Reducing EMI in Class D Audio Applications

The Basics

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Reducing EMI in Class D Audio Applications: The Basics

Bill McCulley

Sr. Tech Marketing Engineer
Americas Audio & LV/LP Amps

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Outline

- **What is EMI?**
- **The Class D Amplifer and EMI**
- **Dealing with EMI – Techniques and approaches**
- **Creating a “quiet” Class D building block**

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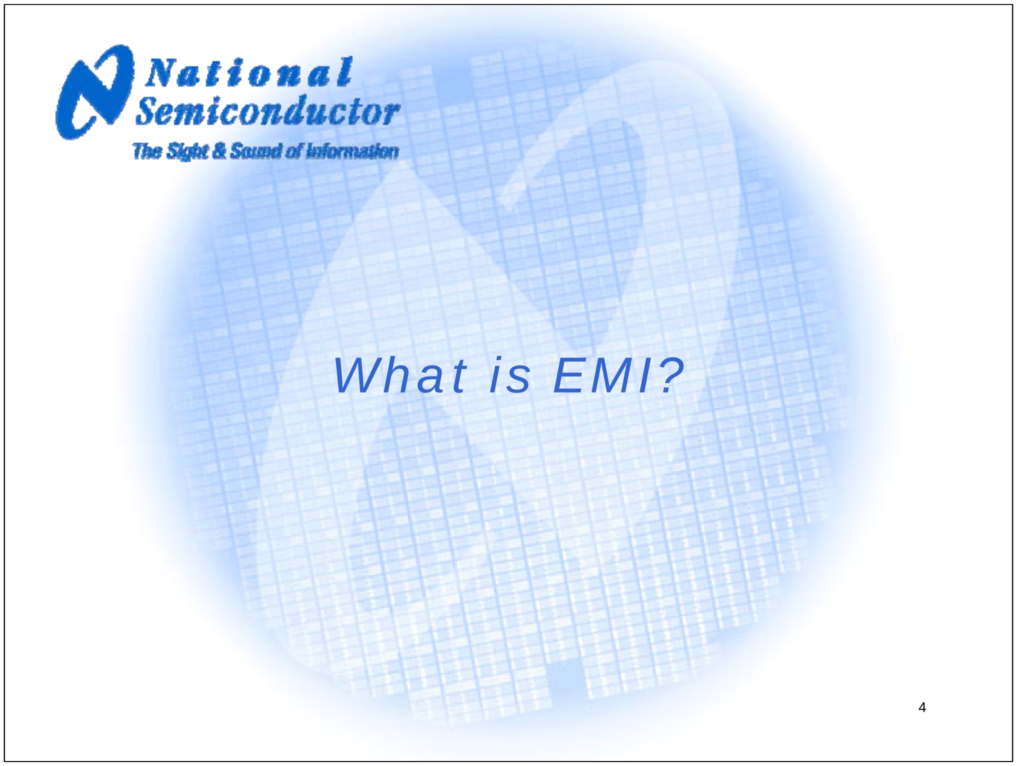
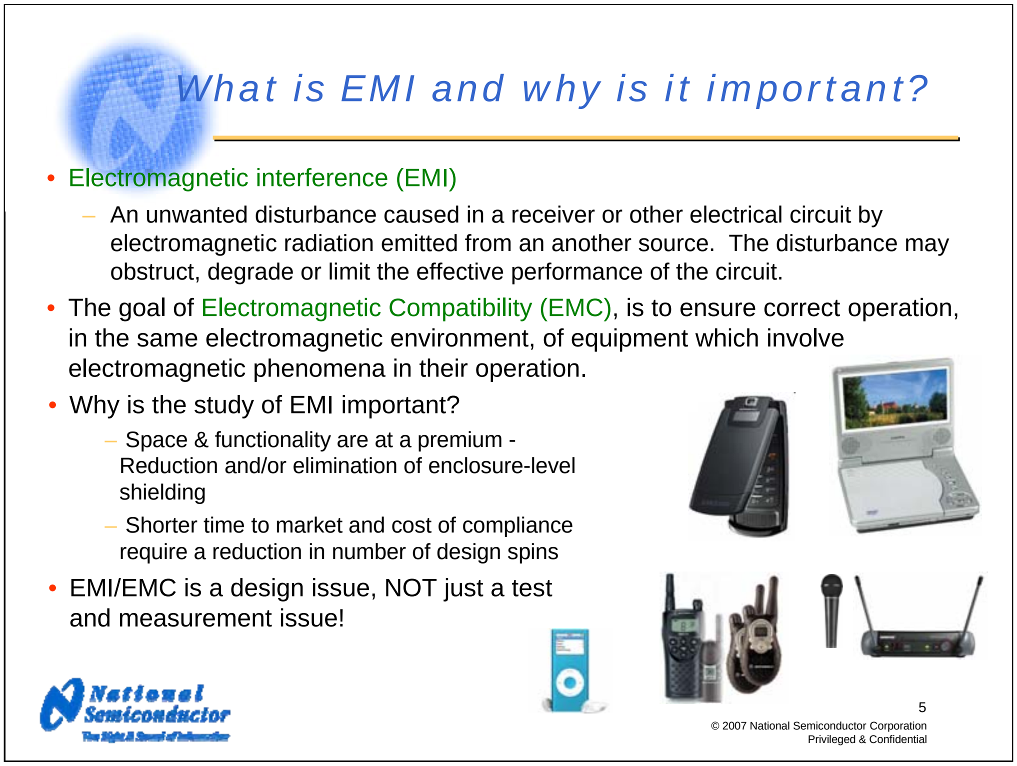
This web seminar gives an overview of Electro-Magnetic Interference in Class D Audio applications and some practical ramifications for the audio designer. It is intended as the first part in a series of webinars to provide information to handle the growing impact of EMI/EMC issues, with a focus on audio applications. Consumer audio and portable applications, with space constraints growing ever more stringent, will have particular relevance.

The seminar will first provide a summary of the terminology and some key points necessary to understanding the phenomenon of EMI. The next section will describe the Class D Audio Amplifer, its emergence as one of the most popular amplifier topologies, and its impact on radiated and conducted emissions for the circuit designer. The seminar then covers some practical guidelines of dealing with the Class D topology with regards to EMI in a circuit design. The final section wraps up with National's ongoing efforts to create a "Quiet" Low-EMI Class D Amplifier



Our first section will cover the basics of understanding Electro-magnetic Interference, or EMI. It will cover some basic definitions, give an overview of the salient points of EMI theory for the designer, and emphasize the importance of EMI issues for the system designer.



Electromagnetic interference (EMI) is an unwanted disturbance caused in a receiver or other electrical circuit by electromagnetic radiation emitted from an external source. The disturbance may interrupt, obstruct, or otherwise degrade or limit the effective performance of the circuit. The goal of Electromagnetic Compatibility (EMC), is to ensure correct operation, in the same electromagnetic environment, of different equipment which involve electromagnetic phenomena in their operation.

