NEUROGUIDE SIGNAL GENERATOR MANUAL AND TUTORIAL

(Sine Wave segments were selected for illustrative purposes only)

Introduction:

The signal generator is used to calibrate and test the digital signal processing properties of NeuroGuide as well as to serve as an educational program by which the principles of digital signal analyses can be learned and explored. Concepts such as frequency, time, phase delays, noise, amplitude and coherence can be tested and evaluated. EEG data can be simulated by approximating the selected mixtures of signals to match the signal parameters and scalp locations of the EEG.

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Step #1: Launch NeuroGuide and click File>Open>Signal Generation

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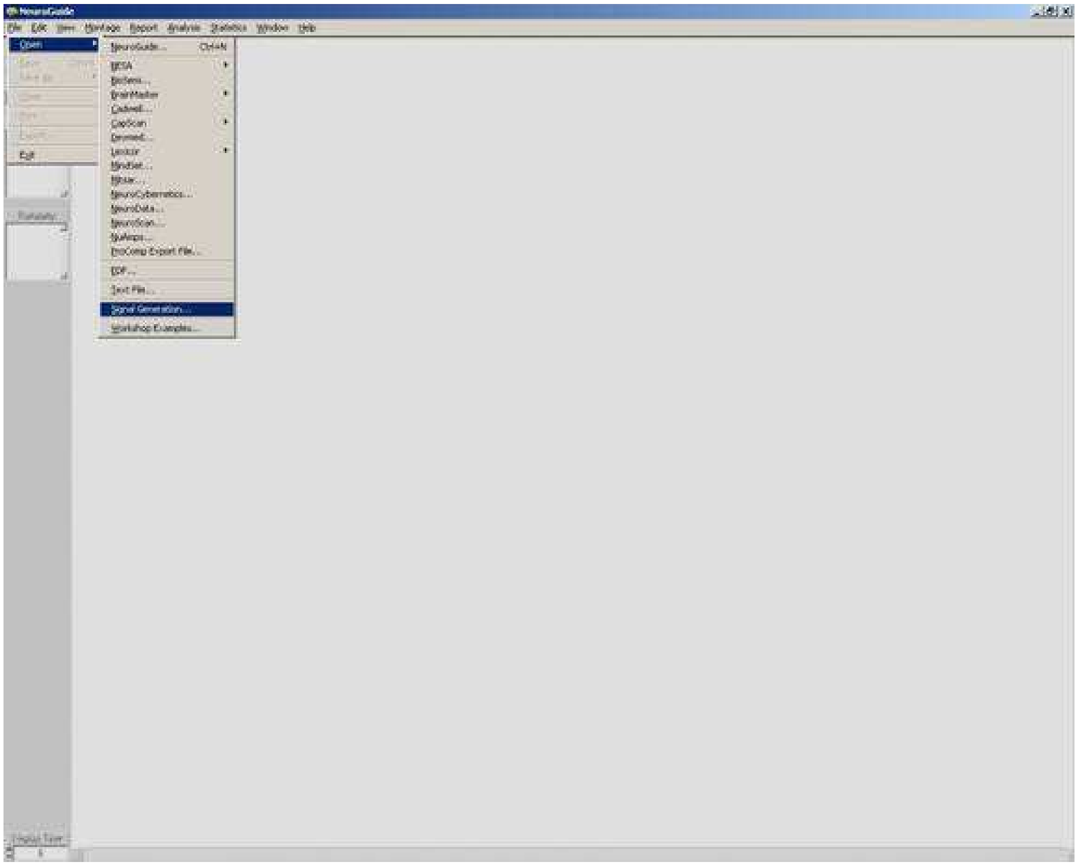

Step #2 - Use Mouse to Select EEG Channels, Waveforms (sine, sawthooth, square and pulses), Frequencies (1 to 30 Hz), Amplitudes (uV), Phase Delays (degrees) and "Noise" (% S/N ratio)

