Analysis of two-tone interference

Using tonotopic zero-based encoding

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Why should an auditory model be able to explain two-tone interference?

- If it can't solve this "trivial" waveform interaction, how could it be expected to properly handle the sounds of the real world?
- I will show here how my zero-based algorithm accounts for two-tone interference in terms of the migrations of real zeros caused by various modes of waveform interactions.

"Assumptions can be dangerous, especially in science. They usually start as the most plausible or comfortable interpretation of the available facts. But when their truth cannot be immediately tested and their flaws are not obvious, assumptions often graduate to articles of faith, and new observations are forced to fit them. Eventually, if the volume of troublesome information becomes unsustainable, the orthodoxy must collapse."

John S. Mattick,
Scientific American, October, 2004

Is the current auditory paradigm based on a faulty assumption?

- In its most fundamental aspects it has failed to explain experimental data such as two-tone interference.
- Correspondingly, we must consider its well-known inability to approach, even modestly, the ear's ability to:
    - separate, locate, and identify environmental sounds,
    - provide a suitably robust speech recognizer,
    - replicate the cocktail party effect.
- A different paradigm is needed; one that begins with good answers for two-tone interference.
- To begin, let's look at the sequence of essential auditory functions.

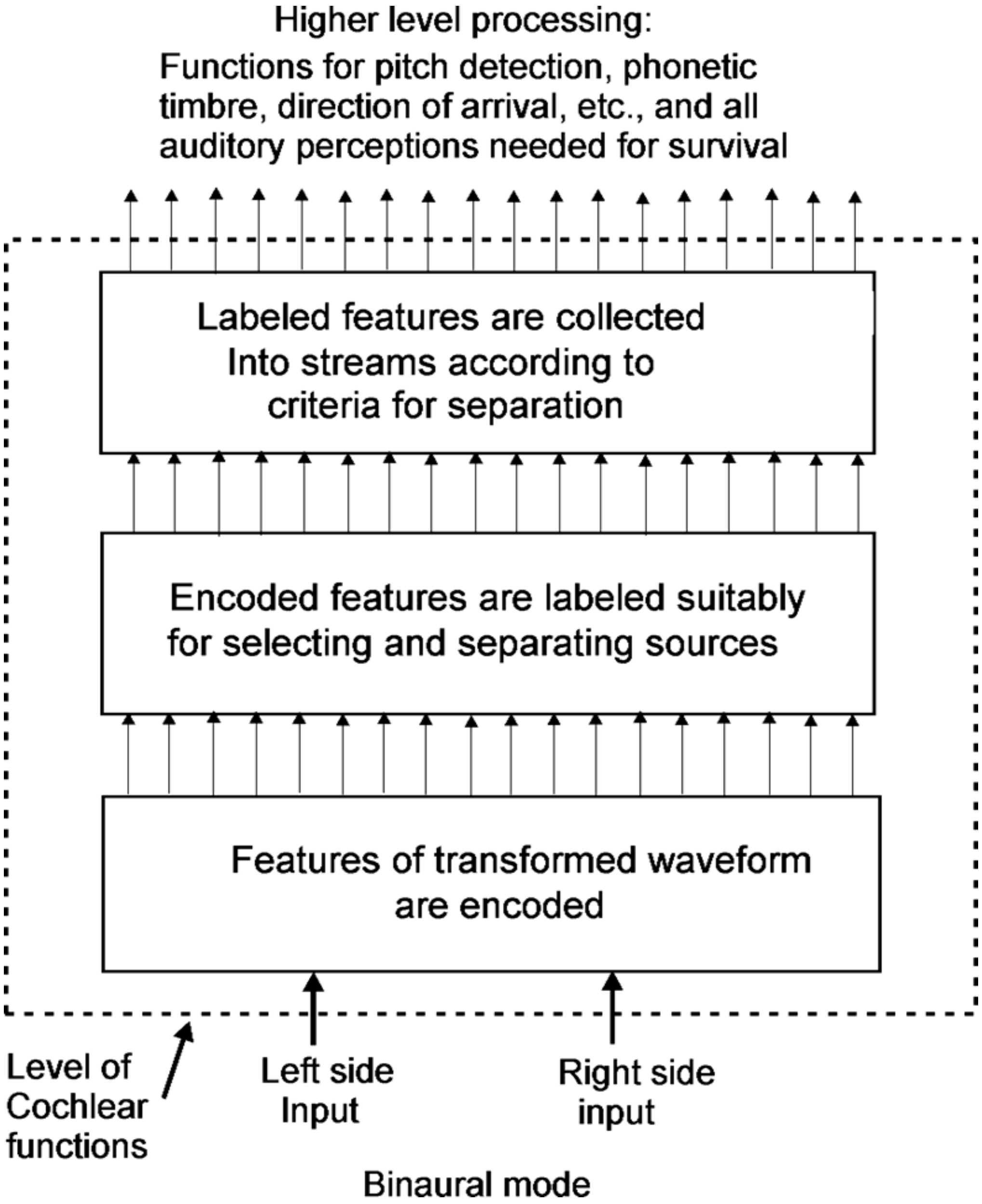


Figure 1: Processing functions at or near cochlear level that are needed for separating, identifying, and selecting sound sources

