

## Clock Synchronization for MRI Recordings

In order to remove the extremely high voltage scanner artifact in EEGs recorded in the magnet, it is essential to capture the scanner triggers accurately (the triggers mark the beginning of the TR Blocks, Slices, or sequences). One way to do this is to use very fast sampling rates, such as, 10,000Hz, which is the approach we had been taking until recently. Another method is to use precise clock synchronization, where the clock controlling the amplifiers is synchronized with the scanner clock. These operate at different frequencies, so it can be challenging to synchronize them precisely. We have met that challenge, and we are pleased to announce that clock synchronization is now available.

What does this mean in terms of our MagLink systems? First, with precise synchronization, there is no need to use the fast AD Rates. There is nothing to be gained from using AD Rates beyond 500Hz or 1000Hz, unless of course the faster AD Rates are needed to resolve the fast EEG frequencies of interest. The lower AD Rates results in smaller file sizes, and more rapid analysis. Synchronization also greatly simplifies our fMRI Artifact Reduction algorithm, eliminating the need for the correlation correction and decimation (as well as the low pass filtering to avoid aliasing). Clock synchronization is a more accurate way to capture the scanner triggers, and the result is a cleaner gradient artifact suppression. Most simply stated, you will be able to acquire data in the magnet using the same AD Rates you would use outside the magnet, and the scanner artifact will be removed more accurately and easily with greater effectiveness.

By way of an example, EEG was recorded in a Philips 3T magnet during a standard echo-planar gradient sequence. Stimuli were checkerboard flashes, presented at a rate of 7-8Hz. The intent was not to create VEPs, but rather to induce an obvious driving response or entrainment in the EEG recording. EEG data were obtained with a sampling rate of 500Hz.

The figures below show the EEG data before and after the scanner artifact was removed. The red 5's along the bottom indicate the start of each TR Block. The blue 1's are the stimulus presentations. The large voltages seen on the right side in Figure 1 are due to the amplitude of the artifact and to DC offsets.

The main feature to note is the effective real-time removal of the scanner artifact using clock synchronization (Figure 2). The stimuli were presented to induce a recognizable change in the recordings, and this can be clearly seen.

The color display at the bottom of Figure 2 shows the results of the Continuous Wavelet Transform (CWT), where the power analyses for a selected channel (CP3) are shown over time. Frequency is represented on the y-axis and signal intensity is denoted from weak to strong by color changes from blue to white. Note the frequency specific increase at approximately 8Hz that occurs about 1.5 secs after the stimuli are presented, and continues throughout the rest of the displayed interval (the long, narrow, pink-white band). This is simply a verification that the EEG data are genuine.

Click [here](#) to see a video showing the data files in more detail.

See also the **Additional Validation Recordings** section below.

