INVESTIGATION OF THE EARLY-TIME BEHAVIOR OF RADAR TARGETS EXCITED IN THE RESONANCE REGION

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It is known that the pulse response of a radar target is dominated by a number of distinct specular reflections from scattering centers when the excitation is within the realm of physical optics. If the excitation waveform has frequency content primarily within the resonance region, the response is composed of an early-time period during which the excitation field is traversing the target followed by a late-time period which is a pure natural resonance series.

The late-time portion of the target response has received much attention recently for use in radar target discrimination. Its physical composition is to give a global view of the target; the natural frequencies are aspect independent and are functions of the complete target geometry. The early-time period of a target response is more complicated. As the waveform passes across the scattering centers, specular reflections occur as in physical optics scattering, representing the local behavior of discontinuities on the target. In addition to these, the early-time scattered field is composed of the resonances of smaller substructures and the building resonances of the overall structure. It is important to understand these physical phenomena if the early-time period is to be used for target discrimination.

This paper investigates the importance of various components of the early-time scattered field response for excitations in the resonance region (pulse widths approximately 20%-50% of maximal target transit time). An association will be made between the physical structure of the target and the features observed in the early-time scattered field response. Both the theoretical responses of canonical targets and the measured responses of realistic aircraft models are considered.

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I. Objectives

- Improve understanding of early-time backscatter response
- Explore resonance phenomena in the early-time
- Interpret transient response using both temporal and spectral representations
- Improve resolution of scattering centers in early-time response
- Investigate potential target discrimination methods based on early-time response

II. Transient Responses

- Wire Stick Models

  MOM solution (0.- 10.0 GHz) & Inverse FFT

- Scale Model Aircraft

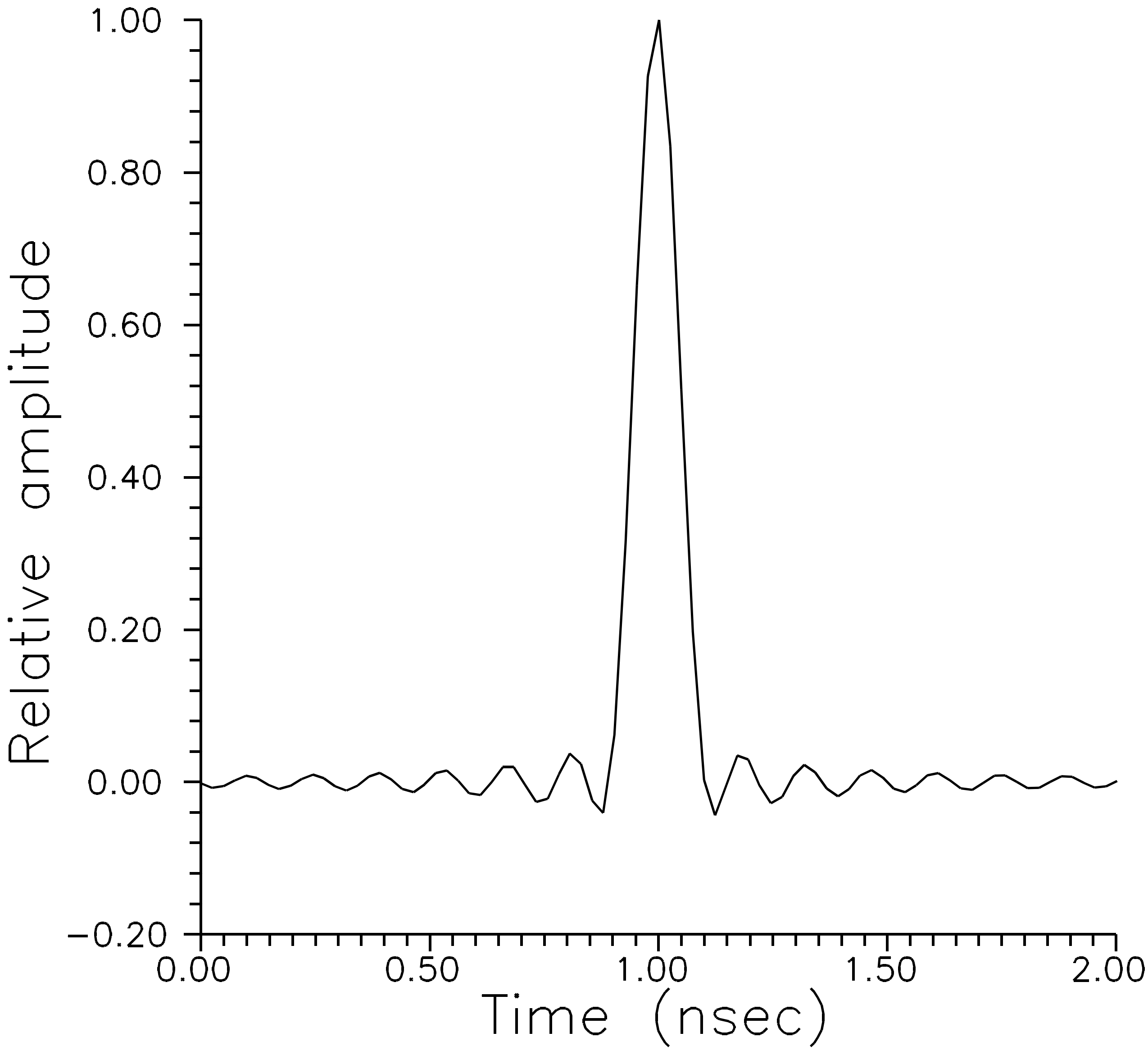
  B52 (1:72 and 1:144) B58 (1:48 and 1:96)

  HP-8720B Network Analyzer - stepped frequency measurements

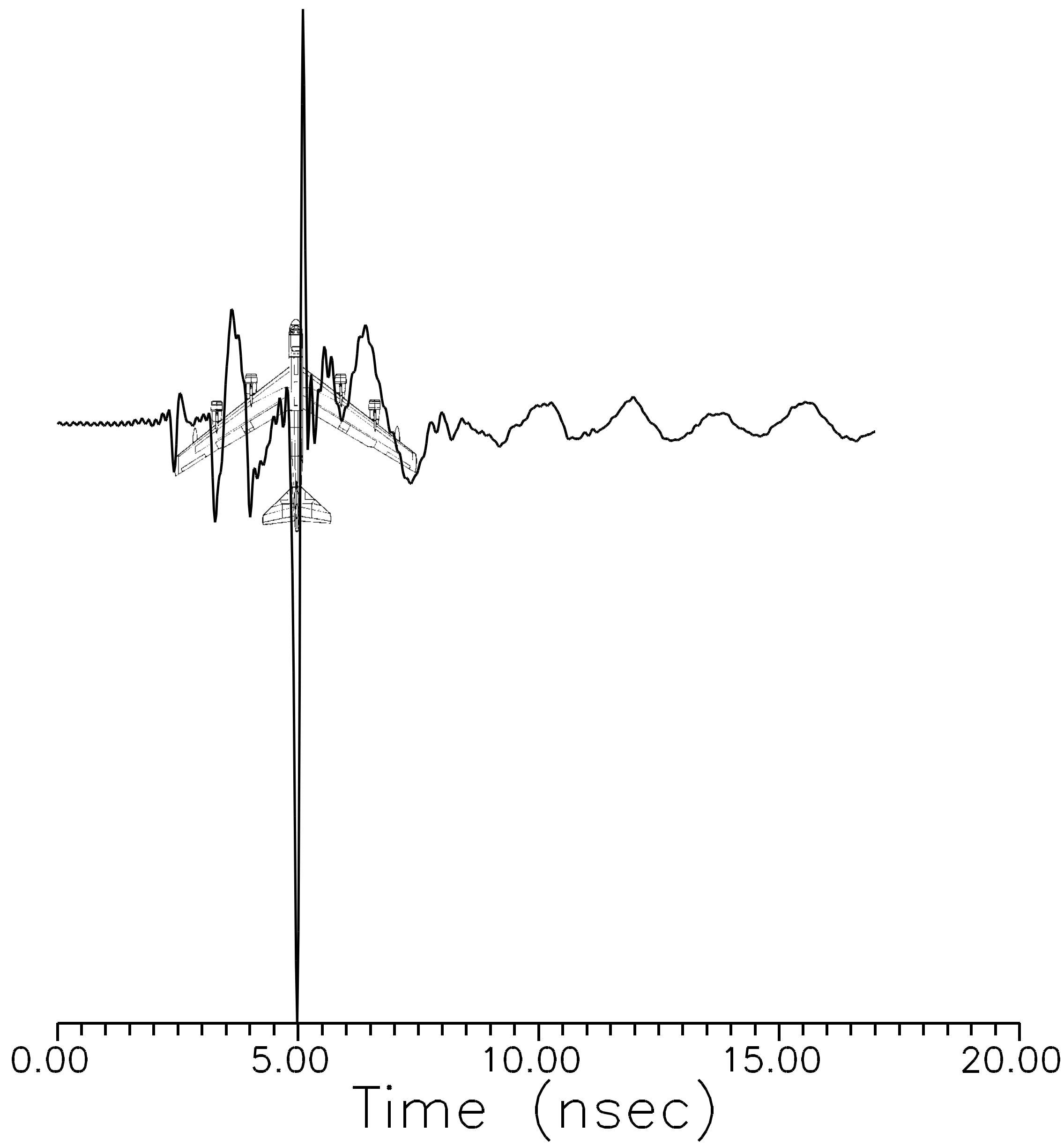
  (0.2 - 7.0 GHz) & Inverse FFT

  14.0" diameter calibration sphere

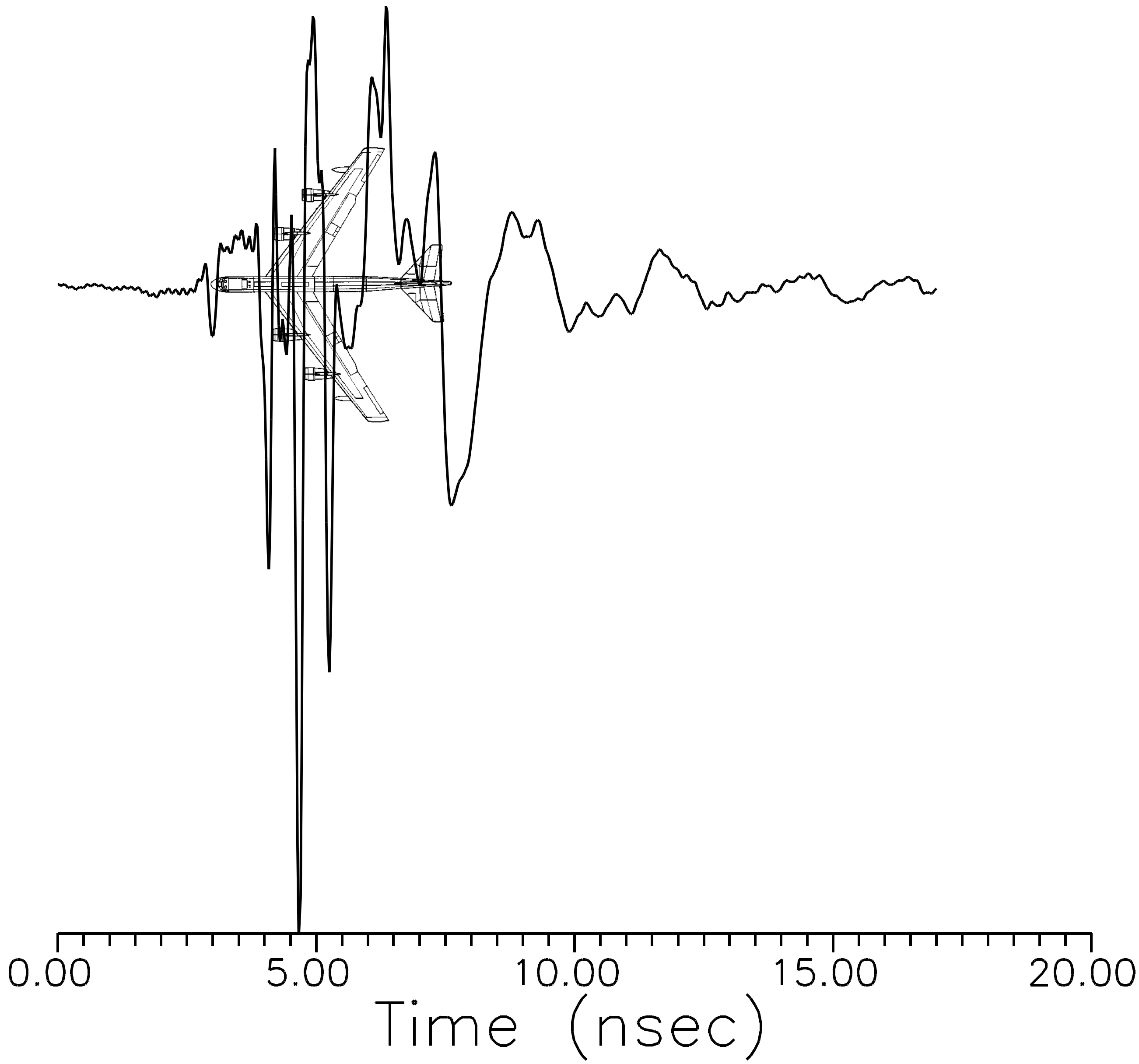
  Gaussian Pulse Duration = 0.2 ns - approximately 1/10 aircraft length



