Considerations in Grounding and Shielding Computer-Controlled Audio Devices

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Adding computer control to audio devices raises design issues, such as electromagnetic emissions tests, digital power and grounding systems, shielding and filtering schemes. This paper describes the emissions test process and reviews product design methods, such as proper grounding, shielding and filtering, which are shown to improve product and system performance both in emissions testing and in the field.

Introduction

Computer controlled audio is new ground for many designers and users. New territories such as computer platforms and the good and bad realities of graphical user interfaces are one hurdle to overcome, electromagnetic interference (EMI) issues are another. Many audio equipment designers have little high frequency (megahertz and above) design experience. Adding computer control to any audio device involves using microprocessors to control the device's parameters. Inherent in microprocessor systems is the use of a system clock, the heartbeat of all microprocessors. U.S. government regulations require any device with a clock above 9 kHz to pass electromagnetic compliance (EMC) tests. Other countries have similar requirements. The purpose of these tests is to control electromagnetic pollution by setting standards for unlicensed electronic equipment [1]. In order to pass these government regulations, designers are faced with new challenges over and above the already daunting task of keeping computer controlled audio quiet.

Compliance

Most countries require safety and electromagnetic compatibility tests on electronic equipment. In the United States, Underwriter's Laboratories (UL) 813 requires professional audio equipment operating above 42.4 volts peak to pass its safety tests. Safety organizations in other countries require similar tests. CSA in Canada and the document IEC 65 in the European Union (EU) countries cover similar safety issues. This paper discusses another arena of device testing covering electromagnetic compatibility testing. Similar to safety agency approval, the Federal Communications Commission (FCC) in the US, requires tests on products that contain an oscillator clock operating above 9 kilohertz. The FCC segregates devices into three categories: intentional radiators, unintentional radiators and incidental radiators. Intentional radiators emit radio frequency (RF) energy by design, through "radiation or induction." An unintentional radiator is defined as a device that "intentionally generate(s) radio frequency energy for use within the device, or that send(s) radio frequency signals by conduction to associated equipment... but which is not intended to emit RF energy by radiation or induction." Incidental radiators include DC motors or mechanical switches that generate RF during operation, although they are not intentionally designed to do so.

Part 15 section B of the FCC rules applies to most computer controlled audio equipment which usually fall under devices considered "unintentional radiators." The approval tests are grouped into two classes or compliance levels. Class A approval covers devices designed for use *exclusively* in business or industrial environments. Less stringent Class B approval covers devices intended for use in homes. Note that devices designed for use in a business or a home are considered Class B devices. Special product labeling and user information requirements are also dictated in Part 15.

The FCC requires testing both conducted and radiated emissions. Conducted emissions through the line cord and I/O cables are tested separately than the radiated emissions that travel through the air.

Independent testing facilities are located throughout the U.S. For those new to FCC testing, shopping for a reliable testing facility combined with staff with clear communication abilities is invaluable. Finding a test facility that encourages participation in the testing process can save hundreds of troubleshooting hours and provides hands-on education with specific product problems. The average cost for testing facilities is approximately $150 per hour. An "average" device may take a full day to fully test, though as few as 4 hours can be expected for devices that require no alterations to pass the required tests. If the device fails, the tests can take considerably longer.

Part 68 of the FCC rules requires registration of equipment connecting to the telephone communications network. Equipment which contains a modem or a telephone input or output may fall into this category.

For imported equipment, the FCC holds the importer responsible for compliance with its requirements. This is also true in the European Union countries.

Other countries have similar EMC requirements. Industry Canada covers Canada. The EU has similar requirements contained in its EMC Directive, 89/336/EEC. [The European Union countries include Belgium, Denmark, France, Germany, Great Britain, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal and Spain. Others countries considering joining the EU include Austria, Czech Republic, Finland, Hungary, Norway, Poland, Slovakia, Sweden and Turkey.]

A not-so-subtle difference between FCC and EU testing involves the EU requirement to also undergo *immunity* tests. These tests classify equipment into various performance degradation levels with regard to the devices ability to reject external EMI and still continue to operate as designed. Many EU standards are still being refined and are expected to be continually updated as technologies change. The EU's EMC Directive is designed to allow manufacturers to self test their equipment. Equipment must be marked with the "CE marking" and a Declaration of Conformity must be prepared.

An excellent source for further information on all of these compliance issues is Compliance Engineering magazine (See the Bibliography).

Design Methods to Achieve Compliance

There are at least two methods that reduce the radiation from a clocked device. The first is shielding. Surround the device and its cables with a conductive shield. (Where and how to properly connect this shield is covered later.) The second method is to reduce the radiation at its source. Removing the clock is the most obvious way to reduce emissions. Doing so during emissions testing is more educational than one might think, Reducing the source of the emission can reduce or eliminate the need for shielding. More important, however, is the fact that reducing the radiation source also improves a device's noise and immunity performance.

