Electrophysiology Lab EMI/RFI Issues

& Mitigation Solutions

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EEGs (electroencephalograph) record the electrical activity of the brain measured at the scalp with electrodes. EEGs operate in the microvolt (μV) range and are very susceptible to EMI from elevated electric and magnetic field emissions. There are two (2) types of input coupling (AC or DC) at the EEG input buffer / instrumentation amplifiers: AC coupled EEGs have better low frequency quasi-static DC noise immunity because the input buffer / instrumentation amplifiers have isolation capacitors limiting the electrode signal bandwidth to 0.1 Hz to 1000 Hz; and, DC coupled EEGs do not have isolation capacitors and therefore the frequency range is DC (0 Hz) to 1000 Hz. DC coupled EEGs are more susceptible to quasi-static DC EMI sources (ie. moving vehicles, elevators and any adjacent trains). Radio Frequency Interference (RFI) can be a problem when the RF source is in close proximity (less than 1 m) to EEG headsets, cables and EEG processors; however, EEGs provide built-in RFI filters at the inputs to attenuate spurious and intentional RFI signal noise.

Common to all impedance electrode and lead based diagnostic medical instruments, (i.e., EEGs, EKGs, EMGs, etc.), the patient, the electrodes and the leads become a complex antenna system susceptible to electromagnetic interference (EMI) from ambient alternating current (AC) power line 50/60 Hz and higher harmonic magnetic field emissions. Interior building electrical distribution systems and external primary distribution / transmission systems generate time-varying AC magnetic fields that couple with any conductive object including wires, electronic equipment and people, thereby inducing circulating currents and voltages due to electromagnetic induction. Electromagnetic induction will generate signal noise in the lead wires and input amplifiers of electrophysiology instruments (i.e., EEGs, EKGs, EMGs, etc.) when the ambient magnetic flux density level is above the EMI susceptibility threshold of 1 milligauss (mG) peak-to-peak (p-p) compromising data collection and signal integrity. An appropriately designed six-sided AC magnetic shield will attenuate (reduce) the time-varying AC magnetic fields levels to below 1 mG p-p EMI threshold permitting an optimal environment for recording electrophysiology data.

Elevated ambient quasi-static DC magnetic fields and AC ELF magnetic fields from moving ferromagnetic masses (i.e., elevators, trains, metal carts, etc.) and unshielded building electrical sources will produce challenging EMI issues with EEGs due to electromagnetic induction: induced currents and voltages on EEG electrodes, signal cables, input buffer / instrumentation amplifiers and analog signal processing circuits because of magnetic field coupling. This magnetically induced "noise" will appear on the recorded EEG signals compromising signal integrity and limiting critical information. Most EEGs have either passive or active digital notch filters to remove unwanted 50/60 Hz power frequency noise, but these filters can remove important Gamma Band (32 to 100 Hz) data as shown in the EEG Brain Wave Band Frequencies in Table 1:

Table 1: EEG Brain Wave Bands

Brain Wave Type	Frequency Band
Delta Wave	0.1 Hz – 3 Hz
Theta Wave	4 Hz to 7 Hz
Alpha Wave	8 Hz to 15 Hz
Mu Wave	7.5 Hz to 12.5 Hz
SMR Wave	12.5 Hz to 15.5 Hz
Beta Wave	16 Hz to 31 Hz

Six-sided thick seam welded highly conductive shielding plate AC ELF magnetic shielded EEG rooms attenuate the 50/60 Hz and higher harmonic component magnetic fields to 0.1 mG p-p and less in the Bx, By and Bz axis measured from 0.5 m to 2.5 m elevation at the center of the shielded room and 0.5 m from the shielded walls except at the shielded door. When properly grounded, the six-sided shielded EEG room is electrically grounded and RF emissions (i.e., electric field, plane wave and microwave) will be attenuated by more than -30 dB to – 40 dB (field reduction of 31 to 100) depending on the RF source / device location, frequency and effective radiated power (ERP). Actual RF attenuation will be limited without proper Penetration Controls discussed in the next section and the AC ELF magnetic shielded EEG rooms will be "leaky RF shielded rooms" by definition.