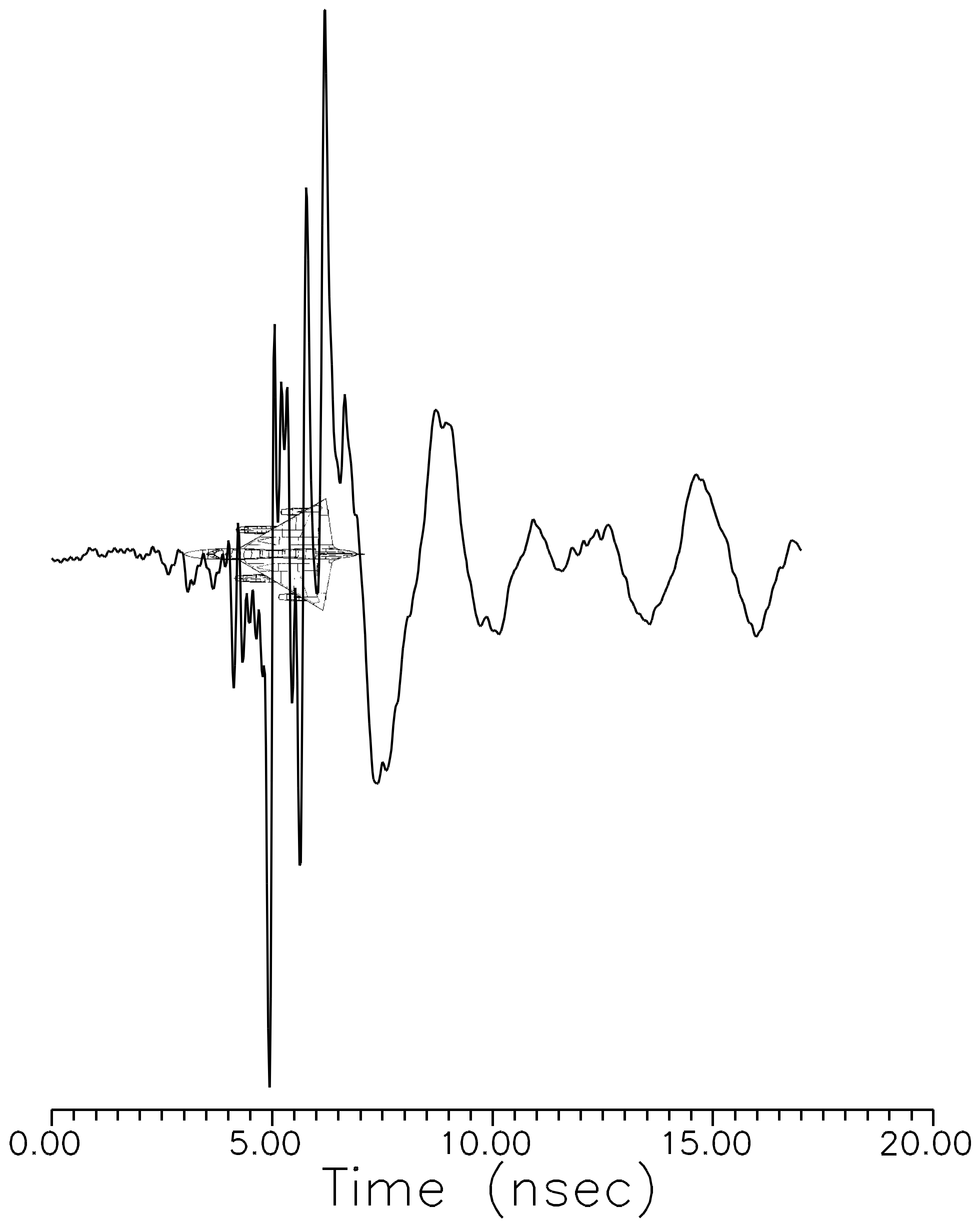
Equivalent transmitted (truncated) Gaussian pulse for measurement of B-52 and B-58 models in the 0.2-7.0 GHz band.



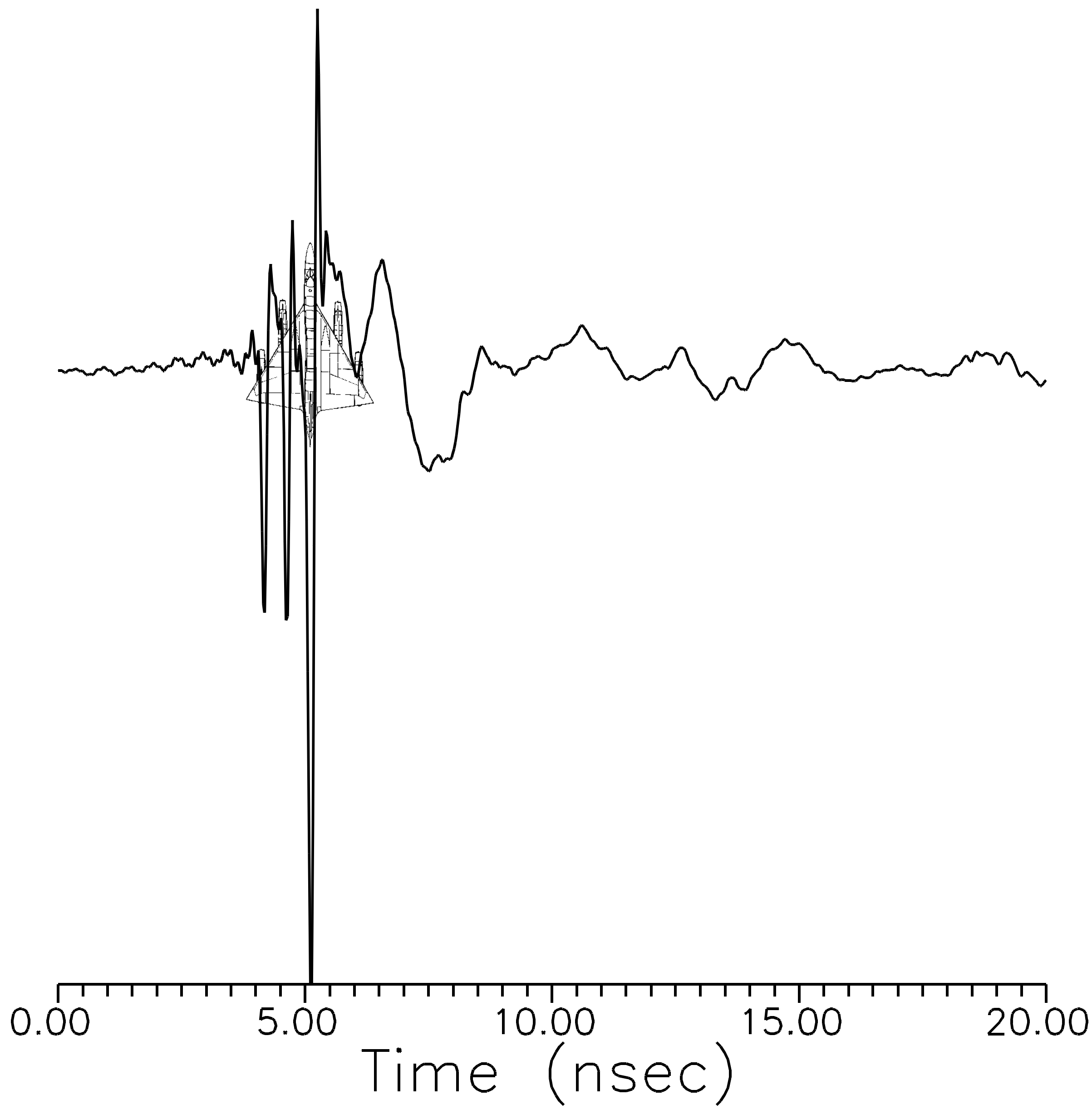
Wing-on response of B-52 measured in the frequency band 0.2-7.0 GHz. Gaussian weighting function used.