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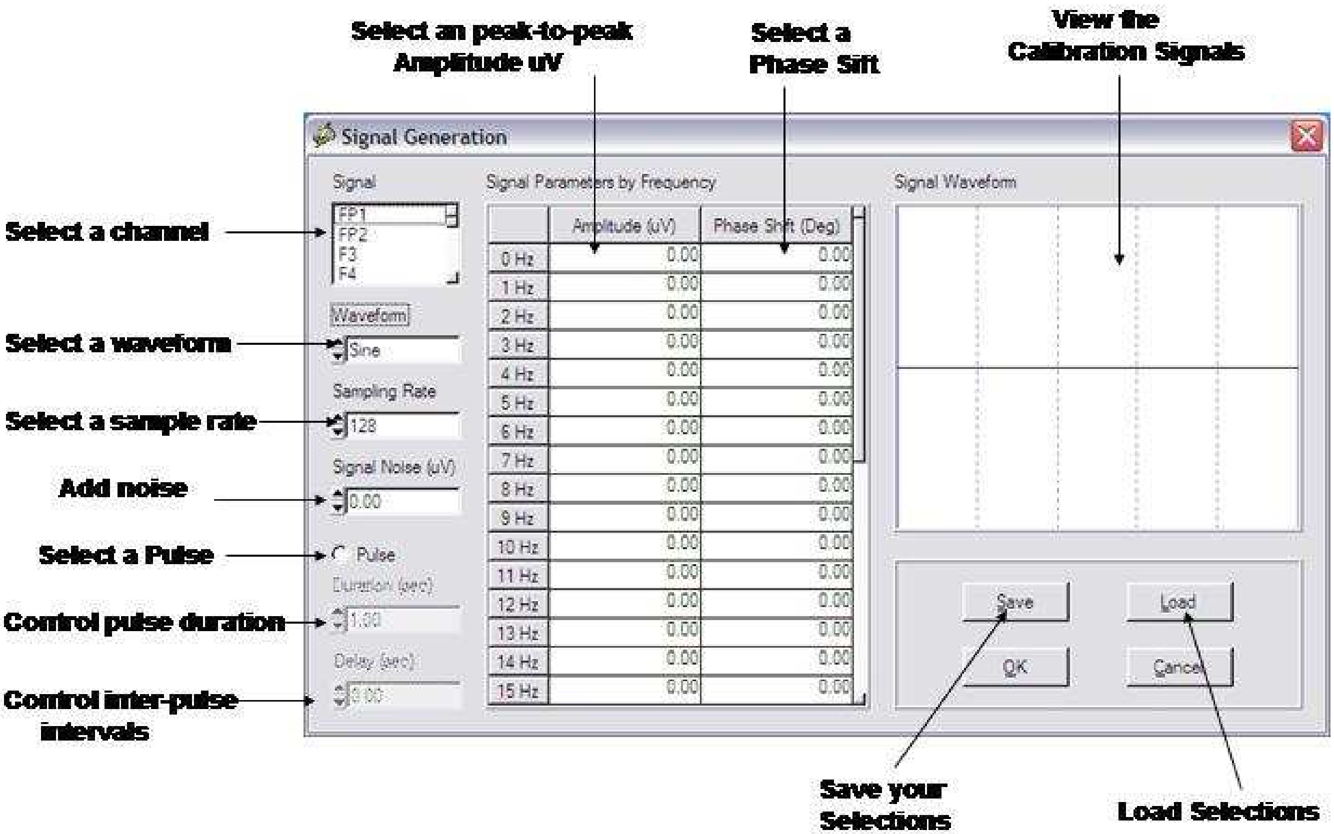
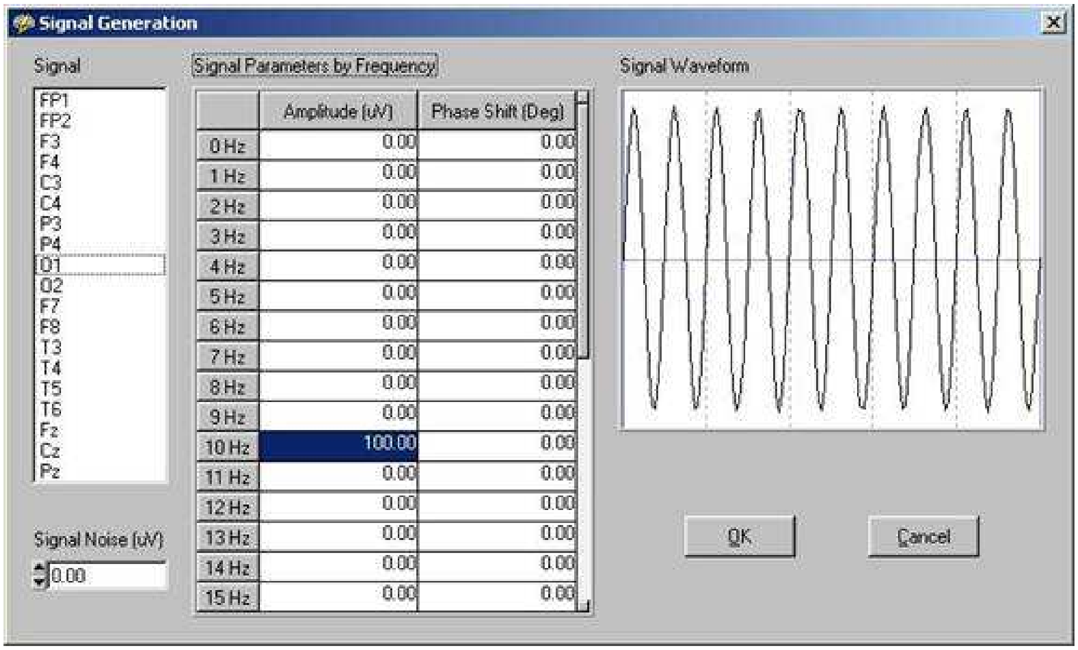
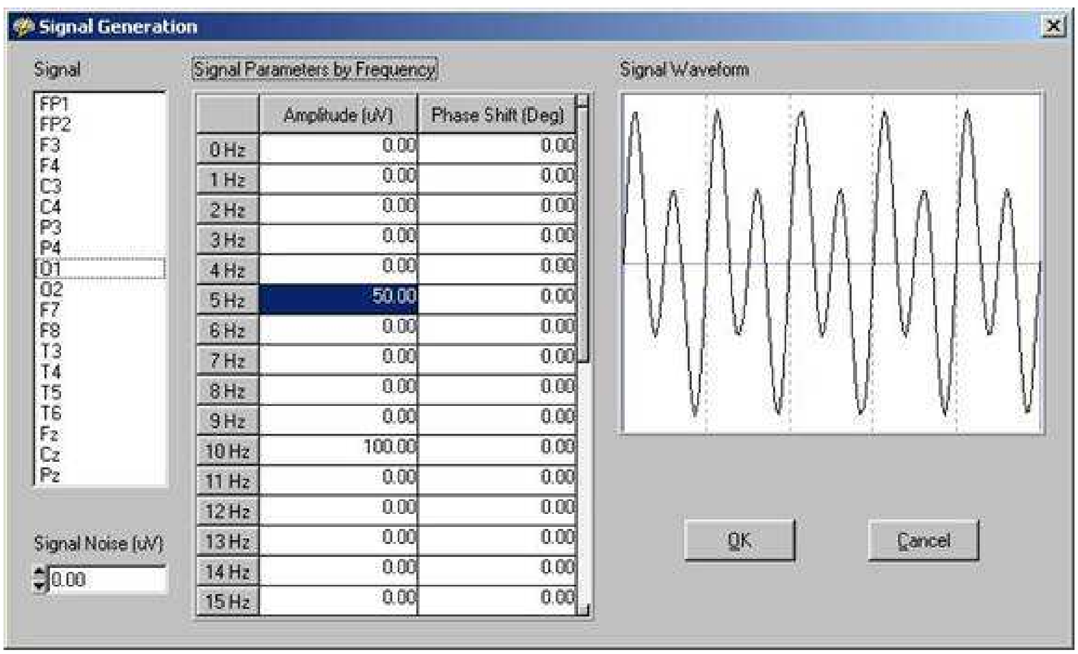


