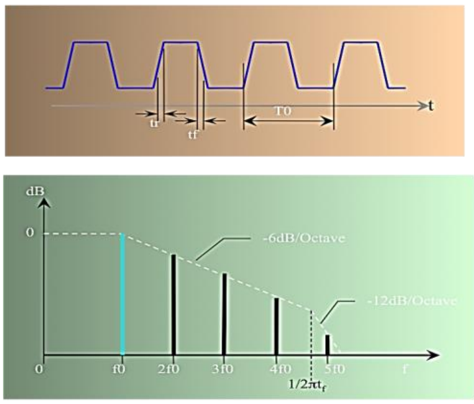
Active EMI / RFI Management

Electromagnetic Interference (EMI) and Radio Frequency Interference (RFI) is one of the most challenging problems that the electronic design world faces. Solutions to these problems have a direct and significant impact on the performance, speeds, power, weight, costs and time to market of a product.
Billions of dollars and countless frustrating hours are spent in this effort to secure compliance to regulations laid down by governing bodies across the world. The current approach is by and large one of trial and error and very often degrades system performance and is not the most cost effective either.
QST specializes in “Active Solutions” based on modulation techniques to spread the energy spectrum of periodic and aperiodic switching signals like clocks over a wider frequency band. This is an extremely effective way to combat these EMI compliance challenges and this article will be focused on this technology.

Statement of the problem:

What is EMI / RFI?

EMI / RFI quite simply put, is the emission of unwanted electromagnetic energy. This energy is the equivalent of electrical smog and if not tightly regulated can interfere with the operation of other equipment. EMI is not caused by a single source but is typically the result of some change in voltage or current. The higher the frequency of change and the larger the voltage or current change, the greater the EMI challenge.
For example, this switching waveform of a clock train can be viewed in the frequency domain as the sum of the frequency components of its Fourier decomposition. The amplitudes of these peaks are determined by the Voltage (amplitude), Duty cycle and Rise and Fall times of the signal.



A real world signal with finite Rise and Fall times t_r and t_f and Period T_0

The Fourier Series for a periodic signal f(t) can be expressed as

$$f(t) = \frac{a_0}{2} + \sum_{n=1}^{n=\infty}(a_n \cos n\omega_0 t + b_n \sin n\omega_0 t)$$

Figure 1 – Frequency Domain Representation of a Periodic Signal

The Fourier series of a periodic signal f(t) is given by

$$f(t) = \frac{(a_0)}{2} + \sum_{n=1}^{\infty} (a_n \cos n\omega_0 t + b_n \sin n\omega_0 t) \qquad \text{(Equation 1.1)}$$

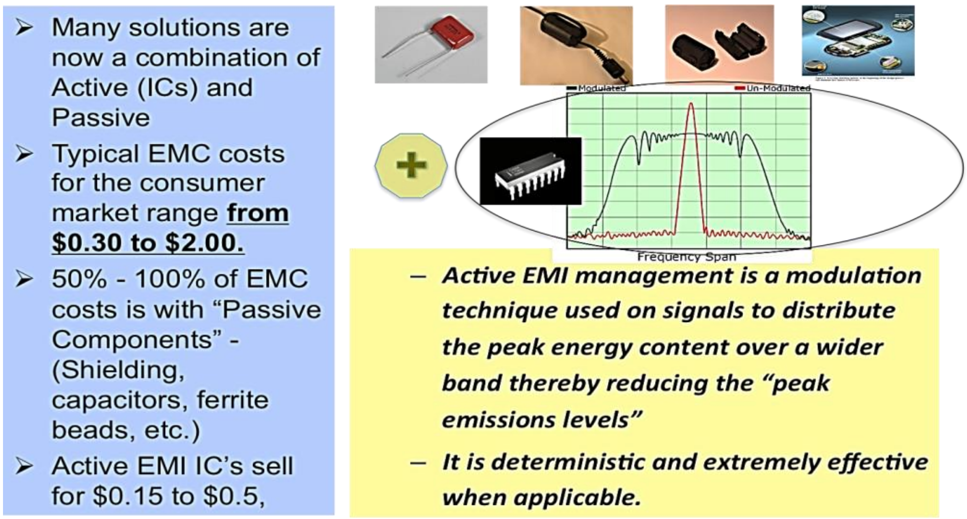
For a square wave this reduces to

$$f(t) = K(\sin\omega_0 t + \frac{\sin 3\omega_0 t}{3} + \frac{\sin 5\omega_0 t}{5} + \frac{\sin 7\omega_0 t}{7} \ldots\ldots) \qquad \text{(Equation 1.2)}$$