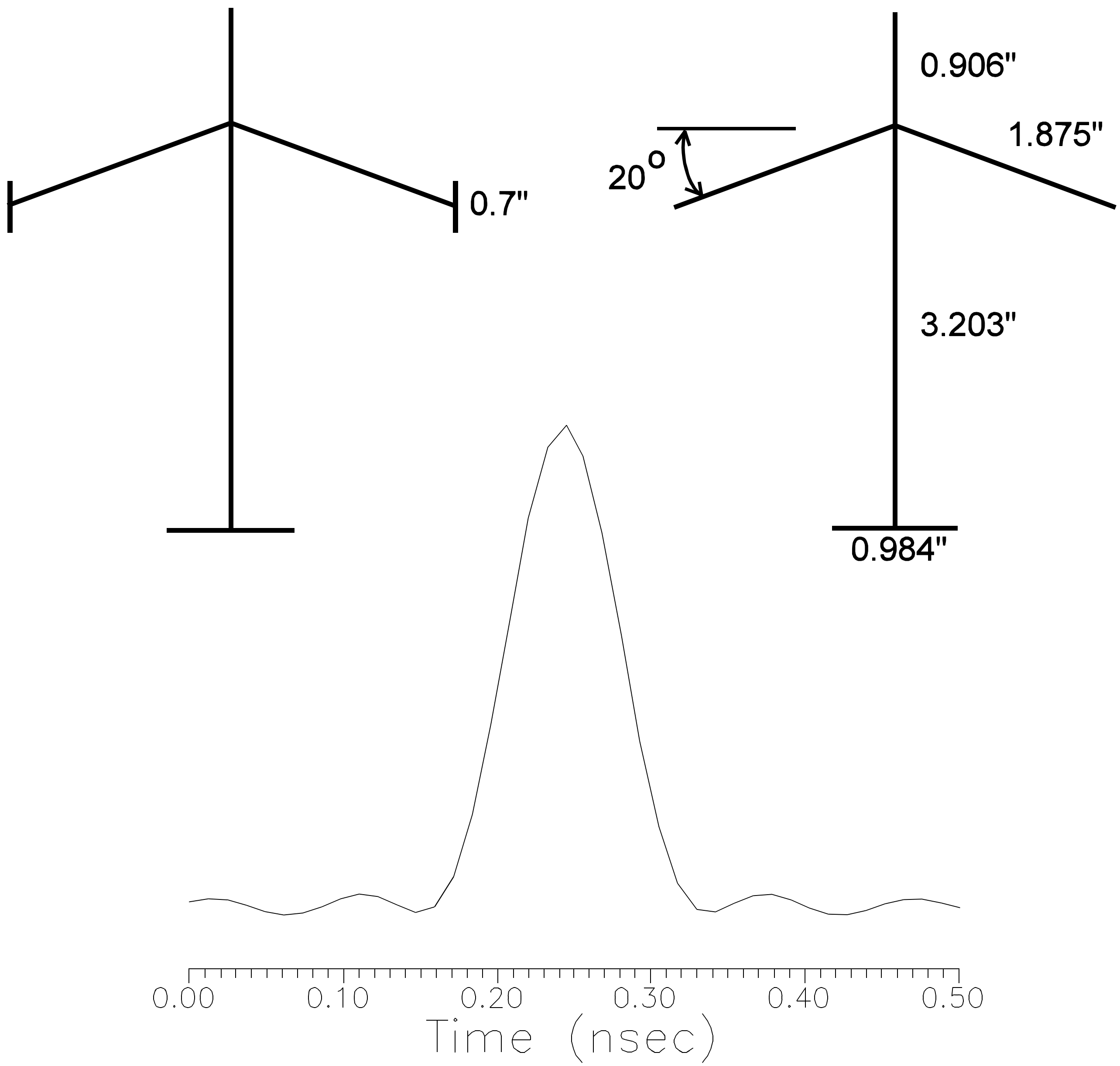
Nose-on response of B-52 measured in the frequency band 0.2-7.0 GHz. Gaussian weighting function used.



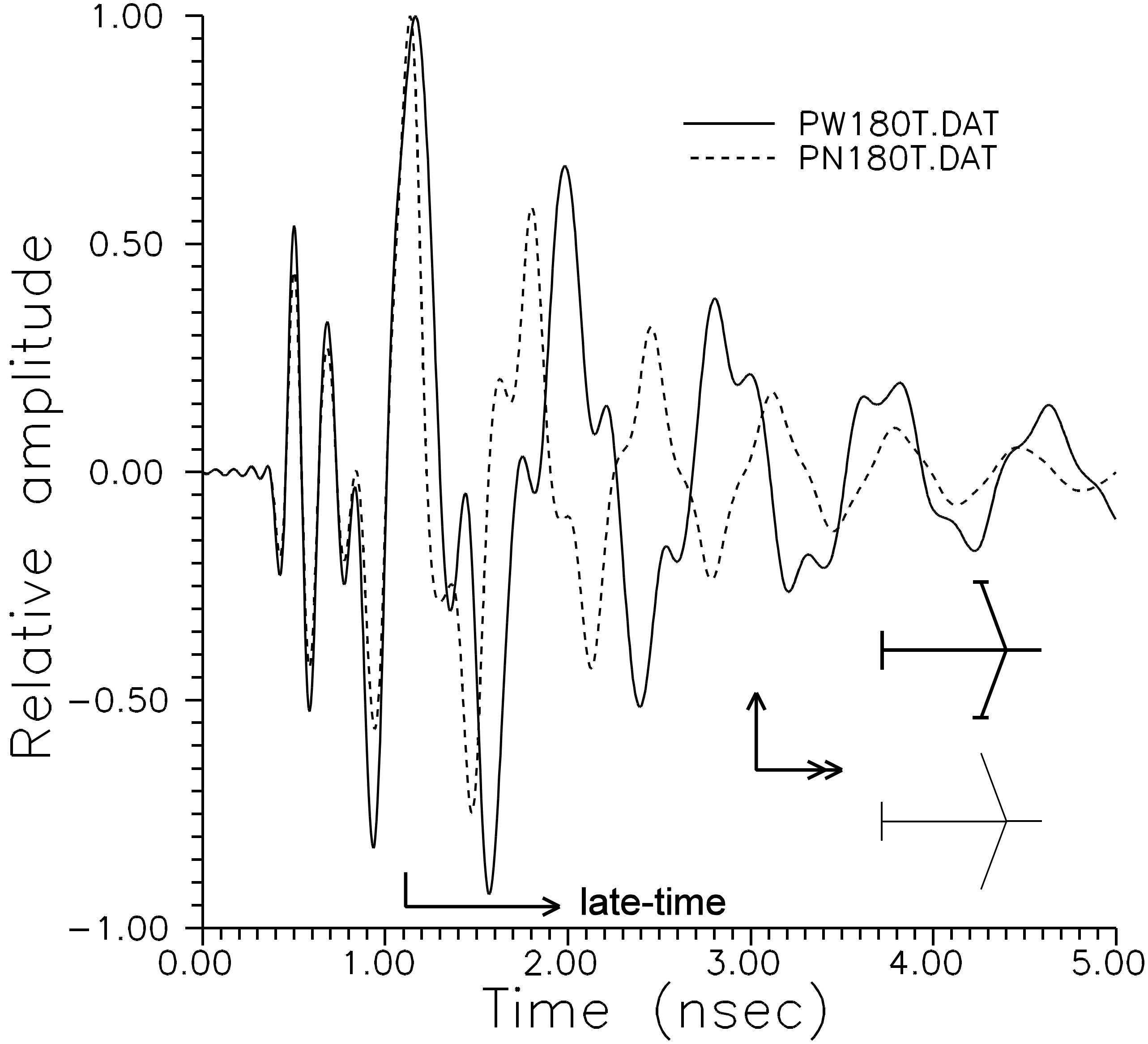
Nose-on response of B-58 measured in the frequency band 0.2-7.0 GHz. Gaussian weighting function used.



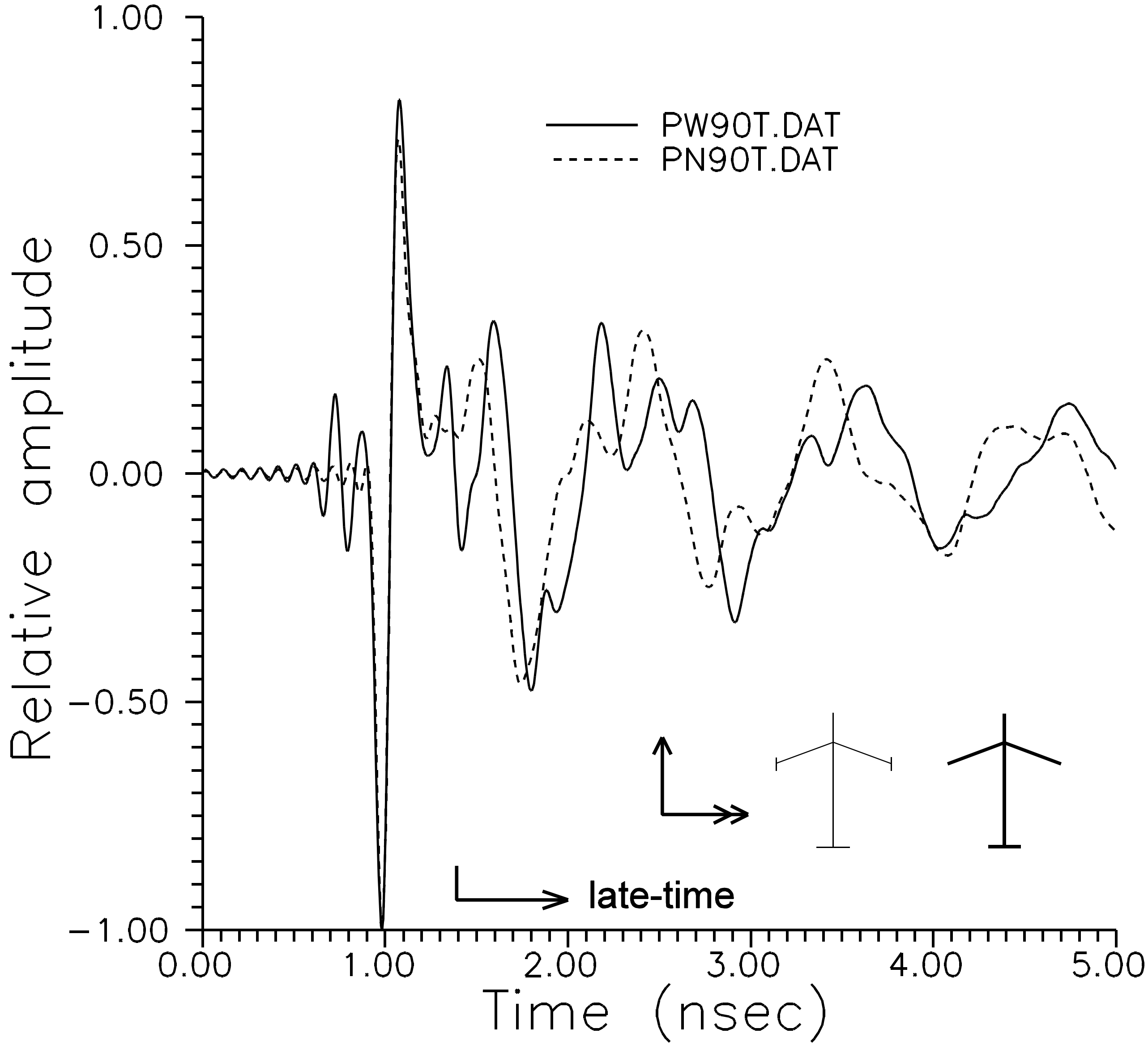
Wing-on response of B-58 measured in the frequency band 0.2-7.0 GHz. Gaussian weighting function used.



Two stick-wire airplane models used in early-time analysis, and truncated Gaussian excitation pulse.



Tail-on responses of stick-wire airplane models with wing tips (PW180.DAT) and without wing tips (PN18-0.DAT).



Wing-on responses of stick-wire aircraft models with wing tips (PW90.DAT) and without wing tips (PN90.DAT).

III. Late-time Response Model

- Baum's SEM model (1971)

$$r_L(t) = \sum_{k=1}^{K} c_k e^{-\sigma_k t} \cos(\omega_k t + \phi_k) \qquad t > T_L \tag{1}$$

K number of resonances excited by incident wave

$\boldsymbol{s_k = \sigma_k + j\omega_k}$ aspect independent k'th natural resonance frequency

$\boldsymbol{c_k, \phi_k}$ aspect dependent amplitude and phase

$\boldsymbol{T_L}$ beginning of the late-time period

IV. Early-Time Models

- Altes 1976 models early-time impulse response as

$$h_e(t) = \sum_{m=1}^{M} h_m(t - \tau_m) \tag{2}$$

$\boldsymbol{h_m(t)}$ localized impulse response at mth scattering center excited at time τ_m

- can be very specular or include natural oscillations

- $\boldsymbol{h_m(t)}$ expanded as power series in frequency or a series of integrals and derivatives of delta functions in time

$$h_m(t) = \sum_{n=1}^{N} A_{mn} \delta^{(n)}(t) \tag{3}$$

$\boldsymbol{n<0}$ implies n'th integral and $\boldsymbol{n>0}$ implies n'th derivative

V. Duality of Early-Time and Late-Time Response

- Take the Fourier transform of (3)

$$H_e(\omega) = \mathscr{F}\{h_e(t)\} = \sum_{m=1}^{M} H_m(\omega) e^{-j\omega\tau_m} \qquad \textbf{(4)}$$

$H_m(\omega) = \mathscr{F}\left\{h_m(t)\right\}$ is transfer function of m'th scattering center

- Hurst and Mittra suggest transfer function can be approximated as an exponential function

$$H_e(\omega) = \sum_{m=1}^{M} a_m e^{-\omega\alpha_m} e^{-j\omega\tau_m} \qquad \omega>0 \qquad \textbf{(5)}$$

- Note that (5) is analogous with Baum's temporal late-time response model. $(\sigma_n \rightarrow \alpha \text{ and } \omega_n \rightarrow \tau)$

- Suggests early-time discrimination scheme analogous to time-domain E-pulse technique which uses late-time data.

