Chapter 30: Cross-Frequency Coupling

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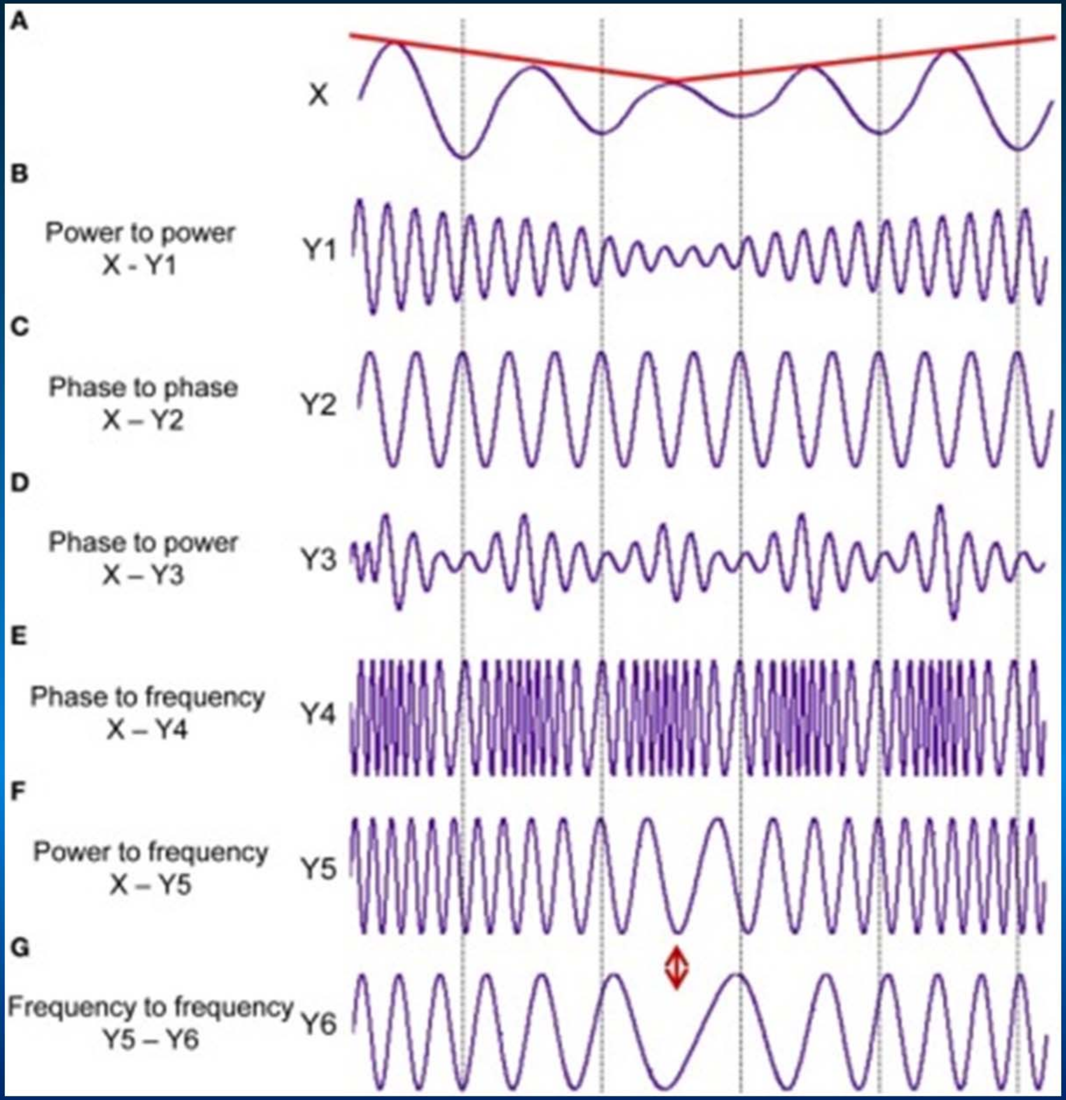
Types of Cross-Frequency Coupling



X Space X Time X Condition

Adopted from Jirsa & Müller, 2013

Other Types of Cross-Frequency Coupling?

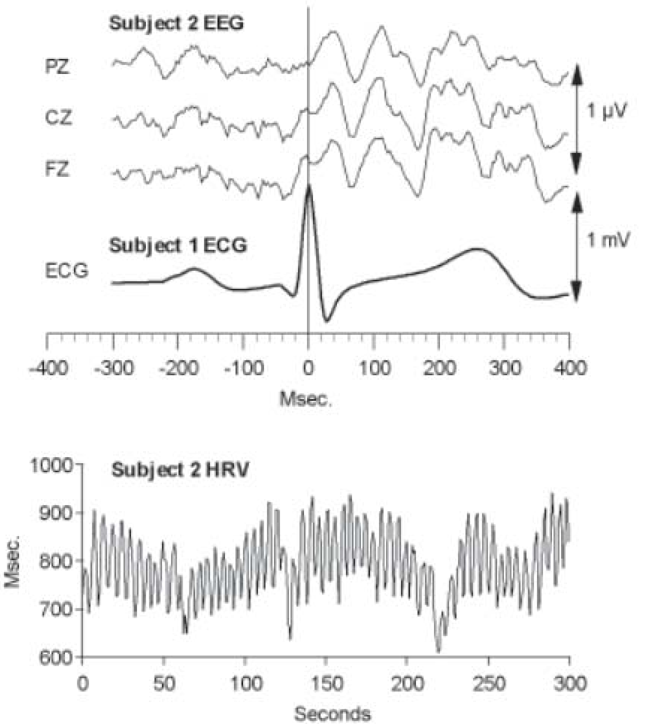


Figure 6. Heart-brain synchronization between two people. *The top three traces are Subject 2's signal averaged EEG waveforms, which are synchronized to the R-wave of Subject 1's ECG. The lower plot shows Subject 2's heart rate variability pattern, which was coherent throughout the majority of the record. The two subjects were seated at a conversational distance without physical contact.*

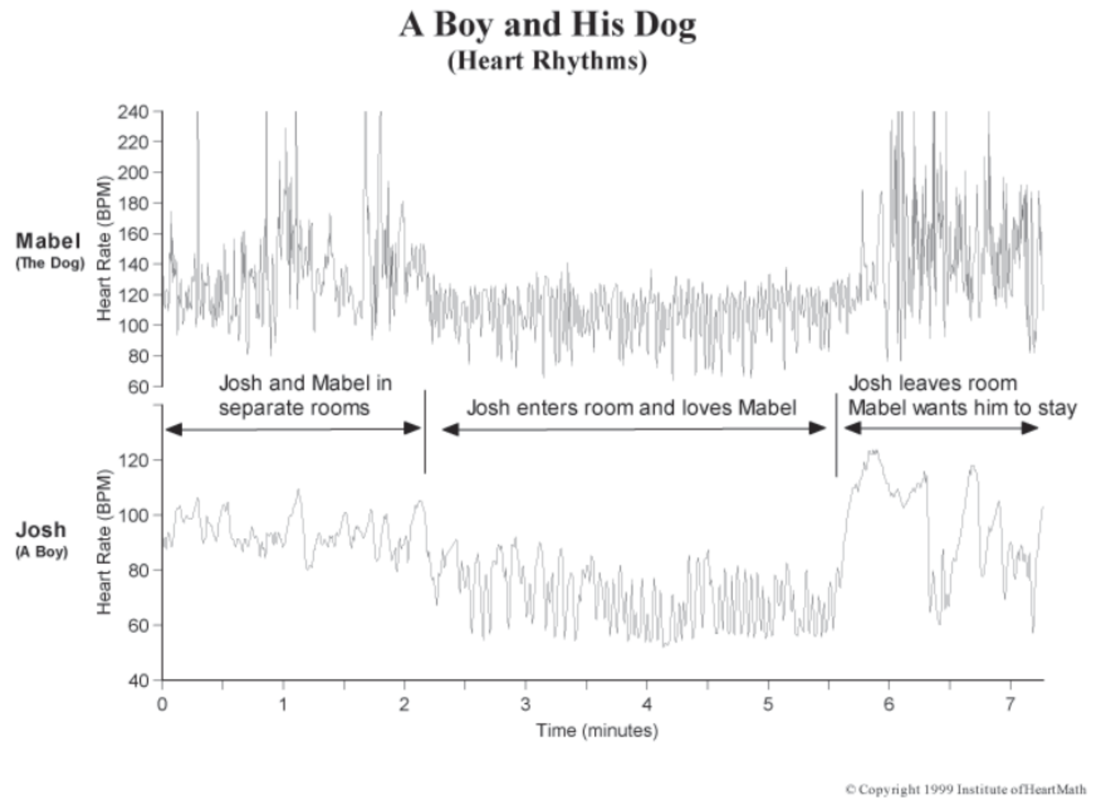


Figure 11. Heart rhythm patterns of a boy and his dog.
These data were obtained using ambulatory ECG (Holter) recorders fitted on both Josh, a boy, and Mabel, his pet dog. When Josh entered the room where Mabel was waiting and consciously felt feelings of love and care towards his pet, his heart rhythms became more coherent, and this change appears to have influenced Mabel heart rhythms, which then also became more coherent. When Josh left the room, Mabel's heart rhythms became much more chaotic and incoherent, suggesting separation anxiety!