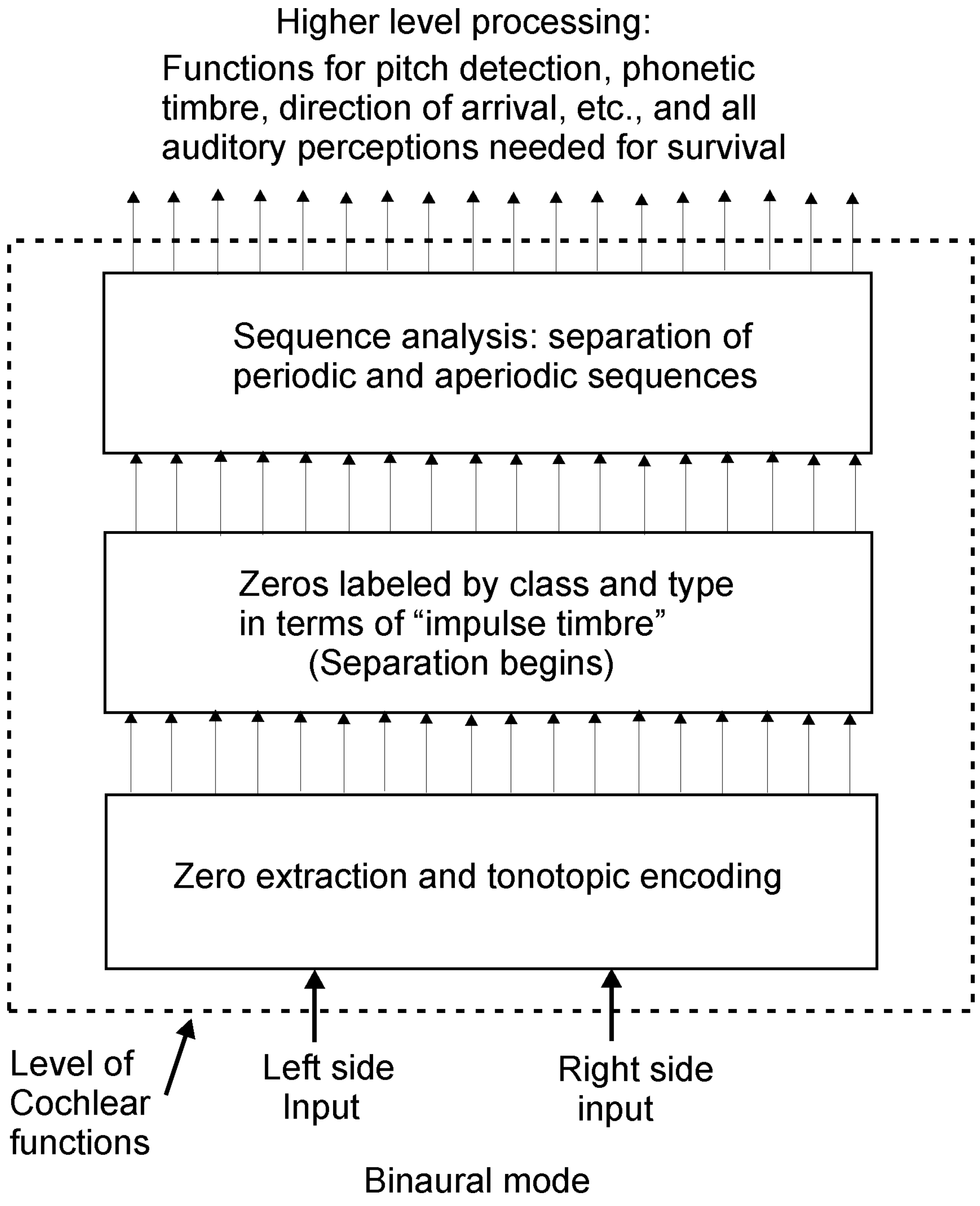
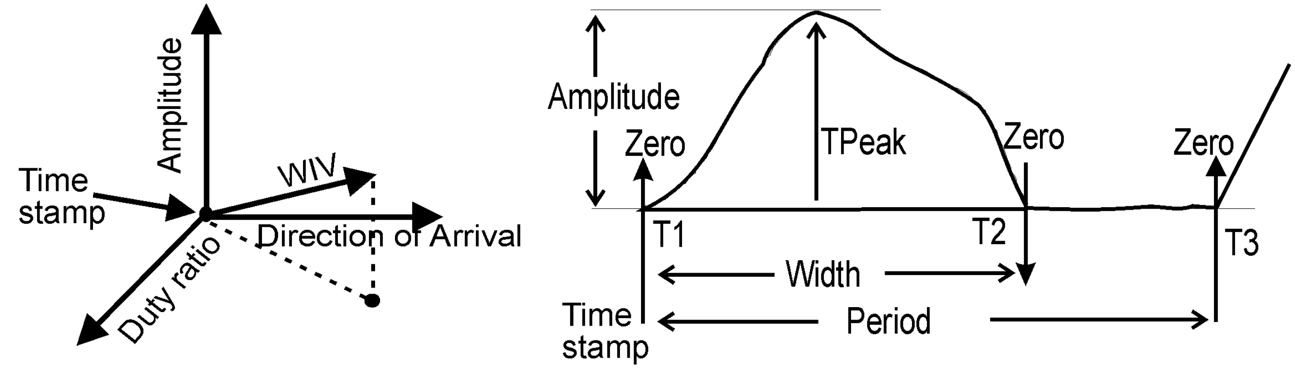


Figure 2: Implementation of cochlear-level functions using zero-based encoding



(a) Waveform information vector

(b) Derivation of WIV parameters
duty ratio = width/period

Figure 3: The waveform information vector (WIV) is proposed as a fundamental unit of acoustic information. It is based on elements of time, space, and energy.
(A concept proposed by Epicurus, 300 B.C.)