VI. Short Duration Fourier Transform

- Short-Duration Fourier transform (SDFT) or wavelet theory approach useful for identifying subresonances immersed within early-time.
- Short duration windows allow identification of specular reflections as vertical bands, but obscures low frequency resonances
- Long duration windows allow identification of resonances as horizontal bands, but includes early-time transfer function (3) which blurrs results.
- SDFT does not account for distinct change between early and late-time responses.

VII. Frequency-Time Plots

- Frequency-time plot - Fourier transform all data to right of T_0
- Need to identify transition time T_L between early and late-time
- Identification of transition time is very clear

VIII. Distance-Time plots

- Want to make specular reflections more distinct
- Note that real or imaginary part of early-time spectrum behaves as

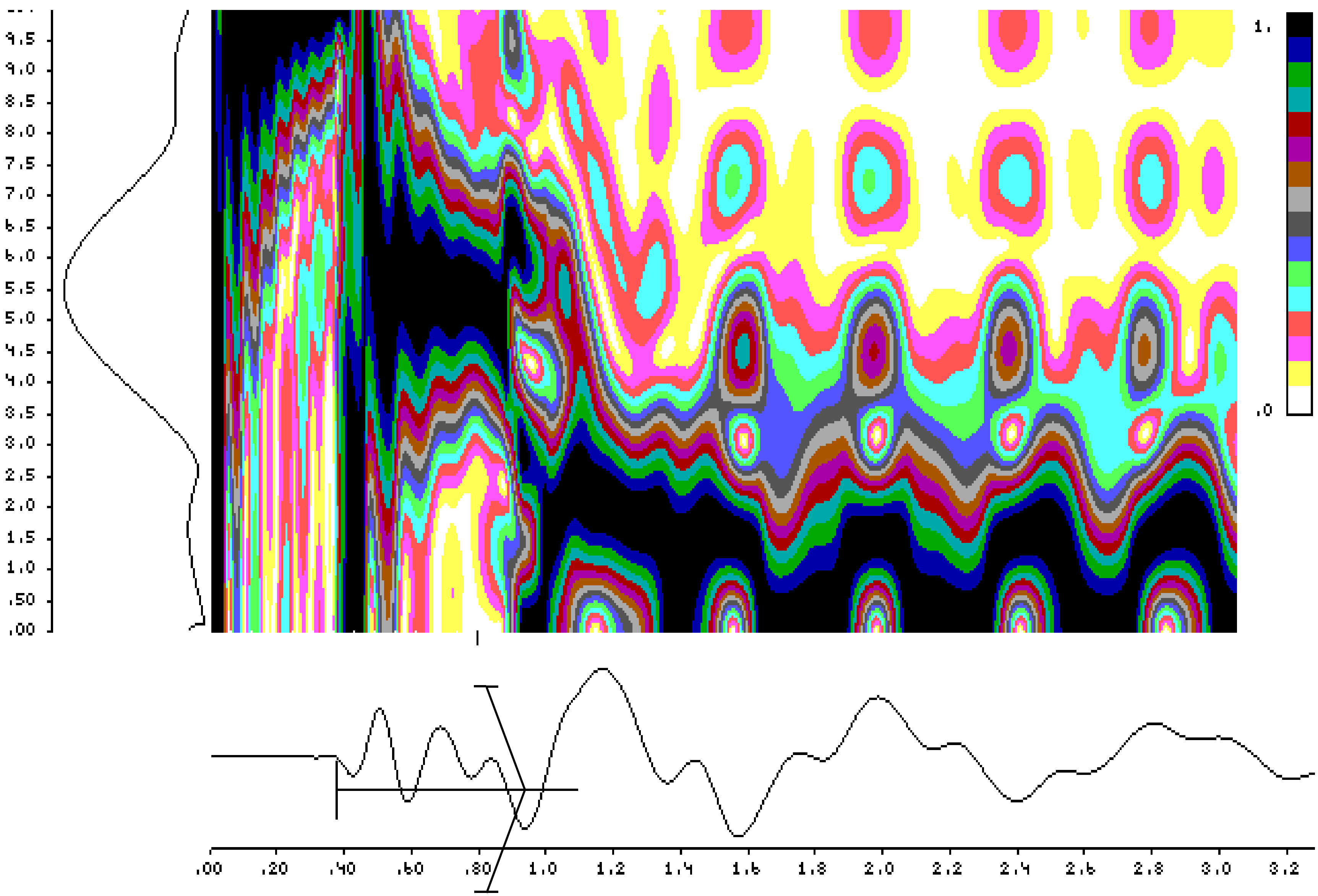
$$H_e(\omega) = \sum_{m=1}^{M} b_m e^{-\omega\alpha_m} \cos(\omega\tau_m) \qquad \omega>0 \qquad \textbf{(6)}$$

- The Fourier transform of (6) is a time domain function given as

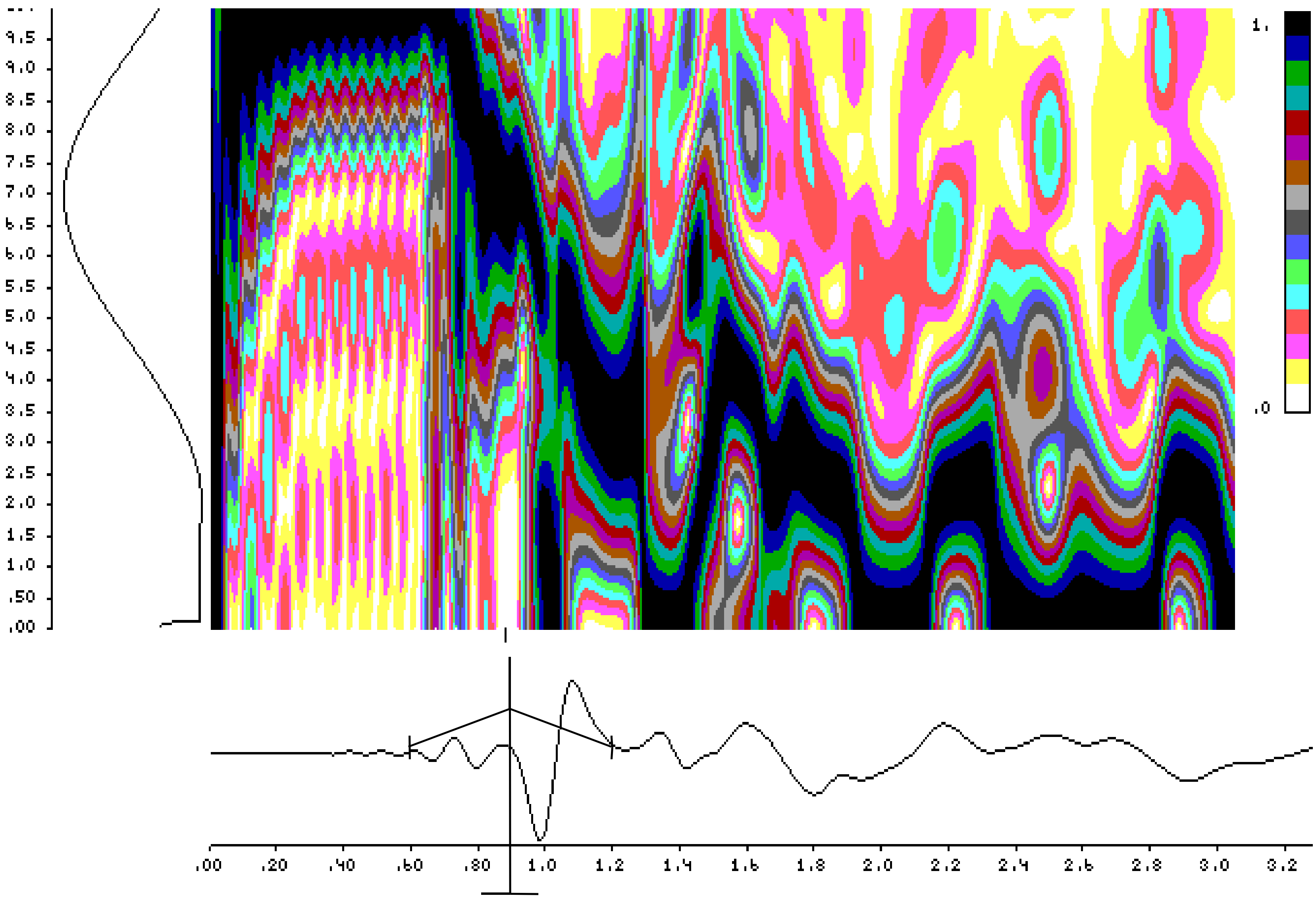
$$w(t) = \left|\mathscr{F}\left\{Re\left\{U(\omega)\,\mathscr{F}\left\{h_e(t)\right\}\right\}\right\}\right| \qquad \textbf{(7)}$$

  and should display peaks typical of damped sinusoids, with the peaks centered at τ_m.