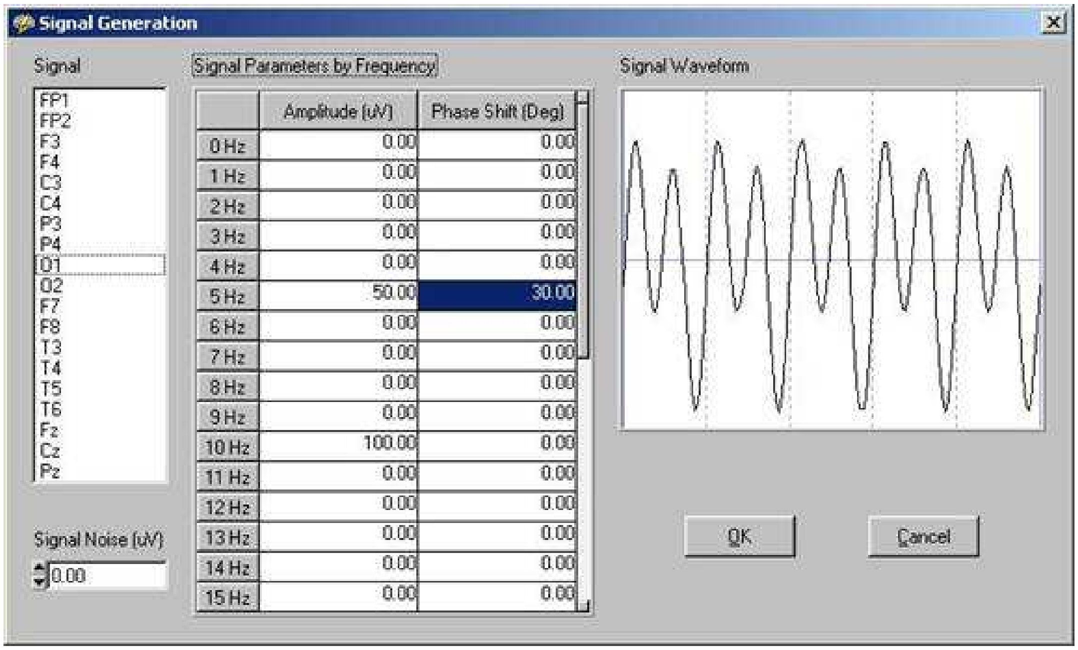
2a - Click a channel to select a location in Lexicor format (e.g., O1), then double click a Frequency (e.g., 10 Hz), then double click Amplitude (uV) and type in a value (e.g., 100 uV).



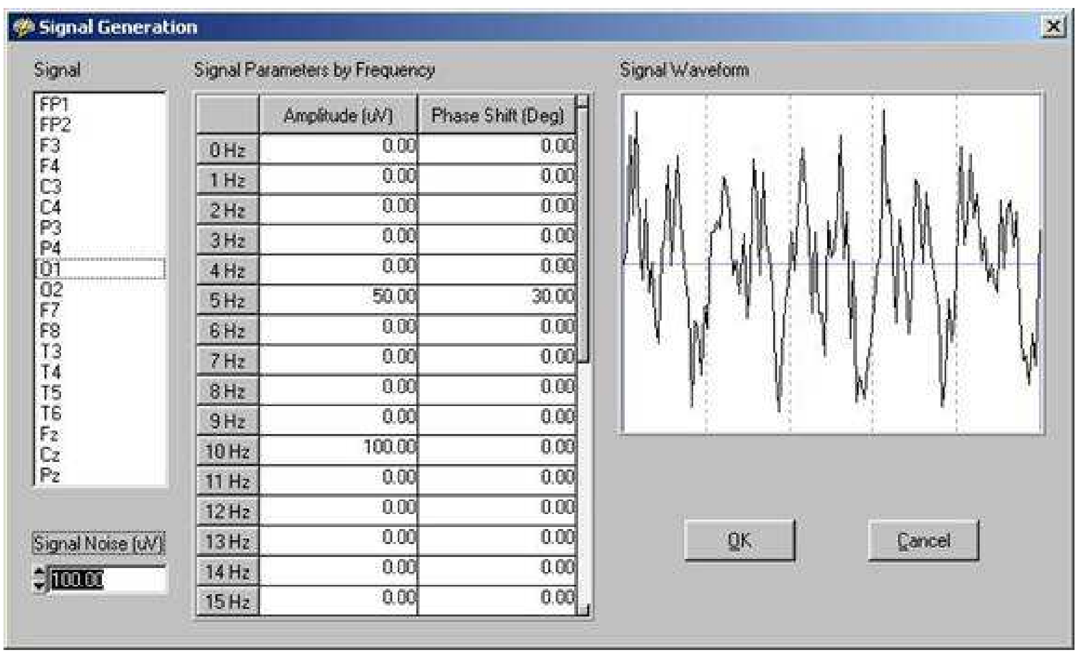
2b – Mix sine waves in by double clicking the amplitude of a different frequency, e.g., 5 Hz and type 50 uV.



2c – Shift the Phase of the 5 Hz signal by double clicking “Phase Shift (Deg)” at 5 Hz and type 30.



