# KIMMEL GERKE *Bullets*

MEMBER AMERICAN CONSULTING ENGINEERS COUNCIL

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## Welcome to KGB

And the Midwest Expo issue of our "personal communications" to our friends and clients. Please stop by and say hello. . .we're in Booth 652, on the main floor in the middle of the action. . . May 15-16-17 at the St. Paul Civic Center.

**This issue focuses on design,** and the EMC concerns like **regulatory compliance** (FCC, VDE, VCCI), and **immunity** to threats such as static (ESD), radio transmitters (RFI), and power glitches. We have a quick overview of these issues, plus an indepth article on using ferrites.

While the last issue focused on architecture, or EMC concerns "outside the box", this issue concentrates "inside the box", the domain of the designer. In the early design stages, most EMC fixes are inexpensive and easy to implement. As the design progresses, however, costs to make changes quickly increase. Let a problem get into the field, and a lack of a few ten cent parts can easily cost thousands of dollars. There is a tremendous payback on "doing it right" in design.

We'd like to help you "do it right" too. . .give us a call about our "country doctor design review" approach.

Best regards,

Daryl Gerke, PE, and Bill Kimmel, PE

## Please Requalify

Please return the enclosed post card if you wish to continue Kimmel Gerke Bullets. Since many businesses no longer deliver bulk mail, we suggest using your home address. (Besides, if you change companies. . . not uncommon today. . .you'll continue to receive the *KGB*.)

## Shows and Conferences

Here are some shows in which we'll be participating over the next six months. Give us a call, or drop us a line if you'd like information on any of these events.

**Midwest Electronics Expo. . .**This is the largest electronics show in Minnesota, and is aimed at the general technical community. We're supporting two IEEE sponsored sessions on EMC and on Power Disturbances. We're also exhibiting. . . stop by and see us at Booth 652, May 15-17 at the St. Paul Civic Center. Free for advance registrations. . . call us if you still need a free pass.

**1990 Conference on Electrostatics. . .**An international conference on electrostatic discharge (ESD), at the Minneapolis Metrodome Hilton, June 18-20. We'll present a paper titled "ESD as an EMI Problem" at 11:20 AM on Monday, June 18.

**1990 International IEEE EMC Symposium. . .**The annual IEEE conference on interference, held in Washington DC, August 21-23. Daryl and Paul Cook (Amador Corporation) will present a paper on "60 Hz Magnetic Field Susceptibility Tests of CRT Displays."

**EMC EXPO 1990. . .**An international conference on EMC scheduled in Silicon Valley (San Mateo, CA) October 17-19, 1990. We'll be presenting a three hour tutorial session, titled "Twenty Common EMI Mistakes. . .and How to Avoid Them."

**Fifth Annual Minnesota EMC Event. . .**The local EMC show of the year, co-sponsored by Amador and Kimmel Gerke Associates, will be held Thursday, October 25, 1990 at the Thunderbird Hotel in Bloomington, MN. Mark your calendars to attend. . . free to preregistered attendees. And if you have a topic to present, let us know — we're looking for new EMC ideas that can be covered in 30 minutes.


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# News and Reviews

Here are some observations and comments on EMC issues faced by equipment design engineers.

**Regulations and Compliance. . .** New FCC requirements apply to systems with clock frequencies over 108 MHz — instead of testing for radiated emissions from 30 MHz to 1 GHz, you must now test up to 5 GHz, depending on clock speeds. In addition, the FCC has a new increased fee program effective May 21, 1990. (No new taxes, remember?)

New European Community (EC) limits in 1992 will include susceptibility to electrostatic discharge (ESD) and to high level fields. If you are designing equipment for sales in Europe, now is the time to consider these requirements. . . not in 1992.

**Printed Circuit Boards. . .** Quite a bit can be done to "suppress the source" at the printed circuit board level. Multi layer boards are typically 20-30 dB more quiet than one or two level boards, but even the simplest boards can often be tamed down. The key is to identify the noisiest circuits and traces, typically clocks and other highly repetitive circuits.

We suggest hand placement and routing of clocks and critical control lines, since auto routers don't know or care about EMI. Keep these lines short, direct, and away from board edges and I/O circuits.

We also suggest decoupling all clocked circuits, since often the power spikes are a bigger problem than the signal lines. This is particularly important with CMOS devices, with their momentary "shorts" of power to ground. And don't neglect high frequency decoupling where the power enters the board.

**Shielding. . .** If you can't suppress it, then you must contain it. That's the job of any shield. The secret here is to get a six sided box around the "source", and then to control leakages. Fortunately, even thin materials, like foils or metalized plastic, are adequate by themselves for most commercial applications. The problem areas are the holes (ventilation, CRT windows, seams) and the conductive penetrations (wires, cables, power, etc.)