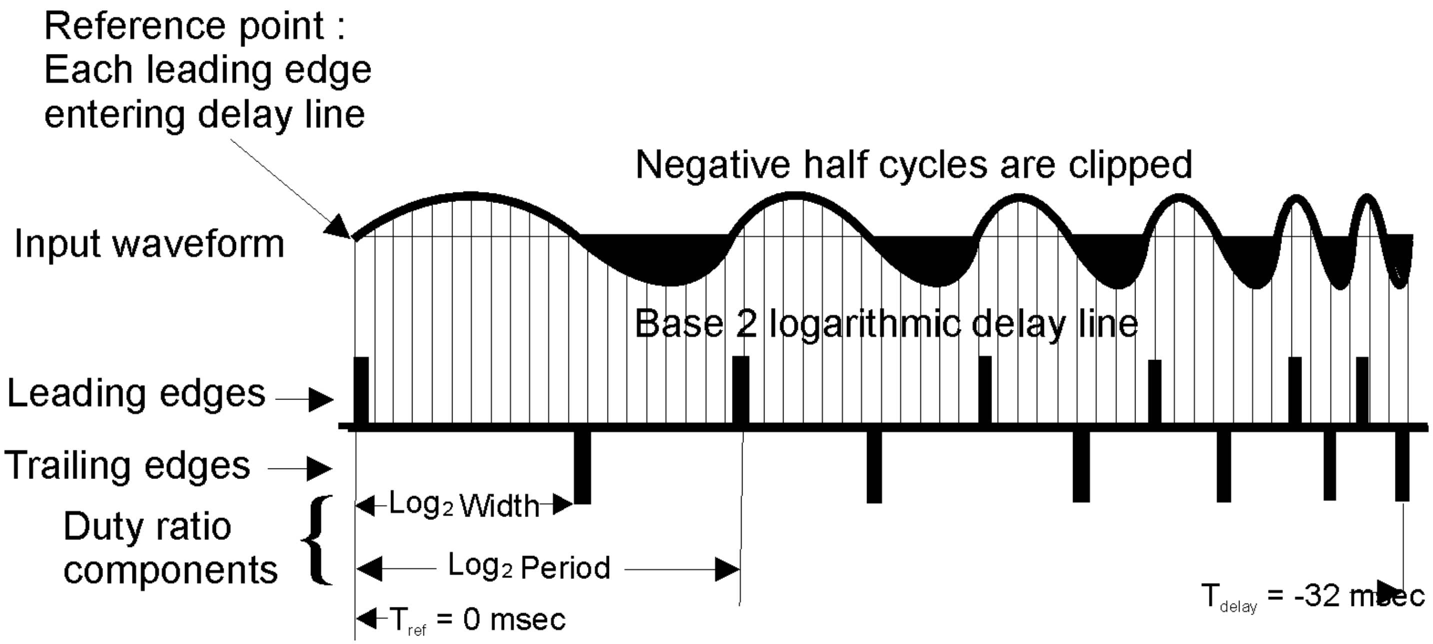
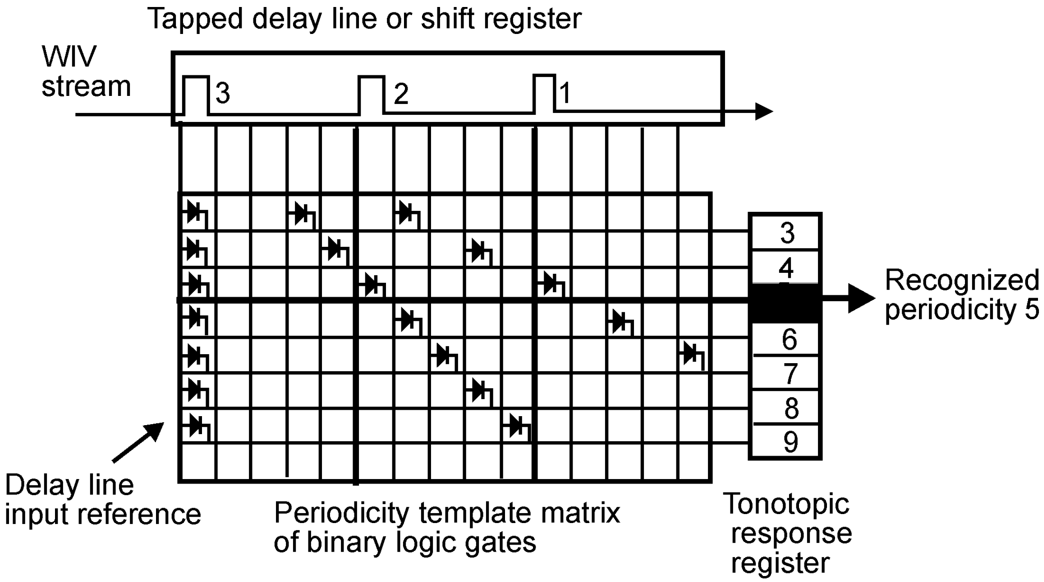
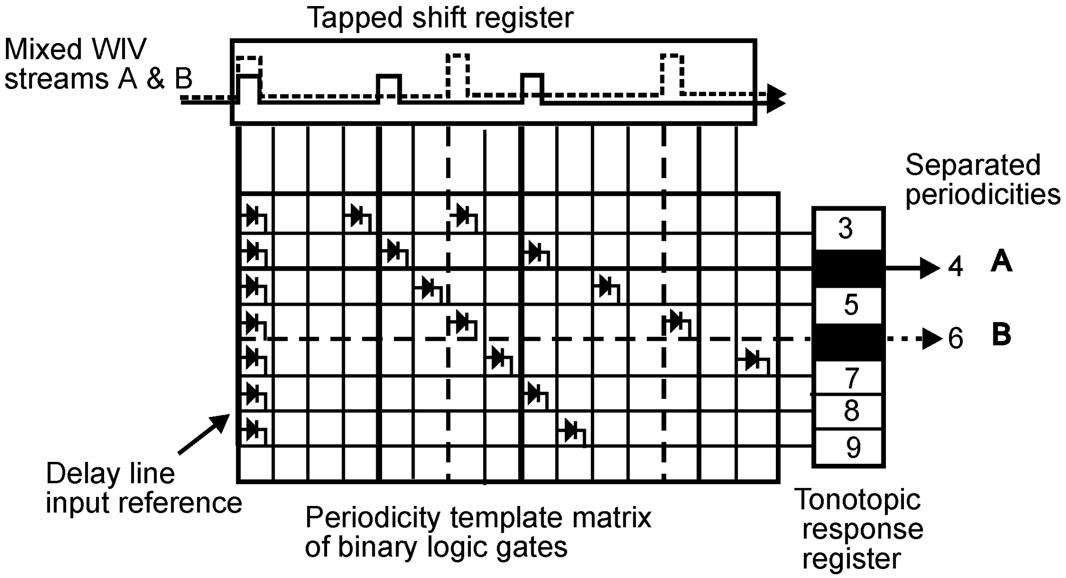


Figure 4: Method of extracting WIV parameters

- No non-linear mathematical assumptions are used other than half-wave rectification and logarithmic delay which are known to exist in the cochlea.