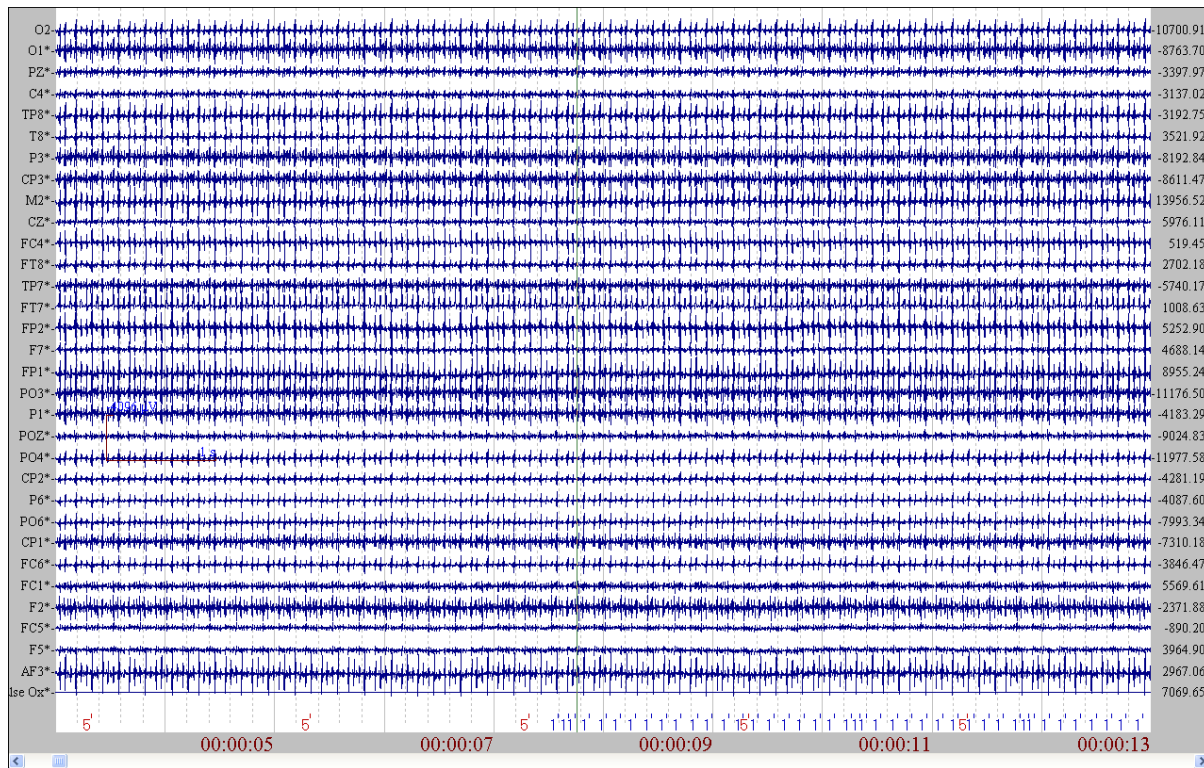


Figure 1. Raw Scanner Artifact

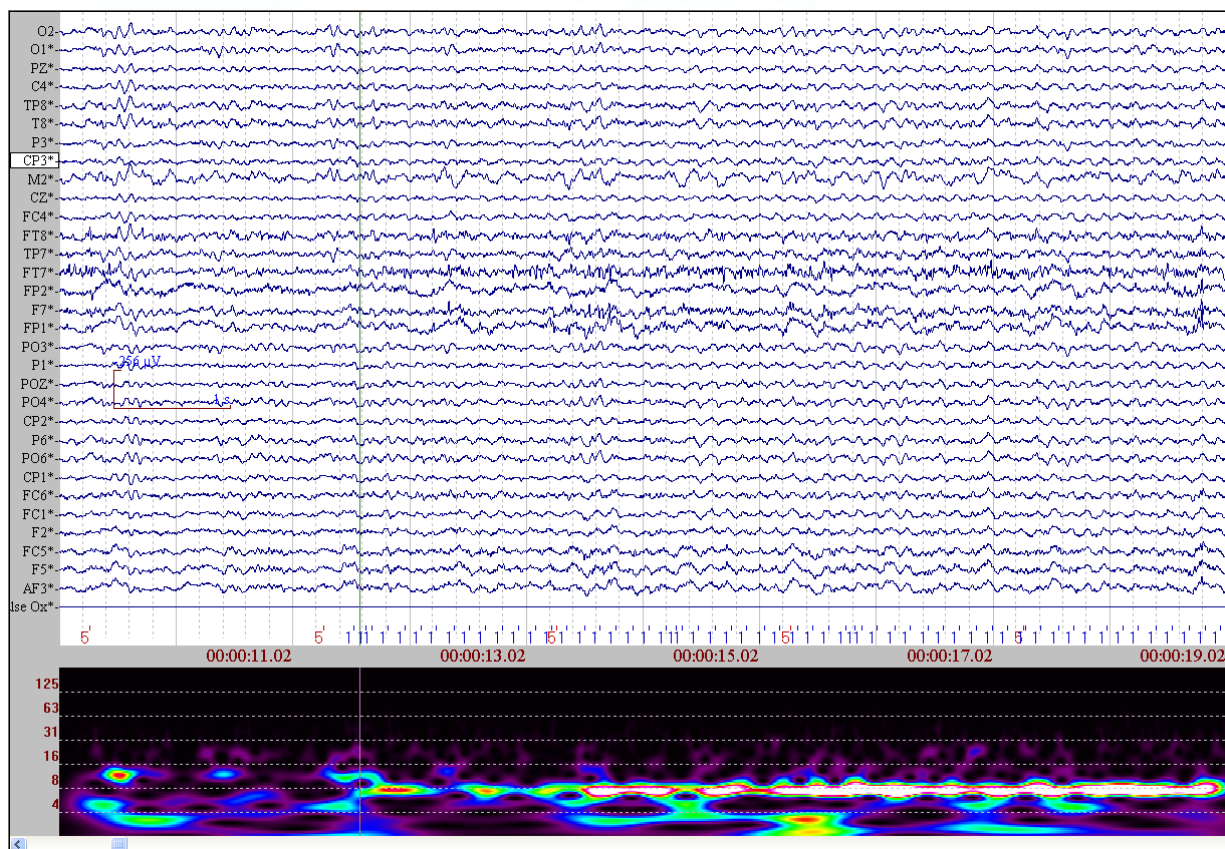


Figure 2. EEG Post Correction

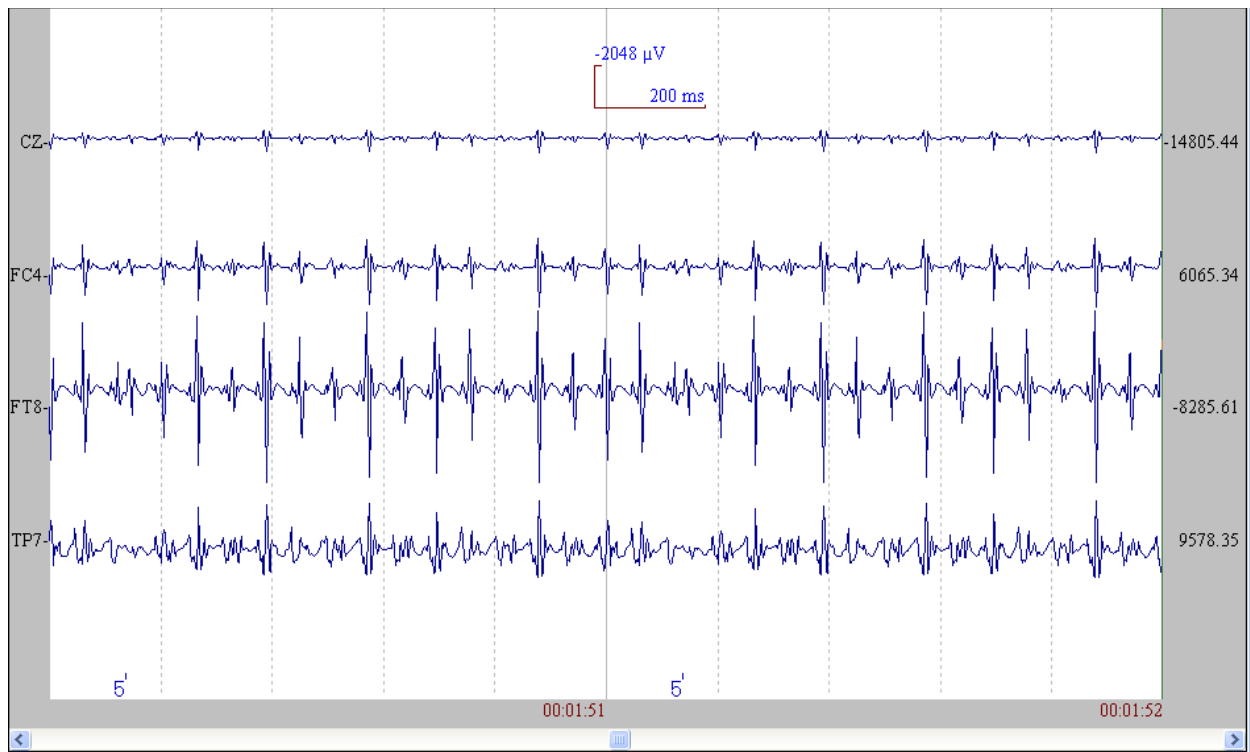
Clock synchronization has been found to be extremely effective, using “normal” sampling rates (e.g. 500 Hz for this example), in capturing the scanner triggers precisely and removing the sequencing artifact as shown for real-time correction in this example. It represents the latest advance in our development of the MagLink System. Thus far, testing has included Philips and Siemens 3T magnets.