Why is EMI important?

•Space and functionality has become a premium – especially for portable and consumer applications. Engineers are being forced to reduce or eliminate enclosures and system-level shielding altogether and instead use better segregation at the circuit level, or suppress the EM noise through other means. Looking at a small sampling of consumer audio products to the right, each of these has seen their size decrease and functionality increase with each passing year.

•At the same time, shorter time to market, and the overall cost pressures for compliance are requiring a reduction in number of design spins. This will require the use of best design practices to ensure EMC within and outside of the system. Multiple spins after EMI problems become evident are intolerable in today's margin-squeezed consumer market.

Just as design for cost (DFC) and design for manufacturability (DFM) have become standard, so too must Design for EMI/EMC.

Electromagnetic Interference (EMI)

- EMI encompasses two aspects:
  - Susceptibility – the scope to which equipment is affected by emissions generated from other electromagnetic waves
  - Emissions – the scope to which equipment generates undesirable radiated noise with the potential to upset other equipment
- This class will focus on reducing unintended emissions
- Emissions are generally divided into two distinct types:
  - Radiated emissions are those which leave a circuit board, trace, or wire, and propagate through the air in the form of electromagnetic waves to interfere with a nearby receiver.*
  - Conducted emissions - energy which escapes a system through wires or cables. Conducted emissions may cause problems directly or may manifest themselves as radiated emissions.

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* A "receiver" in this case refers to any circuit whose operation is affected by the reception of radiated emissions – a PCB trace, stub, or a part lead all can be receivers of EMI

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Electromagnetic Interference encompasses two aspects – or to look at it from another way, from a source perspective and a destination perspective.

(1)Susceptibility is the scope to which equipment is affected by emissions generated from other electromagnetic wave.

(2)Emissions is the scope to which equipment generates undesirable radiated noise with the potential to upset other equipment.

This class will focus on emissions, that is on how to control unintended emissions in your audio application. Though the degree to which you control unintended emissions may make your job of ensuring controlling susceptibility, especially within your system, easier!

Emissions are generally divided into two general types. There may be other types, such as inductive/capacitive coupling, which could be considered a subset of one of these two.

(1)Radiated emissions are those emissions which leave a circuit board, trace or wire, and propagate through the air in the form of electromagnetic waves to interfere with a nearby receiver. It is important to note that a "receiver" refers to any circuit whose operation can be affected adversely by the reception of EM radiation – such as a PCB trace, stub or even the lead of an IC.

(2)Conducted emissions refers to energy which escapes a circuit or system through wires or cables. Conducted emissions may cause problems directly or may manifest themselves as radiated emissions

Common mode and Differential mode noise

- Common Mode Current – not insignificant for Cables
  - In general, differential mode current powers what you want to power – ethernet, video, ultrasound.
  - The outgoing flow current is matched by an incoming flow of current.
  - However, cable radiation is almost never at the harmonics of the actual differential mode signal frequency. Rather, it is usually due to residual clock-harmonic noise.
- Differential mode current – PCB traces
  - Radiation from PCB traces and unintended antenna usually stems from differential mode current, the forward current being that on the trace and the return current being that on the ground plane below that trace.

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Common Mode Current is not insignificant for Cables.

In general, differential mode current powers what you want to power – ethernet, video, ultrasound.

The outgoing flow current is matched by an incoming flow of current. All well and good, right? Not quite. Cable radiation is almost never at the harmonics of the actual differential mode signal frequency. Rather, it is usually due to residual clock-harmonic noise. And this noise is common mode noise. As little as 10 uA can put a cable out of specification.

Differential mode current – PCB traces

Radiation from PCB traces and unintended antenna usually stems from differential mode current, the forward current being that on the trace and the return current being that on the ground plane below that trace.

Unintended Antennas – a key culprit behind radiated emissions

$$\lambda = \frac{Velocity\_of\_Light}{Frequency \cdot \sqrt{\epsilon_r}} = \frac{300}{f(MHz) \cdot \sqrt{\epsilon_r}}$$

ϵ_r is the relative permittivity/dielectric constant

- Most antennas are λ/4 long, which is the shortest of several possible lengths good for receiving signals
- In the case of air, permittivity is 1, but in the case of traditional FR4 or glass-epoxy PCBs, this is approximately 4.8.
  - This effect means a signal traveling the trace is slower than if it were traveling in air - essentially, a "wavelength shortening" effect.
  - A 200MHz signal has a quarter wavelength in air of 16.7 cm. *But in an inner layer PCB trace, it is $16.7/4.8^{1/2}$ = 7.6 cm.*
- Reciprocity – an antenna that is effective at receiving is also good for transmitting.
- If the dimensions of one or more accidental antennas approach quarter wavelength at frequencies at which those antennas are excited noise currents, radiated emissions will occur and EMI problems could result.
- It is important to understand that "packets of coulumbs" moving along – CURRENT – is the driving force for radiation.

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In order to understand EMI, it is useful to understand Antennas. Unintended Antennas are responsible for radiated emissions and are the key culprit behind EMI problems in digital systems. As we will see, the Class D Audio amplifier is in essence a digital system from the perspective of radiated emissions.

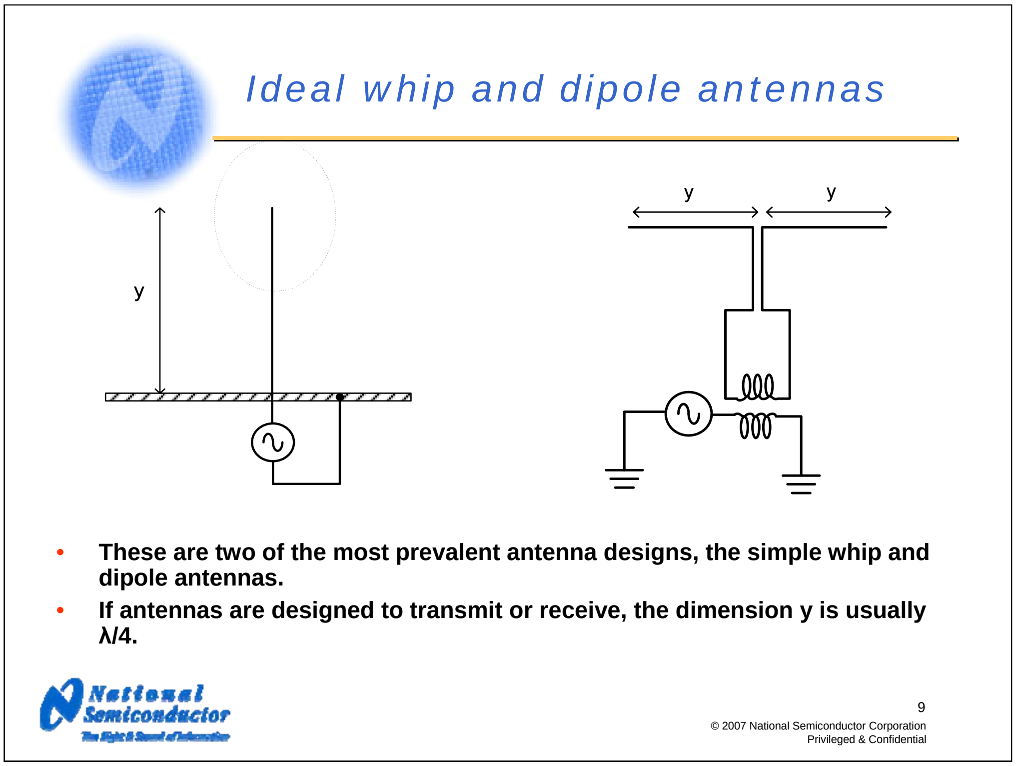
Antenna theory has its own set of jargon, which can sometimes confuse the Audio designer. But it all comes down to basic physics. The wavelength in meters of a signal is equal to the velocity of light in meters divided by the frequency times the square of the relative permittivity.