(a) Illustrating functions of the periodicity sorting matrix



(b) Illustrating separation of two intermixed synchronous periodic sequences, A and B

Figure 5: Ultra-simplified periodicity sorting matrix (PSM)

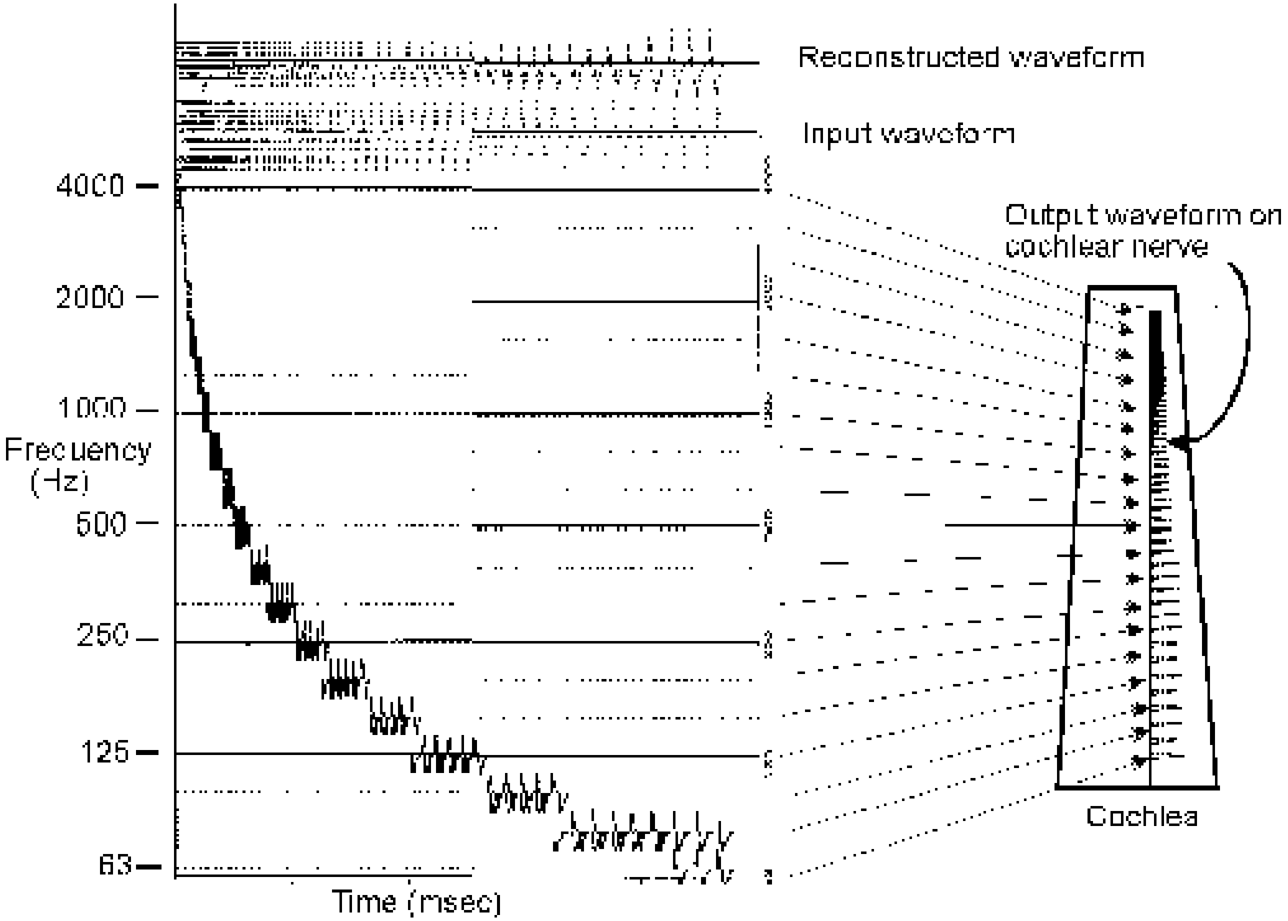
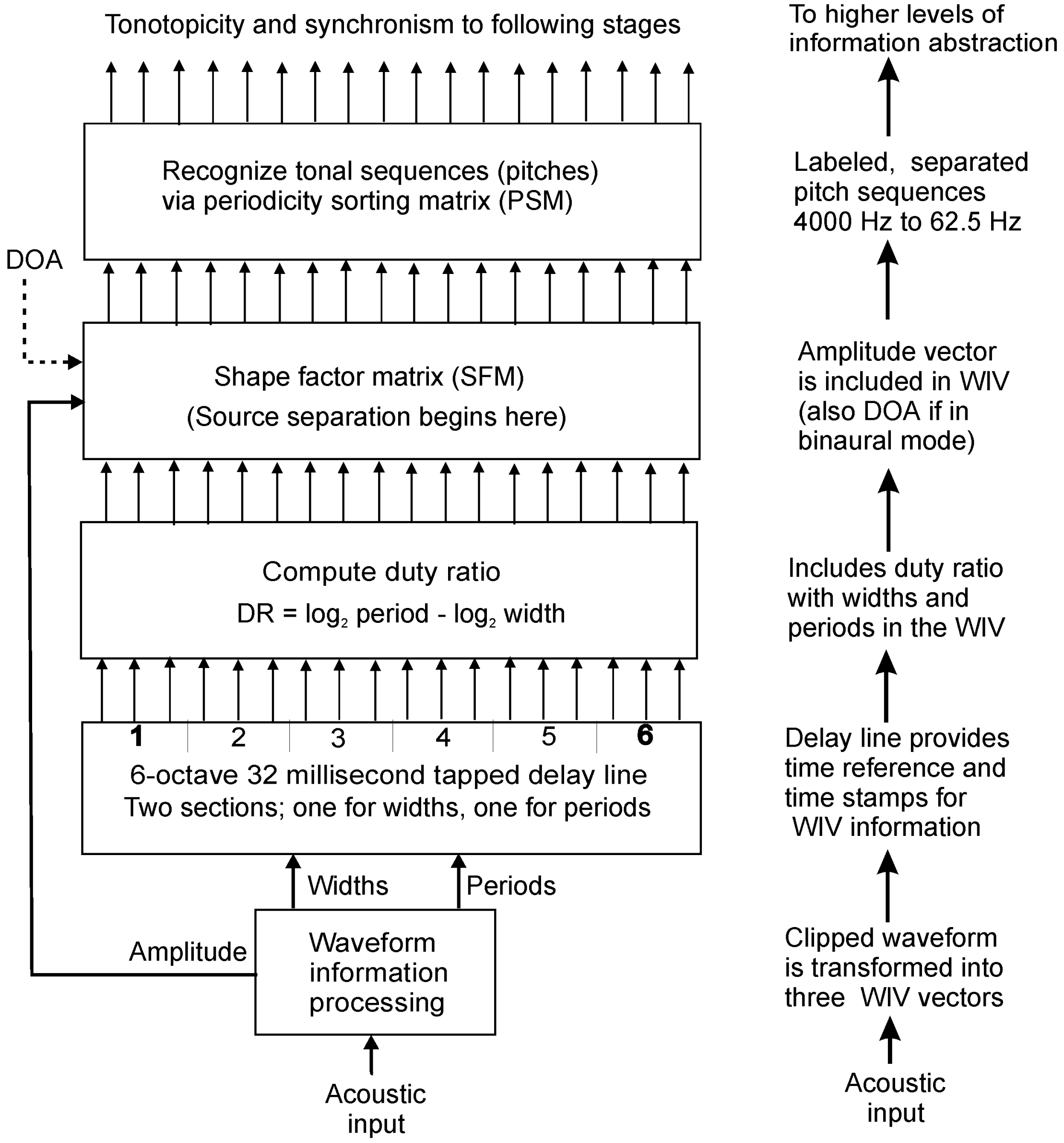