Existing MagLink Systems with SynAmps RT amplifiers may be upgraded to include the clock circuitry (hardware upgrade). Contact [sales@neuroscan.com](mailto:sales@neuroscan.com) for details. New systems will have scanner-amplifier clock-synchronization capabilities included automatically.

## Additional Validation Recordings

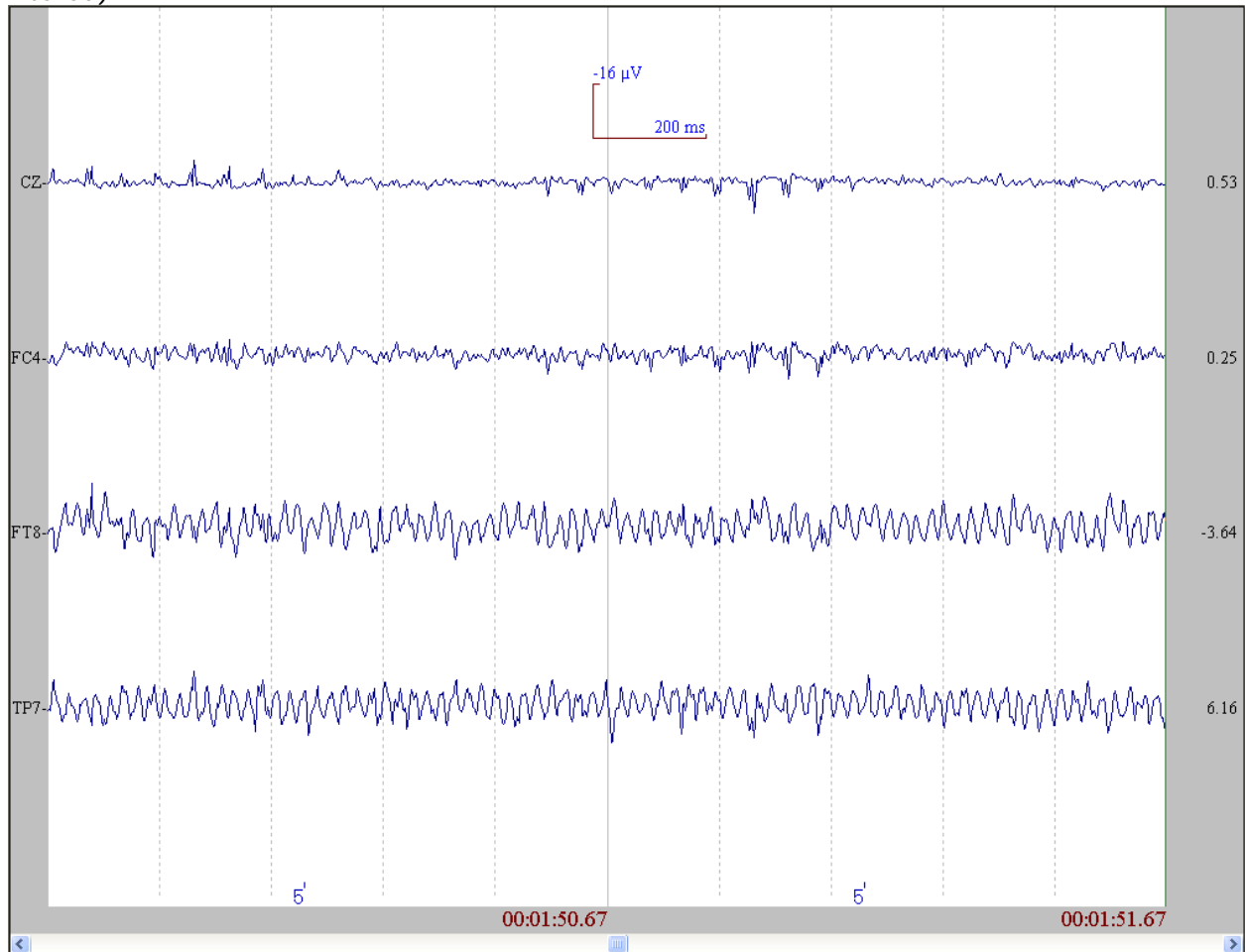
Further validations of the clock synchronization recordings were made using a honey dew melon for the subject. The melon provides a “phantom” head with electrical impedances similar to those recorded from a human head. Use of this “phantom” provides a realistic measure of recording conditions with levels of gradient artifact comparable to that obtained from human subjects, but without biological/physiological signals such as EEG, myogenic activity, and ballistocardiogram. Recordings were made with clock synchronization off and on, sampling the data with a 500Hz AD rate.