Most antennas are λ(Lamda)/4 long, as this is the shortest of several lengths that are optimum for receiving signals.

In the case of air, the permittivity is 1, but in the case of a dielectric such as FR4 (which is one of the most common PCB materials), this is approximately 4.8. If a conductor is immersed in dielectric material, the speed of the signal wave traveling on the trace is slower than if it were traveling in air. One way to look at this is as making the wavelength effectively shorter, thus allowing shorter antenna lengths to be good receivers.

So a 200MHz signal, were it traveling in air, has a quarter wavelength of 16.7 cm. But on a PCB inner layer trace, it would be less than half - 7.6cm.

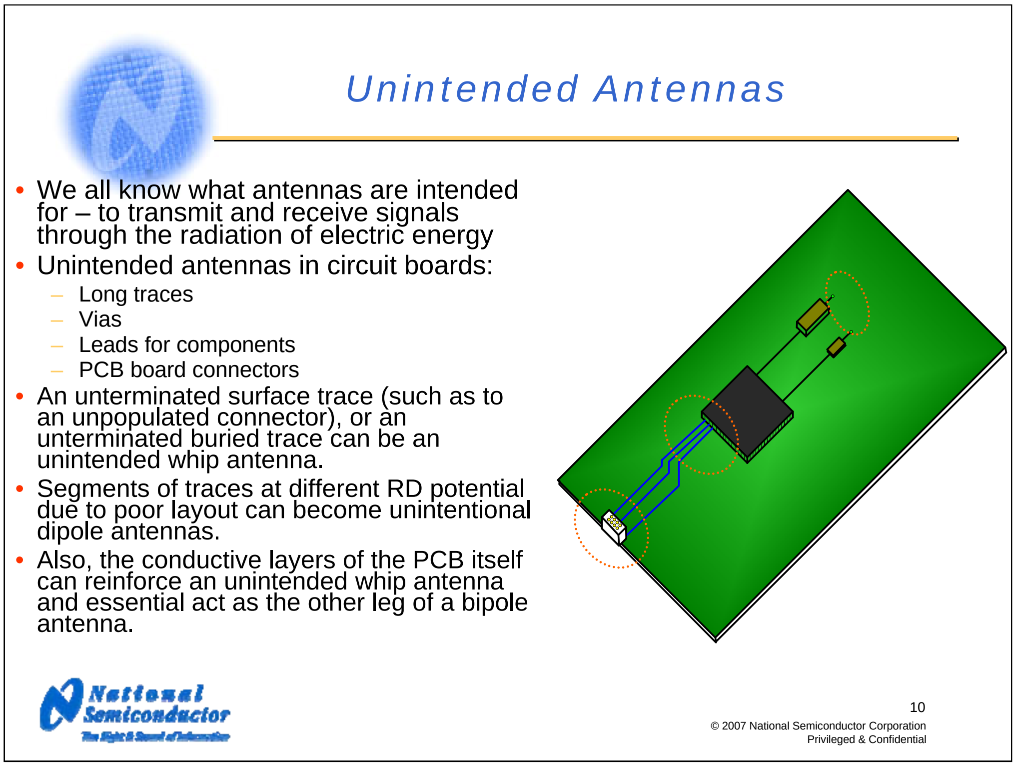
One essential principle underlying electromagnetism is that of reciprocity. A flow of current can creates and electric field, just as a change in electric flux can induce a



These are two of the most prevalent antenna designs, the simple whip and dipole antennas.

If antennas are designed to transmit or receive, the dimension y is usually λ/4.

An interesting observation is that the whip is essentially one half of a dipole with the horizontal ground essentially being “induced” to act as the other half of a dipole. This has particular relevance as we move into looking at “accidental” antennas in PCB circuit boards.



We all know what antennas are intended for – to transmit and receive signals through the radiation of electric energy

But, in a circuit board, there may be a whole realm of unintended antennas

- •Long traces
- •Vias
- •Leads for components
- •PCB board connectors

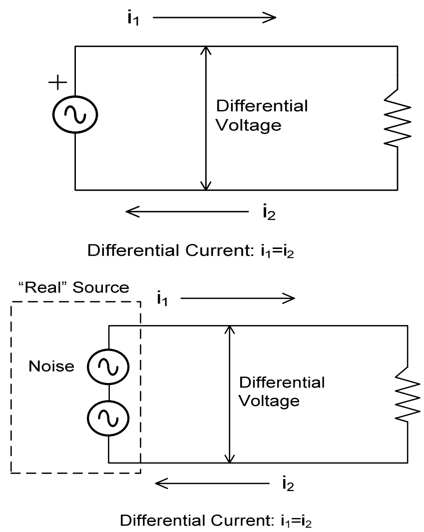
An unterminated surface trace (such as to an unpopulated connector), or an unterminated buried trace can be an unintended whip antenna.

Segments of traces at different RD potential due to poor layout can become unintentional dipole antennas.

Also, the conductive layers of the PCB itself can reinforce an unintended whip antenna and essential act as the other leg of a bipole antennas, possibly increasing the radiation in a dipole pattern

Common mode and Differential mode noise

- Differential Mode current
- A signal current is often described as being transported between two points in a circuit via a trace or wire. The return current path – usually the ground plane of a PCB board – is often taken for granted without any real thought of how it fits into this path.
- In the case of differential current, the currents of the two wires are equal in magnitude but opposite in direction. Voltage on either of the two wires may be positive, negative or zero with respect to ground at any instant.
- Differential mode noise is essentially the noise that appears in series with the desired signal.



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Currents drive emissions which end up EMI. It is important to look at the two types of noise that are prevelant in order to select an effective countermeasure.