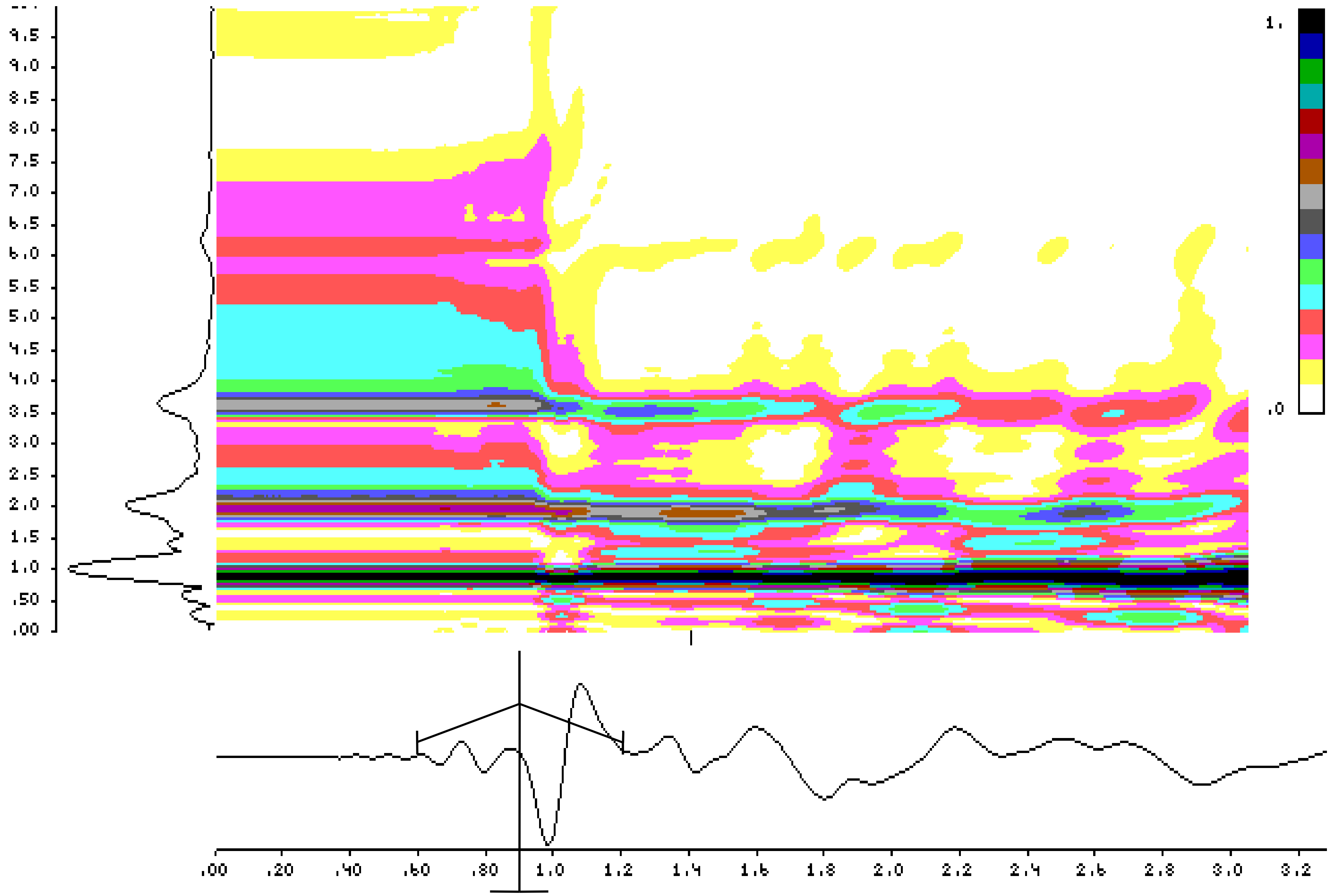
- Quantity (7) seems to be insensitive to subresonances, and yields a clearer picture of specular reflections in early-time.



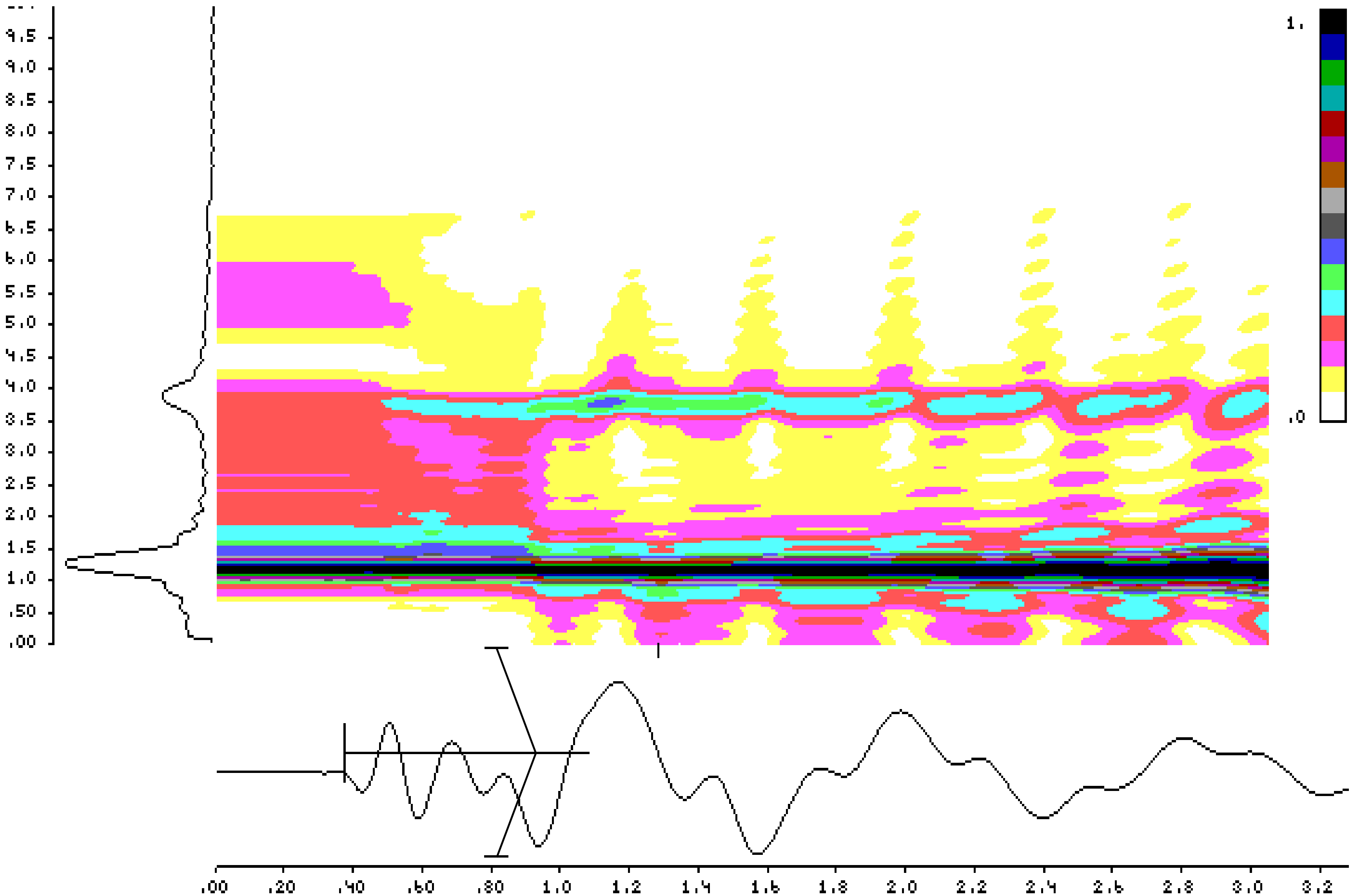
Short duration Fourier transform of tail-on response of wire-stick model aircraft with wing tips. Rectangular window of duration 0.4 nsec used. Horizontal axis is time in nsec, vertical axis is frequency in GHz.



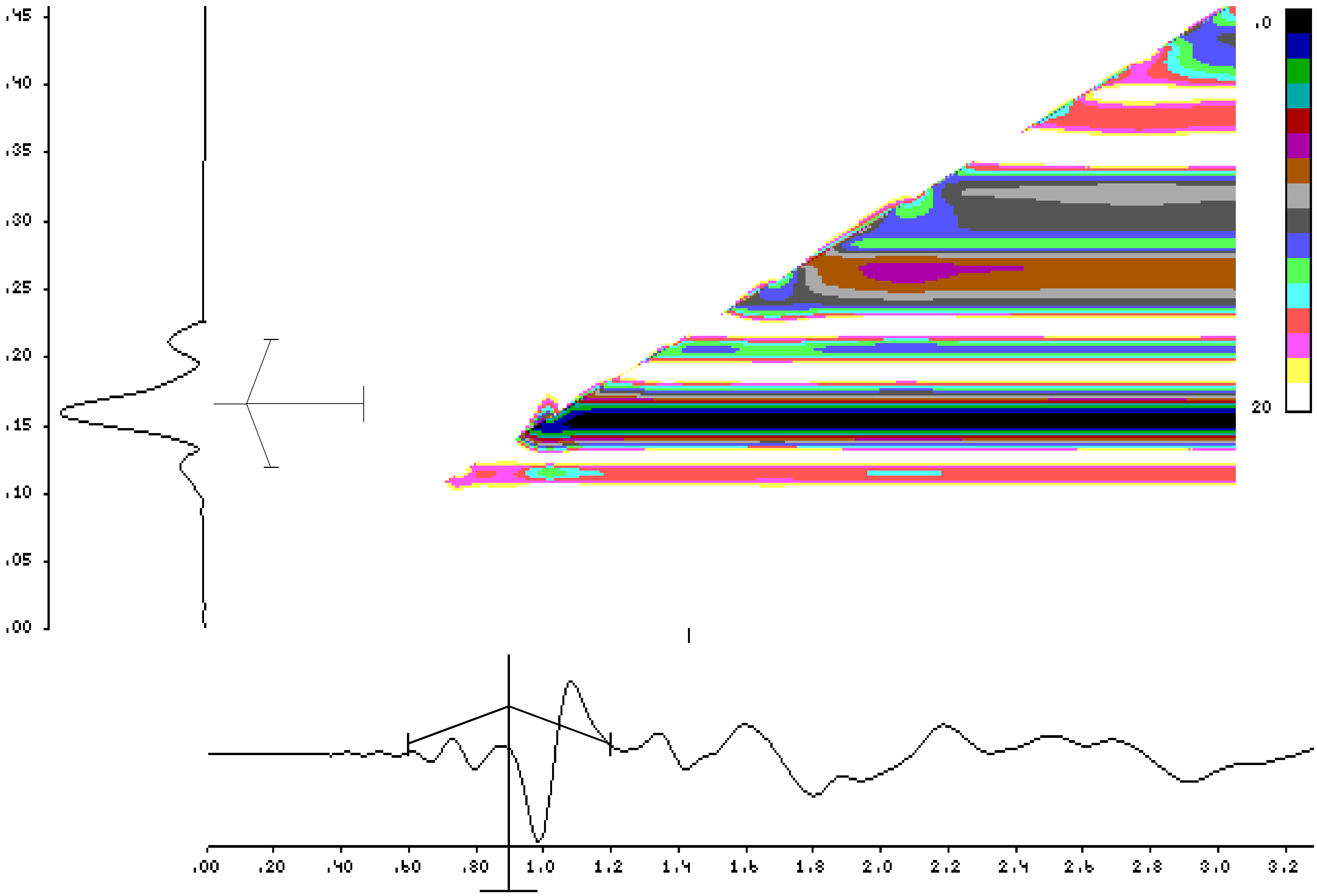
Short-duration Fourier transform of wing-on response of wire-stick model aircraft with wing tips. Rectangular window of duration 0.3 nsec used. Horizontal axis is time in nsec, vertical axis is frequency in GHz.