Shown in Figure 1 is an example of the raw scanner artifact recorded from the melon (2secs displayed). This provides a realistic view of the artifact, with no “signal” (no biological EEG) in the recordings. The large voltages seen on the right are due to the amplitude of the artifact plus the DC offsets.



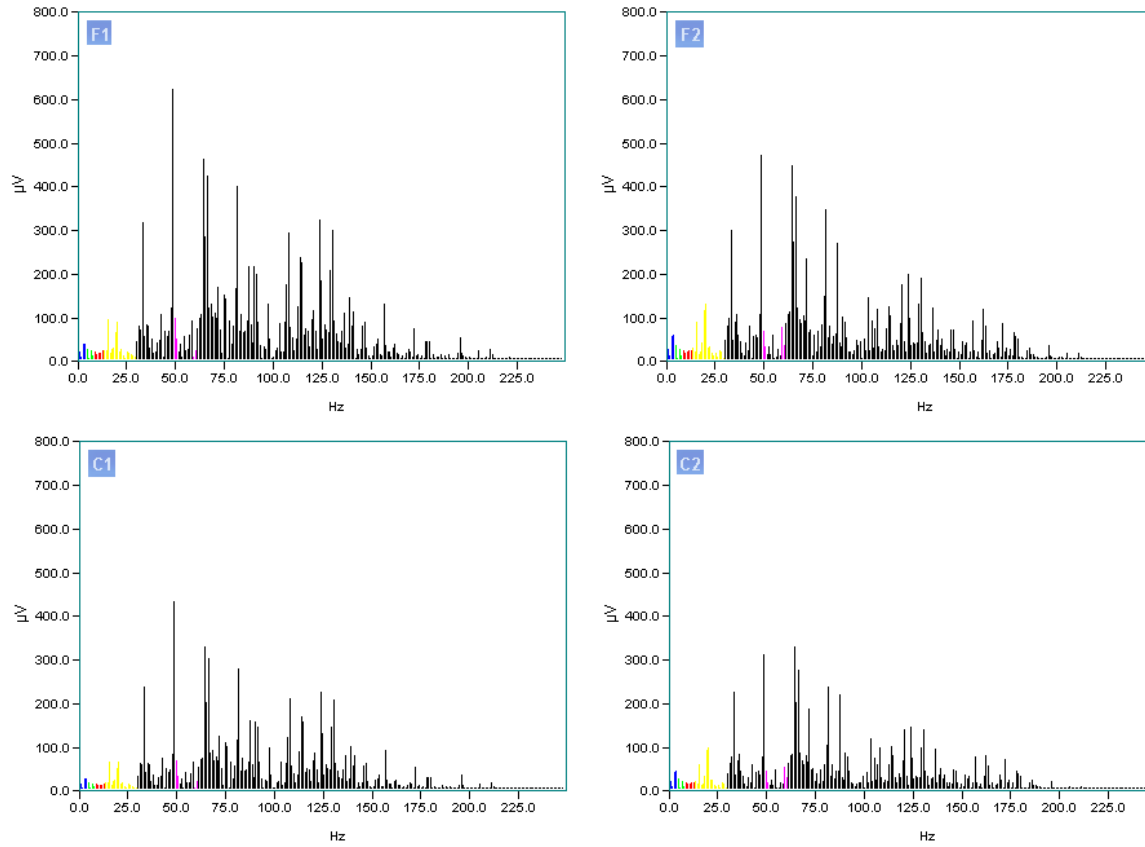
**Figure 1. Raw Scanner Artifact recorded from honey dew melon.**

The next figure shows the corrected data from the melon (clock on, pump off, high pass filtered).