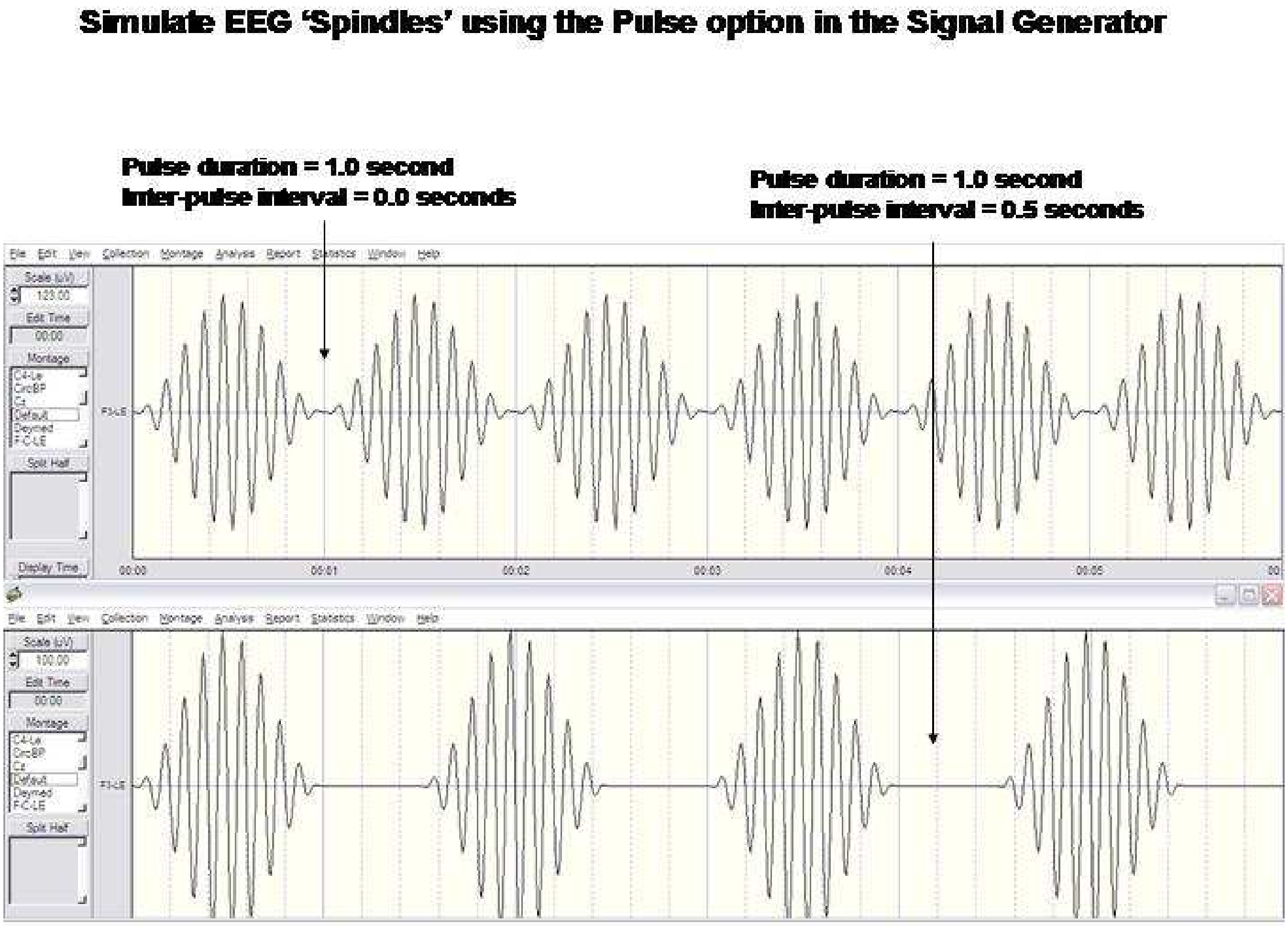
2d – Add "Noise" to the 5 Hz signal by double clicking the window below "Signal Noise (uV)" and type 100. This adds 100 microvolts of noise to the 5 Hz signal located at O1.



2e – Repeat Steps 2a to 2d for each channel with or without adding phase delays and/or noise or multiple frequencies, etc. Unselect any value by double clicking in the appropriate box and set the value = 0. The Channel is the primary selection and then the amplitude, frequency or mixtures of frequencies and phases and noise are the secondary selections.

Step #3 - Simulate EEG "Spindles" by selecting pulse and then select the frequency and amplitude of the intra-pulse structure, duration and inter-pulse intervals of the simulated spindles.

3a - Generate Pulses of different durations and inter-pulse intervals. Use this tool to simulate EEG "Spindles".



3b - Simulate any EEG by comparing the auto and cross-spectral values and then entering these values into the appropriate channels and appropriate parameter selection locations. Use the Signal Generator feature of NeuroGuide to learn about digital signal processing in general as well as various analytical programs including LORETA and other inverse solutions.

Step # 4- Click OK, then Click Edit>Select All to view FFT results

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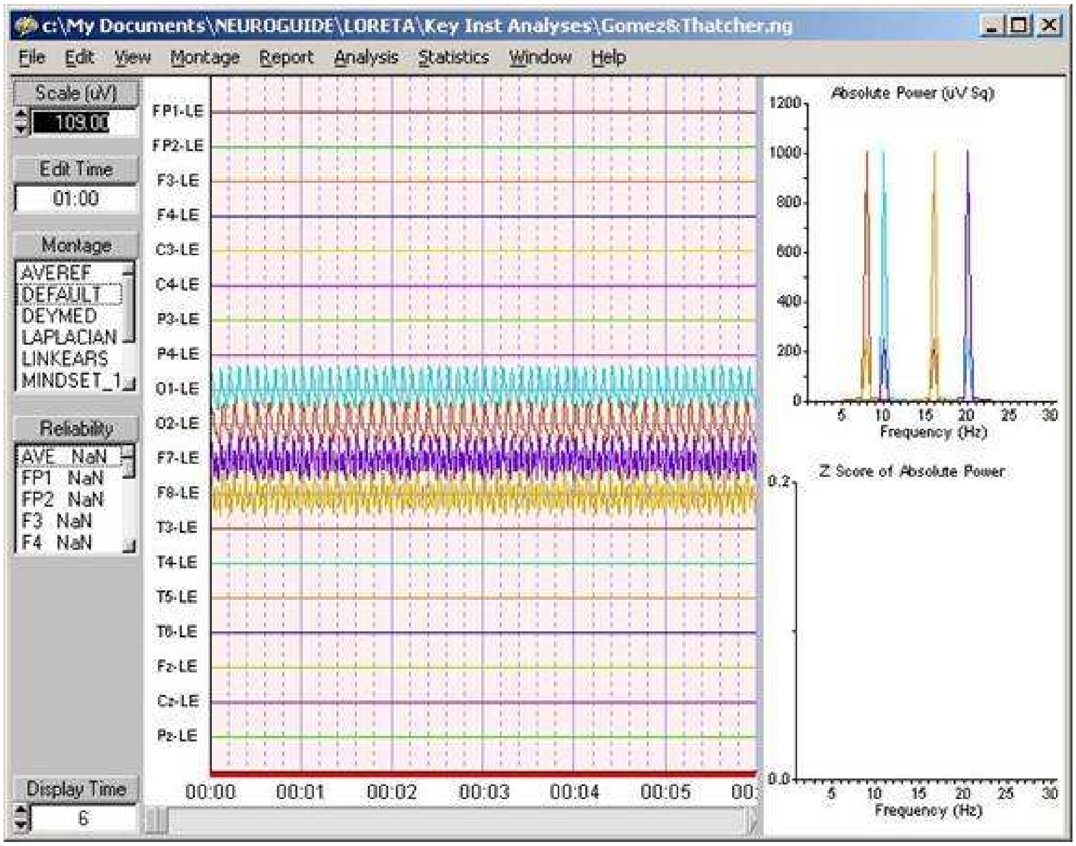

Step #5 - Click File>Save As to save the signals in NeuroGuide or Lexicor format (*.ng or *.dat).

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Step – 5a - Follow the NeuroGuide Manual Instructions (step #6) to save as NeuroGuide (*.ng) or Lexicor (*.dat) files.