Figure 6: Example of PSM display showing its 6-octave range and its inherent tonotopicity matching that of the human cochlea. The displayed signal is a sequence of periodic pulses with repetition rates decreasing in one-third octave steps.

WIV-based definitions:

- A WIV = one period
- Two *equal* WIVs in sequence = one tonal event; I call it a "teset" for **T**wo **E**qually-**S**paced **E**vents in **T**ime.
- Tesets should be treated as independent events.
- Uninterrupted sequences of similar tesets have a pure tonal quality.
- Interrupted sequences of similar tesets have a rough tonal quality or timbre.
- Sequences of assimilar tesets have atonal timbre, often with phonetic attributes.

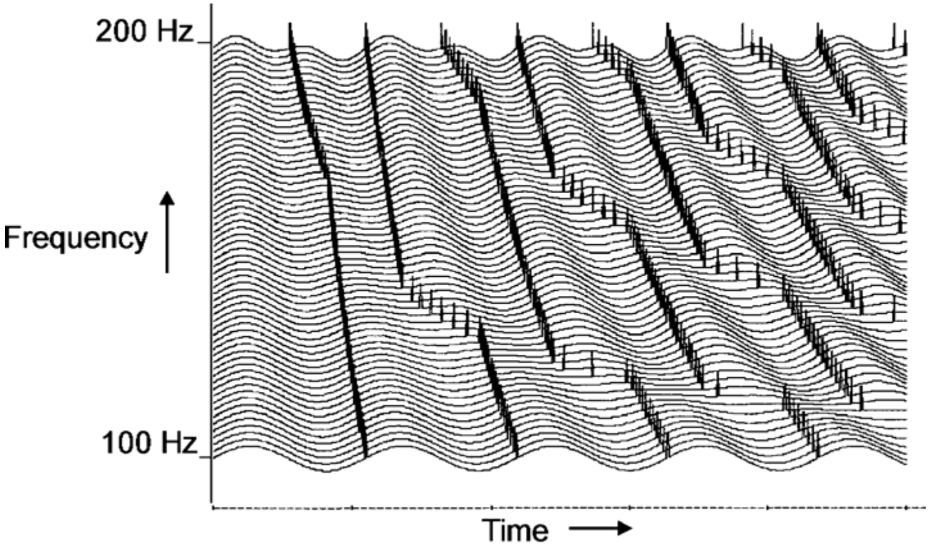


(A) Functions in tonotopic processing from input to the level of periodicity separation