Common Mode and Differential Mode Currents -

Differential Mode noise

A signal current is often described as being transported between two points in a circuit via a trace or wire. The return current path – usually the ground plane of a PCB board – is often taken for granted without any real thought of how it fits into this path.

The two conductor path is shown to the right.

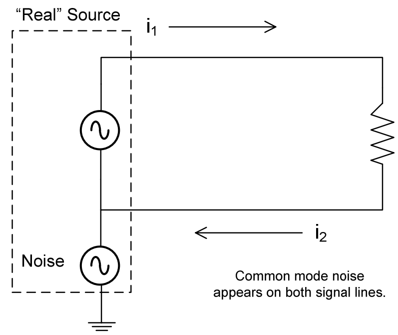
In the case of differential current, the currents of the two wires are equal in magnitude but opposite in direction. Voltage on either of the two wires may be positive, negative or zero with respect to ground at any instant.

The signal in a single ended output is defined in similar manner, but the return current is the ground plane of the circuit.

Differnential mode noise is essentially the noise that appears in series with the desired signal.

Common mode and Differential mode noise

- Common-mode noise appears on both of the two lines that form the signal path. If the noise signal voltage is zero, then the load sees the normal signal voltage.
- One end of the load is essentially ground while the other end has the signal voltage with respect to ground.



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Common-mode Noise

Common-mode noise appears on both of the two lines that form the signal path. If the noise signal voltage is zero, then the load sees the normal signal voltage. One end of the load is essentially groun while the other end has the signal voltage with respect to ground.

If a common mode noise source is greater than zero, then both the forward and return lines of the signal are equally contaminated by noise.

> The outgoing flow current is matched by an incoming flow of current. However, cable radiation is almost never at the harmanics of the actual differential mode signal frequency. Rather, it is usually due to residual clock-harmonic noise.
>
> So the current is common to almost all the wires.

EMI Considerations - Importance

- **Why should we try to reduce or eliminate EMI?**
  - **External standards may require it**
    - **FCC Class B, C**
    - **Industry Specific Standards (Mil-Std-461/2, Medical, Automotive requirements)**
  - **It is good system design practice**
    - **Successful testing often hinges on good EMI system architecture**
    - **Margin of tolerance for noise may require it**
    - **Designing for EMI in advance is much cheaper than fixing EMI/EMC issues after PCB layout and assembly.**

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The theory and practice of managing EMI is difficult. Understanding why it is even more important nowadays is crucial to motivating you to do a good system design which takes it into account.

First of all, EMI constraints may be imposed by external standards. Some of these standards and qualifications will not allow you to operate in that market without passing them!

(1)FCC standards, which encompass virtually all consumer products produced and sold in the US

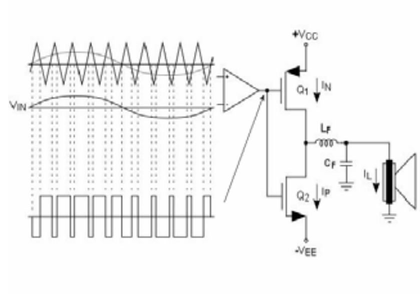
(2)Industry specific standards, which may entail even higher levels of emissions compliance, such as Military standards, medical or automotive requirements.

Secondly, it is good system design practice to account for EMI. Successful testing of a product usually hinges on good electromagnetic system architecture. Margins of tolerance, especially on cutting edge design products may require it. And also, designing with EMI in mind, is much cheaper than fixing EMI/EMC issues after PCB layout and assembly.

We will now introduce one of the most common Audio Amplifier topologies, the Class D Amplifier. As we will see, the benefits of the Class D amplifier are not without a price – especially with respect to unintended radiated and conducted emissions.

The Class D Audio Amplifier

- The Class D audio amplifier modulates a high frequency square wave by the incoming analog signal.
- The square wave itself could be fixed frequency, variable frequency, or simply pulses with no fixed frequency.
- In general, a low-pass filter, typically a 2-pole Butterworth is used to filter the high frequency square wave and recover the original audio signal. In newer, “filterless designs” the filter encompasses the inductance of the speaker itself.



- One popular Class D topology is PWM, or pulse width modulation, uses the modulation technique of having a fixed frequency and changing the duty cycle to create a moving average after a low pass filer (shown above).

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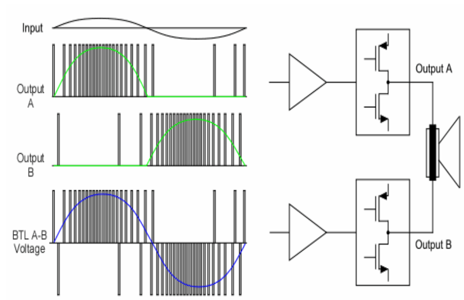
One popular Class D topology is PWM, or pulse width modulation, uses the modulation technique of having a fixed frequency and changing the duty cycle to create a moving average after a low pass filer (shown to the right). In Pulse width modulation is the modulation technique of having a fixed frequency and changing the duty cycle to create a moving average after a low pass filer. The total time of the cycle does not change but the size of the positive portion and negative portion change in opposite but equal amounts.

The Class D Audio Amplifier (cont)

- Delta-Sigma modulation –
  - Uses a pulse of fixed width and then based on the integrated error signal, a pulse is outputted only when the error reaches the threshold.
  - The smaller the output signal level, the fewer number of pulses and the time between pulses will be greater.
  - As the output signal level needs to increase the outputs will have additional pulses with the amount of time between pulses decreasing.



- Some designs will allow the density of pulses to increase to the point pulses can be added together (concatenated) to form a larger pulse.
- Larger pulses will increase the output signal level closer to the supply rails increasing maximum output power and efficiency. Since the number of pulses and density is based on the output signal level Delta-Sigma may be thought of as pulse density modulation.

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Delta-Sigma (Δ-Σ) Modulation is a modulation technique where the error signal is integrated. As the error signal changes and exceeds a threshold the output will create a fixed width pulse. Delta-Sigma can be described as pulse density modulation. The modulator sends pulses of fixed width out as needed to create the analog signal.

Uses a pulse of fixed width and then based on the integrated error signal, a pulse is outputted only when the error reaches the threshold.

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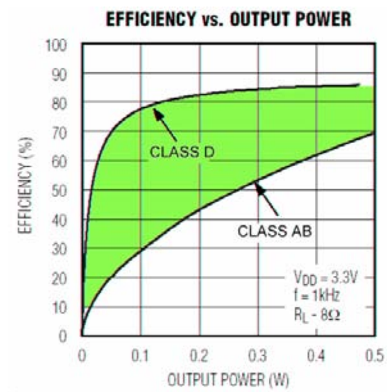
The graphic below shows how a Delta-Sigma modulator might work.