From: McCraty, 2003

Types of Cross-Frequency Coupling

- Apriori CFC
- Specify both frequency bands (power and phase)

- Mixed Apriori Exploratory CFC
- Specify one frequency bands (power or phase)

- Exploratory CFC
- Explore all bands

Types of Cross-Frequency Coupling

- Power-Power
- See chapter 27

- Method 1 – Compare power time series of different freq. band over time.

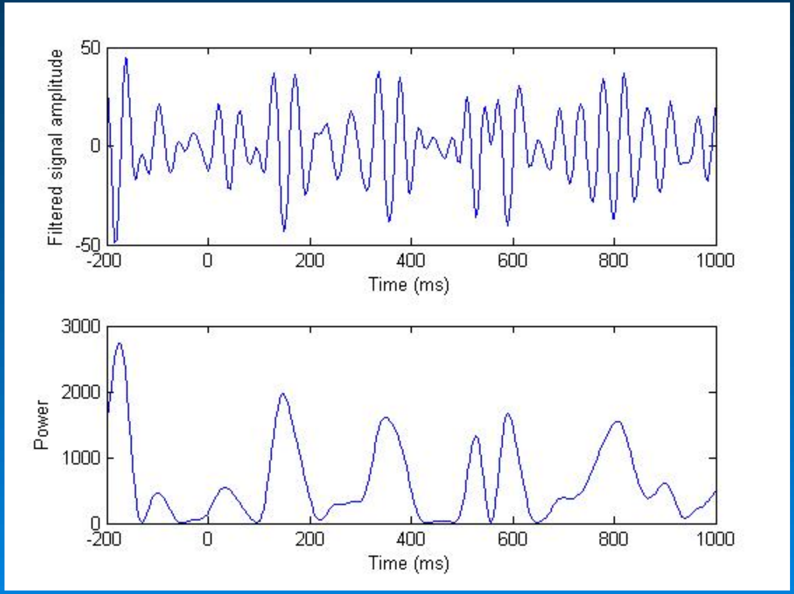
- Method 2 - Compare power time over trials.

- Method 3(?) – Compare different freq. at different times (prediction idea)

Types of Cross-Frequency Coupling

- Phase – Amplitude

Fig. 30.1



➢ Usually a low F phase is coupled with a high F power/ amplitude

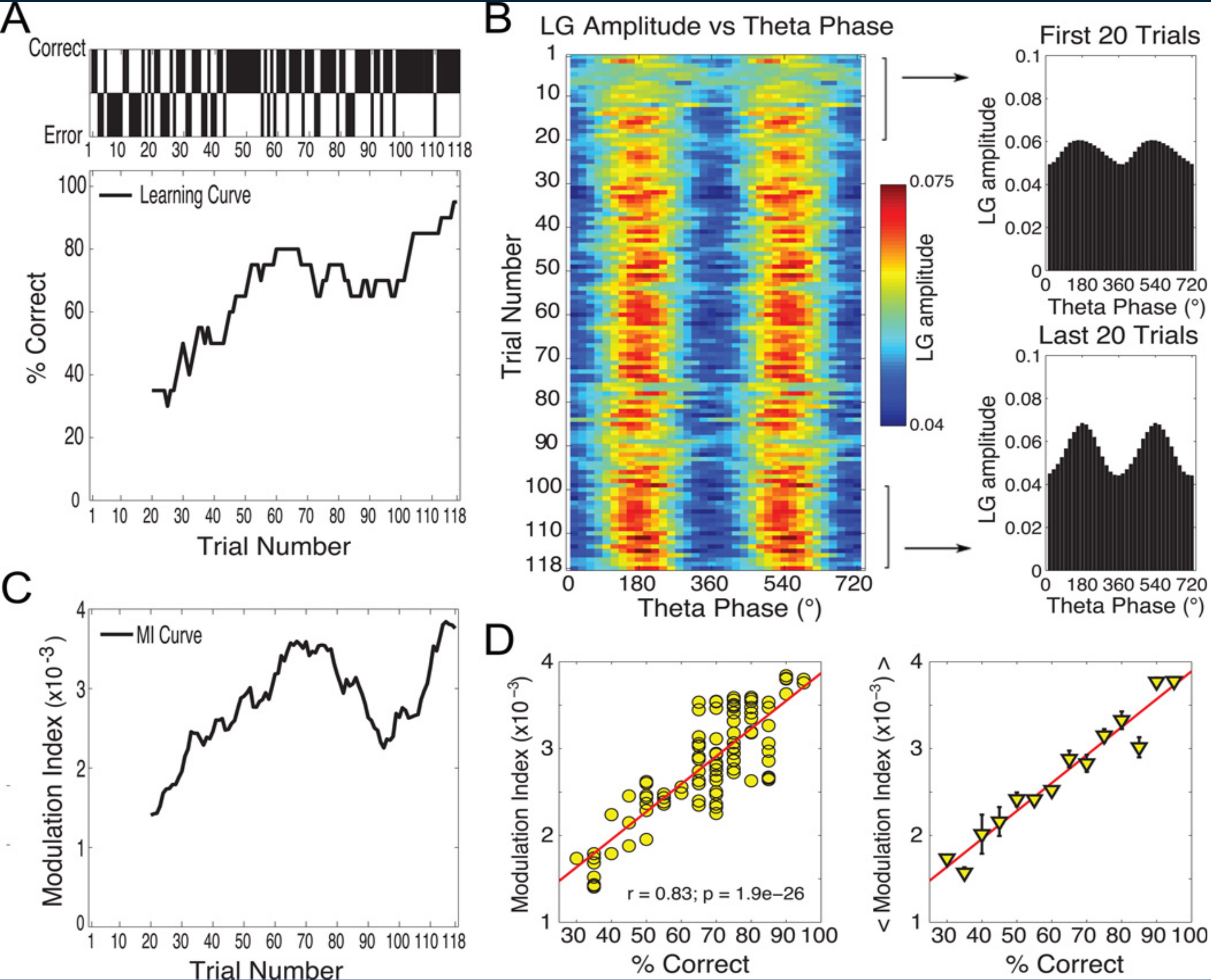
Types of Cross-Frequency Coupling

- Apriori Phase-amplitude Coupling (PAC)
- "gamma oscillations might emerge at a particular phase of the theta cycle and thereby recruit cell assemblies involved in processing at that time" (Jensen & Colgin, 2007).

- "Feedback valence information is encoded [in the Nucleus Accumbens], in part, by the precise timing of bursts of gamma oscillations relative to alpha iEEG phase (Cohen et al., 2009, P. 883).

- More?