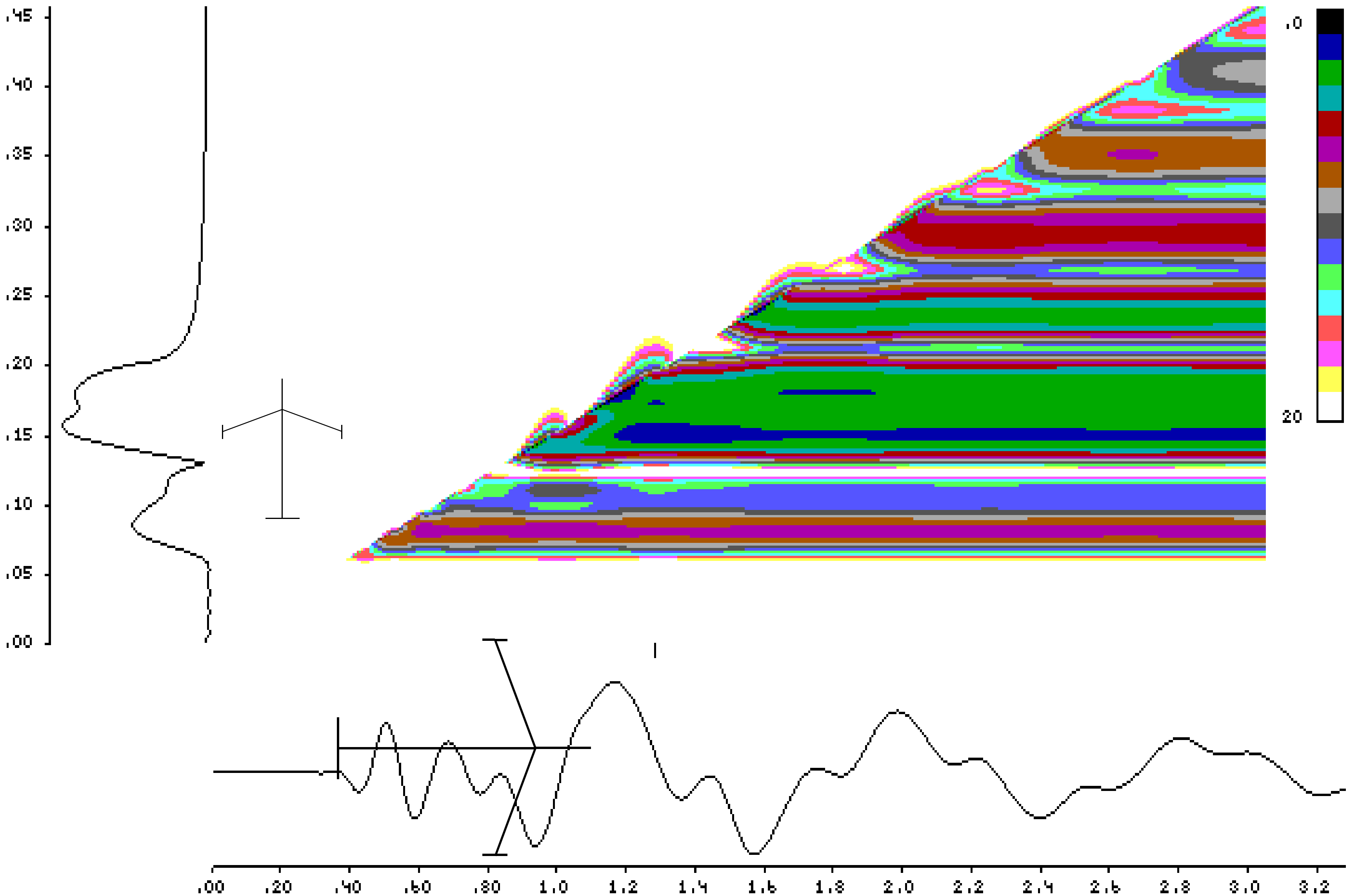
Frequency-time plot of wing-on response of wire-stick aircraft model with wing tips. Horizontal axis is time in nsec, vertical axis is frequency in GHz.



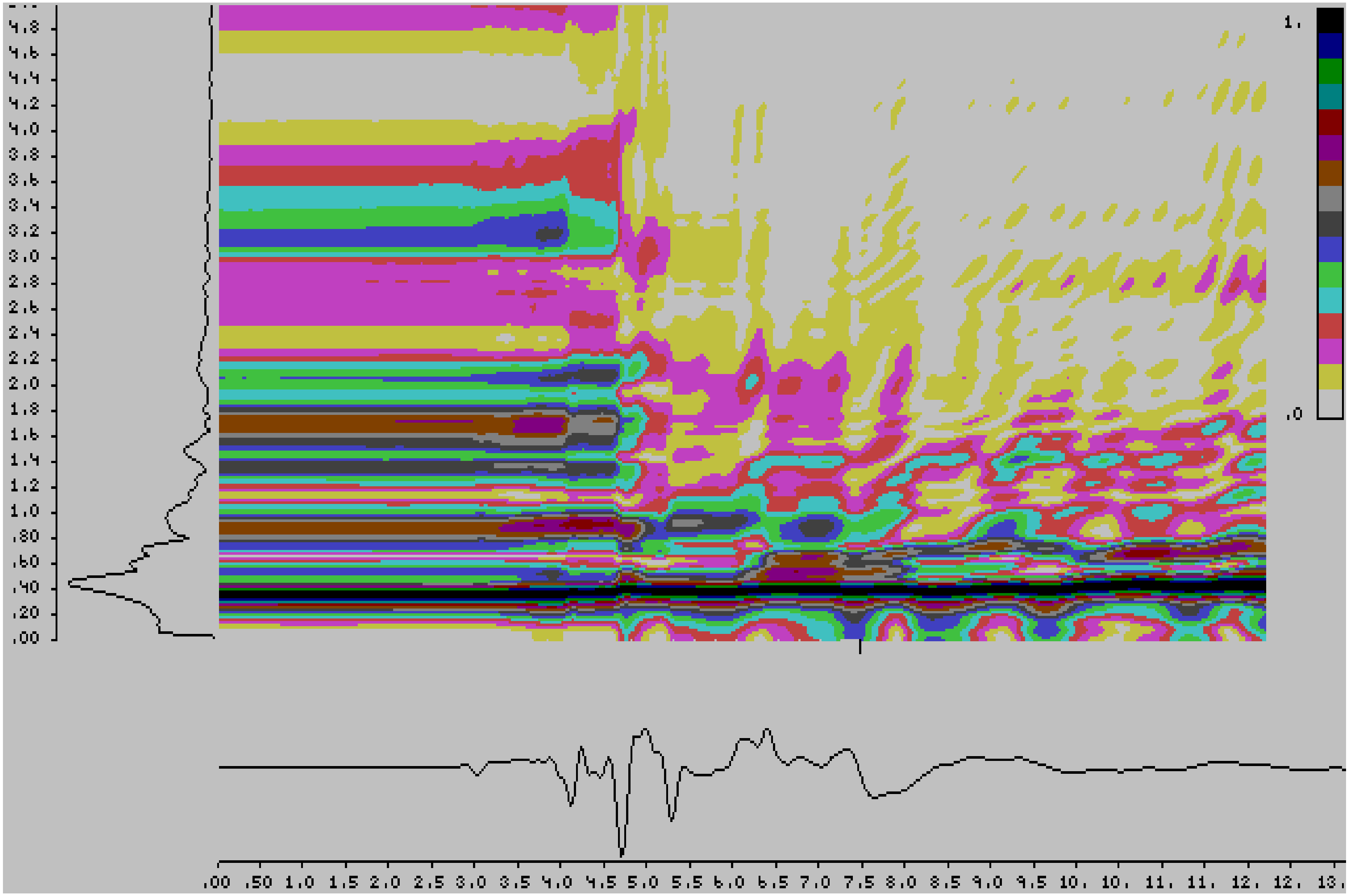
Frequency-time plot of tail-on response of wire-stick aircraft model with wing tips. Horizontal axis is time in nsec, vertical axis is frequency in GHz.



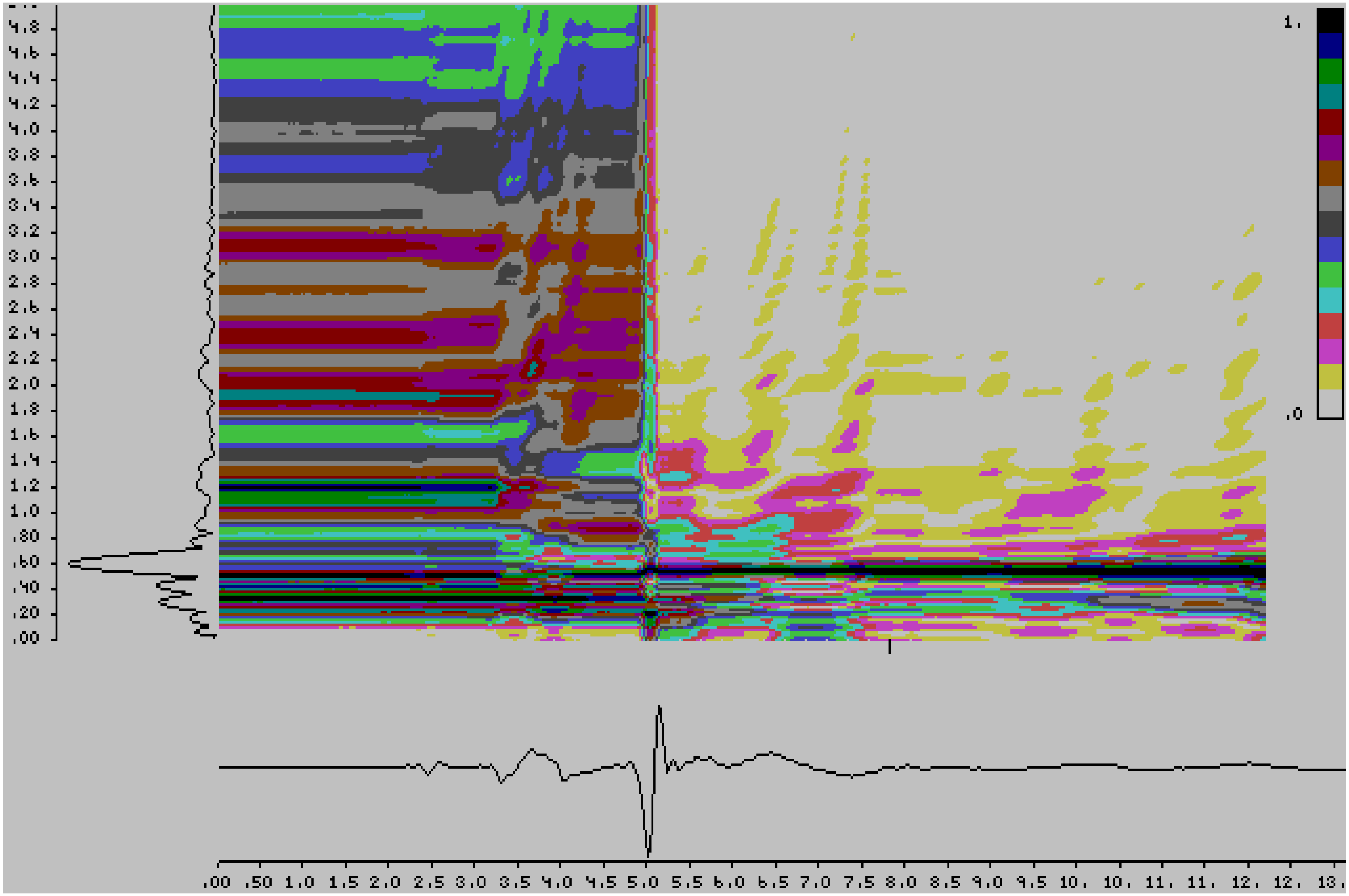
Distance-time plot of wing-on response of wire-stick aircraft model with wing tips. Horizontal axis is time in nsec, vertical axis is distance in m.



