no — -1 points

5. What is the nominal interconnect level?

- low (-60 dBv) — -2 points
- medium (-20 dBv) — 0 points

- high (+4 dBv) 2 points

6. Is the cable shielded?

   for high impedance interconnect (greater than 1k ohm):

- Foil 4 points
- Braid 1 point
- none -4 points

   for low impedance interconnect (less than 1K ohm):

- Foil 2 points
- Braid 2 points
- none -2 points

7. Is the cable twisted?

- 1 or more twist per inch 2 points
- less than 1 twist per inch 1 point
- no -4 points

8. What is the surrounding EMI environment?
   NOTE: A very hostile environment would be one with considerable dimmed lighting, nearby high power RF transmitters or nearby heavy industry.

- Very hostile -10 points
- Hostile -5 points
- Average 0 points
- Mild 5 points

9. What is the system's dynamic range?

- less than 60 dB 2 points
- around 75 dB 0 points
- greater than 90 dB -2 points

10. What is the length of the interconnect?

	Balanced	Balanced & low imp	Unbalanced not low imp
less than 20 feet	2	2	-1
around 20 - 50 feet	0	0	-2
greater than 50 feet	4	0	-4

11. Have separation and routing been used to advantage?

- yes 2 points
- no -1 points

While this table maybe an over simplification I believe it will predict EMI potential for most typical audio systems found today. With the results from the table combined with some common sense tempering, that is hopefully provided by the remainder of this article, I hope it will prove to be a useful and practical tool in evaluating EMI considerations in audio.

Readers wanting more in-depth information on this subject may refer to the following:

Giddings, P.: "Audio Systems Design and Installation" H W Sams and Company, Indianapolis IN, 1990

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