Apriori CFC Phase –Amplitude

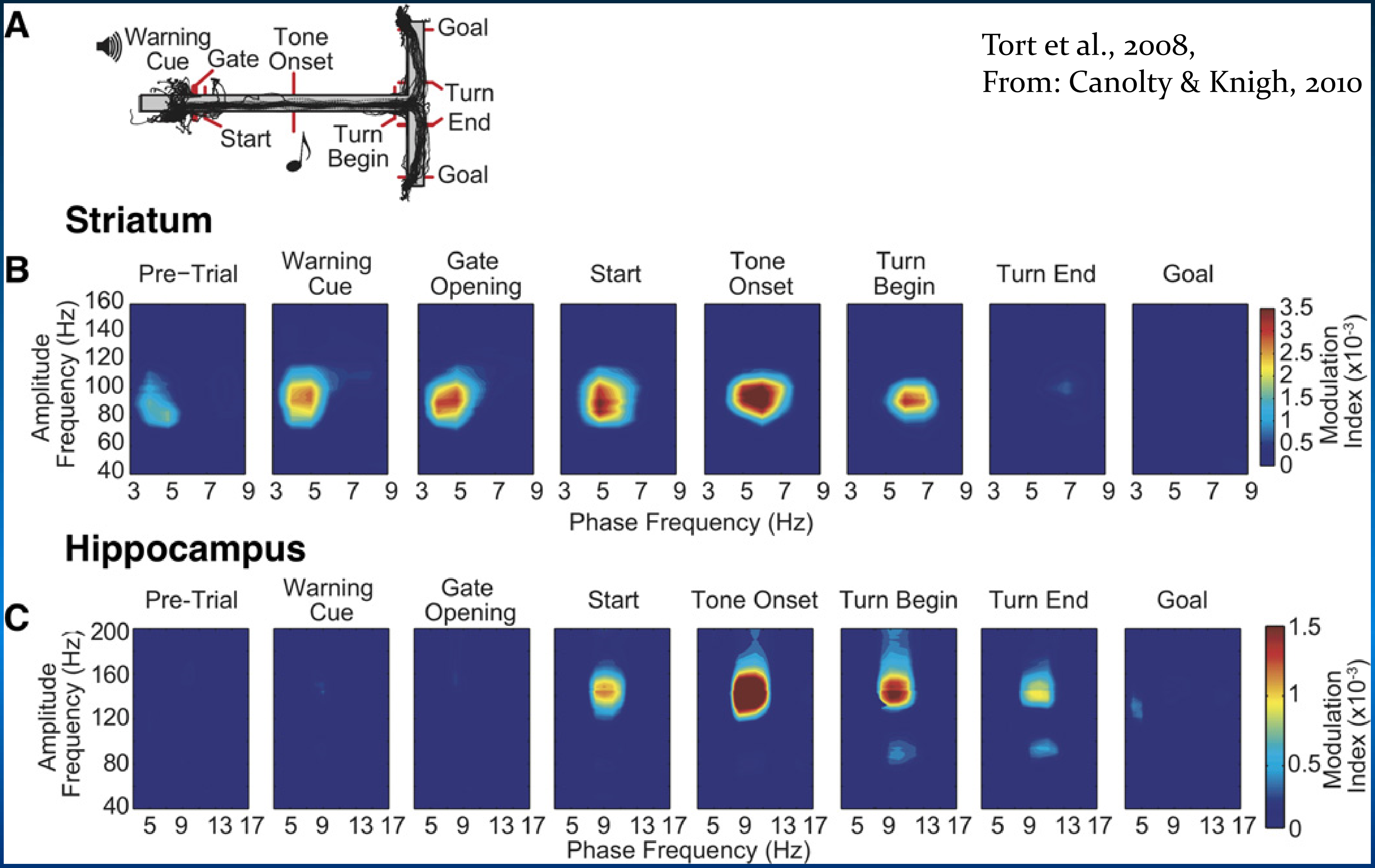


Hippocampal theta/gamma cross-frequency coupling correlates with learning and task performance
Theta modulation of low gamma (LG) amplitude in the CA3 region during context exploration increases with learning. A) Behavioral profile of a representative rat during learning of the task. Shown is the animal's performance (correct, black bar up; error, black bar down) at each trial of the session (Upper) and the associated learning curve computed by using a sliding window of 20 trials (Lower). B) Pseudocolor scale representation of the mean CA3 LG amplitude as a function of the theta phase for each trial in the session (Left). The mean LG amplitude per theta phase averaged over the first and last 20 trials is also shown (Right). C) CFC modulation index (MI) curve computed by using a 20-trial sliding window. (D) Linear correlation between theta-LG coupling strength and task performance. The correlation between the MI and learning curves (Left) and the average MI value over each mean performance percentage (Right) are shown.