Let's examine how radiated emissions occur in a printed circuit board (PCB). The clock is a significant source of the radiation. Every transition of the clock, from high to low and vice versa, creates sharp transients in the power supply rails, in both the power and the ground. The inductance in these power and ground traces along with the power and ground transients cause radio frequency potentials to develop. The traces literally act as antennas. Since the traces act as antennas and the input and output (I/O) cables can be connected to them, the I/O cables also act as antennas. Similar to removing the clock, removing the I/O cables is also quite educational during emissions testing.

The example in Figure 1 shows the problem [2]. Here, two inverters hooked to the same supply rails are shown. The first inverter drives an internal circuit while the second drives an output cable. The first inverter might be the clock buffer, the second might be a computer control cable. A typical PCB trace inductance is approximately 20nH per inch. At l00 MHz, an inch long trace between the two inverters would be 12.5 ohms.

$$Z = 2 \pi f L \text{ (ohms)} \qquad \text{[Eq 1]}$$

Even if the second inverter is not being toggled, the voltage introduced by the first inverter causes the output rails, and therefore the output signal to modulate with the clocked signal. This common mode energy on the supply rails is independent of the signal driving the second inverter. The common mode voltage can be 200 millivolts and can produce radiated signals many times the acceptable FCC limits.

It is seen from Equation 1 that two methods exist for reducing this common mode voltage build-up on the power supply rails. Either reduce the frequency (or amplitude) of the radiation source (f) or reduce the inductance (L) of the circuit by keeping the traces short. Note that reducing the circuit's inductance also entails keeping the loop area of both supply rails, as well as the rest of the circuit, small.

Simply using wider traces does little to reduce a trace's inductance. Much more effective is to use a grid pattern which provides many parallel conductors between points. A ground or power plane is the ultimate version of a gridded trace pattern. Figure 2 [3] clearly illustrates the relationship between loop area and trace inductance. The PCB in figure 2a shows a common power and ground layout scheme. This configuration suffers from large current loops (and therefore large loops areas), high power and ground inductance, and high noise. Adding bypass capacitors next to each IC (Figure 2b) reduces the loops area and inductance. Running the traces beneath the ICs (Figure 2c) reduces the loop area, inductance and noise even more. Adding cross-ties (Figure 2d) on another layer creates a gridded trace pattern providing small loop area and very low inductance and noise. The power and ground scheme of Figure 2d can be shown to have one-sixth the inductance, and therefore one-sixth the noise, of the scheme in Figure 2a.

Another subtle practice involves making smooth transitions when bending traces. Sharp comers (90") change the inductance of the trace. Limiting bends to 45° or using curved traces keeps the trace inductance nearly constant from DC to several gigahertz.

Bypassing

As was seen in the above example, careful power supply bypassing reduces the loop area and inductance of a circuit. When a logic gate toggles, current flows between the supply rails and the load. Placing a decoupling capacitor close to the IC allows the high frequency currents to flow in the shorter loop area through the capacitor, thus reducing the high frequency emission (See Figure 3).

Selecting the proper capacitor for the bypassing function is also important. The capacitors used should have low impedance and inductance at the frequencies of interest. The construction of electrolytic and most mylar capacitors is unsuitable for bypassing since their rolled structure affords them high impedance. Ceramic disk capacitors have much more desirable decoupling characteristics. The capacitor leads have more inductance than the actual capacitor. Keeping the leads short helps keep the inductance low.

Reducing Clock Emissions

Do not over-design your clock. Clocks are usually designed to provide fast rise and fall times which improves system synchronization accuracy. Unfortunately fast rise and fall times provide added EM1 radiation. Prepackaged oscillators are designed for fast transition times and high fan-out. Unfortunately, these convenient packages can come with more EM1 than necessary. Changing to a different supplier can drastically change the EM1 characteristics of these packages. Often a simple inverter with a discrete crystal based oscillator circuit provides the designer with a better solution for EM1 control.

Filtering

Applying filters on specific high frequency outputs can reduce emissions. Damping resistors (20 to 50 ohms), ferrite beads and small inductors placed in series with and close to the source of high frequency lines help control emissions. Ferrite beads have very small DC resistance and act as resistors at high frequencies providing smooth high frequency roll off. Beads come in many shapes and sizes. Multiple “turn” beads can be chosen for desired cutoff frequencies. Inductors should be carefully chosen to provide roll off of high frequencies, without compromising the desired frequencies needed for proper circuit operation.