Step – 5b - Follow the NeuroGuide Manual Instructions (step # 6) to save Power Spectra and Cross-Spectra (Step # 6) and to Export to LORETA (Step # 11 in the NeuroGuide Manual).

Step #6 - Example Tutorial by replicating the publication: Gomez and Thatcher "Frequency domain equivalence between potentials and currents using LORETA." Int. J. of Neuroscience, 107: 161-171, 2001.

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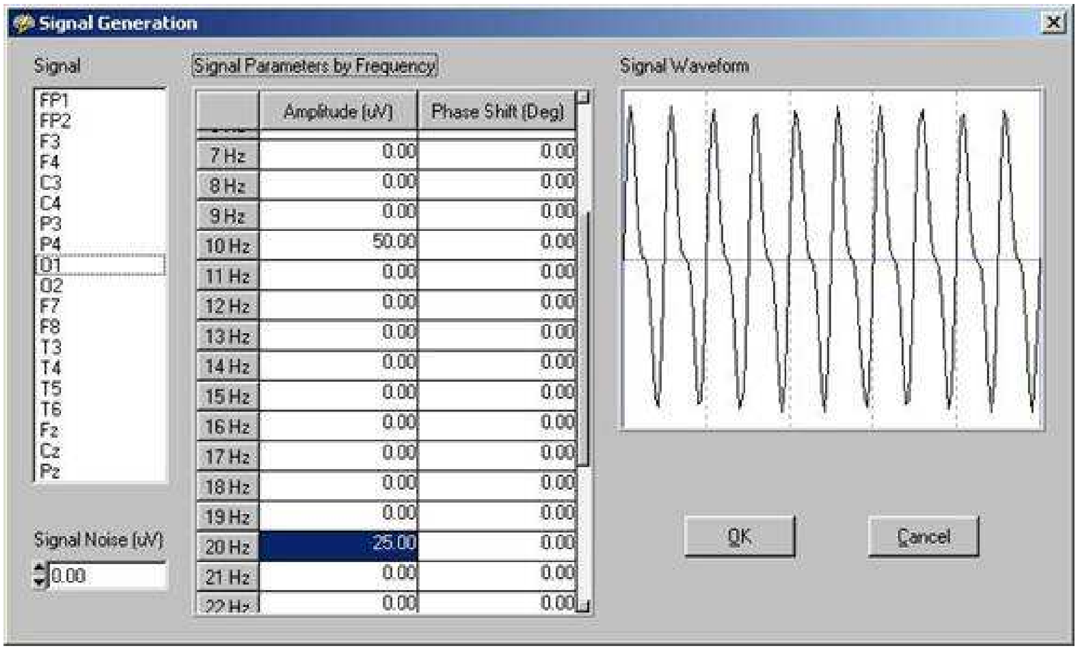
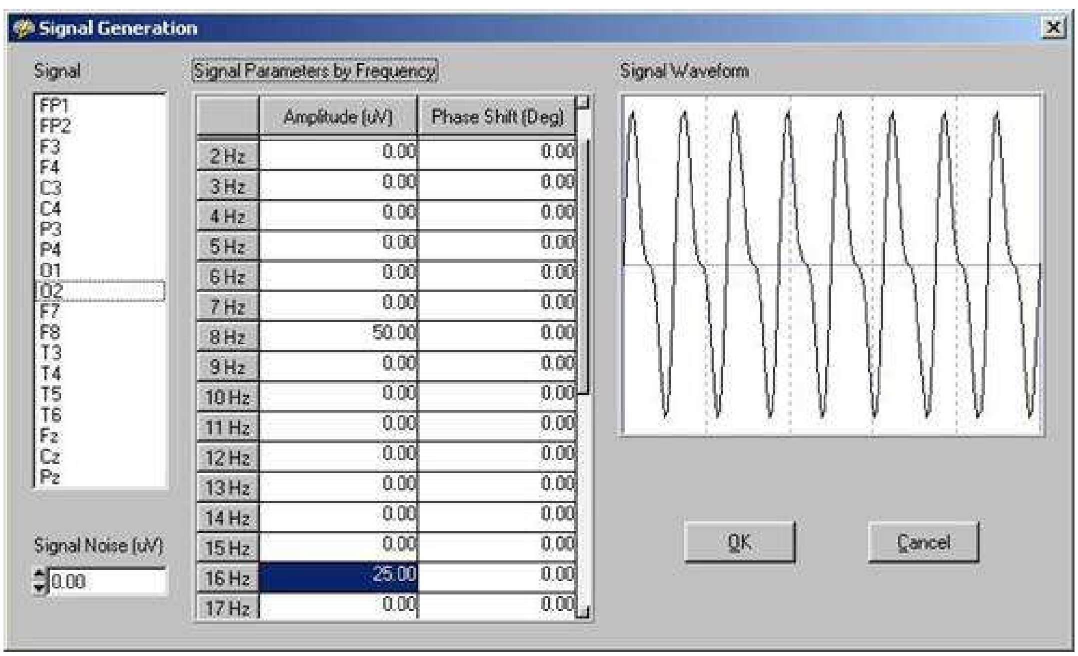
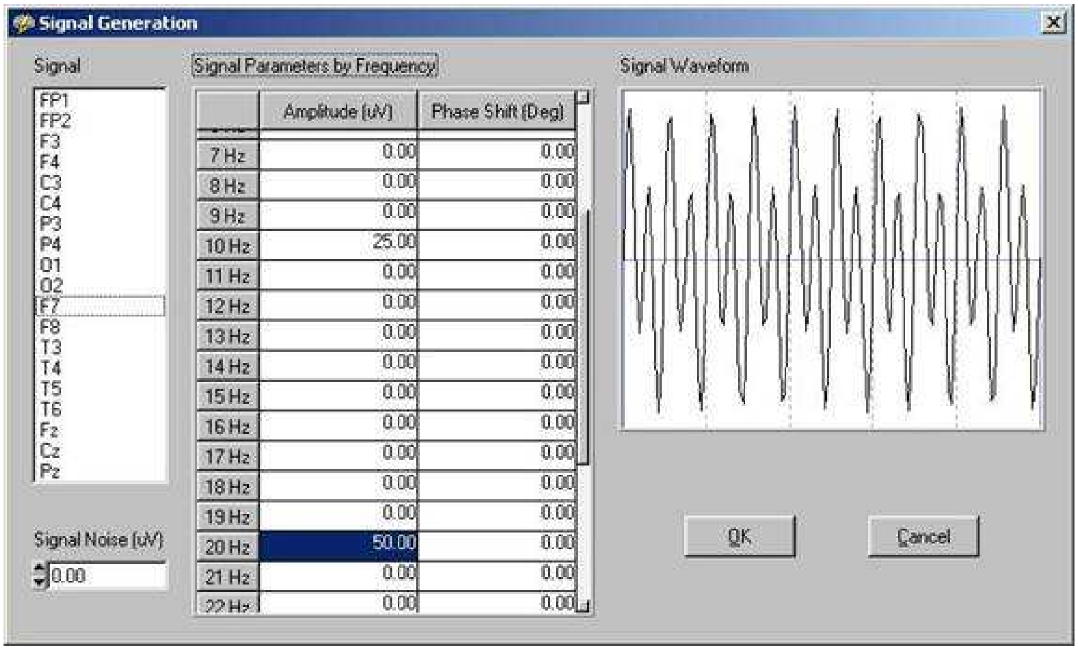
5a- Select O1 at 10 Hz at 50 uV and 20 Hz at 25 uV