From: Canolty & Knigh, 2010

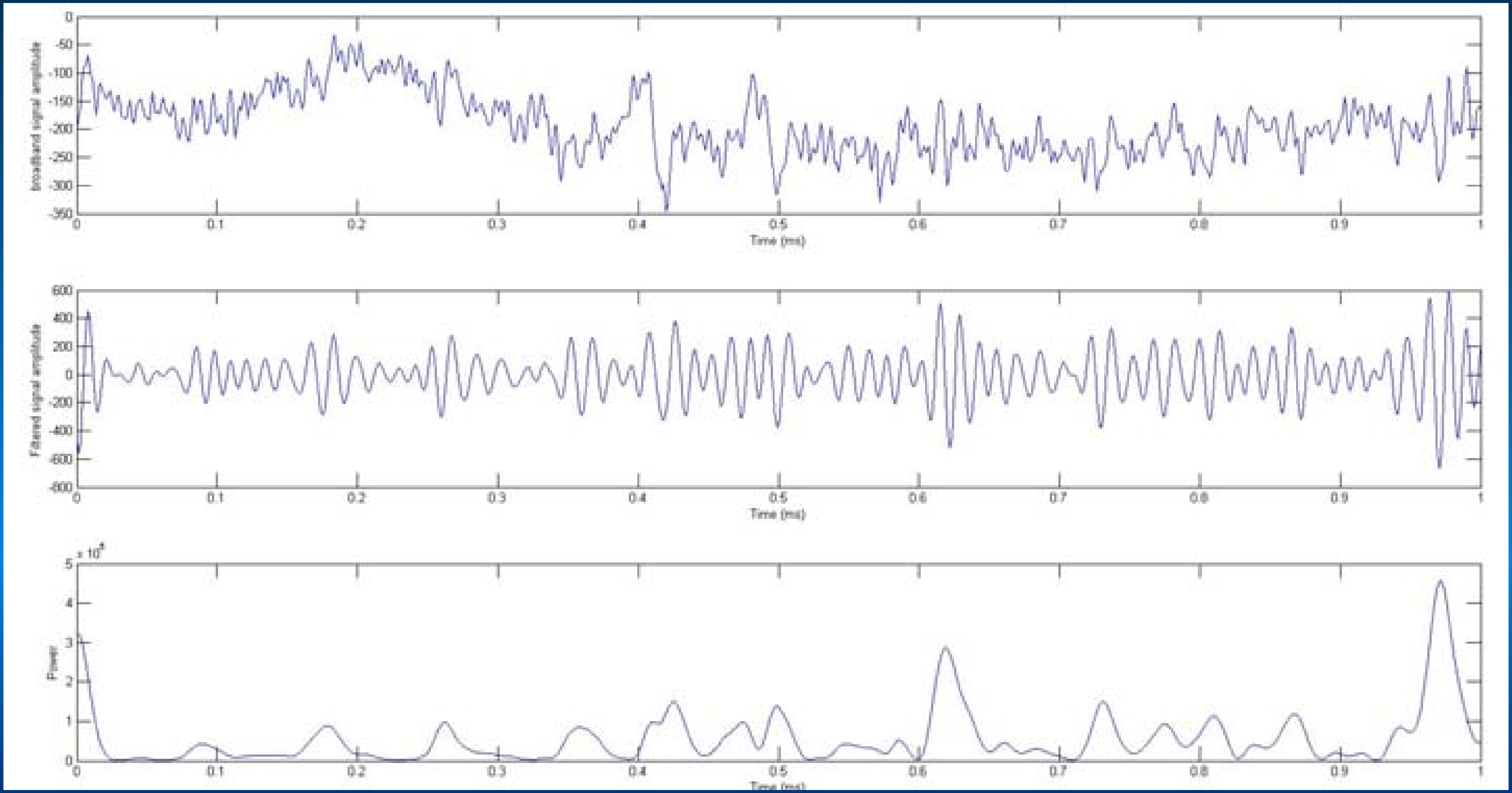
Apriori CFC Phase –Amplitude

Tort et al., 2008,
From: Canolty & Knigh, 2010



Apriori CFC Phase –Amplitude

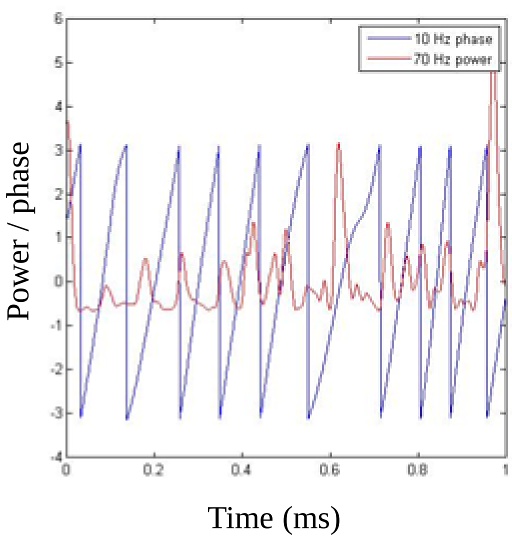
Fig. 30.2



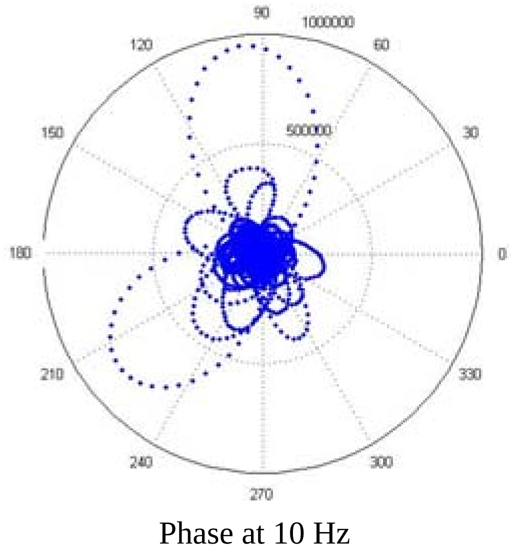
Apriori CFC Phase –Amplitude

Fig. 30.3

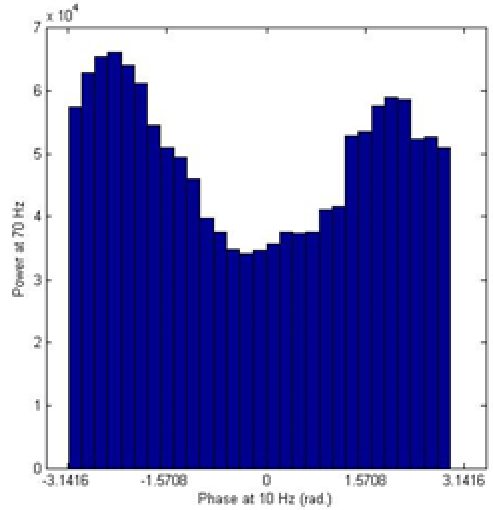
Power & phase over time



Power in phase space

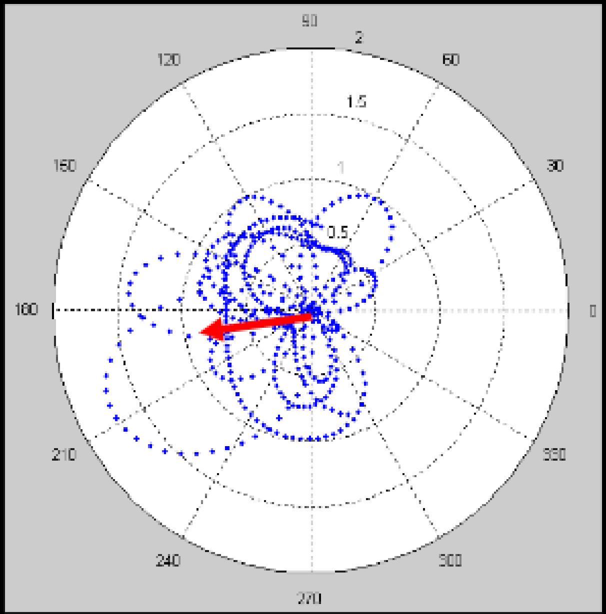


Power distribution in space bins



Apriori CFC Phase –Amplitude

Slide from Mike Cohen



(it's called modulation index instead of phase coherence)

PAC / **Modulation index = .244**

The equation is slightly different than that for phase coherence, but it is similar in essence:

```
> abs(mean(power.*exp(i*phase));
```

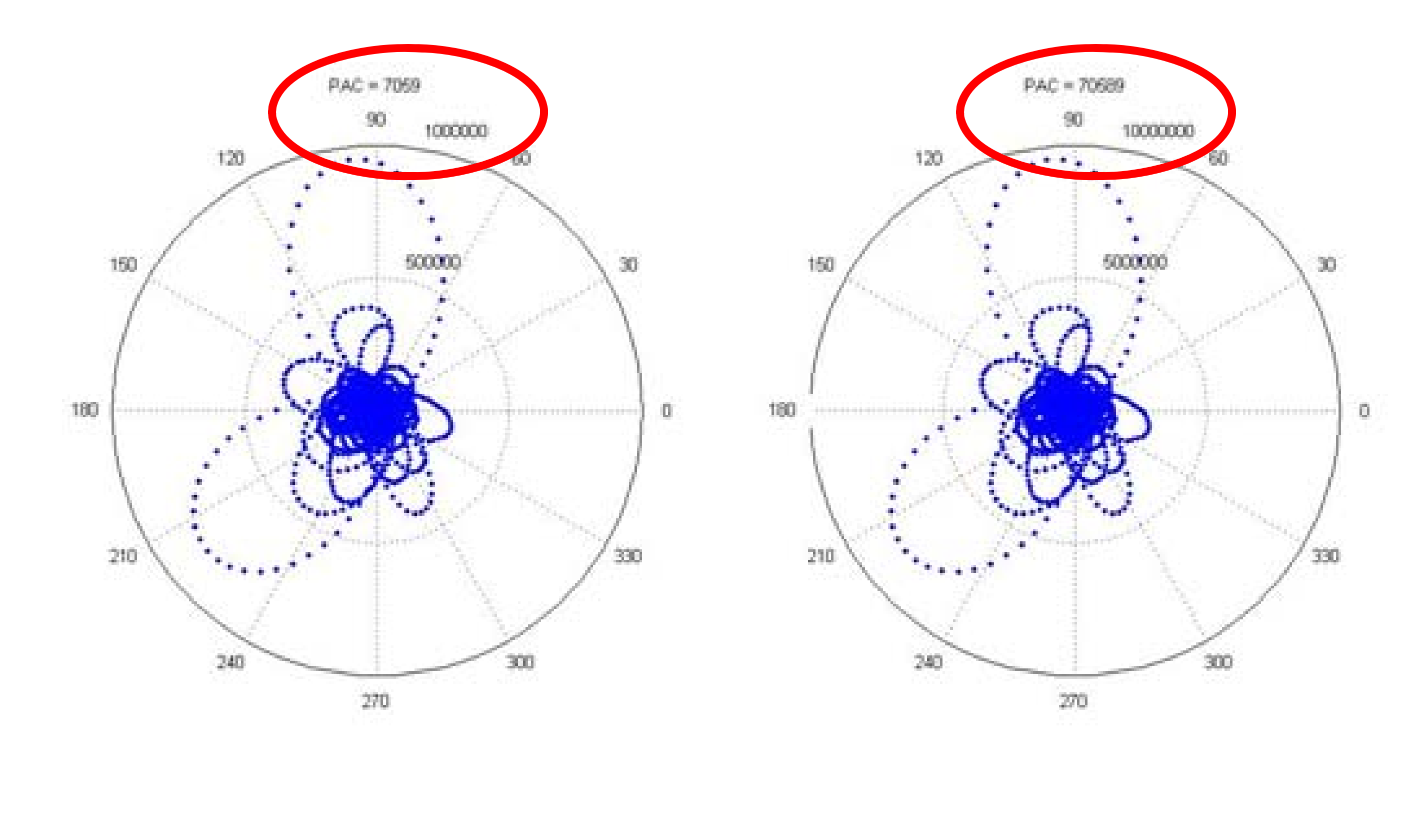
Magnitude of vector	Average across values	Power of higher frequency	Transform to complex plane	Phase angle of lower frequency