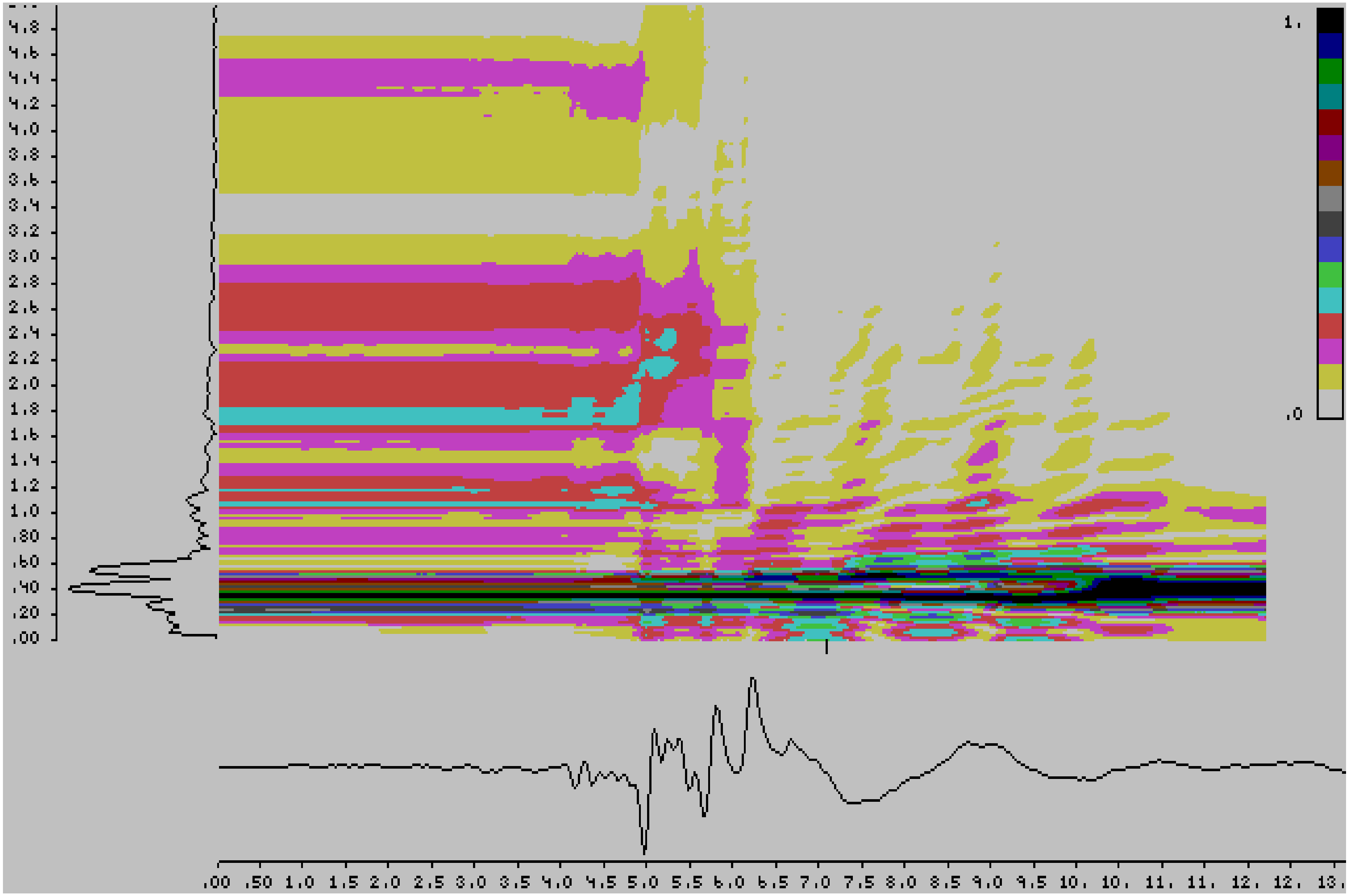
Distance-time plot of tail-on response of wire-stick aircraft model with wing tips. Horizontal axis is time in nsec, vertical axis is distance in m.



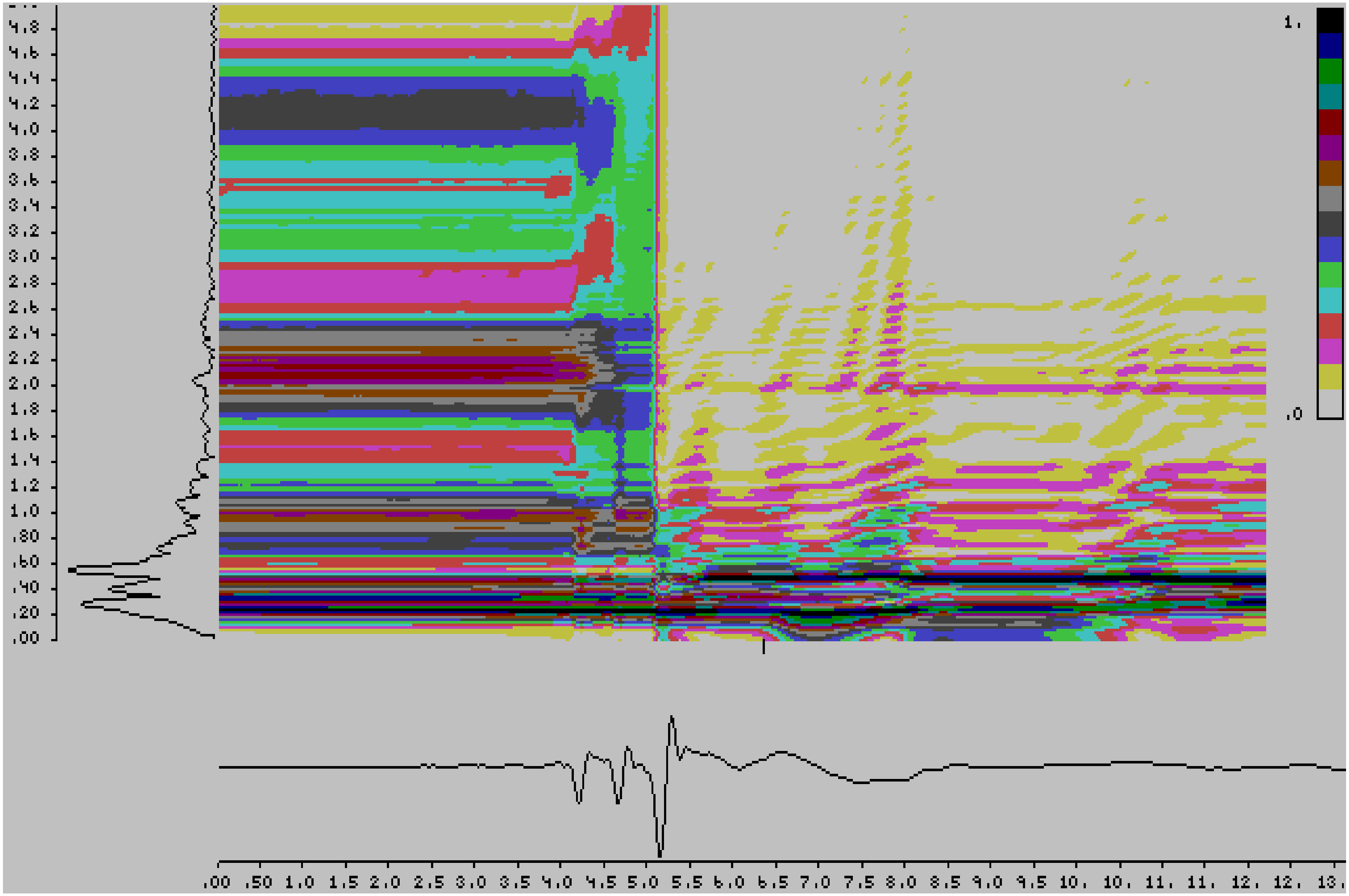
Frequency-time plot of nose-on response of B-52. Horizontal axis is time in nsec, vertical axis is frequency in GHz.



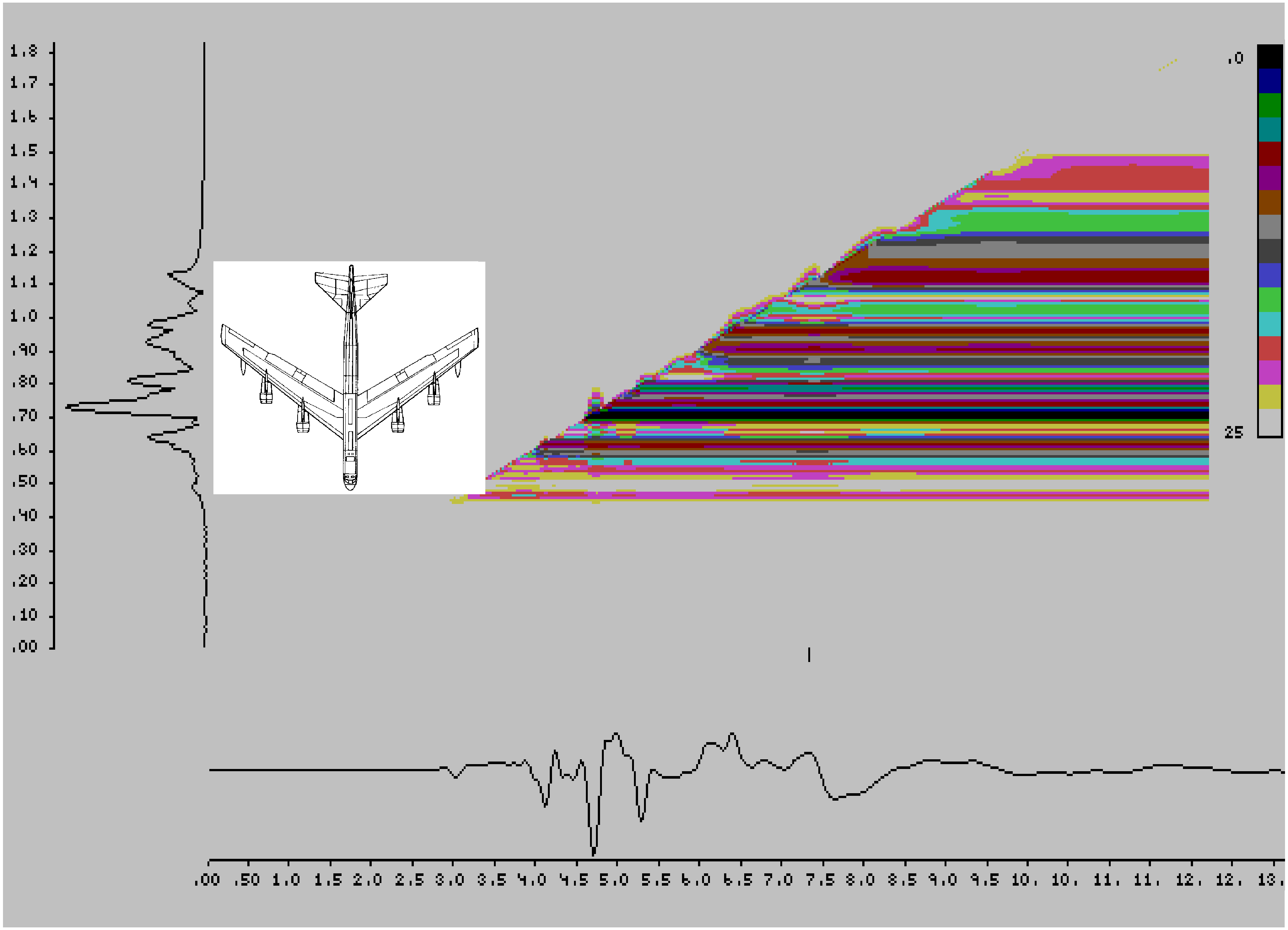
Frequency-time plot of wing-on response of B-52. Horizontal axis is time in nsec, vertical axis is frequency in GHz.