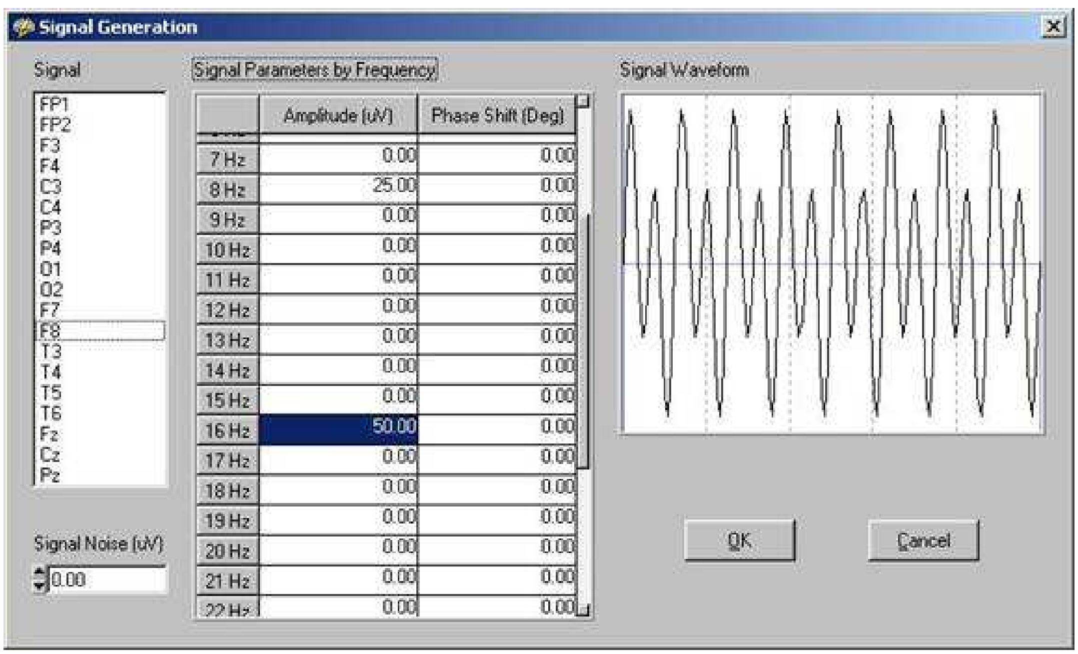
5b – Select O2 at 8 Hz 50 uV and 16 Hz at 25 uV



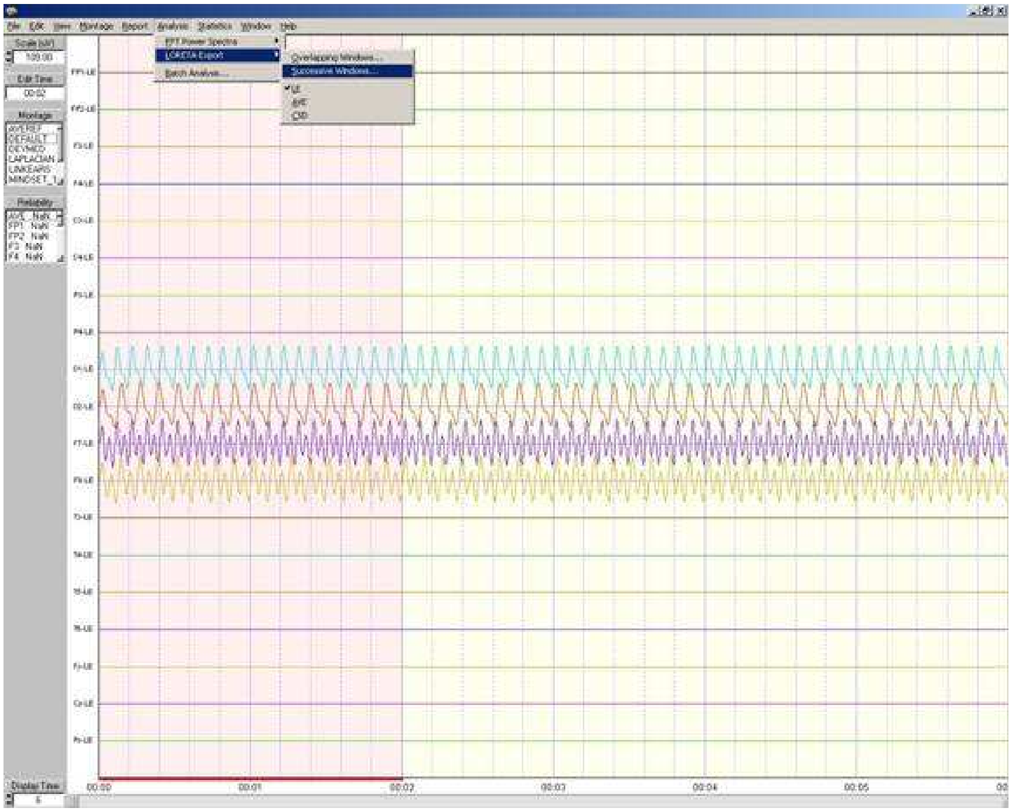
5c – Select F7 at 10 Hz 25 uV and 20 Hz at 50 uV