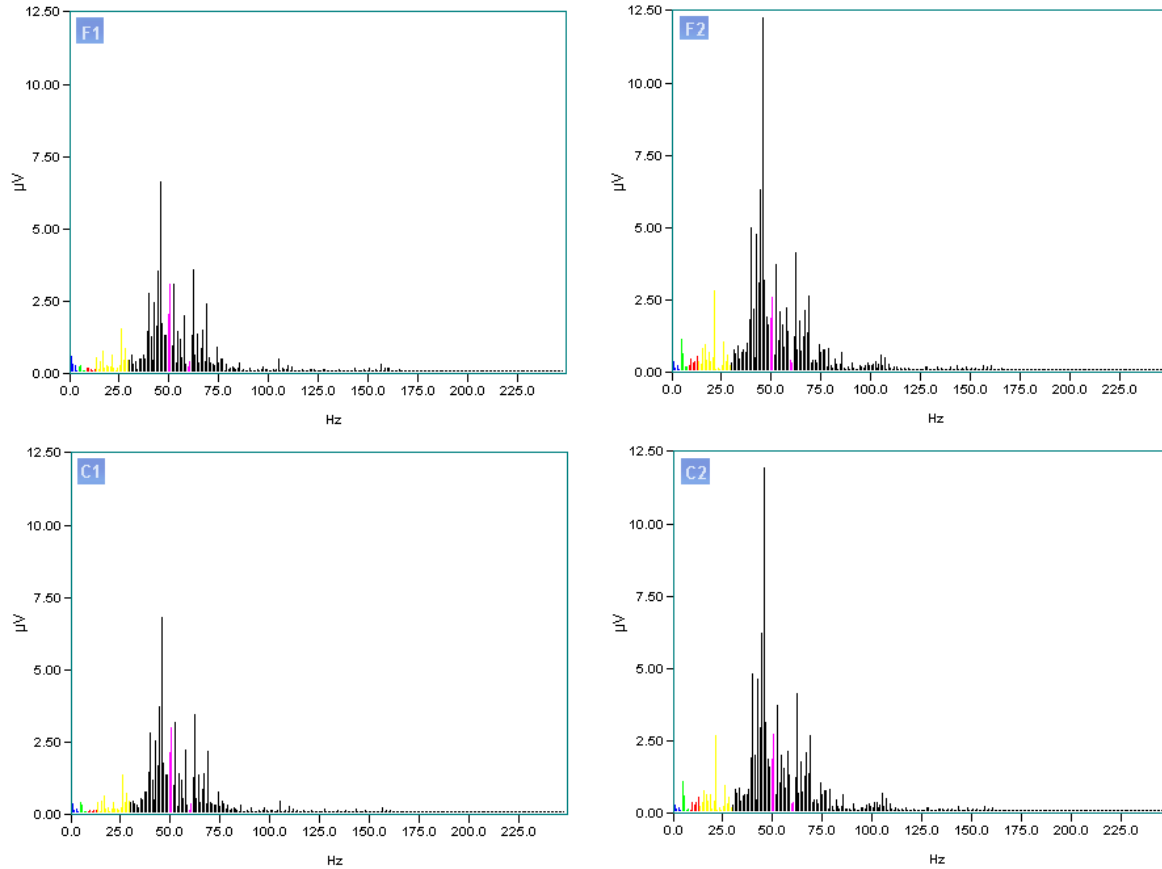
**Figure 2. Corrected data, clock on.** The scanner artifact was removed. High pass filtering was applied to remove the DC offset. Note the low voltage of the residual artifact.

Back to back epochs were created from the continuous data files, the epoched files were baseline corrected to remove DC offsets, and sweep-by-sweep FFTs were computed. Representative channels from a single representative sweep (100th sweep) are shown below.