We suggest that all slots be limited to 1/20 wavelength at the highest frequency of concern. (See "Bullets" in *KGB* #2). For 300 MHz, a typical "EMI design frequency" for today's desktop systems, that translates to 2 inches. At 1 GHz, the upper FCC limit for systems with clocks under 108 MHz, that drops to about 0.6 inches.

We also suggest that all penetrations, such as shields or cables, be bonded or decoupled at the point of penetration. . . no pigtails or long leads. This is a leading cause of FCC/VDE failures, with poorly terminated wiring acting as undesired antennas.

We've just finished a shielding R&D project for a supplier of vacuum plating on plastics. The results were quite good, and that client has made our report available for public distribution. Call us if you'd like a copy.

**Cables and Connectors. . .** External cables often act as large antennas, coupling energy both to and from the system to which they are connected. This can cause problems for FCC/VDE emissions, and also for electrostatic discharge and radio frequency susceptibility problems.

We suggest metal connectors with a full circumferential termination of cable shield to connector for any cable shield that must work above 1 MHz. . . no pigtails. We also suggest high quality shields when the cable shield must work above 10 MHz. . . below 10 MHz this is not very critical.

**Power supplies. . .** These can be both a direct source of EMI, plus also providing some "sneak paths" for other energy to enter or leave the system.

Filters are the main line of defense here, but if they are not properly installed, they can be rendered totally ineffective. For high frequencies, filters must be installed at the shield penetration, or energy will couple around the filter. Watch out for unfiltered power lines, such as auxiliary sockets, which may allow power lines to act as antennas that reradiate energy from inside the box.

An increasing problem today is parasitic capacitive coupling within switching power supplies, which can cause common mode currents to flow on the input power leads. The faster the switcher, the more likely the problem. This can easily cause FCC or VDE conducted failures.

## A KGB Bullet

A common mistake in using bypass capacitors is not considering the self-resonance of the capacitor and the lead inductance. At 20 nh/inch, even relatively short lead lengths can result in bypassing with an inductor (above the resonant frequency) instead of a capacitor (below the resonant frequency.) The following table gives some examples:

| | Total Lead Length | | |
|---|---|---|---|
| | 1/4" | 1/2" | 1" |
| 500 pf | 100 MHz | 72 MHz | 50 MHz |
| 1000 pf | 72 MHz | 51 MHz | 36 MHz |
| 0.01 uf | 23 MHz | 16 MHz | 11 MHz |
| 0.1 uf | 7.2 MHz | 5.1 MHz | 3.6 MHz |
| 0.3 uf | 4.2 MHz | 2.9 MHz | 2.1 MHz |
| 0.5 uf | 3.2 MHz | 3.2 MHz | 1.6 MHz |

# Book Review

Just finished reading *Grounding and Shielding in Facilities* by Ralph Morrison and Warren Lewis, a new book just out from Wiley Interscience. The book's main focus is on low frequency issues, such as instrumentation and power. It emphasizes safe grounding practices, that can provide EMI help while still meeting the National Electrical Code safety requirements. Worthwhile if you are involved with facilities or systems engineering.

# Focus on Ferrites

Ferrites are your friends: they eat undesired energy. But the application of ferrites is subject to misunderstandings. In this issue, we will try to show how easy it is to design a filter using a ferrite and capacitor.

The key is KISS — Keep it simple, stupid. We believe in using simple methods which quickly give reasonable approximations. You don't need a page full of input parameters and a supercomputer — a pencil, paper and calculator to make a quick calculation will get you close enough — then you can fine tune it in the lab.

**T, L, or Pi**. . . A common question is do I use a T or Pi filter? The implicit assumption is that an L filter is not worth considering, yet there are conditions where the performance of an L filter will match a T or Pi filter.

In simple terms, filters are most effective when maximum impedance discontinuity exists between the filter and the source or load. That means that a high impedance source or load should face a low impedance filter element, and a low impedance source or load should face a high impedance filter element.

Thus, you will find it ineffective to put a ferrite in series with a high impedance input circuit — ferrites need current to work on, so a shunt capacitor is needed. Similarly, it is ineffective to put a shunt capacitor at the output of a driver, since they are usually low impedance. In this case, it is better to insert a small series impedance (such as a ferrite) before the capacitor.

In the real world of electronics, we typically see high input impedances and low output impedances. And our filters should be designed accordingly. Strangely enough, commercial power line EMI filter effectiveness are typically specified using a 50 ohm source and load. Where do you ever see 50 ohms, outside of coax and test instruments?