The Class D Audio Amplifier – some common elements

- The primary and common benefit of all Class D topologies is their inherent power efficiency.
- To achieve this efficiency all Class D amplifiers continuously switch the output from rail-to-rail generally far above the audio range (commonly recognized as 20Hz-20kHz).
- Typically the switching frequencies are more than ten times the highest frequency of interest in the input signal.
- In most Class D amps, a feedback path is also used along with an error signal to improve the Total Harmonic Distortion and Noise (THD+N), power supply rejection ratio (PSRR) and other performance characteristics.



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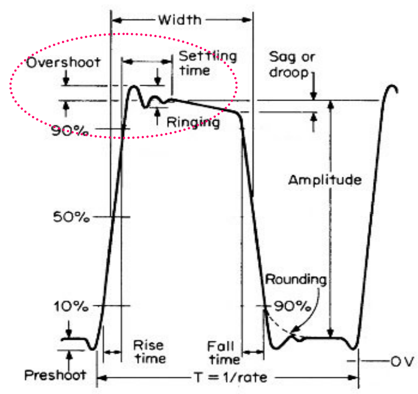
While there are different modulation techniques for Class D with improvements made to the basic modulation technique to increase performance, the primary and common benefit of all Class D topologies is their inherent power efficiency.

While the modulation may vary, all Class D amplifiers continuously switch the output from rail-to-rail, at a frequency determined by the modulation frequency; generally far above the audio range (commonly recognized as 20Hz-20kHz).

Typically the switching frequencies are more than ten times the highest frequency of interest in the input signal. In most Class D amps, a feedback path is also used along with an error signal to improve the Total Harmonic Distortion and Noise (THD+N), power supply rejection ratio (PSRR) and other performance characteristics.

Class D and the Square Wave

- Overshoot occurs at the edges of a waveform.
- For a square wave the wave is changing very rapidly during rise or fall and there will be some overshoot causing the waveform to go higher than the maximum and lower than the minimum for a very short time.
- Overshoot creates additional high frequency content in the output spectrum and is undesirable for EMI and audio performance. Essentially, overshoot is a trade-off of very fast rise/fall times.
- Schottky diodes from the output to the supplies and GND are often used to clamp the amount of overshoot.



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The benefits of efficiency are apparent – lower power consumption, longer battery life, and smaller, easier thermal designs.   But this efficiency is not without cost.

What typifies the Class D Audio amplifier is the square wave which is modulated by the incoming audio signal. In order to drive efficiencies up (the primary benefit of the Class D Amp), a sharp, rapidly switching square wave is used. But this leads to some undesirable artifacts:

Overshoot occurs at the edges of a waveform.

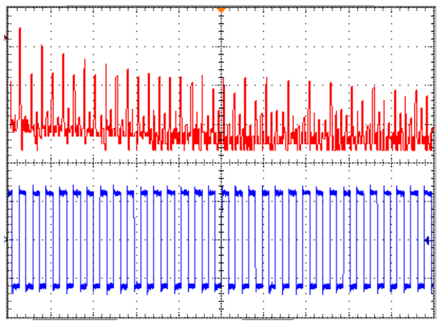
For a square wave the wave is changing very rapidly during rise or fall and there will be some overshoot causing the waveform to go higher than the maximum and lower than the minimum for a very short time.

Overshoot creates additional high frequency content in the output spectrum and is undesirable for EMI and audio performance. Overshoot is a trade off of very fast rise/fall times.

Sometime the overshoot is enough of an issue that Schottky diodes from the output to the supplies and GND are used to clamp the amount of overshoot.

Traditional Pulse Width Modulation (PWM) Class D Audio Amps

- Traditional Class D amplifiers based on the principal of pulse-width modulation (PWM) achieve their efficiency by fast switching.
- The fast switching times and nearly rail-to-rail swings result in extremely high efficiency, but this switching occurs at one specific frequency (e.g. 330kHz), so the frequency spectrum is filled with high frequency harmonics – leading to RF emissions, noise, and EMI.



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A traditional PWM based Amplifier, which can be configured either as single ended or bridge tied load, features fast switching times and very close to rail-to-rail swings with extremely high efficience.

This switching occurs at one specific frequency (e.g. 300kHz), so the frequency spectrum is filled with high frequency harmonics – leading to RF emissions, noise, and EMI.

The figure below shows the harmonic content that would be seen from this periodic, fast switching signal.

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EMI Reduction – Techniques and approaches

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The prevalence of Class D Audio Amplifiers and their growing popularity make it imperative for the Audio designer to consider how to reduce, if possible the EMI generated by this topology.

First things...Design for EMC

- Key thing to remember: PCB floor planning is an essential part of circuit design.
- Designing for EMC at the system level should focus on defining and segregating functional blocks into
  - High speed, noisy and aggressor circuits (i.e. the output of a rapidly switching digitial output IC)
  - Sensitive, “victim” circuits (i.e. the input of a precision amplifier feeding a high resolution DAC)
- Any conducting loop, long trace length, and large surface areas on which sensitive components are located are vulnerable to EMI.

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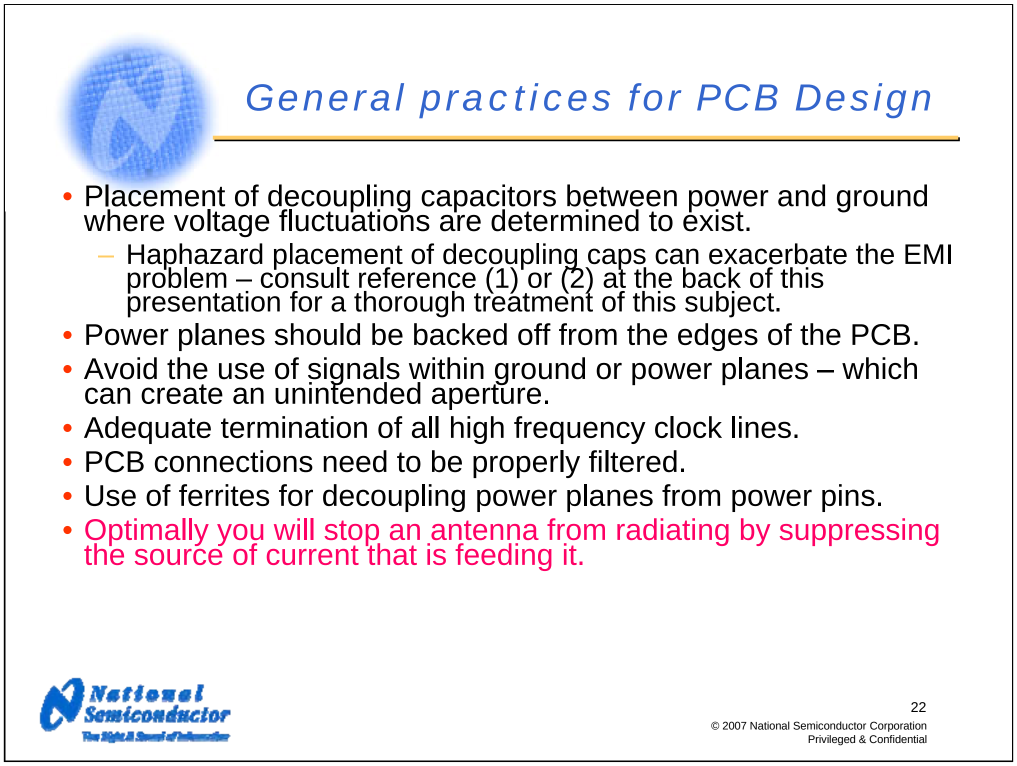
PCB floor planning is an essential part of circuit design.
Designing for Electromagnetic compatibility at the system level should focus on defining and segregating functional blocks into:
- High speed, noisy and aggressor circuits (i.e. the output of a rapidly switching digitial output IC)
- Sensitive, “victim” circuits (i.e. the input of a precision amplifier feeding a high resolution DAC)