Apriori CFC Phase –Amplitude

Fig. 30.2

Confounds

- PAC would be arbitrary affected by power fluctuations

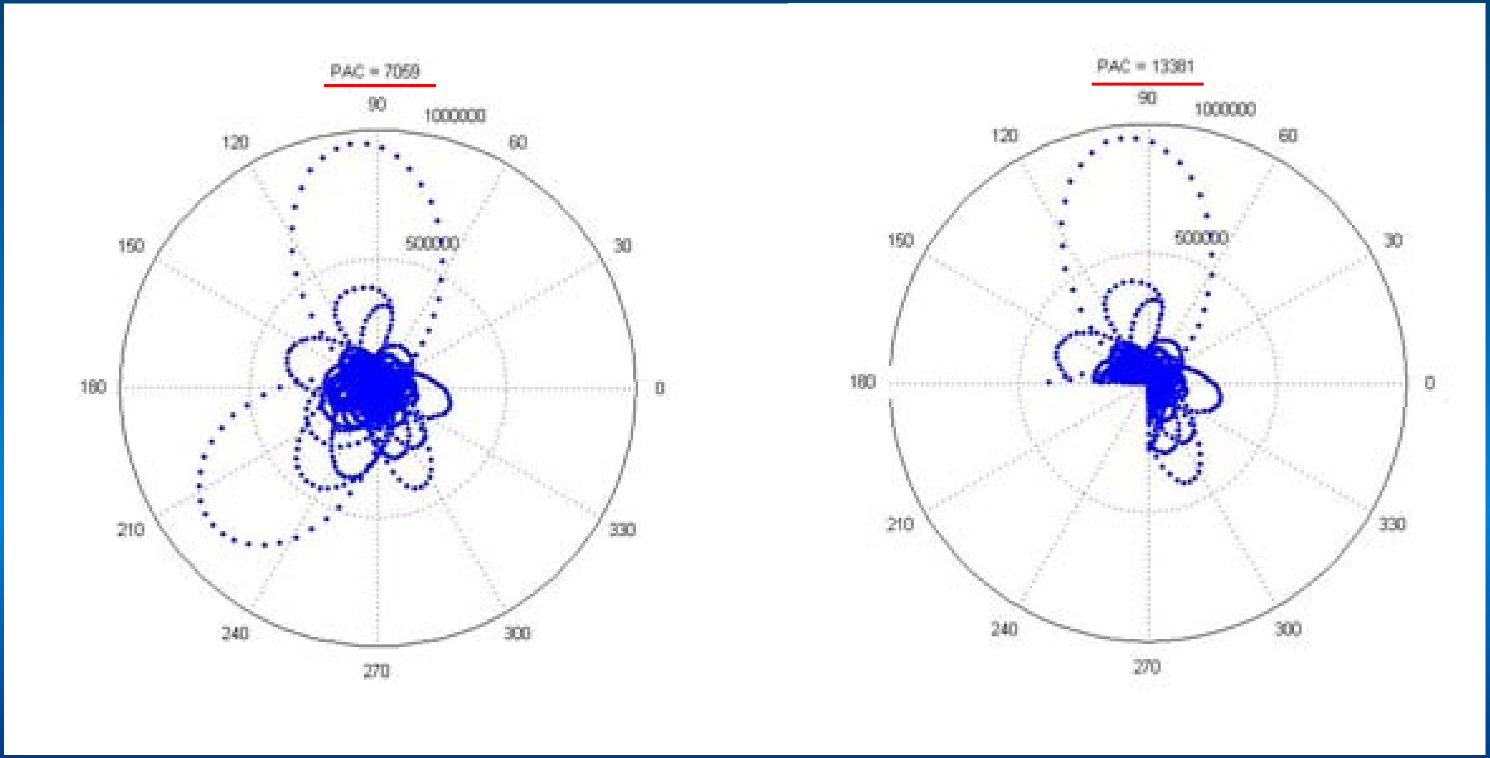


Apriori CFC Phase –Amplitude

Fig. 30.2

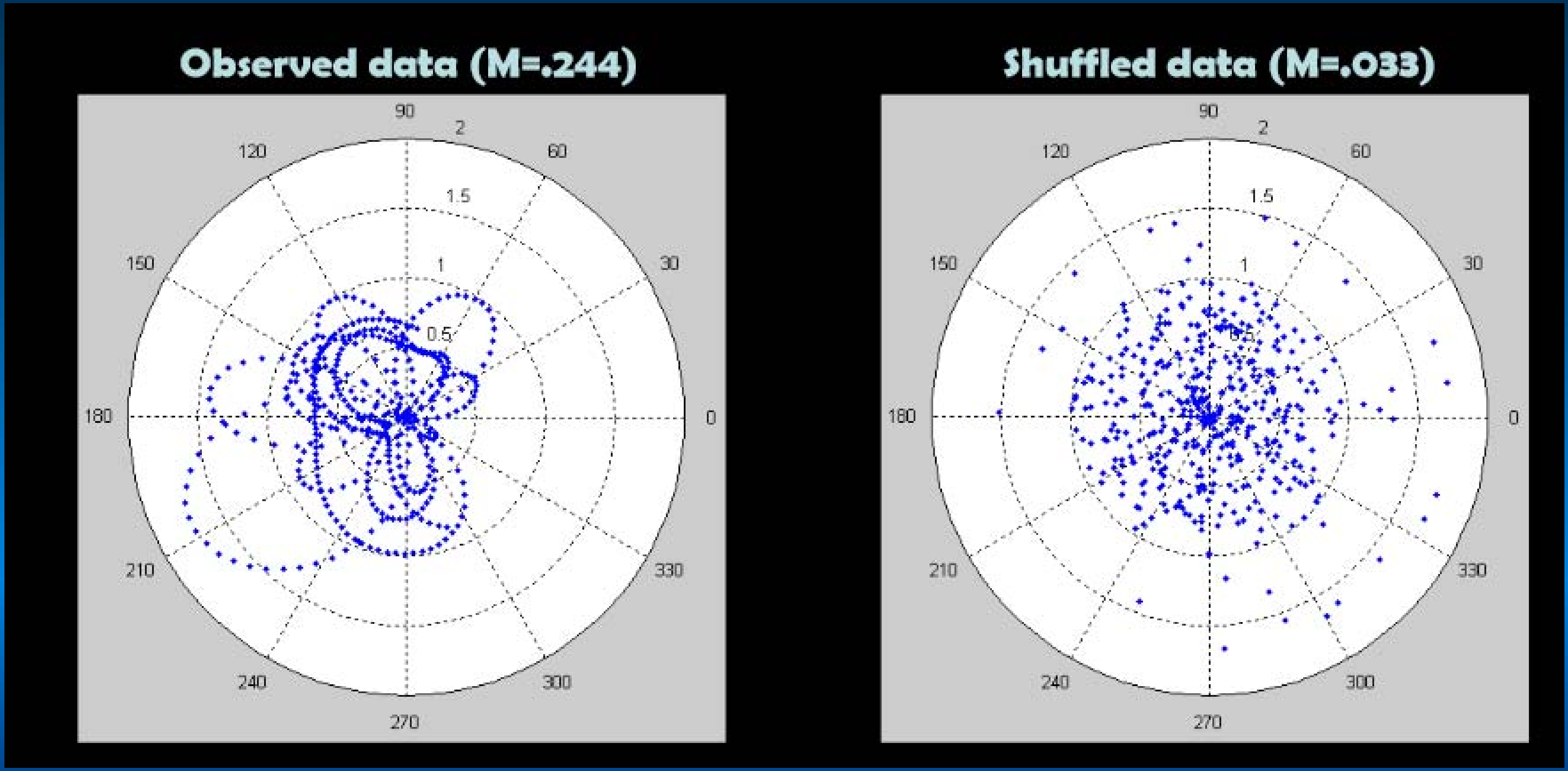
Confounds

- PAC would be affected by non-uniform distribution of phase angles.



