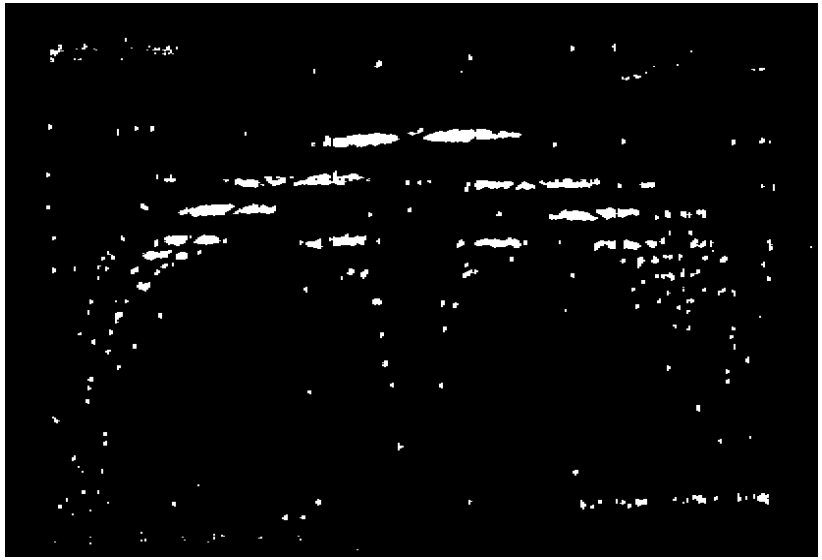
Combination Tones

and two-tone interference



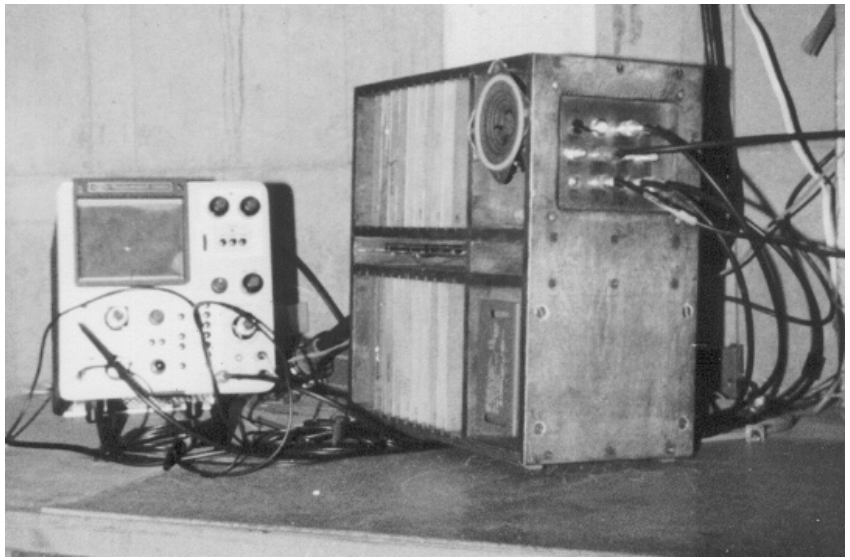
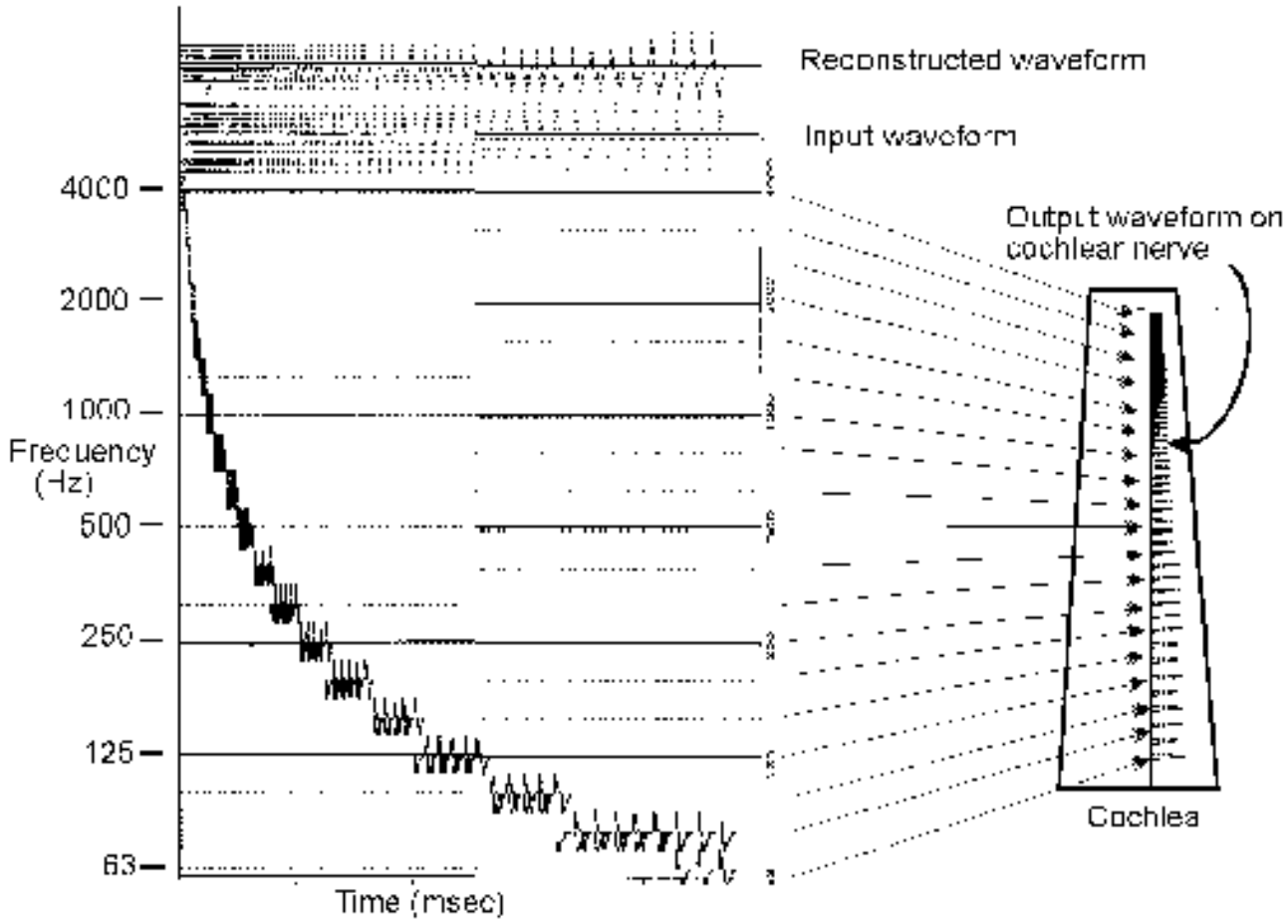


Figure 3: Photograph of combination tones taken from a hard-wired experimental periodicity sorting matrix that had 24 increments per octave instead of the 12 used in the present software PSM, and which *operated in real time*. Note fewer stray responses due to the better octave resolution and a higher sampling rate.