Remember - Any conducting loop, overly long trace length, and large surface areas on which sensitive components are located are vulnerable to EMI.



As part of the system design, it is essential to include PCB floor planning as part of the circuit design – right upfront with the electrical engineer, the system architect, and the PCB layout engineer, and manufacturing engineer.

Some general guidelines:

Placement of decoupling capacitors between power and ground where voltage fluctuations are determined to exist.

> Haphazard placement of decoupling caps can exacerbate the EMI problem – consult reference (1) or (2) at the back of this presentation for a thorough treatment of this subject.

Power planes should be backed off from the edges of the PCB.

Avoid the use of signals within ground or power planes – which can create an unintended aperture.

Adequate termination of all high frequency clock lines.

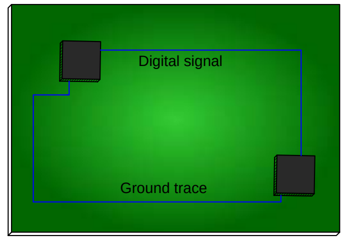
PCB connections need to be properly filtered.

Use of ferrites for decoupling power planes from power pins.

Optimally you will stop an antenna from radiating by suppressing the source of current that is feeding it.

Avoid accidental antennas & loop antennas

- In addition to the previously covered accidental antennas, good PCB design will avoid loop antennas
- While not as obvious as the example to the right, loop antennas encompass any path in where both forward and return currents are on a well-defined conducting path:
  - Traces on two sided PCBs with digital signals (example)
  - Large IC packages (BGAs) with digital signals themselves
  - present a variety of loop antennas
  - Surface trace on multilayer board carrying clock or digital signals
  - Buried traces near the edge of multilayer PCBs carrying digital signals
- Guidelines for suppression of radiation from PCB loop antennas:
  - Place traces with high speed periodic signals between ground and power planes or between two ground planes
  - If two layer PCBs must be used, keep loop areas as small as possible.
  - Consider adding ferrite absorbers on top of semiconductor packages if necessary



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In addition to the previously covered accidental antennas, good PCB design will avoid loop antennas

While not as obvious as the example to the right, loop antennas encompass any path in where both forward and return currents are on a well-defined conducting path:

Traces on two sided PCBs with digital signals (example)

Large IC packages (BGAs) with digital signals themselves

present a variety of loop antennas

Surface trace on multilayer board carrying clock or digital signals

Buried traces near the edge of multilayer PCBs carrying digital signals

Guidelines for suppression of radiation from PCB loop antennas:

Place traces with high speed periodic signals between ground and power planes or between two ground planes

If two layer PCBs must be used, keep loop areas as small as possible.

Consider adding ferrite absorbers on top of semiconductor packages if necessary

Techniques for Class D Audio Amps

- The use of LC filters can greatly reduce EMI, and are a traditional method for audio amplifiers.
  - Size and cost of filters increases with output power levels.
- Keep traces from Audio Amp to the speaker as short as possible! PCB traces or wires act as antennas with significant radiation occurring once the trace length reaches one quarter the wavelength of the signal they carry
- Other options include routing PCB traces that carry high frequency signals between ground planes, and using insulated components and toroid inductors.
- For filterless Class D systems, the trace and cable length connecting the amplifier's output to the speakers will likely be the largest source of RF emissions.

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The use of LC filters can greatly reduce EMI, but LC filters are large and expensive, with size and cost increasing with output power levels. PCB traces and wires essentially act as antennas with significant radiation occurring once the trace length reaches one quarter the wavelength of the signal they carry – so a general rule is to keep traces as short as possible.

Other options include routing PCB traces that carry high frequency signals between ground planes, and using insulated components and toroid inductors. For filterless Class D systems, the trace and cable length connecting the amplifier's output to the speakers will likely be the largest source of RF emissions.

Techniques

- Traditional practices such as placing ferrite beads in series with the loudspeakers close to the amplifier can be effective. Ferrite beads act as an RF choke, attenuating high frequency signal components.
- Ferrite beads are effective over a relatively narrow frequency range, and may not provide enough attenuation over the output noise bandwidth.
- Shielding can also be used if PCB layout and filtering cannot reduce the EMI to an acceptable level.
- The power supply is another possible EMI source. A Class D amplifier draws current in large, short duration pulses related to the output switching edges that appear on the power supply lines. Power supply related EMI can be minimized with proper layout and bypassing techniques.

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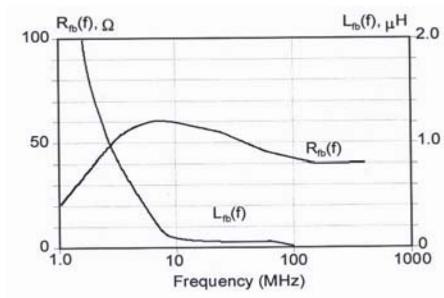
Traditional practices such as placing ferrite beads in series with the loudspeakers close to the amplifier can be effective. Ferrite beads act as an RF choke, attenuating high frequency signal components.

However, ferrite beads are effective over a narrow frequency range, and may not provide enough attenuation over the output noise bandwidth. Shielding can also be used if PCB layout and filtering cannot reduce the EMI to an acceptable level.

The power supply is another possible EMI source. A Class D amplifier draws current in large, short duration pulses related to the output switching edges that appear on the power supply lines. Power supply related EMI can be minimized with proper layout and bypassing techniques.

Ferrite Bead Basics

- A model for ferrite beads: a resistor and inductor in series, both values dependent on frequency. For EMI suppression purposes, the frequency dependent resistance is dominant, but because R_{dc}=0 there is no voltage drop.
- The graph of the resistance and inductance as a function of frequency show that the resistive part of the bead typically exceeds the inductive reactance beyond a certain frequency. For EMI relevance, look for the resistance will be greater than the inductive reactance at the frequencies of interest.