Flourescent ballasts, in EEG rooms, can generate RFI as do many of the new LED low energy lighting systems. Remote ballast placement outside of the AC ELF magnetic shielded room will significantly reduce the RFI impact within the EEG shielded room. LED lighting may require EMI/RFI testing to document the frequency and field strength emissions to verify EMC listed product specifications.

RF Shielded Enclosure Requirements & Issues

RF shielded enclosures must have all surfaces covered with conductive (i.e., copper, aluminum, galvanized steel, etc.) and / or ferromagnetic (i.e., low carbon steel, silicon-iron, annealed nickel-iron alloy, etc.) metal layer(s) composed of plates, sheets, foils or mesh. All metal joints must be conductively bonded (i.e., welded, braised, soldered) or mechanically secured forming a contiguous conductive metal layer. All Penetration Controls listed below must be conductively bonded or mechanically secured with RF gaskets to the contiguous conductive metal layer and the RF shielded enclosure single point grounded. Finally, the RF shielded enclosure design specification must list the operational bandwidth (i.e., 14 kHz to 1 GHz or 10 GHz), required Shielding Effectiveness (SE) in units of decibel (i.e., -60 dB for Mission Critical Rooms and -90 dB and higher for MRIs and sensitive RFI research instrumenta-

tion) and include performance testing after construction according to the IEEE 299-2006 *Standard Method for Measuring the Effectiveness of Electromagnetic Shielding Enclosures* with calibrated, professional grade RF equipment.

All RF Shielded Enclosures Require Penetration Controls

1. RF shielded doors & RF shielded windows (10 dB higher than shield);
2. RFI power filters - single or three phase (i.e., 20 amp to 400 amp max);
3. RFI signal filters (i.e., telephone, fire alarm, data, control, signal, etc.);
4. Honey Comb RF HVAC Filters (i.e., supply & return);
5. WBC (waveguide-before-cutoff) pipe penetration filtering devices for MEP support services (ie. sprinklers, pipes, drains,
6. gasses, etc.); and,
7. RF gaskets with supplemental RF conductive tape to ensure a fully RF sealed enclosure.

RF EEG Shield Performance Plus RF Penetration Controls

Depending on the RF source / device location, frequency and effective radiated power (ERP) in reference to the six-sided thick seam welded highly conductive shielding plate AC ELF EEG shielded room without RF Penetration Controls, the predicted RF electric field strength attenuation should be over -40 dB (field reduction of 100) with the EEG room door covered with plate. **Without the appropriate RF Penetration Controls, the six-sided 1/4" thick shielding plate seam welded AC ELF magnetic shielded EEG room will be considered a "leaky RF shielded room" and not compliant with the RF testing protocols in IEEE 299-2006 *Standard Method for Measuring the Effectiveness of Electromagnetic Shielding Enclosures.***

Appropriate RF Penetration Controls can be added to the EEG AC ELF magnetic shielded room to provide a professionally designed combined AC ELF magnetic and fully IEEE-299 compliant RF shielded EEG room. A combined AC ELF/RF shielded room would include RF Penetration Controls (i.e., RF door, honey comb filters, WBC penetrations, gaskets, RF tape, etc.) plus RFI power and signal filters. This combined AC ELF / RF shielded EEG room will achieve full RF compliance to performance bandwidth and attenuation specifications. Final RF shielding performance requires RF testing according to the IEEE 299-2006 *Standard Method for Measuring the Effectiveness of Electromagnetic Shielding Enclosures.*

Table 2: Electric & Magnetic Field Shielding Performance

Magnetic Fields[a]	10 -20 dB @ 10HZ - 30Hz
	20 - 40 dB @ 30 - 3,000 Hz
	60 - 80 dB @ 10kHZ - 500 kHz
	80 dB @ 500 kHZ - 1GHz
Electric Fields[b]	30 - 50 dB @ 10Hz - 1 kHz
	50 - 70 dB @ 1jHz - 10kHz
	70 dB @ 10kHz - 1GHz
	70-90 dB 1GHz - 10GHz

a. RF attenuation depends on penetration type and quantity and RF filtering devices.
b. RF attenuation depends on penetration type and quantity and RF filtering devices.