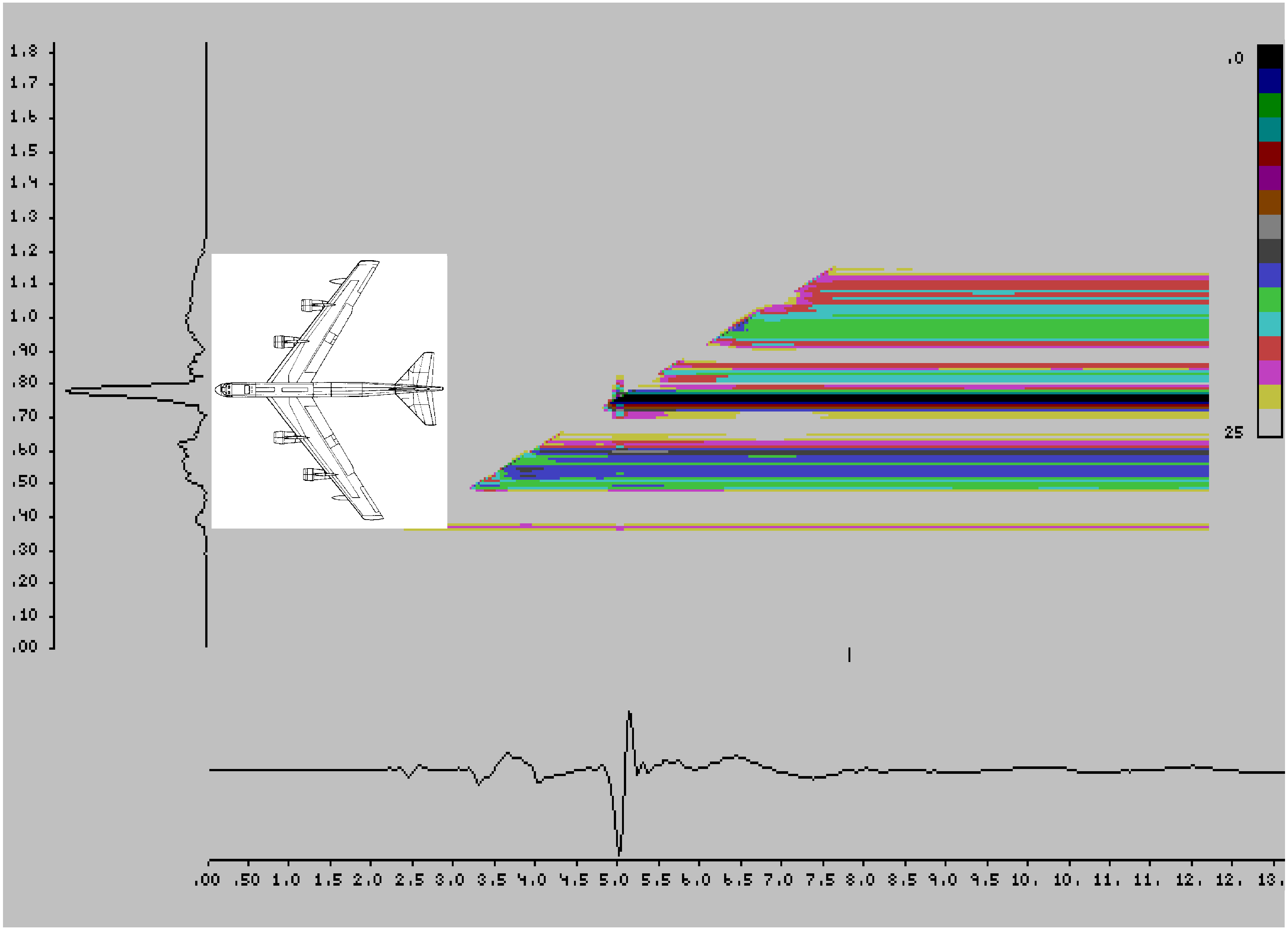
Frequency-time plot of nose-on response of B-58. Horizontal axis is time in nsec, vertical axis is frequency in GHz.



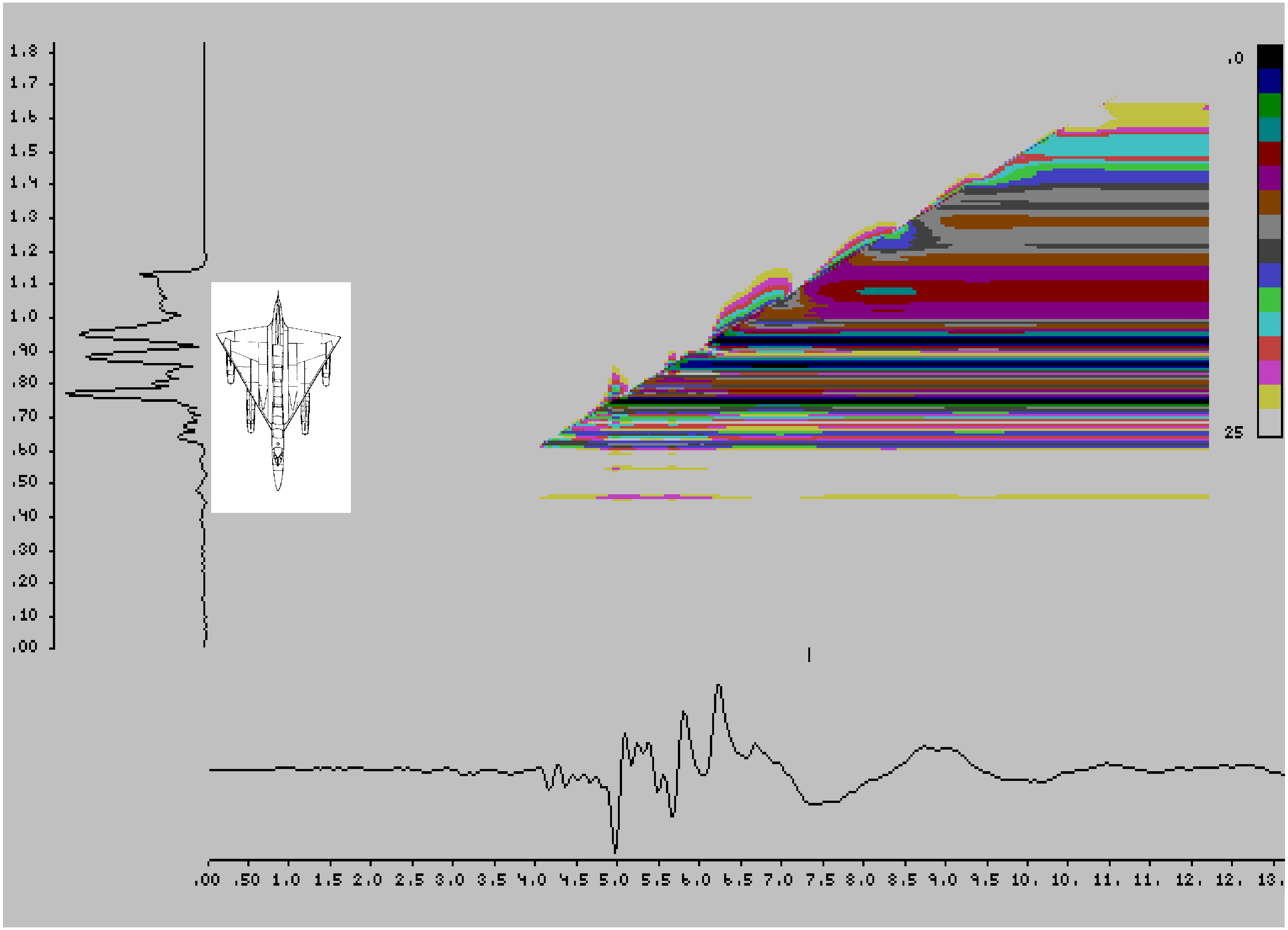
Frequency-time plot of wing-on response of B-58. Horizontal axis is time in nsec, vertical axis is frequency in GHz.



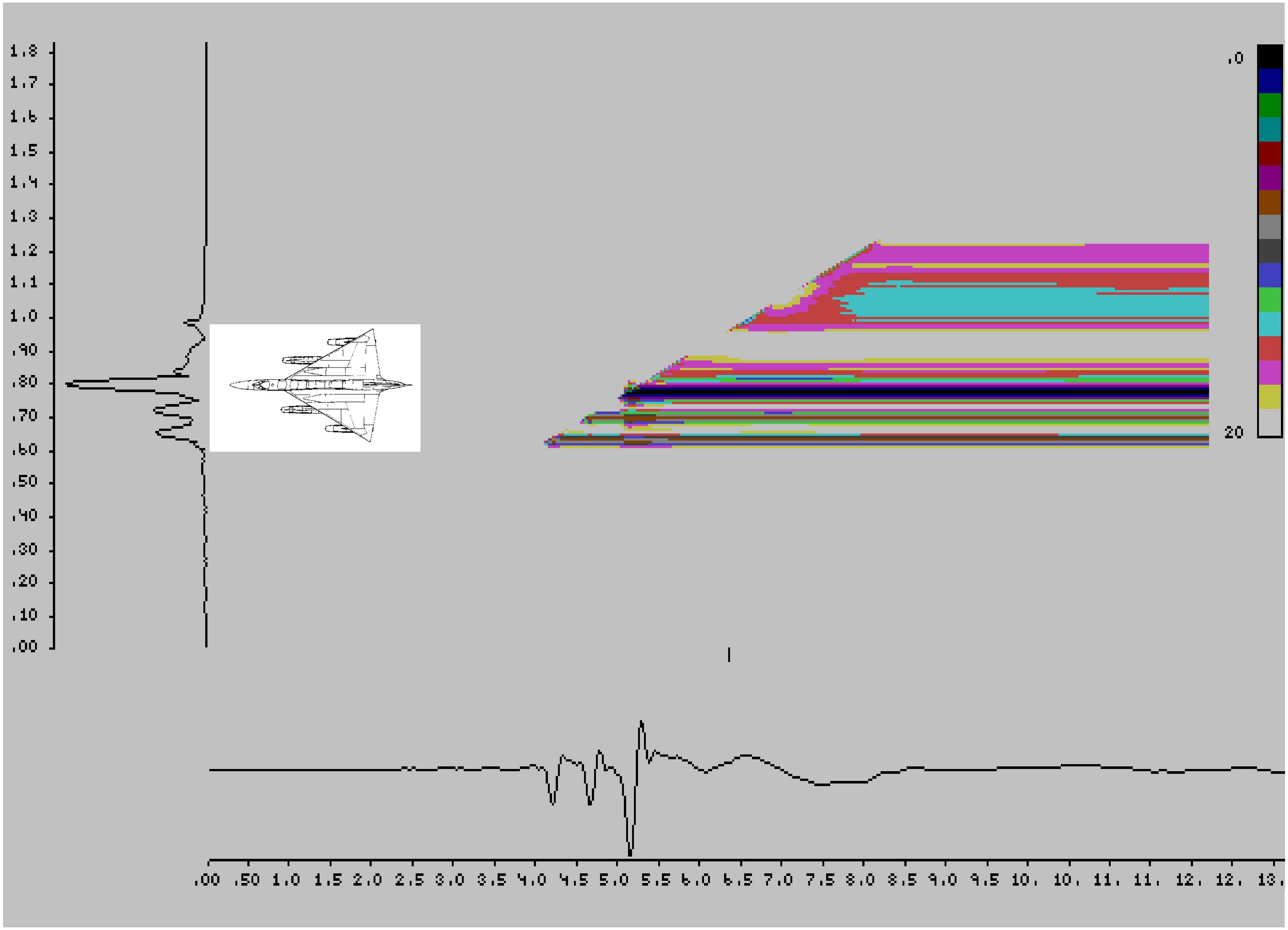
Distance-time plot of nose-on response of B-52. Horizontal axis is time in nsec, vertical axis is distance in m.



Distance-time plot of wing-on response of B-52. Horizontal axis is time in nsec, vertical axis is distance in m.



Distance-time plot of nose-on response of B-58. Horizontal axis is time in nsec, vertical axis is distance in m.



Distance-time plot of wing-on response of B-58. Horizontal axis is time in nsec, vertical axis is distance in m.

IX. Conclusions

- Resonance contribution to early-time response is important especially when scattering centers are shadowed or targets are high Q.
- SDFT is useful for resolving subresonances
- Frequency-time plots useful for determining transition time
- Distance-time plots useful for resolving scattering centers in the presence of subresonances