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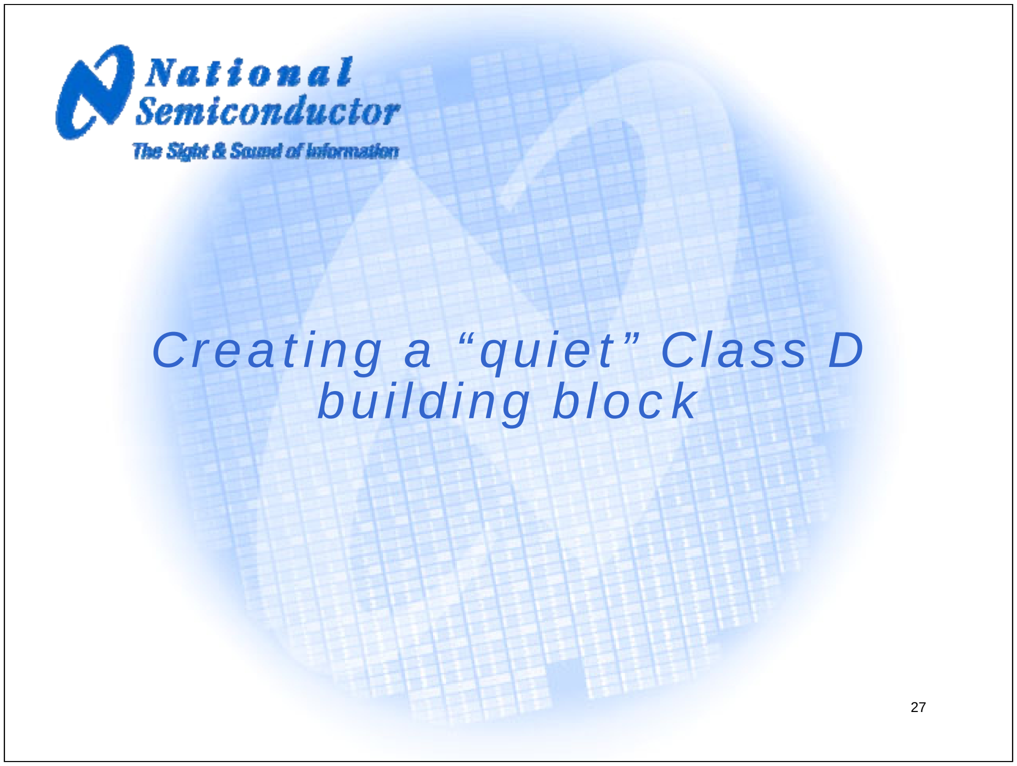
In order to better understand the use of ferrite beads, it is useful to see break the ferrite bead down into a resistance and inductance element.

The simple model for ferrite beads is a resistor and inductor in series, both values dependent on frequency. For EMI suppression purposes, the frequency dependent resistance is dominant, but because R_{dc}=0 there is no voltage drop.

To illustrate the functionality of a ferrite bead, let us look at the graph of the resistance and inductance as a function of frequency.

The graph of the resistance and inductance as a function of frequency show that the resistive part of the bead typically exceeds the inductive reactance beyond a certain frequency. For EMI relevance, look for the resistance will be greater than the inductive reactance at the frequencies of interest.



Now that we’ve gone over some basic guidelines on reducing EMI in a circuit board design, let us go through some newer approaches that semiconductor manufacturers, including National Semiconductor, are using to reduce EMI at the source: the IC itself.

Spread Spectrum Modulation

- One of the primary difficulties with periodic square waves inherent in Class D Audio Amps is the concentration of energy at the harmonic intervals.
- One approach to deal with this is to move the frequency back and forth – i.e. “dither” the frequency so the energy at any one point in the spectrum is essentially reduced.
- Spread Spectrum Modulation – some history:
  - The spread spectrum techniques is not a recent development, dating back over a half a century, with some of the earliest efforts occurring in communications systems and military radar applications.
  - Spread spectrum modulation techniques have become popular in other applications – particularly clocking circuits.
  - The benefits of the spread spectrum technique can also be seen when applied to Class D audio amplifiers.

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Spread Spectrum Modulation –

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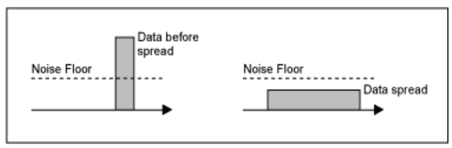
> In the past decade, spread spectrum modulation techniques have become popular in other applications – particularly in clocking circuits. The benefits the spread spectrum technique has brought to those applications can also be seen when applied to Class D amplifiers.

Spread Spectrum Modulation

- A spread spectrum modulator adjusts the switching frequency of the output bridge in a band around a center switching frequency (for example, a 300 kHz center frequency with a +/- 30% frequency spread).
- As long as the frequency variation remains random, the actual method for varying the frequency can range from a simple sweep to uncorrelated jumps in carrier frequency.
- Effects on spectral energy:
  - Total amount of spectral energy is not decreased, however peak energy decreases.
  - Total energy is spread over a wide frequency band, as shown in the figure below.
  - Result - Noise exists over a wider bandwidth but the peak noise at any one frequency will be less than what is generated by a fixed frequency device.



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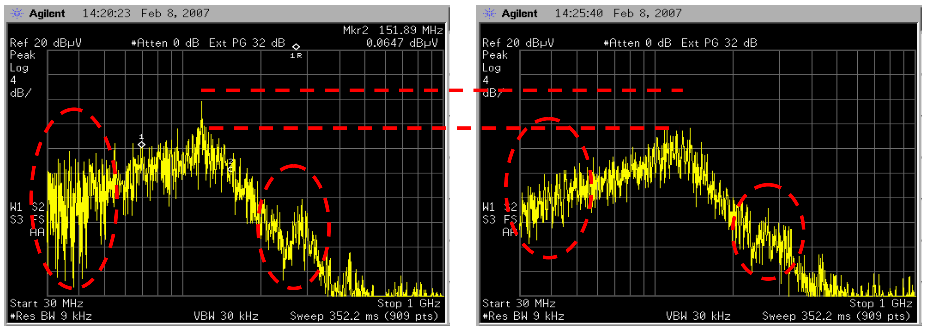
A spread spectrum modulator adjusts the switching frequency of the output bridge in a band around a center switching frequency (for example, a 300 kHz center frequency with a +/- 30% frequency spread).

As long as the frequency variation remains random, the actual method for varying the frequency can range from a simple sweep to uncorrelated jumps in carrier frequency. The spread spectrum modulation scheme has some key advantages: high efficiency and low THD+N are maintained, while the radiated noise and EMI is reduced.

It is important to note the total amount of energy is not decreased. Peak energy decreases, however, the total energy remains the same, and is spread over a wide frequency band, as shown in the figure below. Noise exists over a wider bandwidth but the peak noise at any one frequency will be less than what is generated by a fixed frequency device.