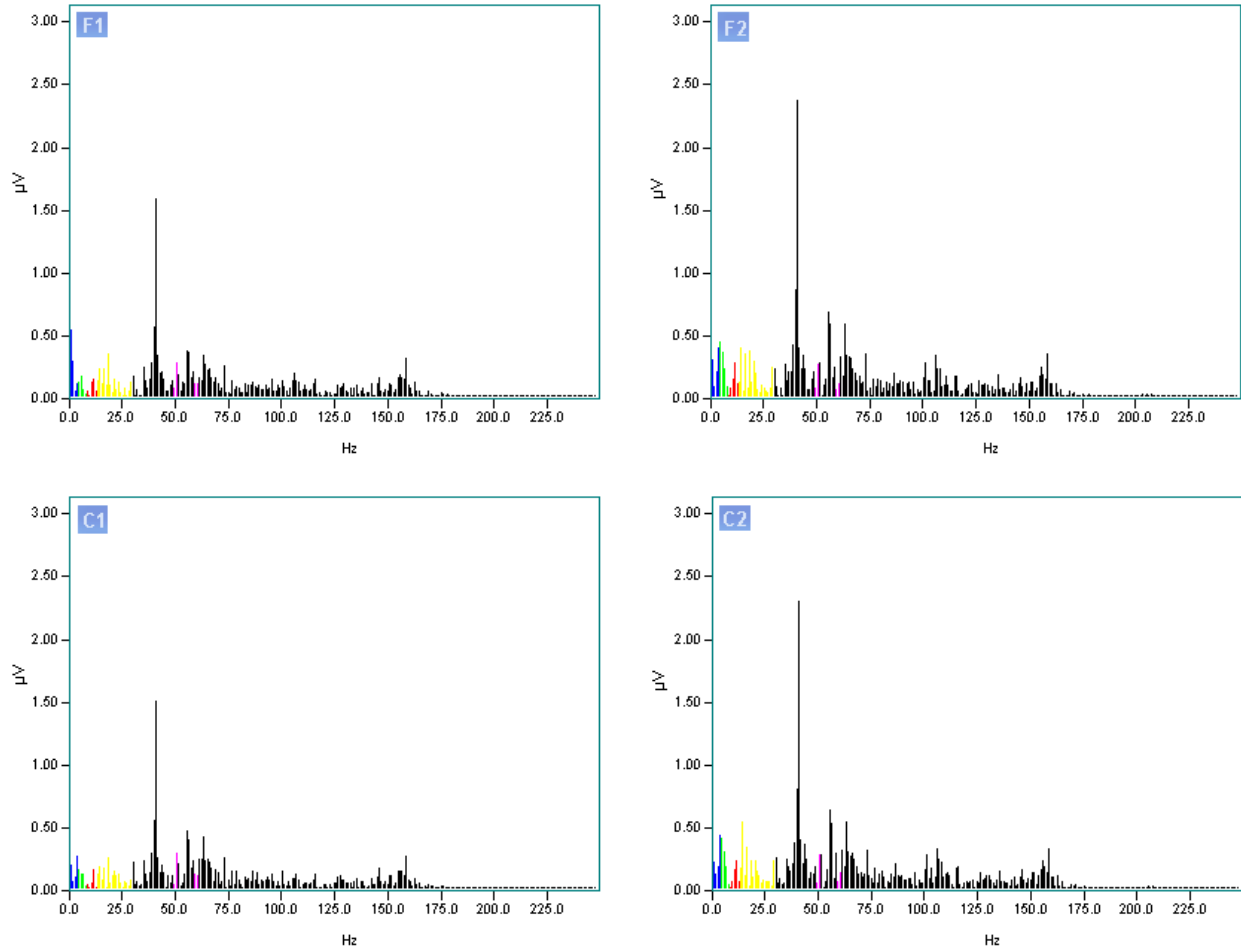
**Figure 3. Clock Off, Uncorrected.** Note the broad band noise and voltage scale (amplitude in some frequencies exceeded  $300\mu\text{V}$ ).

COMPUMEDICS  
*NeuroScan*



**Figure 4. Clock Off, Corrected.** Same file with the scanner artifact removed. Note the greatly reduced voltage scale. Nearly all frequency bands in all channels had amplitudes less than  $3\mu\text{Vs}$ . This particular scanner was showing a peak around 42Hz, which is something we typically do not see.

COMPUMEDICS  
*NeuroScan*



**Figure 5. Clock On, Corrected.** With the synch clock on, the amplitudes in nearly all frequency bins and from nearly all channels were less than  $0.5\mu\text{Vs}$ .

**Conclusions.** These results, as well as those from other recordings in other magnets, all indicate that the clock reduces the scanner noise and improves the recording markedly. The amplitude of the scanner artifact was generally below  $0.5\mu\text{Vs}$ .

The main purpose of these simulated recordings was to demonstrate that it is possible to obtain very low noise recordings (where there is no “signal”) when using clock synchronization. Click [here](#) to see a video with the complete data files.