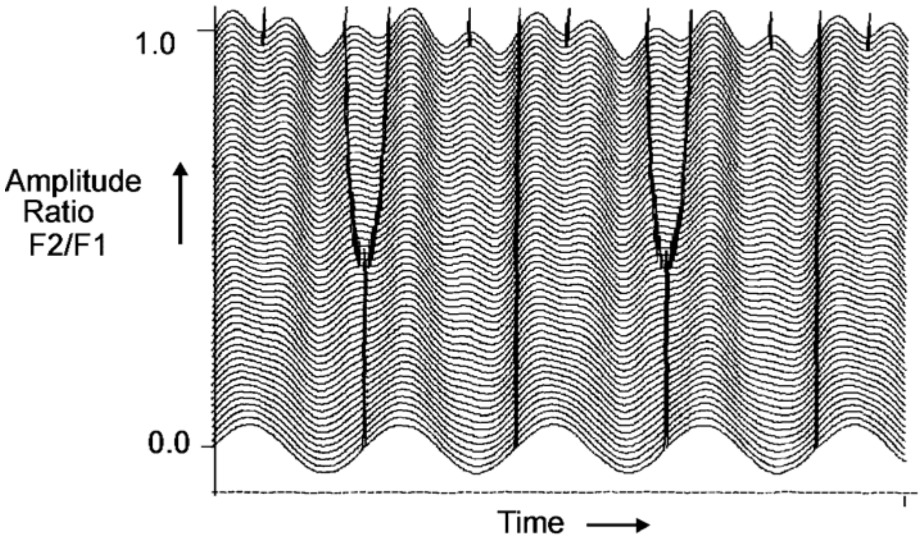
(B) Stages in extracting information from sound waveforms

Figure 7: Flow chart and summary of functions needed to demonstrate the effects of zero migration in two-tone interference

- Zero migration in two-tone interference shows how interference questions could be answered. I have investigated:
    - Effects of amplitude of F2 relative to F1
    - Effects of frequency variation of F2 relative to F1
    - Effects on periodicity responses to zero migrations and showing generation of subtones

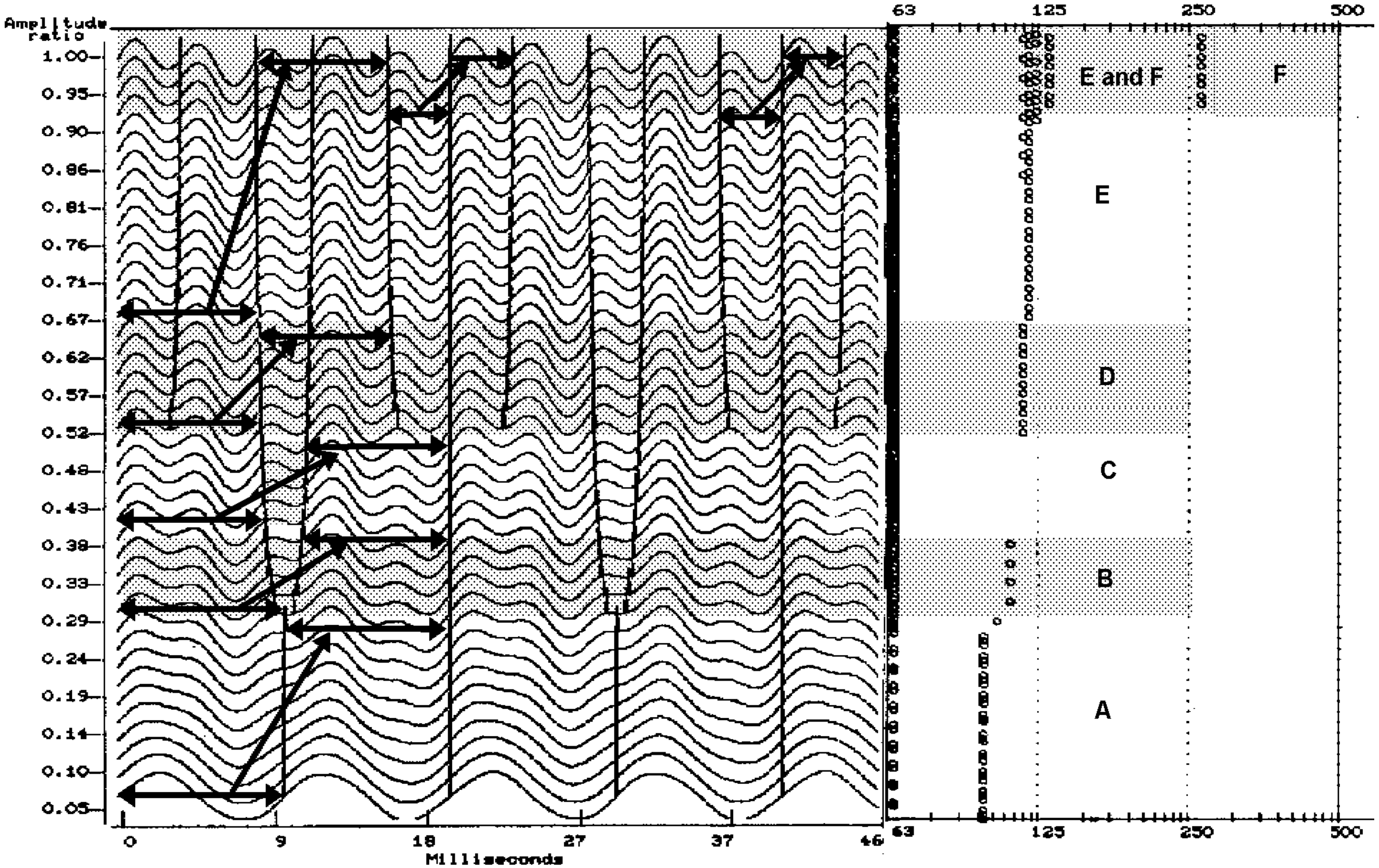


(a) Two sine waves, F1 fixed at 100Hz; F2 increasing from 100 Hz to 200Hz, equal amplitudes.



(b) Two sine waves, F1 fixed at 100Hz, F2 fixed at 250 Hz Amplitude ratio F2/F1 increases from 0 to 1.0

Figure 8: Migration of zero crossings in two-tone interference with; (a) frequency ratio F2/F1 and (b) amplitude ratio A2/A1. Zero trajectories are the dark lines



(a) Zero migrations in amplitude ratio F2/F1 from 0.05 to 1.0

(b) Periodicity responses (Hz)

F1 = 100 Hz   F2 = 250 Hz

Figure 9: Responses of periodicities (small circles) to transitions in zero trajectories as F2/F1amplitude ratio increases from .05 to 1.0. Double-pointed arrows represent single periods. A periodicity (teset) requires *two sequential equal* periods. Intervening zeros are allowed so that intermixed periodicities (E and F) exist simultaneously.