Apriori CFC Phase –Amplitude

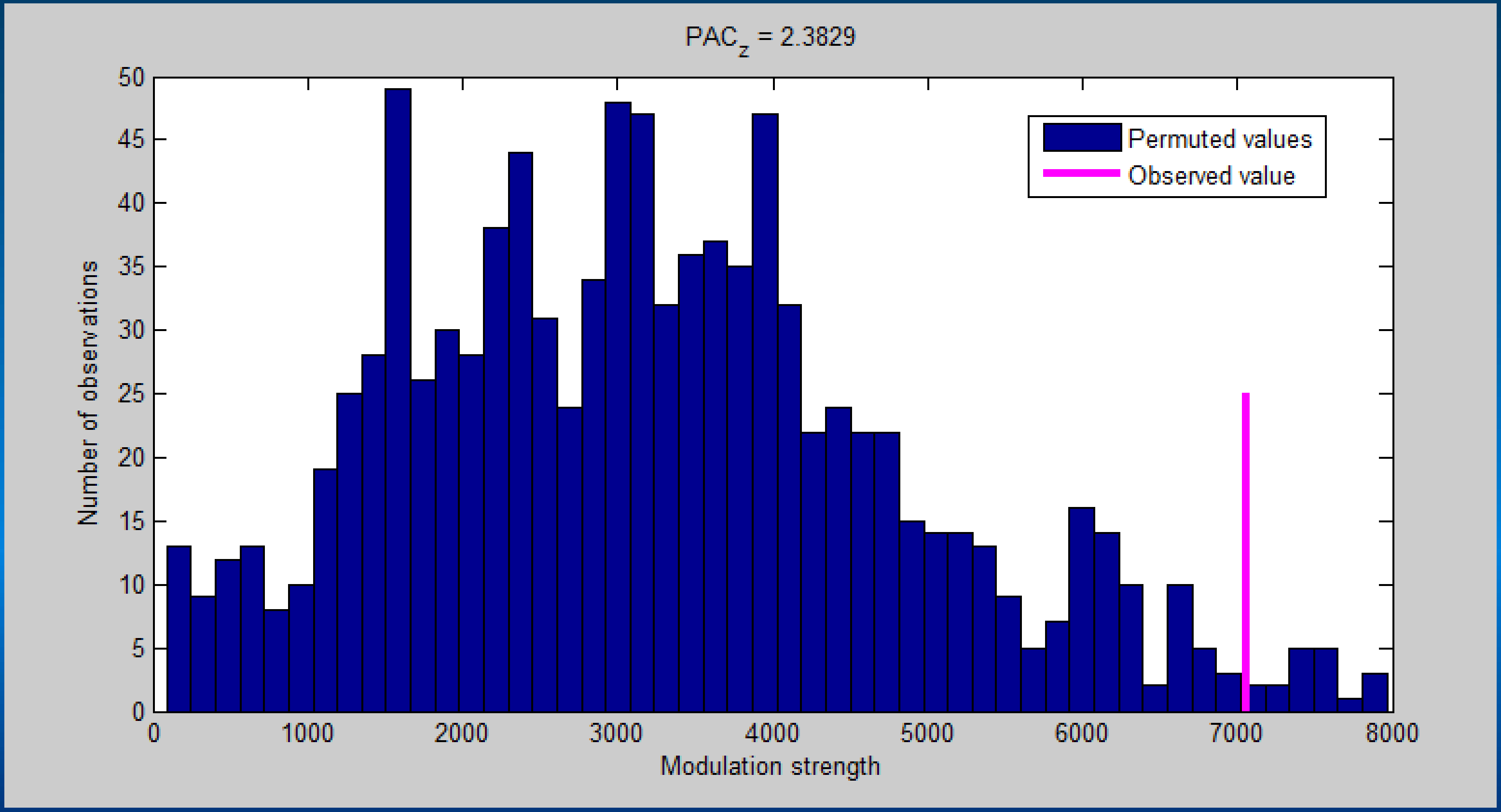
- Solution: Non parametric permutation testing



Apriori CFC Phase –Amplitude

- Solution: Non parametric permutation testing

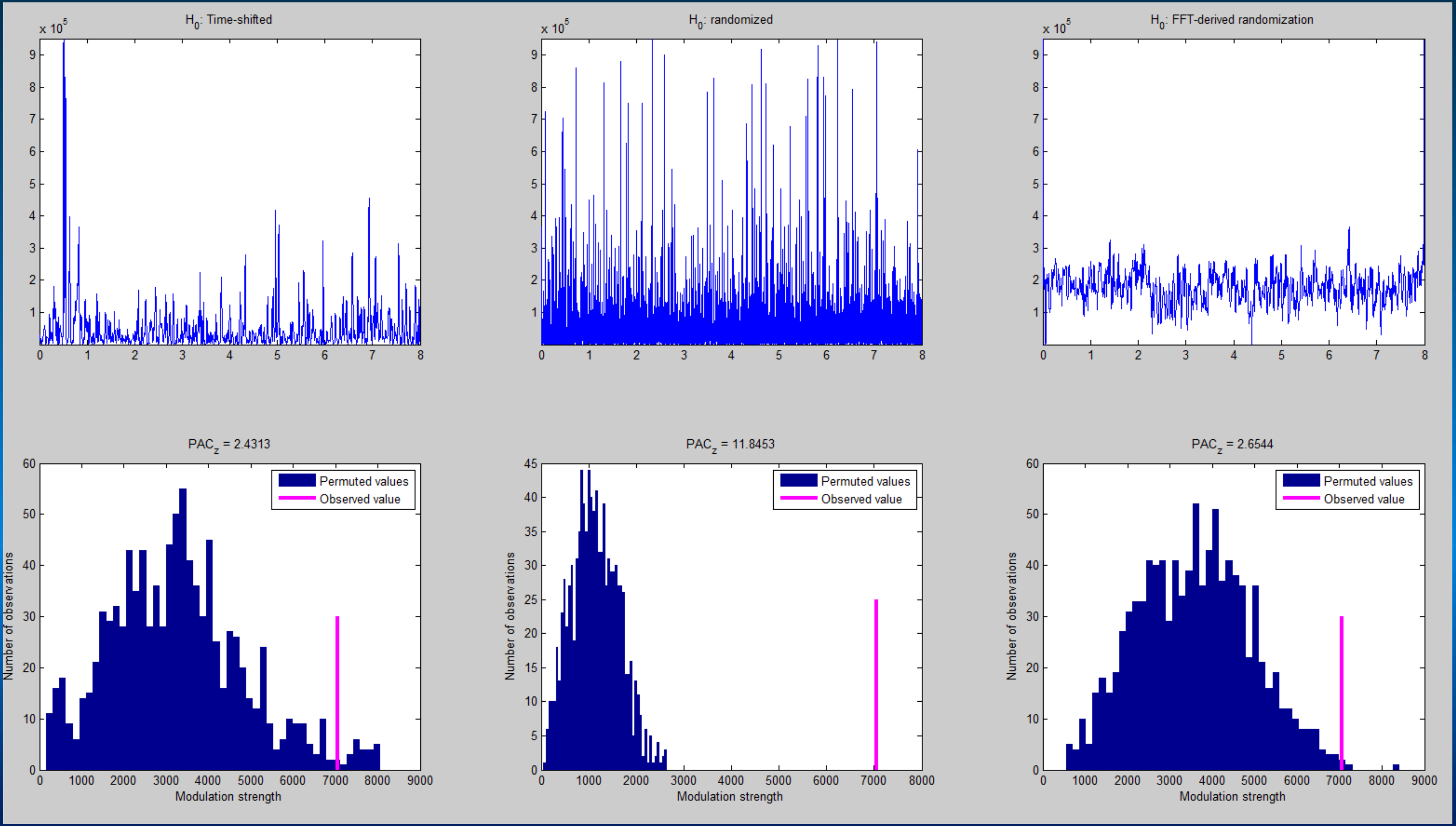
Fig. 30.5



Apriori CFC Phase –Amplitude

- Different methods for computing PACz

Fig. 30.6



Apriori CFC Phase –Amplitude

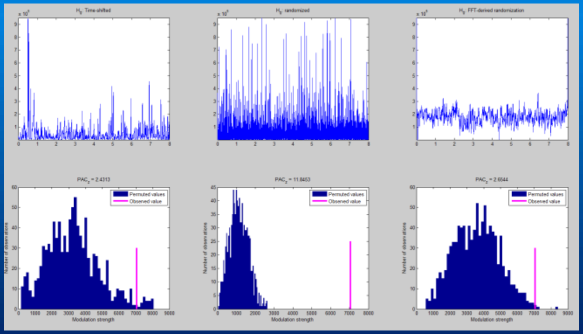
- Different methods for computing PACz

- Thoughts about validity?