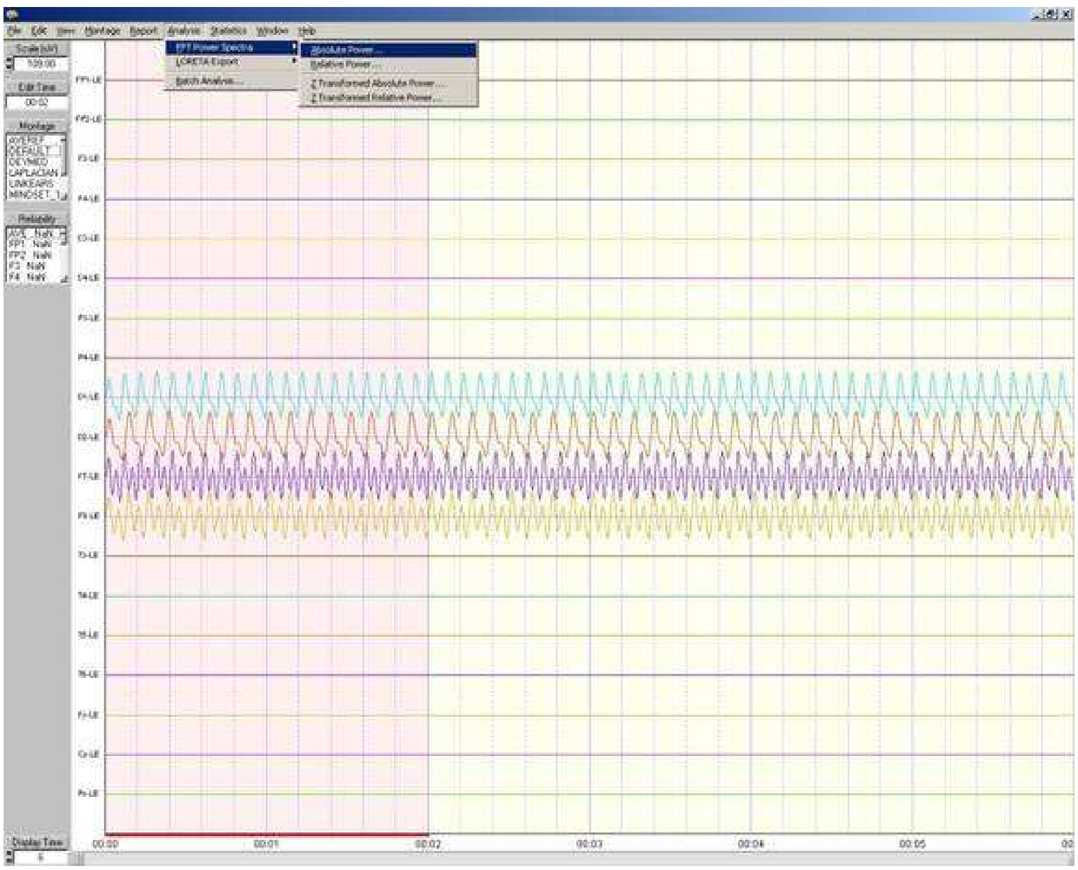


5d – Select F8 at 8 Hz 25 uV and 16 Hz at 16 uV



5e – Click OK and then click File>Save As NeuroGuide (*.ng) or Lexicor (*.dat) for purposes of further analysis. For example, save the power spectra and/or export the digital time series to LORETA.





APPENDIX – A

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Gomez and Thatcher, 2001 used the Key Institute mathematical equations to validate LORETA and cross-validated their math by comparing the forward solution and the inverse solution using MRI 3-D voxel locations and the surface scalp EEG currents and potentials (Based on the Reciprocity Theorum, Helmholtz, 1853). The results of the Gomez and Thatcher, 2001 study is also consistent with Tesche, C. and Kajola, M. "A comparison of the localization of spontaneous neuromagnetic activity in the frequency and time domains." Electroencephalography and Clin. Neurophysiology, 87(6): 408-416, 1993.

One can test the facts and the science of LORETA for themselves using the NeuroGuide signal generator and the Gomez and Thatcher, 2001 frequencies and locations which is only one of several tools available to test LORETA (see Appendix B and C) not to mention the mathematical concepts of linearity between frequency and time and between electrical potentials and currents (Helmholtz, 1853 physics of "Reciprocity" and the "Lead Field", Malmivuo and Plonsey, 1995).

It makes no difference whether one exports signals in the time domain or in the frequency domain (as demonstrated in the Gomez & Thatcher, 2001 and the Tesche et al, 1993 publications as well as by mathematical simulation in step # 5). Caution must be exercised when using LORETA to be sure to physiologically validate using the surface linked ears, average reference and current source density data. This is not to indicate that LORETA is not a valid mathematical and scientific methodology, to the contrary, it is an important contribution. We are emphasizing the fact that LORETA is valid when used by competent professionals who take the time to validate the source solutions by evaluating the surface EEG distributions and physiology in order to guard against localization error. For example, scalp recorded EEG with large amplitude alpha in O1 and O2 should appear as high current density in areas 17, 18 & 19 in LORETA.

APPENDIX – B
Mathematics and Results of Gomez & Thatcher, 2001

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Note: There are three instances when multiplication of matrices is communtative: 1- by a null matrix, 2- by an identity matrix and, 3- multiplication by a scalar. The equation below is a valid equality when using a scalar as we do.

$$\lambda A = \{\lambda a_{ij}\} = \{a_{ij}\lambda\} = A\lambda \qquad \textbf{Eq. 1}$$

We apply this communtative property in the following manner. For S = KJ, where K is the lead field matrix, J = current and S = the sensitivity of the sensors (depending on the model used and the conductivity, etc.). S is an N x W matrix for the scalp potentials (EEG/MEG), where N is the number of sensors and W is the number of time samples. J is a 3M x W matrix, where M is the number of sources and W is the same time samples as for S. Then the inverse solution is a linear combination of the signal S in the sensors

$$J = T \cdot S \qquad \textbf{Eq. 2}$$

Where T is some generalized inverse of K, where the minimum norm solution is

$$T = (pinv(K' \cdot K = K)) = K' \qquad \textbf{Eq. 3}$$

K' is the transpose of K, and · represents matrix multiplication and pinv(X) is the Moore-Penrose pseudoinverse (Menke, 1984). Pascual-Marqui et al, 1994 use the mathematical method that they refer to as "Low-Resolution Computed Tomography" (LORETA) to add physiological foundations and to avoid the minimum norms's problems in localizing deep sources by using the Laplacian Operator B and W as a weighting matrix. The LORETA equation is

T = {pinv(WB'BW)}K'[pinv(K inv(WB'BW)K'} Eq. 4

The critical factor in these considerations is that the real number FFT computed by the cross-spectrum (Hermitian matrix as a scalar real number) as represented in equation 1 is a linear operator such that for any inverse solution of the form in equation 3 is equivalent to:

FFT(J) = FFT [T · S] = T · FFT[S] Eq. 5

Equation 5 is the formula that Gomez and Thatcher (2001) used. Gomez and Thatcher (2001) simulated the linear equivalence by a combination of sine waves and confirmed the linearity of equation 5 as any one can do by using the NeuroGuide signal generator as described in step # 5 for oneself.