Loading clock signals with bypass capacitors can help reduce high frequency ringing that may be present in clock, thus reducing emissions. Care should be taken to ensure that this practice does not increase the emissions at frequencies beyond the bandwidth of the oscilloscope one may use to verify reduced clock overshoot. This practice works better on high source impedance components, thus forming a desirable RC network.

Cable Emissions

Due to the high frequency common mode signals present on the power supply rails (as seen above Figure l), the I/O cables and the line cord act as RF antennas. The antenna’s resonant frequency can be changed simply by moving or twisting the cable. This is quite a new concept for audio designers. Simply moving a cable changes the entire frequency response of the system. Just as above with PCB design, the radiation of the cables can be controlled through shielding, filtering and bypassing. Bypassing the I/O conductors to ground shunts the high frequency energy and reduces emissions. The important issue is which ground do you bypass to? Bypassing to the PCB’s digital ground may make the emission worse. Remember, the digital power and ground are the source of the emissions in the first place. The best (and only) ground that reduces emissions is earth ground. In audio products with a three pin line cord, it is no coincidence that the unit’s chassis is required to connect to the “earthed” green wire. The proper ground to bypass I/O cables to is chassis ground. However, even a few inches of trace length from the I/O to chassis ground will render our bypass capacitor useless since the trace inductance quickly swamps the capacitor’s effectiveness. Usually the connection to earth involves a long wire whose inductance may not permit reduced emissions to acceptable levels.

Another alternative is to create a “local earth.” This is done by either introducing a large metal surface capable of absorbing the charge without changing potential significantly or by using a shield around the cable.

Shielding

If reducing the source of the emissions does not provide adequate EM1 reduction, shielding becomes the next alternative. Shields simply block electric fields and are only as good as the “local earth’ ground they are connected to. Just like bypassing I/O, shielding I/O requires effective and short connections to chassis ground to keep emissions under control. Again, even a trace of a few inches may render the RF shielding inadequate. This requirement for short connections from I/O cables to the chassis is a new problem for some audio manufacturers. (See [4] for further information on effective shield grounding) Typically metal chassis act as a “local earth” and as the case shield due to their large charge capacity.

Summary

Careful attention to these PCB design issues early in the product design stage saves a great deal of time and money on EM1 control later. High frequency traces and the components driving them need special attention in the PCB design process. Power supplies for these components should be local bypassed, gridded and high frequency outputs should be damped or filtered as needed. All high frequency traces should be kept as short as possible and should be clustered together. Keep the cluster well away from the I/O area.

Conclusion

A review of the electromagnetic interference testing process was covered. Product design methods to achieve compliance with these required tests were also covered. Early understanding of these new requirements for equipment design and distribution are key elements in the evolving computer controlled audio field.

References

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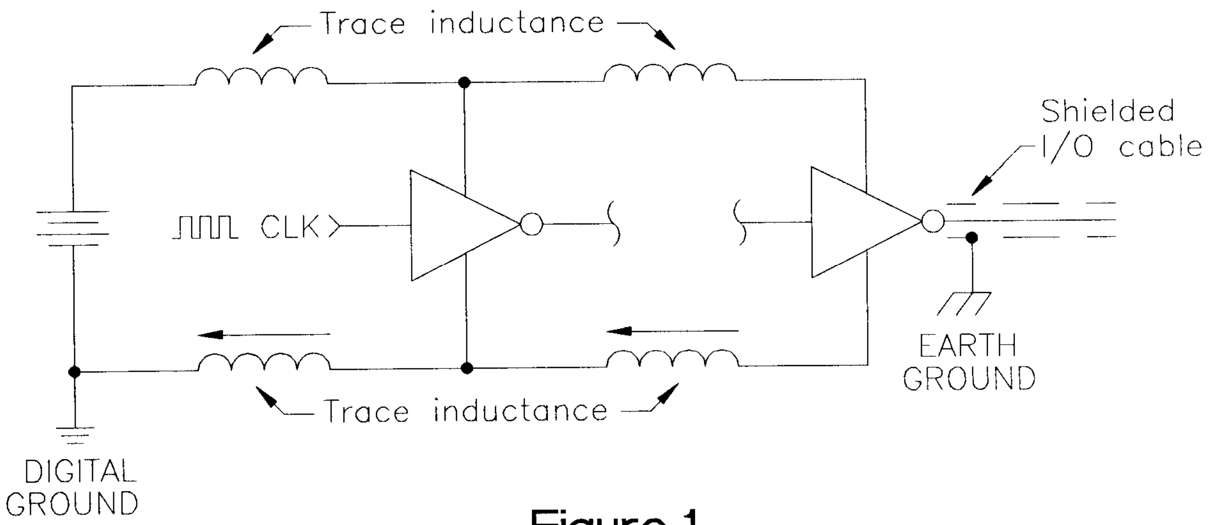

Figure 1

Common made voltage build up in supply rail inductances cause radiation in I/O cables.