- Has this method been cross validated with other tests?

- What is the minimum effect that can be detected? what is the distribution of real PACz effects? What is the real null hypothesis for PAC?

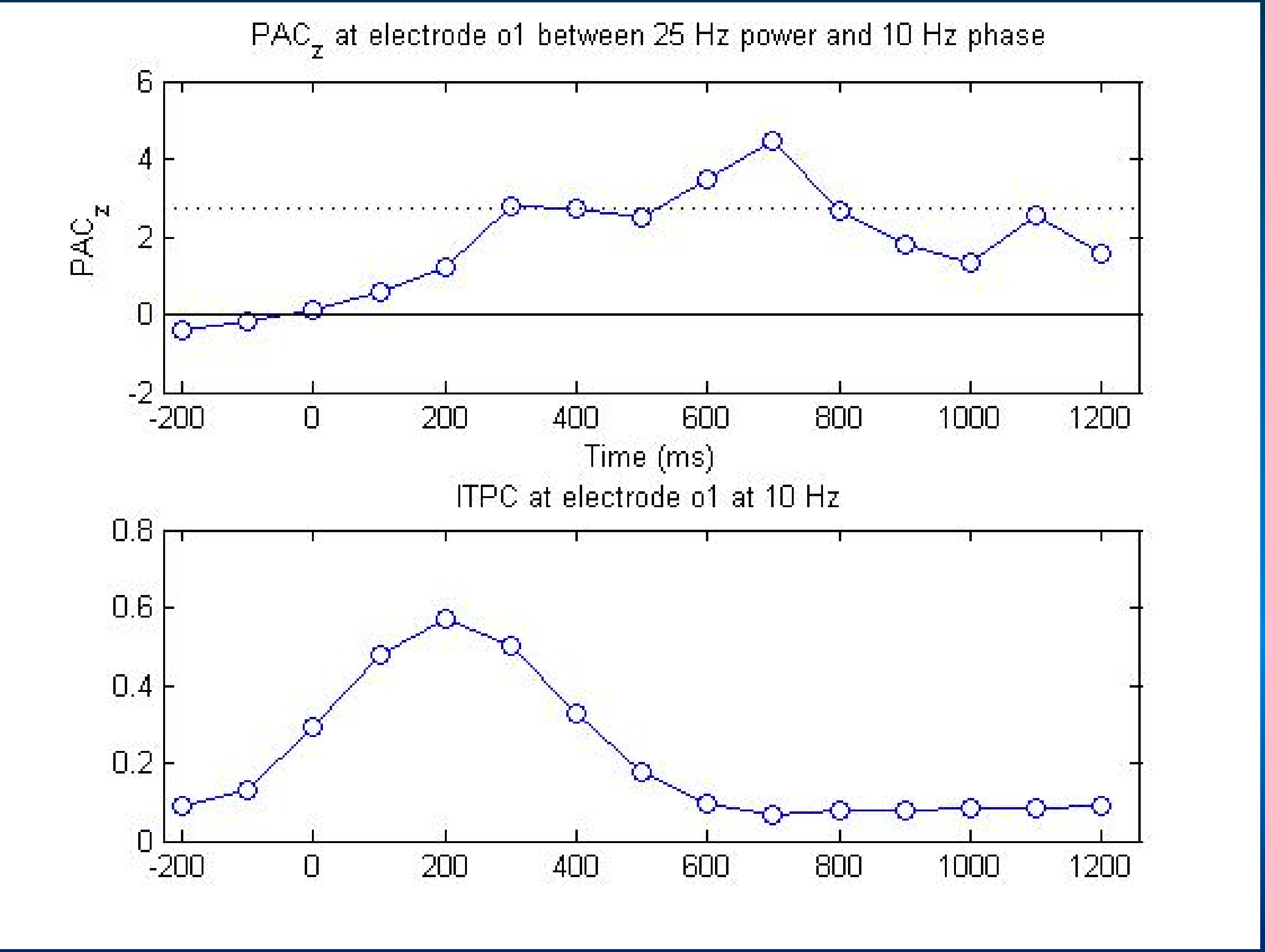
Fig. 30.6



Apriori CFC Phase –Amplitude

- PACz over time!

Fig. 30.7



Apriori CFC Phase –Amplitude

- Separating task related activation and phase:
- Show that PACz is not related to ITPC
- Mention problematic time points when interpreting the results
- Subtract ERP from single trial EEG data before computing PAC 

Apriori CFC Phase –Amplitude

Disadvantages?

- More likely to make type 2 errors (miss an effect)

- Textbook implies that you are more likely to make type 1 like errors by missing other alternative explanations.
- However, because preliminary analyses or analysis that are attempting to *disconfirm* your hypothesis should not be limited by multiple comparisons as these are actually working “against” the hypothesis. Therefor there is no risk of capitalizing on chance when you are testing for alternative explenations.

Mixed Apriori Exploratory CFC

Choose either the low freq. for phase or high freq. for power

Figure. 30.8 A: PACz values at lower freq. for phase when power freq. is 25HZ

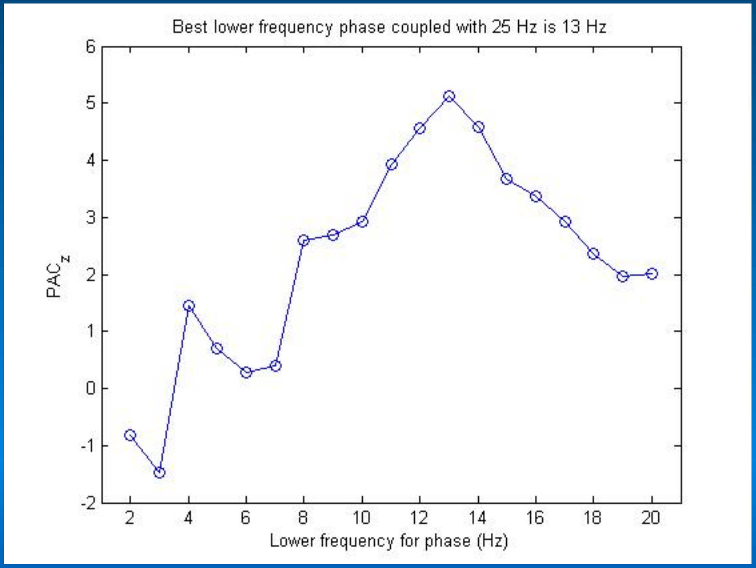
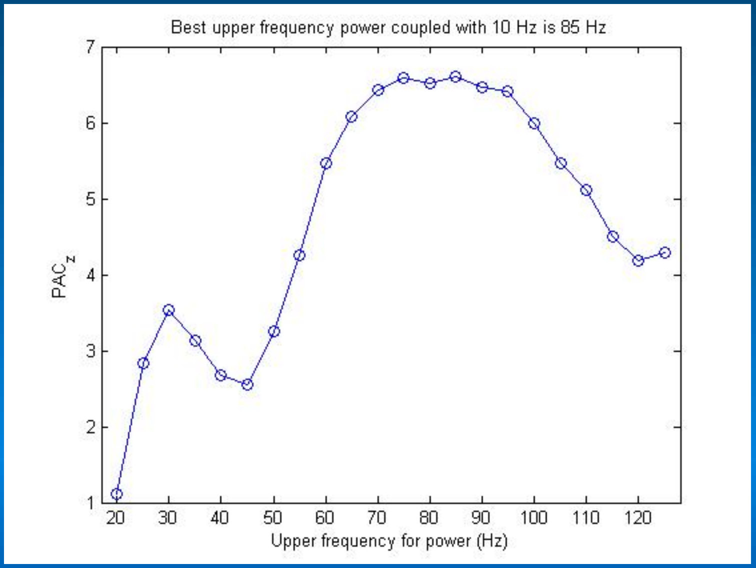