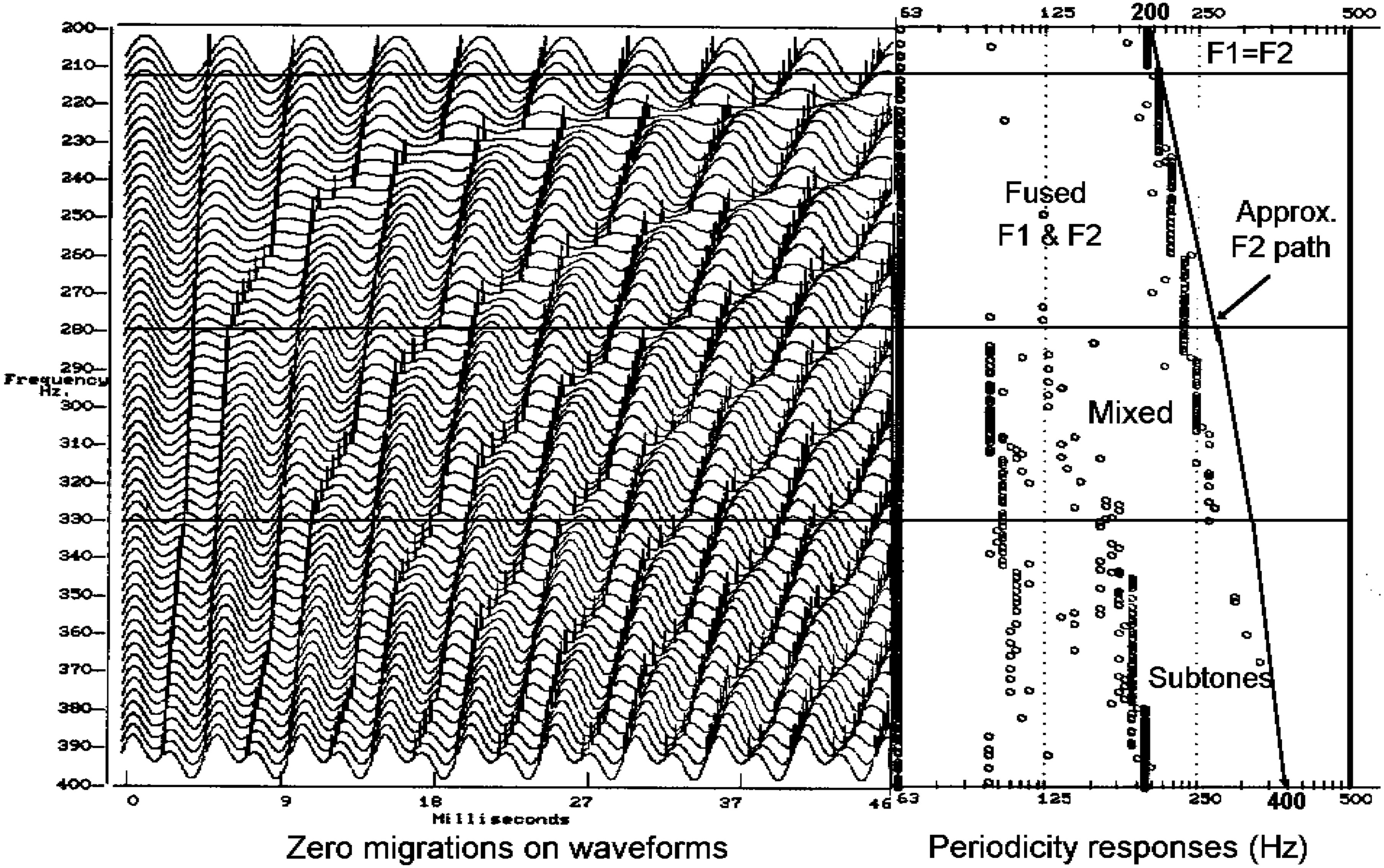


Figure 10: Periodicity responses with F1 constant at 200 Hz as F2 increases frequency to 400 Hz. Amplitude ratio is constant at 1.0