**Quick Design Approach**. . . Use simple algebra to estimate your filter effectiveness. Here are the guidelines:

1. Design the filter by calculating at the high and low frequencies of interest. If you use lossy elements, mid range resonances should not be troublesome.
2. Be sure to include parasitic inductances, and in extreme cases, parasitic capacitances.
3. Compute with absolute values of impedances.
4. Select impedance discontinuity at each stage. Strive for a minimum of 10:1, and maximum of 100:1. If you need more attenuation, use multiple stages.
5. Ignore small impedance factors.

**Ferrite Geometry**. . . What is important in selecting a ferrite? Impedance of ferrites is primarily a bulk effect — so the more pounds the better. But the critical parameters are the length and the inner radius, followed by the outer radius.

The effectiveness of a ferrite decreases as the reciprocal of the inner radius. Thus, it is the inner part of the ferrite that does the most work. It is to your advantage to select a ferrite with as small an inner radius as possible, provided you don't saturate the core (that's discussed below). The outer radius is important, too, but less so than the inner radius.

Effectiveness of a ferrite increases linearly with the length. Thus, doubling the length doubles the impedance. Don't get too exuberant with this fact, however. You will find that there is a definite limit to the effectiveness of the ferrites, and it you add more than a few, you will often get little or no further improvement.

**Saturating a Ferrite**. . . One problem of using ferrites is that they saturate under large net DC or low frequency AC currents. Notice we said "net" current. A ferrite clamped over both the DC and return lines will have no net DC current.

But such practice will eliminate only common mode interference. And if you need differential mode filtering, you will need to reckon with DC. If you are filtering signals, current is negligible, but if you are filtering power, then you must consider the peak currents.

Unless the ferrite is a thin annular ring, they saturate from the inside out. The relationship is $I = 2\pi RHc$, where I is total current (multiplied by N turns), R is radius from center, and Hc is critical magnetic field intensity.

In the most useful ferrites, Hc is about 1.5 Amp/cm, which gives us a convenient relationship of:

$I = 10R$, where R is the inner radius in cm and I is the current at which the ferrite will commence saturation.

Again, the core saturates from the inside out, and it is not fatal to have the inner portion in saturation as long as reduced performance can be tolerated.

In fact, saturation is permissible in certain transient power applications. The high frequency spikes and ringing in power turn-on will be suppressed by a ferrite before the current drives it into saturation. Similarly, inductive kick in turn-off of power circuits will drop the ferrite out of saturation in time to suppress most bursts of noise.

**Impedance of a Ferrite**. . . Calculating impedance of a ferrite is not simple, and it is best to refer to the manufacturers data. They will commonly specify impedance at upper and lower frequency limits, and if those are not in the right range, there are tables for extrapolation. The most widely used ferrite formulation is effective at frequencies above about 30 MHz, and is good up to about 1 GHz. Other formulations are available, with the following two tradeoffs:

1. The range of effectiveness shifts with different ferrites. If you want to cover a lower frequency, then you will lose performance at the high end.
2. Permeability decreases with higher frequency ferrites. This means that higher frequency ferrites will have lower average impedances and lower frequency ferrites will saturate at lower currents.

*(continued on next page)*

## Focus on Ferrites. . . *(continued)*

Multiple Turns. . .The impedance of the ferrite increases with the square of the number of turns. This is useful when trying to get effectiveness at frequencies below 30 MHz. When the impedance starts to falter, you can put a couple of extra turns on the core.

The tradeoff is that winding capacitance will take its toll at higher frequencies. If you space the windings around the core, the capacitance will not be significant. Generally, you can get by with three turns without seriously degrading the high frequency impedance.

If you need more turns, turn to the multiple hole ferrites, or use a single turn ferrite in series to block the capacitive leakage.

Hope this little dissertation has helped you better understand ferrites — they truly are our friends in fighting today's EMI problems!

# Article on Power Disturbances

We're pleased to be a part of the 20th Anniversary Issue of ITEM (Interference Technology Engineer's Master) with an article titled "Power Disturbances and Computers." This annual publication is an excellent EMC resource. . . if you'd like a copy, contact Robar Industries in West Conshohocken, Pennsylvania, at 215-825-1960.

# Power Quality Conference

Bill presented a paper at the "Second National Power Quality Conference for End Use Applications" in late March in San Francisco, titled "EMI Aspects of Power Quality." This conference was sponsored by the Electric Power Research Institute (EPRI), and was attended by many leaders of the power industry. If you have problems or concerns about power related EMC issues, give us a call. . .we're concerned and experienced in this area.



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