Figure. 30.8 B: PACz values at higher freq. for power when phase freq. is 10HZ



Mixed Apriori Exploratory CFC

Avoid circular inference

- Use statistical correction (might reduce power- depending on the number of comparisons)
- Compare conditions – can improve internal validity of the effect
- Use half of the data as exploratory and half as confirmatory (can be done with splitting trials or subjects randomly)

Exploratory CFC

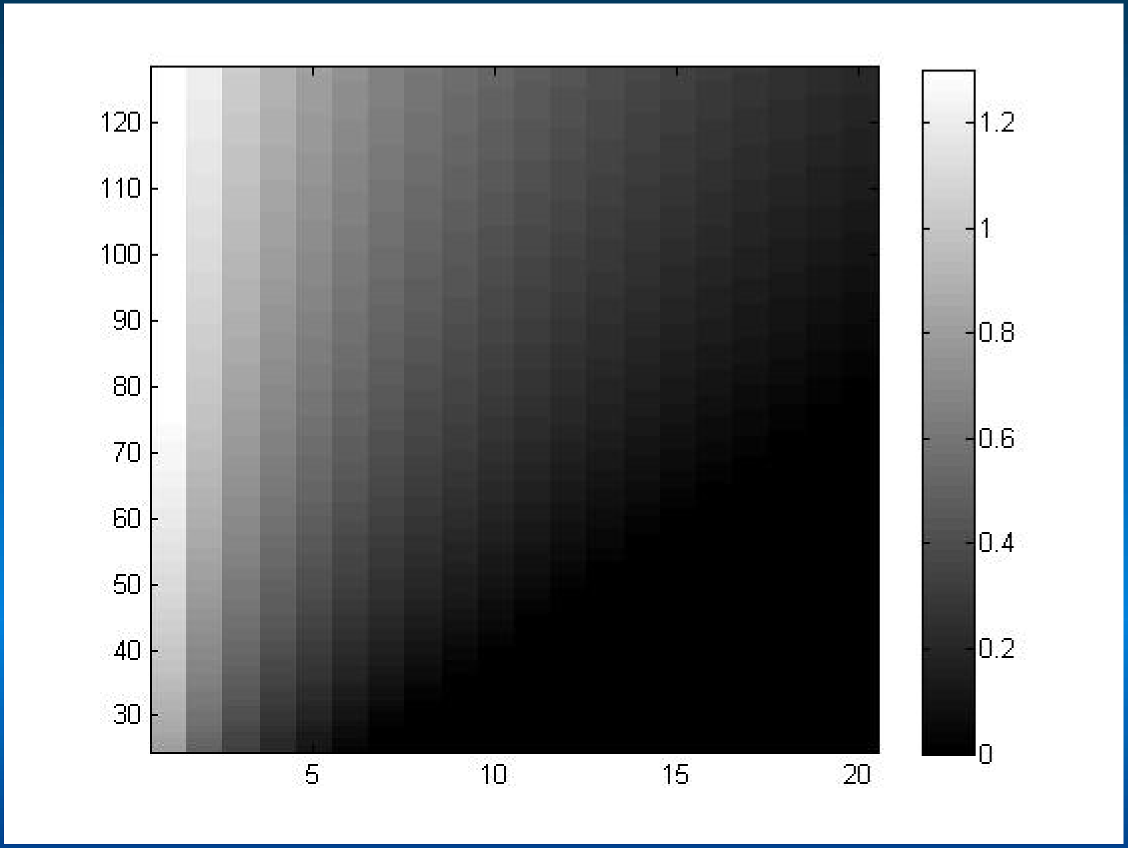
- Figure 30.10

CFC Phase –Amplitude

- General notes
- Its best to use wavelet convolution or filter Hilbert to get phase angles at different times.
- Timing is highly important so use time-frequency parameters that temporal precision over freq. precision .
- Sample at a high rate. Sample at least one cycle of the lower freq (better – five).
- Many trials can get you the power and reliability you need (better than more cycles).
- Avoid analyzing data when ITPC is high.
- Avoid edge artifacts.
- Avoid (unnecessary) multiple comparisons – compare conditions only after finding the best PACz.

CFC Phase –Amplitude

Fig. 30.11



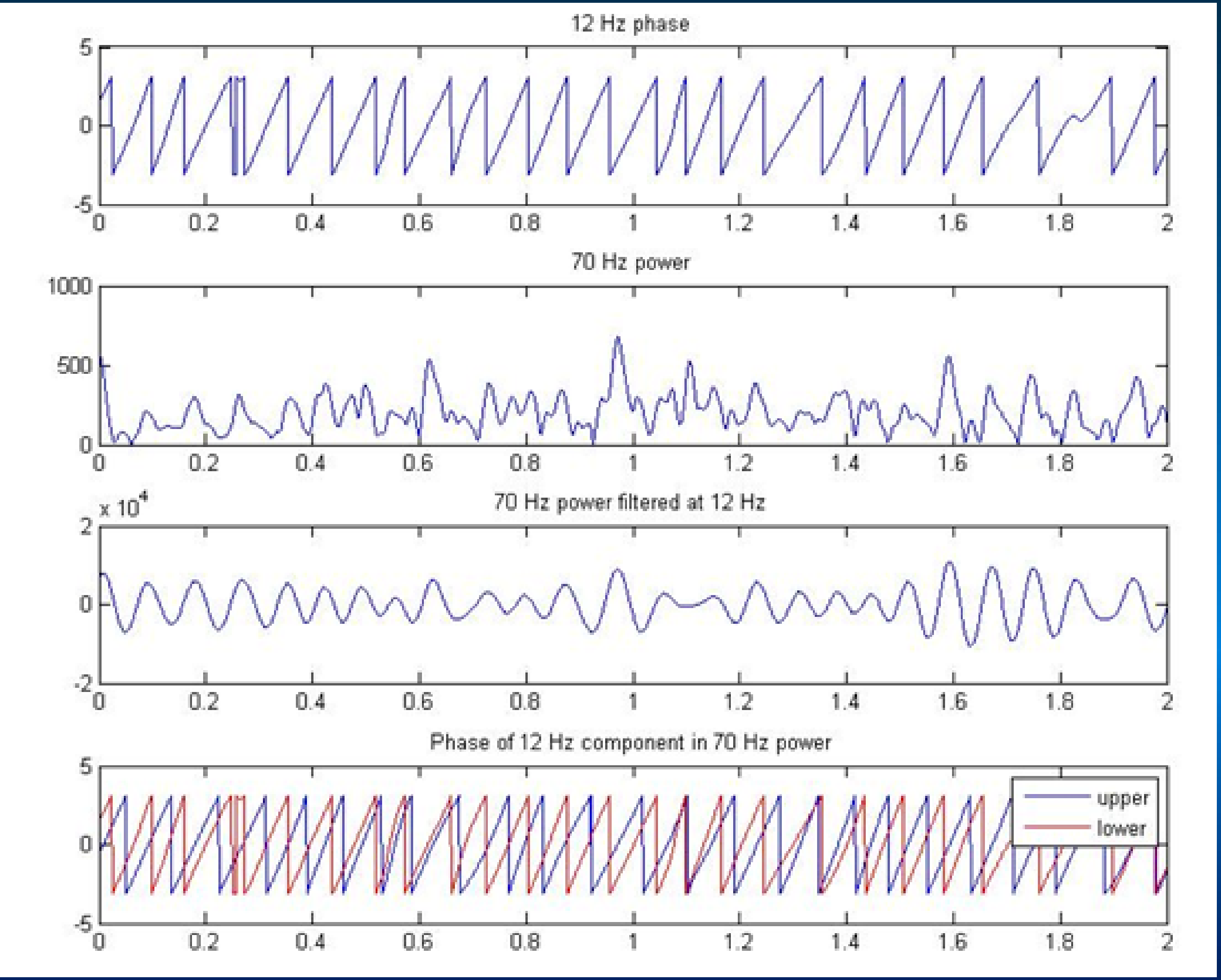
CFC Phase –Phase

- Compute a phase coherence score between phases of different frequencies at a given time-point (more on chapter 34)

➢ phasephase_synch = abs(mean(exp(1i*(lowerfreq_phase-upperfreq_amp_phase))));

CFC Phase –Phase

Fig. 30.12




"That's all Folks!"