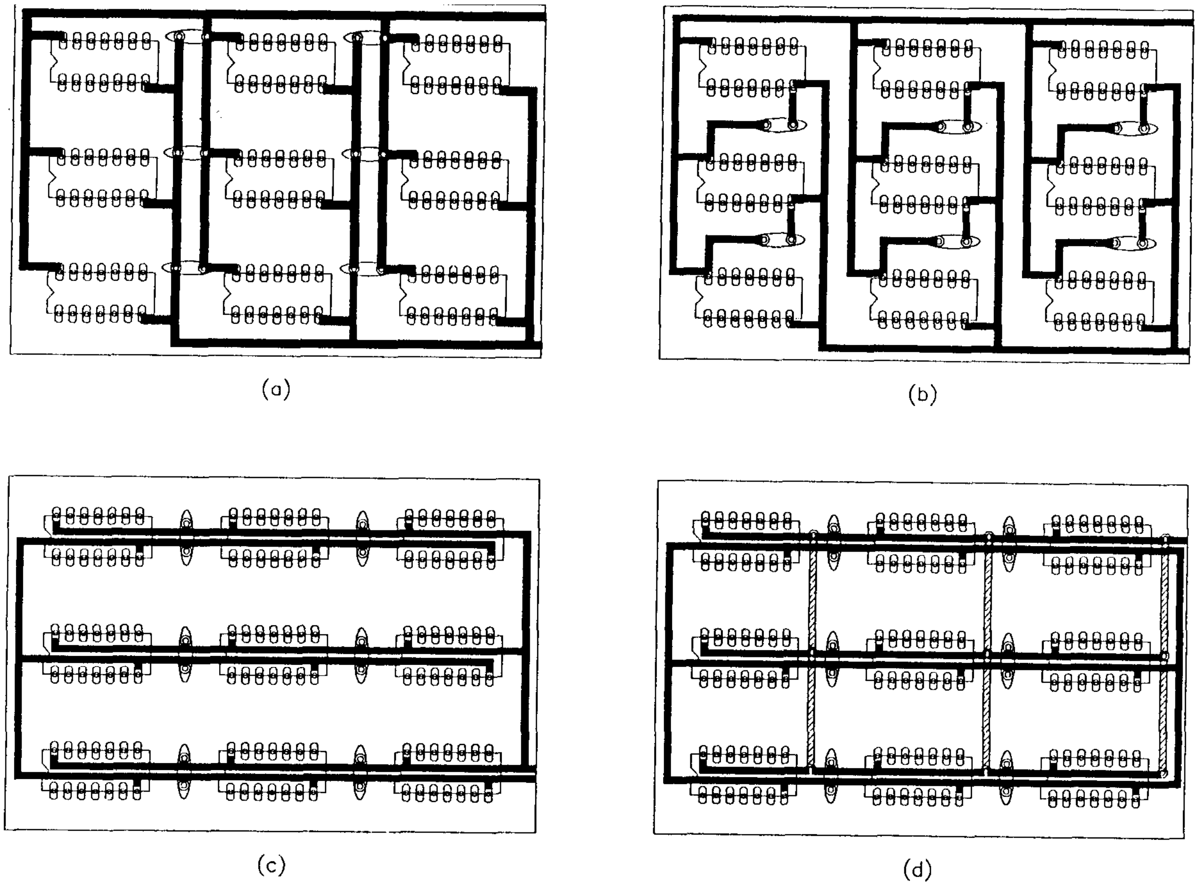

Figure 2

Power and ground bussing on two-sided boards

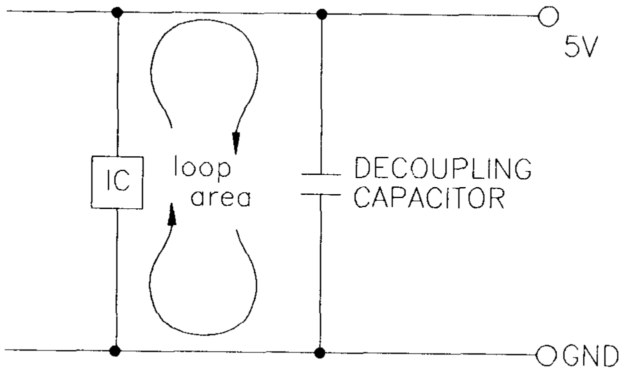

Figure 3

Bypass capacitor should be close to the ICS they serve to reduce the loop area and inductance.