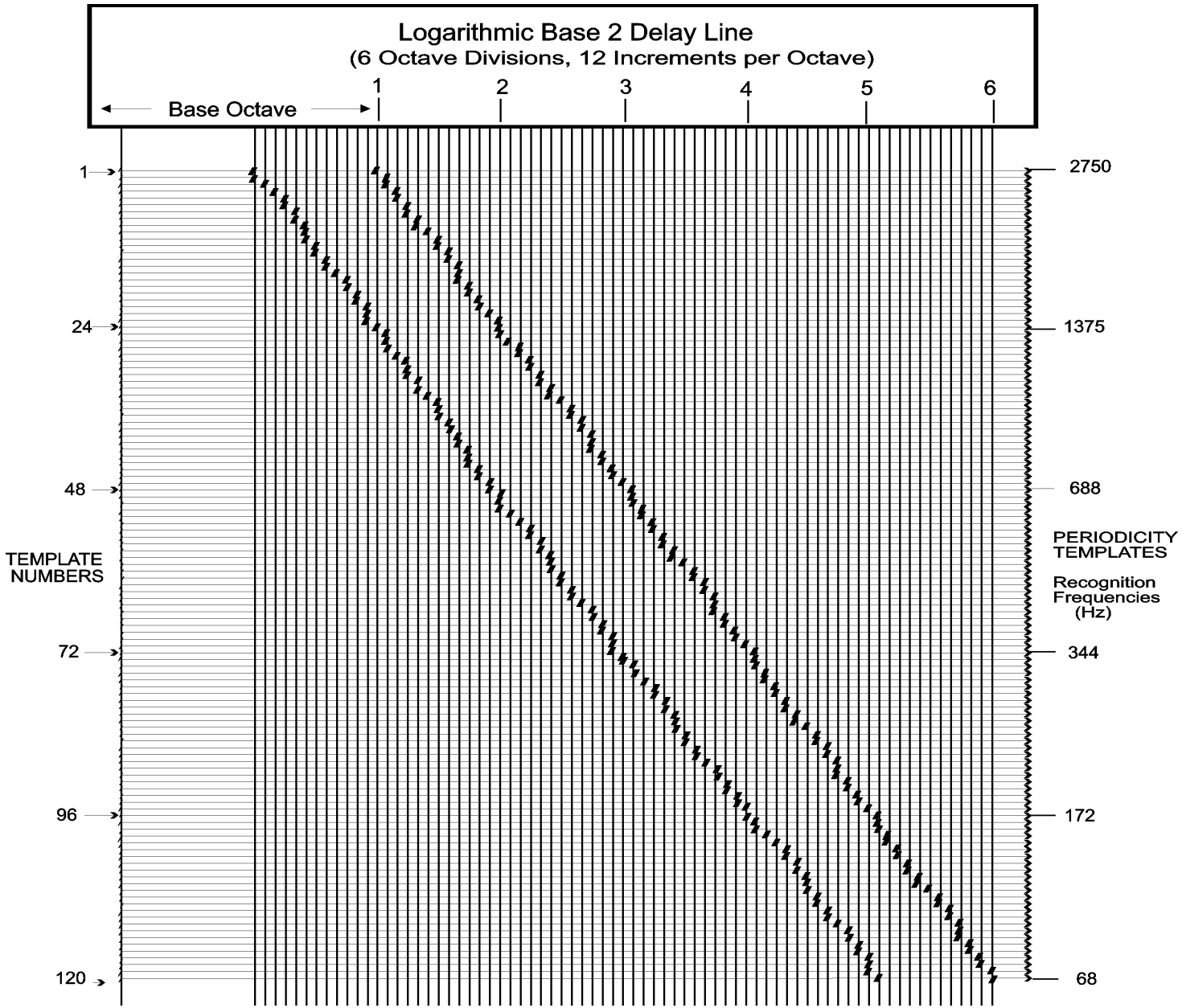
Two-tone interference questions could be answered by the effects of zero migration that generate subtones caused by:

- Variations in amplitude of F2 relative to F1
- Variations in frequency of F2 relative to F1