(For the purpose of this discussion we assume a 50% duty cycle with rise and fall times tending to “0”.)

As can be seen, this is a series of sinusoids of the odd harmonics of the fundamental frequency ω_0 and can be depicted in the frequency domain as shown above in Figure 1.
These energy peaks are the elements that compliance engineers battle.

Managing EMI / RFI



Current Solutions

Solutions today are plenty and can broadly be divided into these categories "**conventional**" and "**non-conventional**". The pros and cons of these are listed below.

(a) Conventional:

Passives: Chokes, Capacitors, Shields, Sprays, Multi-layer PCBs etc

Pros: Easy to use, very well known, point solutions

Cons: Degrade signal and compromise signal integrity, add weight, and bulk, "trial and error" approach, do not provide a system-wide benefit.

(b) Non-conventional:

Active solutions: "Dithering" and legacy (1st-Gen) SS technology.

Pros: Highly effective when applicable, system wide EMI / RFI benefit, deterministic.

Cons: Requires design-in and technical and architectural provisioning to use, not so well known, current generation (1st-Gen) not applicable to numerous applications especially timing sensitive ones and mobile platforms due to excessive, jitter, high power consumption and part-to-part variations.

What is Spread Spectrum Technology?

Spread Spectrum technology in the context of EMI reduction is a method of distributing or spreading the energy concentrated in a narrow band of frequency over a wider band thereby effectively reducing the peak energy levels. This is done in many ways but the basic concept is some form of frequency modulation of a periodic signal.

This is not a new concept and the basic principle is described briefly below

If a sinusoidal signal of frequency fc is frequency modulated by a sinusoidal signal of frequency fm (modulation rate) by a maximum amount Δf the resulting spectrum of the modulated signal is comprised of the carrier frequency and sidebands spaced at intervals of fm over the frequency band Δf

Mathematically, the instantaneous frequency of the modulated carrier can be represented as

$f(t) = f_c + k_f * m(t)$ (Equation 2.1)

where m(t) is the modulating waveform and kf is the frequency sensitivity (Hz/V)

$m(t) = A_m \cos(2\pi f_m t)$ (Equation 2.2)

$f(t) = f_c + k_f * A_m \cos(2\pi f_m t)$ (Equation 2.3)

(Replacing $\Delta f = k_f * A_m$)

$f(t) = f_c + \Delta f * \cos(2\pi f_m t)$ (Equation 2.4)

The instantaneous angle of this modulated wave is given by

$\Theta(t) = \int_0^t (2\pi f(t) dt)$ (Equation 3.1)

$\Theta(t) = 2\pi f_c * t + \frac{(\Delta f)}{f_m} * \sin(2\pi f_m t)$ (Equation 3.2)

We define the ratio of the maximum frequency deviation (Δf) to the modulation rate fm as the Modulation Index β.

$\beta = \frac{(\Delta f)}{f_m}$ (Equation 3.3)

$\Theta(t) = 2\pi f_c * t + \beta * \sin(2\pi f_m t)$ (Equation 3.4)

From equation 3.2 we see that β represents the maximum phase deviation of the FM wave from that of the carrier phase angle.