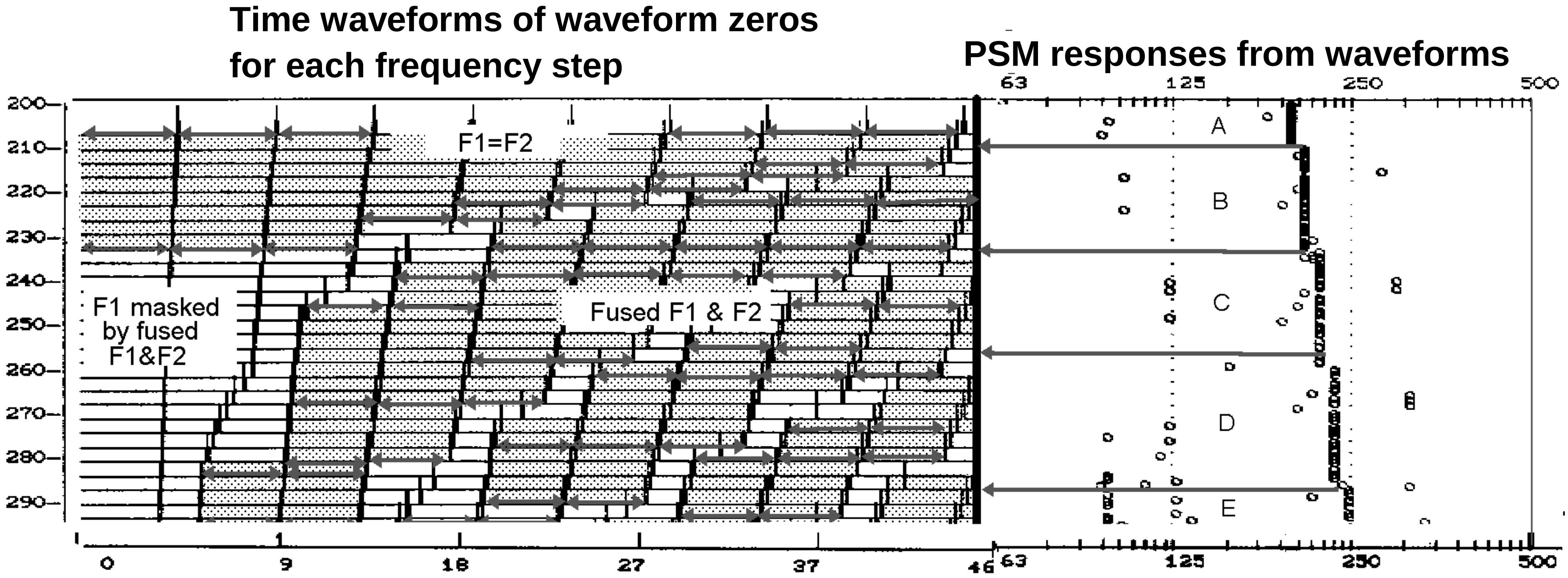


Figure 11: Using only the zero crossing spikes. Analysis of the "fused" portion between 200 and 290 Hz. Fused frequencies are the average of F1 & F2 caused by waveshape changes in two-tone interference.

- Interference of intermixed zero periods causes masking of F1 and the interruptions in teset sequences. Each periodicity hit is PSM's response to the arrival of a teset.

- The scattered responses result from rapid transitions in the zero trajectories.

- Only the algorithm used by the PSM can solve this kind of problem.

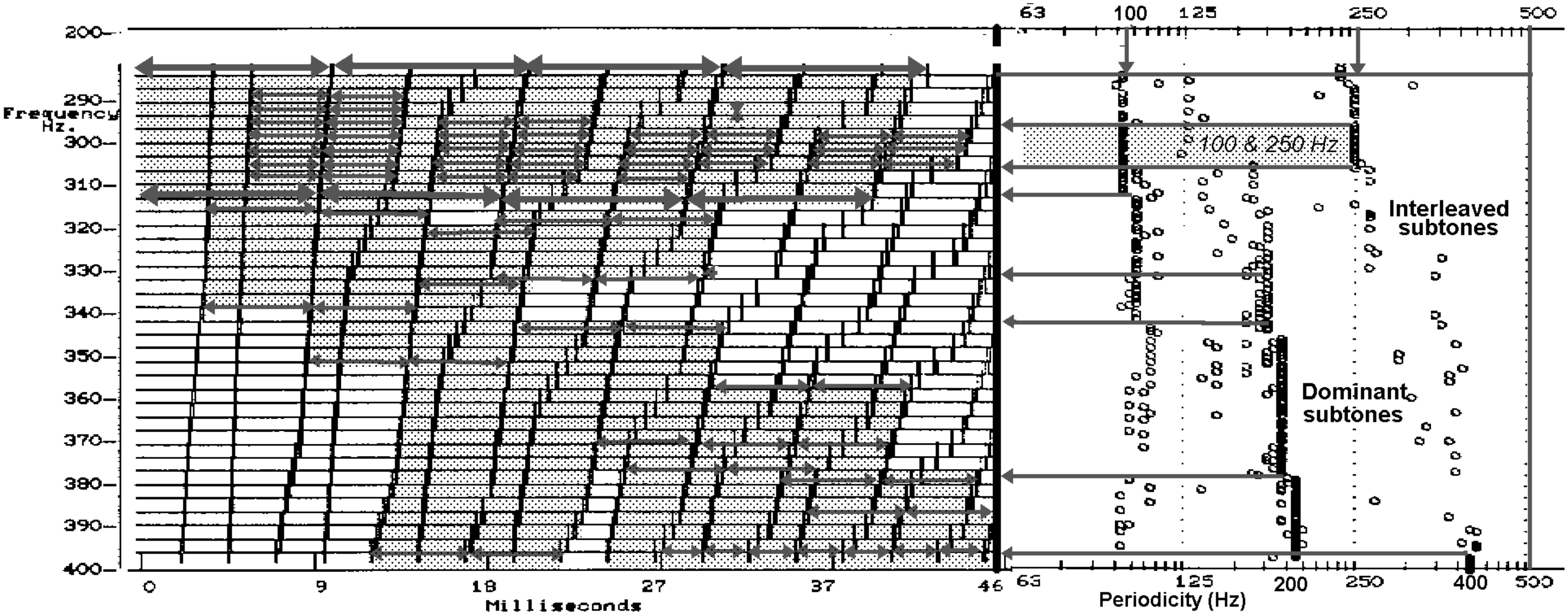


Figure 12: Analysis of F2 increasing from 290 to 400 Hz

- Major transitions in PSM responses:
  - 290 to 315 Hz includes fusion 250 Hz "embedded" within 100Hz subtone
  - 315 to 345 Hz with two interleaved subtones masking the fused tones
  - 345 to 395 Hz shows only one dominant subtone approx. 200 Hz
  - 395 to 400 Hz unmasks F2 at 400 Hz.

Summary:

- Periodicity analysis has tonotopicity similar to the cochlea.

- Periodicity responses are synchronous with waveform.

- Intermixed periodic sequences are separated.

- Two-tone interference creates subtones according to relative amplitudes and frequencies. Thus, interference, *not filtering*, creates masking effects.

- Despite interruptions, sequences of tesets *produce periodic responses*, thus allowing analysis of noise, whispers, and complex mixtures of tones such as music and speech.