Following is an analysis of these effects

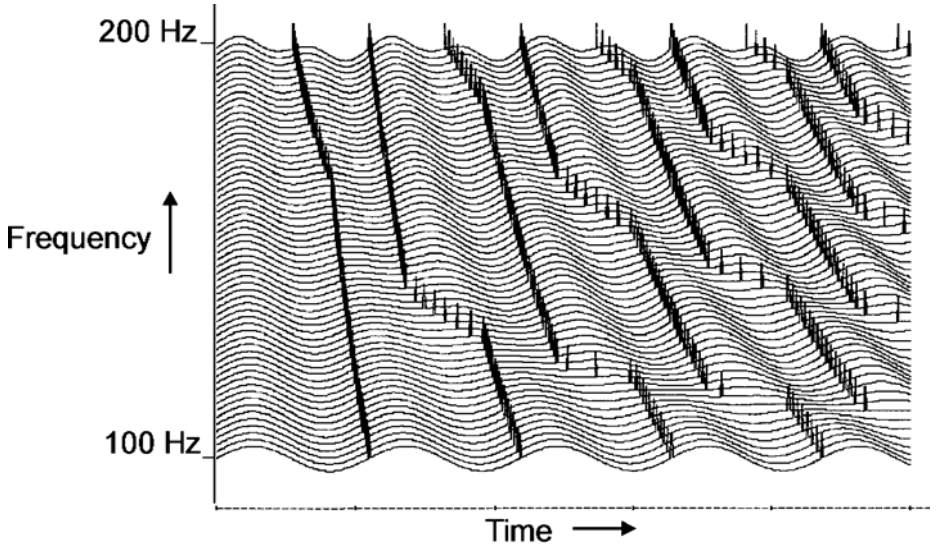


Illustrating the cochlear-like response to a tone source sliding downward in third-octave stepsfrom 4000 Hz to 63 Hz