The FM wave can be represented as

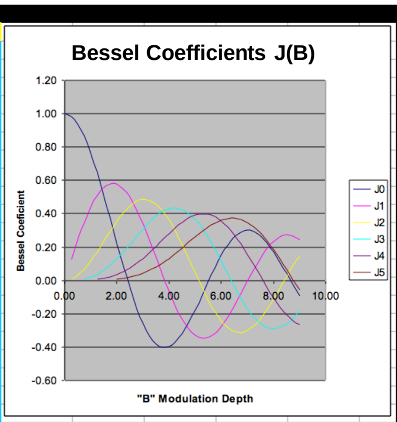
$s(t) = A_c \sin\{\Theta(t)\}$ (Equation 5.1)

$s(t) = A_c \sin\{2\pi f_c * t + \beta * \sin(2\pi f_m t)]$ (Equation 5.2)

This can be evaluated as the Bessel series

$$
\begin{aligned}
s(t) = A_c [\, J0(\beta)\sin(2\pi f_c t) &+ J1(\beta)\{\sin(2\pi f_c + 2\pi f_m)t - \sin(2\pi f_c - 2\pi f_m)t\} \\
&+ J2(\beta)\{\sin(2\pi f_c + 2*2\pi f_m)t - \sin(2\pi f_c - 2*2\pi f_m)t\} \\
&+ J3(\beta)\{\sin(2\pi f_c + 3*2\pi f_m)t - \sin(2\pi f_c - 3*2\pi f_m)t\} \\
&+ J4(\beta)\{\sin(2\pi f_c + 4*2\pi f_m)t - \sin(2\pi f_c - 4*2\pi f_m)t\} \\
&+ \ldots \text{etc.}]
\end{aligned}
$$
(Equation 6.1)

β	J0	J1	J2	J3	J4	J5
0.00	1.00					
0.25	0.98	0.12	0.01			
0.50	0.94	0.24	0.03			
0.75	0.86	0.35	0.07	0.01		
1.00	0.77	0.44	0.11	0.02		
1.25	0.65	0.51	0.17	0.04	0.01	
1.50	0.51	0.56	0.23	0.06	0.01	
1.75	0.37	0.58	0.29	0.09	0.02	
2.00	0.22	0.58	0.35	0.13	0.03	0.01
2.25	0.08	0.55	0.40	0.17	0.05	0.01
2.50	-0.05	0.50	0.45	0.22	0.07	0.02
2.75	-0.16	0.43	0.47	0.26	0.10	0.03
3.00	-0.26	0.34	0.49	0.31	0.13	0.04
3.25	-0.33	0.24	0.48	0.35	0.17	0.06
3.50	-0.38	0.14	0.46	0.39	0.20	0.08
3.75	-0.40	0.03	0.42	0.41	0.24	0.10
4.00	-0.40	-0.07	0.36	0.43	0.28	0.13
4.25	-0.37	-0.16	0.30	0.43	0.32	0.16
4.50	-0.32	-0.23	0.22	0.42	0.35	0.19
4.75	-0.26	-0.29	0.13	0.40	0.37	0.23
5.00	-0.18	-0.33	0.05	0.36	0.39	0.26



As can be seen this modulation results in

(1) An infinite number of sidebands centered around the carrier 2πfc and spaced at intervals of 2πfm, where fm is the modulation frequency.

(2) The amplitudes of the modulated carrier and the corresponding sidebands are given by Ac*J(β)

Sinewave modulation on a Real World Clock.
The peak amplitude of the harmonics are supressed.
ΔE dB spression at the fundamental.