The Spread Spectrum Effect

- Compared to traditional Class D, the spread spectrum modulation scheme has some key benefits:
  - Efficiency and low THD+N are maintained
  - Radiated noise and EMI is reduced



- **Fixed Frequency**
- **Spread Spectrum**
- Near-Field EMI Measurement

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Compared to traditional Class D amplifiers, the spread spectrum modulation scheme has some key advantages

Efficiency and low THD+N are maintained

Radiated noise and EMI is reduced

Spread spectrum technology adjusts the frequency of the switching of both halves of the bridge in a band around the center switching frequency (i.e. 300 KHz with a +/- 30% frequency spread).

Here is an example of the affect spread spectrum modulation has on the EMI profile.

As you can see, there is a significant decrease in spectral energy, as highlighted on the graphs.

EMI: FCC and CE Measurements

- FCC and CE radiated emission standards are shown below and apply to any digital consumer device that is not intended to transmit. All consumer electronic products must be certified before sale in the United States and Europe.
- Emissions Measurements and Certification
  - Device is measured in typical operating state
  - Measurements performed in RF anechoic chamber
  - Emissions measured below FCC/CE limit, device is certified

Frequency Range (MHz)	FCC Class B Limit (μV)
0.45-1.705	48
1.705	48
Frequency Range (MHz)	**CE Class B Limit (dBμV)**
0.15-0.50	56
0.50-5	56
5-30	60

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Before we speak about some quantitative measures of how spread spectrum modulation can benefit the overall EMI profile, we need to cover briefly two of the key standards with respect to consumer devices.

FCC and CE radiated emission standards are shown on this page and apply to any consumer device that is not intended to transmit. All consumer electronic products must be certified before sale in the United States and Europe.

The testing and qualification of EMI is an arduous and lengthy process, requiring special equipment and highly sensitive measurement tools. Typically a designer will contract EMI-testing and qualification to an external (approved) testing laboratory.

Emissions Measurements and Certification will generally encompass several phases:

Device is measured in typical operating state

Measurements performed in RF anechoic chamber

Emissions measured below FCC/CE limit, device is certified

Due to the cost of EMI testing, it is essential to go into the lab with a very high confidence of success. Repeated iterations of testing can quickly doom a project with hard-to-solve EMI problems.

LM48511 Low-EMI Spread Spectrum Boosted 3W Boomer®

Specs:

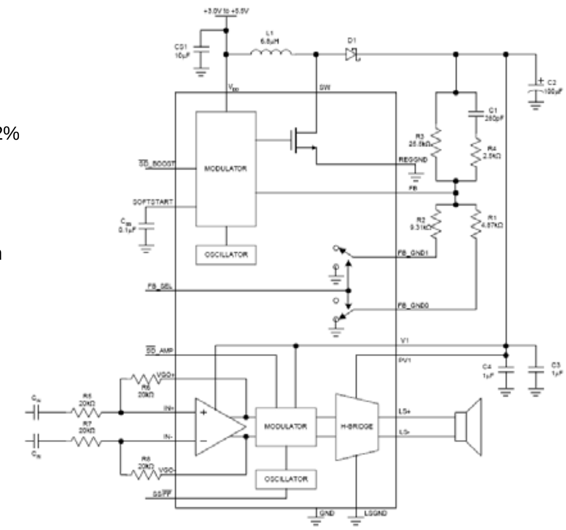
- P_o (5V, 8Ω, 1% THD+N) = 3W
- Iddq at 3V = 9mA (typ)
- Iddq at 5V = 13.5mA (typ)
- THD+N (P_o=100mW) - 5V: 0.03%, 3.6V: 0.02%
- PSRR (217 Hz) - 82dB

Features

- Selectable spread spectrum mode
- 80+% Efficiency
- Independent Regulator & Amplifier Shutdown Controls
- Dynamically Selectable Regulator Output Voltages
- Filterless Class D
- 3.0V – 5.5V operation
- Click and Pop Suppression

Applications

- GPS
- Portable media
- Cameras
- Mobile Phones
- Handheld games



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LM48511 is a spread spectrum modulated class D audio amplifier. It also includes a built-in boost regulator, which drives the input voltage rails of 3-5.5V to 7V, thus boosting the output power and generating a louder possible audio signal than could be achieved on the lower rails.

As can be seen in the block diagram, the spread spectrum modulator feeds the standard H-Bridge which drive the Bridge-Tied Load speaker. In this case, the part enables the user to either use the part with spread spectrum modulation enabled or disabled for testing purposes.

The logic selectable spread spectrum mode eliminates the need for output filters, ferrite beads or chokes. In spread spectrum mode, the switching frequency varies randomly by

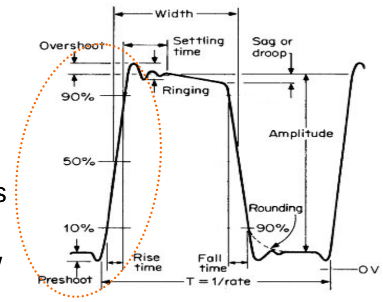
10% about a 330kHz center frequency, reducing the wideband spectral contend, improving EMI emissions radiated by the speaker and associated cables and traces. Where a fixed

frequency class D exhibits large amounts of spectral energy at multiples of the switching frequency, the spread spectrum architecture of the LM48511 spreads that energy over a larger

bandwidth.

Other approaches in creating a better Class D Audio Amp

- Another approach to reducing EMI noise in Class D Audio amps is by changing the shape of the square wave.
- The vast majority of spectral energy is contained in the square wave edges, which result in high-frequency harmonics leading to EMI problems.
- The possibility of edge rate control - how it can be used to lower the EMI profile associated with Class D audio applications will be covered in our next class.



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There are other approaches in dealing with the EMI issues with Class D Audio Amplifiers.

For reference, the traditional square wave with its relevant parameters is shown to the right. As noted, the majority of energy in the high frequency harmonics is contained in the edges of the square wave. These high frequency harmonics can lead to unintended emissions throughout the circuit design.

By changing the shape of the square wave – in particular by "softening" its edge – one can significantly affect the magnitude of high-frequency harmonic energy created.

The subject of adjusting the rise and fall times of the modulating square wave, and how this edge-rate control can be used to lower the EMI profile of a Class D Audio amplifier will be covered in our next class.

References for the study of EMI and PCB Design and Class D Audio Amps

- **References:**

  - **Bruce R. Archambeault & James Drewniak, "PCB Design for Real-World EMI Control", 2002**
  - **Howard Johnson, "High-Speed Digital Design: A Handbook of Black Magic", 1993**
  - **Dougles Self, "Audio Power Amplifier Design Handbook", 4d Ed, 2006**
  - **Robert A. Scholtz, "The Origins of Spread Spectrum Communications", *IEEE Transactions on Communications*, Vol Com-30, May 1982, pp 822-854.**

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