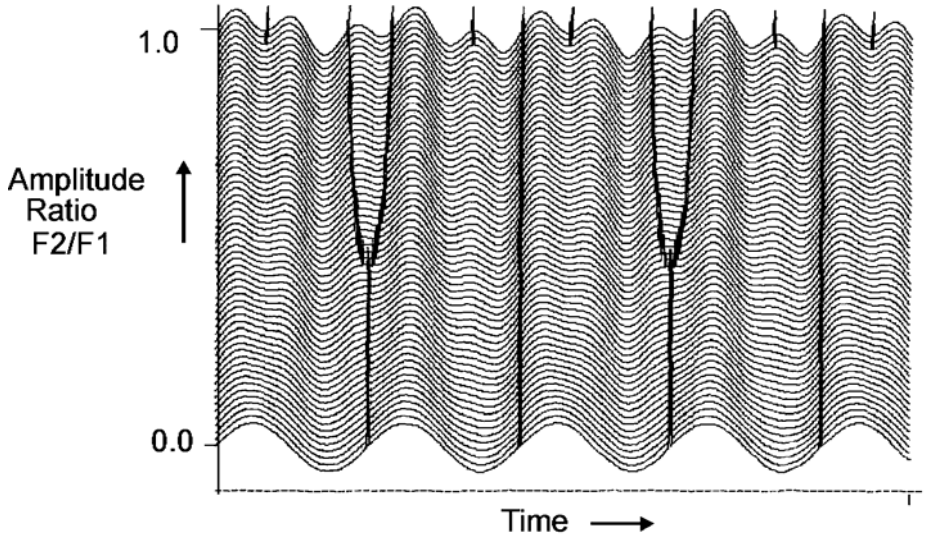


Logic diagram of six-octave PSM

Twelve tones per octave



(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

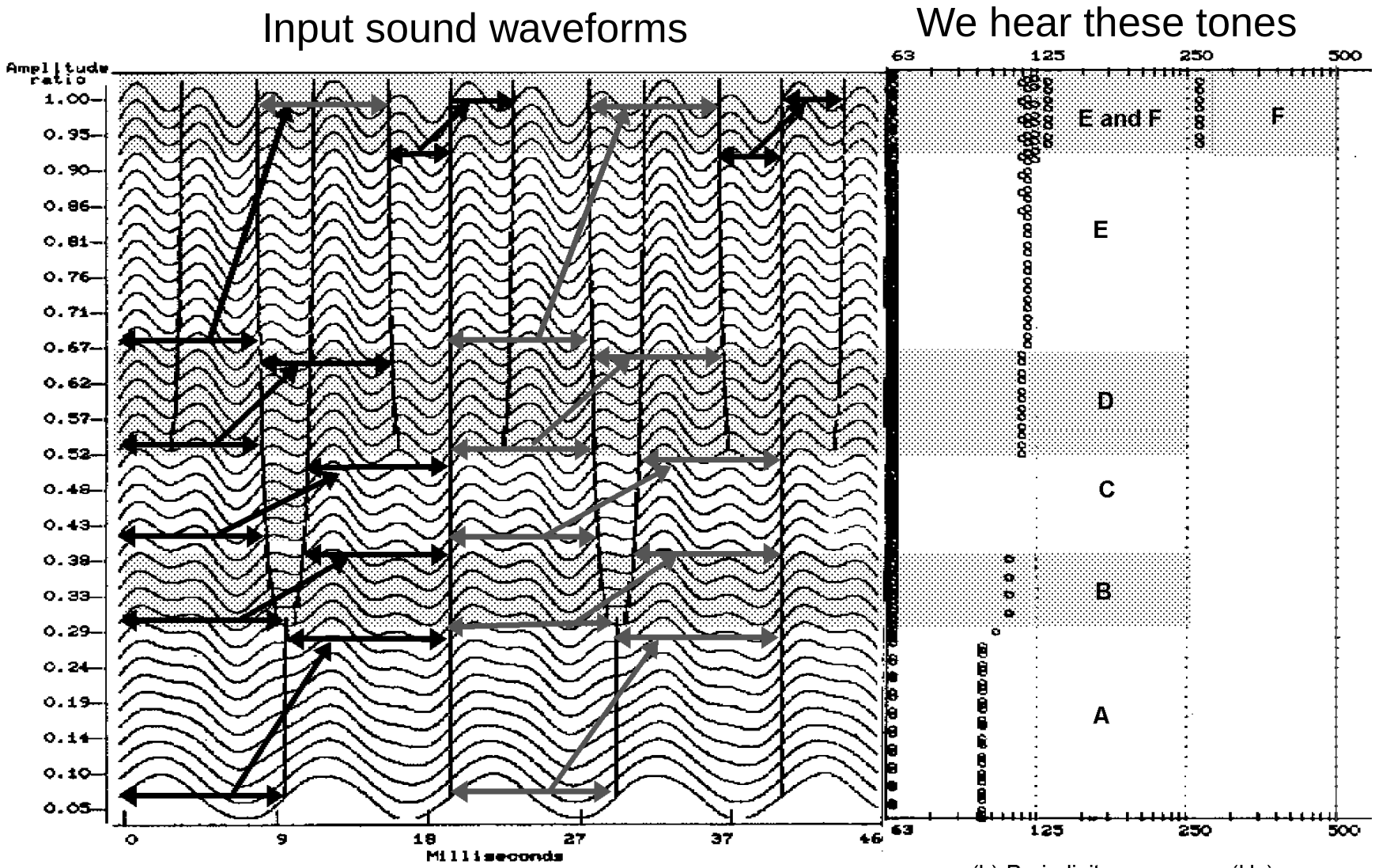


Figure 9: Responses of periodicities (small circles) to transitions in zero trajectories as F2/F1amplitude ratio increases from .05 to 1.0. Double-pointed arrows represent single periods. A periodicity (teset) requires *two sequential equal* periods. Intervening zeros are allowed so that intermixed periodicities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