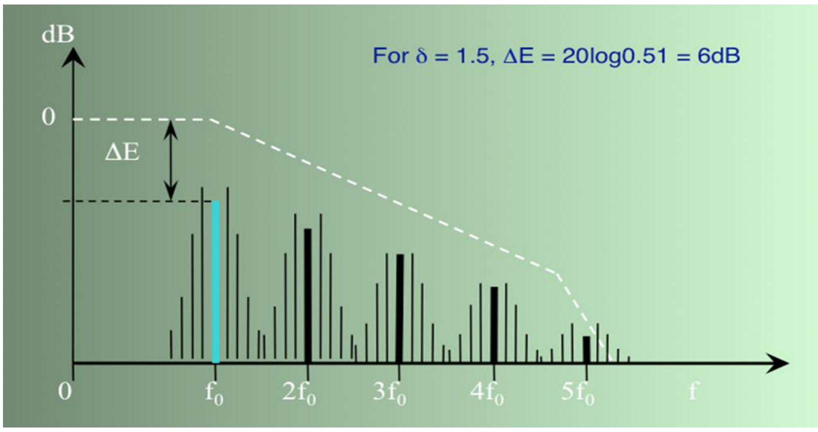
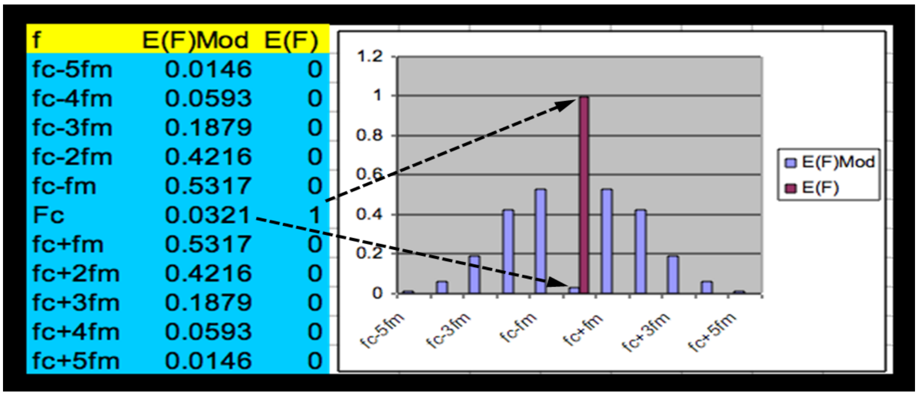


Figure 2 – Frequency Domain Representation of a Sinusoid Modulated Periodic Signal

This is illustrated in the example below.
Let fc = 10MHz, fm = 32kHz, (Δf) = 75kHz, β = (75/32) = 2.34
The amplitudes of the carrier frequency and the sidebands introduced by the modulation are shown below.
As can be seen, the carrier energy component is reduced to 3% of its original value.



f	E(F)Mod	E(F)
fc-5fm	0.0146	0
fc-4fm	0.0593	0
fc-3fm	0.1879	0
fc-2fm	0.4216	0
fc-fm	0.5317	0
Fc	0.0321	1
fc+fm	0.5317	0
fc+2fm	0.4216	0
fc+3fm	0.1879	0
fc+4fm	0.0593	0
fc+5fm	0.0146	0

This redistribution of the energy will also carry through to all harmonics of the carrier frequency. This method has proven to be very effective.

However it does have its limitations, which are revisited below.
Limitations: Not easy to use, requires architectural change, cannot be used in timing-sensitive applications demanding functional compliance and "logo Certification" like USB, HDMI and others.

It is these limitations that have been the driving force behind QST technology based on the Phase Modulation techniques and addresses the numerous limitations of 1st-Gen technology.

Technology Comparison Chart

Comparison	QST Phase Modulation (Active Solution)	Generation 1	Passive Solution
EMI Reduction	*O* system wide	*O* system wide	*X* point solution
Power Consumption	*O* low	*X* high	N/A
Signal Integrity	*O* no impact	*O* no impact	*X* degrades
System Compliance	*O* possible	*X* challenging	possible
Part-to-Part Variation	*O* minimal	*X* high	*O* minimal
Ease of Use	design-in	design-in	*O* drop in
Predictability	*O* predictable	*O* predictable	*X* trial and error

Summary

EMI and RFI can be managed using passive as well as “active” components and the solution is usually a combination of the two. 1st-Gen Active EMI technology is effective but limited in its application to today’s challenges. QST technology is a revolutionary approach to EMI management and offers all the benefits of 1st-Gen technology and can now be used easily and effectively in systems that were once excluded due to performance degradation and functional failures. This technology will enable engineers to push the limits of system performance, confident that they now have flexible, compact, highly effective and cost effective “active EMI” solutions available to them now.