Figure 1 – From Gomez & Thatcher, 2001. This is the three-shell spherical model of the head used to simulate LORETA. Four electrodes (F7, F8, O1, O2) and the reference electrode (A1) are indicated by black rectangles. The coordinates of the electrodes are according to the best-fitting sphere relative to cortical anatomy (Towel et al., 1993). The peaks of beta (for F7 and F8) and alpha activity (for O1 and O2) are indicated in parenthesis. Eight sources (1 to 3) indicated by black circles were located in the interior of the sphere to represent the equivalent current sources such as in the gray matter.

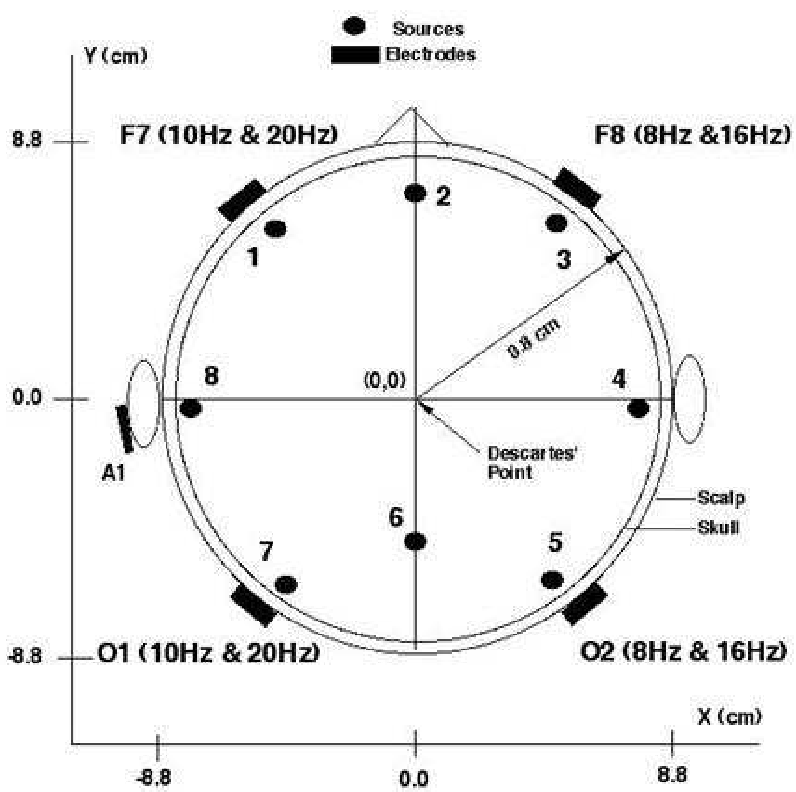
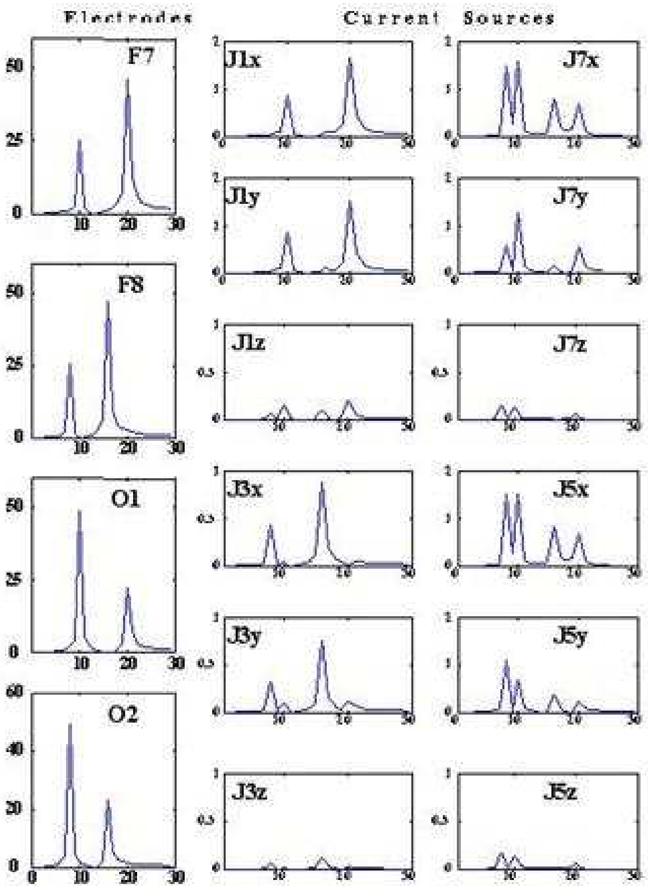


Figure 2 – From Gomez & Thatcher, 2001. Power spectrum of the signals used to simulate LORETA. The spectrum of the signals in the scalp electrodes is shown on the left (amplitude of beta is higher in the anterior regions, alpha amplitude is higher in the posterior regions and a frequency shift toward the lower frequencies in the right hemisphere). The center and right columns are the spectra of the current sources nearest to the electrodes J1, J3, J5 and J7 after calculating the inverse solution. Each source has three components x, y and z. The y-axis of the electrodes is uv^2 /cycle/sec for the electrodes and $(uA/cm^2)^2$ /cycle/sec for current density at each source location. The x-axis is frequency in Hz in all cases. This simulation confirms the mathematical statements and demonstrates a frequency domain equivalence between the spectra of electrical potentials at the scalp and the spectra of currents in the interior of the head model.



APPENDIX – C - REFERENCES

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