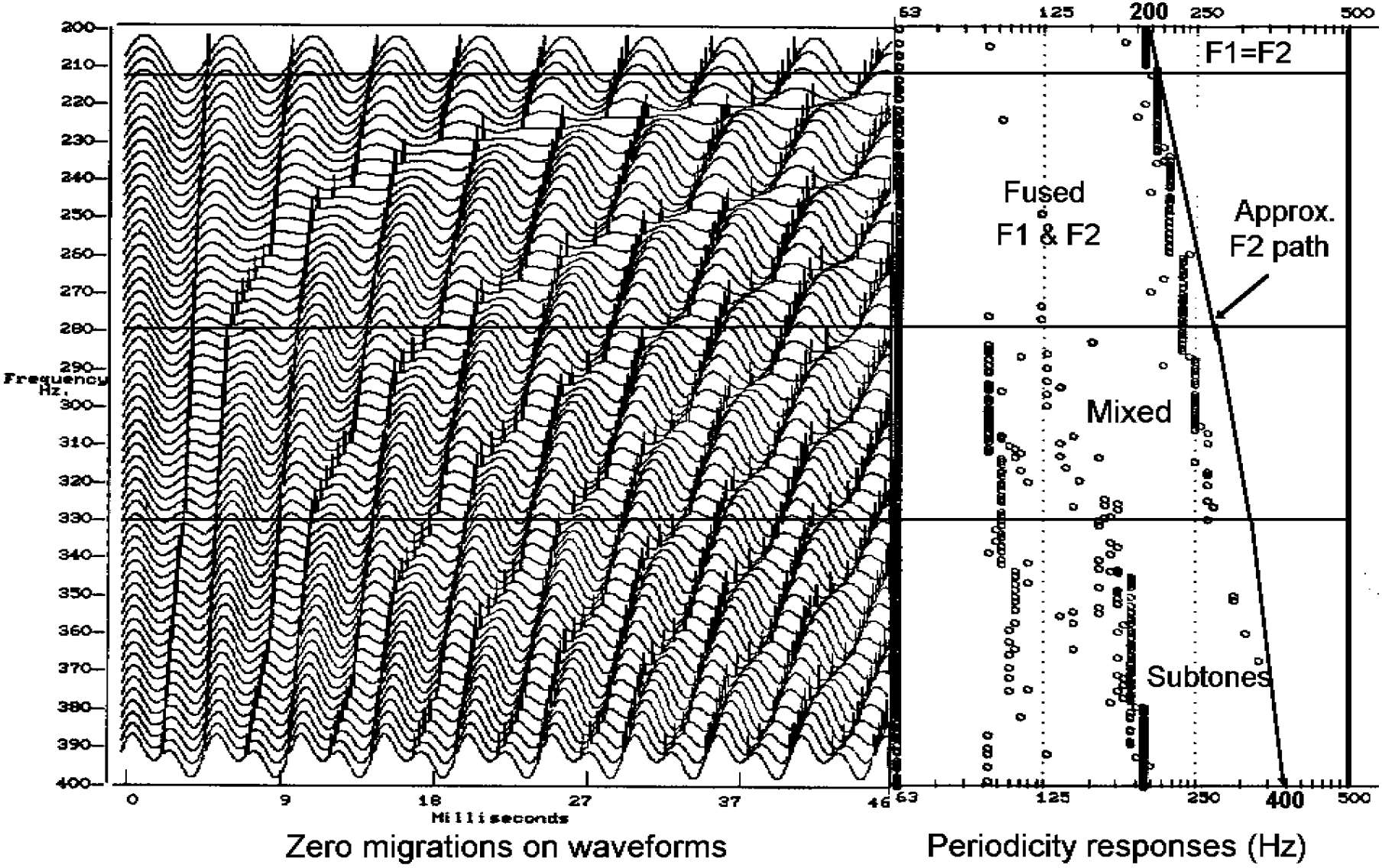


Figure 10: Periodicity responses with F1 constant at 200 Hz as F2 increases frequency to 400 Hz. Amplitude ratio is constant at 1.0

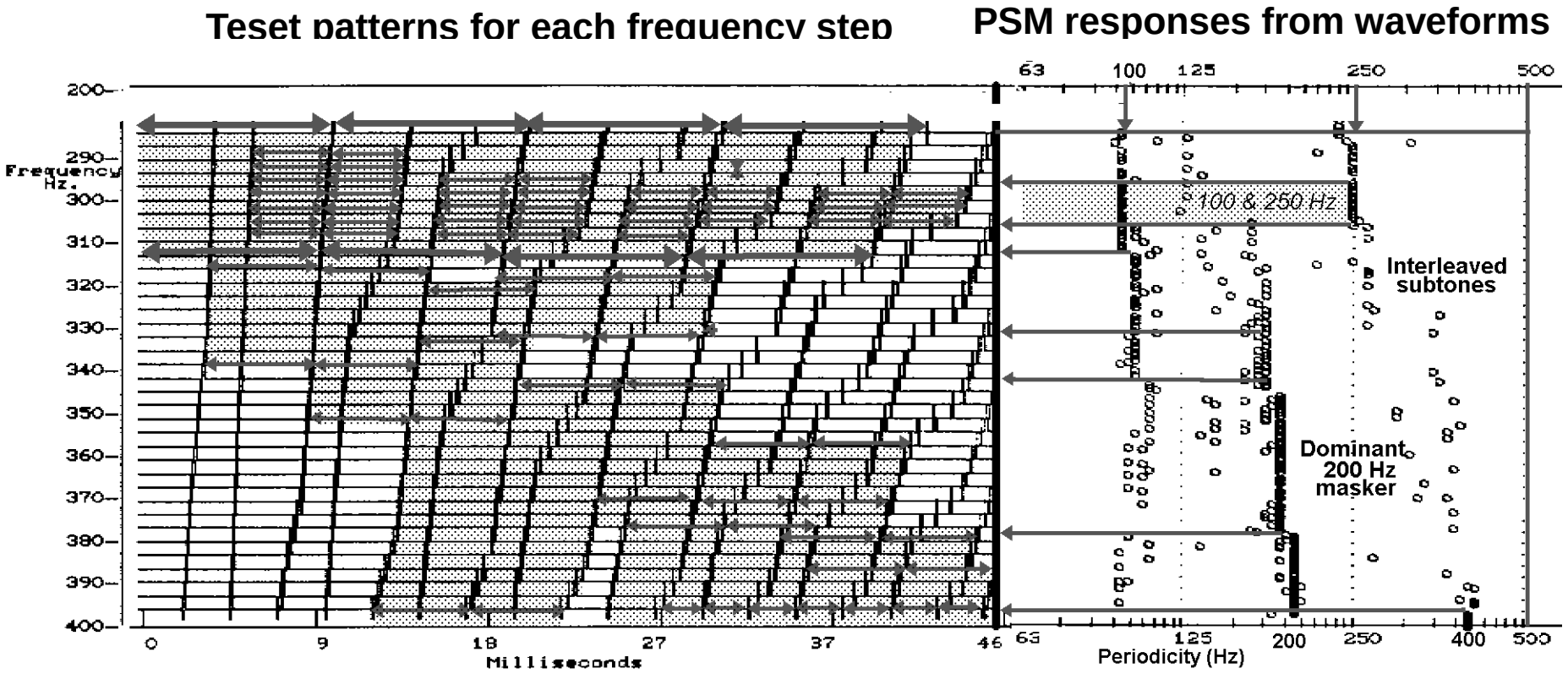


Figure 12: Analysis of F2 increasing from 290 to 400 Hz

- Major transitions in PSM responses:
  - 290 to 315 Hz includes fusion 250 Hz "embedded" within 100 Hz subtone
  - 315 to 345 Hz with two interleaved subtones masking the fused tones
  - 345 to 395 Hz shows only the dominant masker at 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 the 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 separation of components of noise, whispers, and complex mixtures of tones such as music and speech.
- Intensity of auditory perception is proportional to PSM *hit density* as well as signal amplitude.

These results are similar to auditory responses, thus:

- A zero-based approach could be correct for an auditory model.
- Could produce practical ear-like applications not possible with current methods.