# Development of a Technique for Determination of Component Shock Specifications

## FINAL REPORT - VOLUME II

Compilation of Four Coordinate Shock and Fourier Spectra for Simple and Complex Shock Motions

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by

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# FOREWORD

This report is Volume II of a three volume Final Report presenting the results of work performed by MITRON Research & Development Corporation for NASA Marshall Space Flight Center under Contract No. NAS-8-11090 entitled "Development of a Technique for Determination of Component Shock Specifications". The three volumes comprising the Final Report are as follows:

| | |
|---|---|
| Volume I | Methods for Specifying and Extrapolating Shock Conditions. |
| Volume II | Compilation of Four Coordinate Shock and Fourier Spectra for Simple and Complex Shock Motions. |
| Volume III | Digital Computer Program for Shock and Fourier Spectra. |

This project was conducted by the Shock and Vibration Division of MITRON with Mr. Maurice Gertel as Principal Investigator and Mr. Richard Holland as Project Engineer. The program was under the overall cognizance of Messrs Ronald E. Jewell and Thomas Coffin of NASA Marshall Space Flight Center, Propulsion and Vehicle Engineering Division, Structures Branch.

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## SYMBOLS

| | | |
|---|---|---|
| $a$ | equivalent static acceleration | in./sec$^2$ |
| $a$ | Fourier acceleration component | in./sec$^2$ |
| $A$ | normalized acceleration | |
| $d$ | relative deflection response | in. |
| $d$ | Fourier deflection component | in. |
| $c$ | damping coefficient | lb - sec/in. |
| $c/c_c$ | fraction of critical damping | |
| $D$ | normalized deflection (includes $g = 386.4$ in./sec$^2$) | in./sec$^2$ |
| $f(t)$ | function of time | |
| $f_n$ | undamped natural frequency | cycles/sec (cps) |
| $F$ | force | lb |
| $F$ | Fourier operator | |
| $g$ | acceleration of gravity | in./sec$^2$ |
| $G$ | peak acceleration in number of times gravity | |
| $h$ | increment of time | sec |
| $Im$ | imaginary part of | |
| $j$ | $\sqrt{-1}$ . | |
| $k$ | linear stiffness | lb/in. |
| $m$ | mass | lb-sec$^2$/in. |
| $n$ | number | |
| $Re$ | real part of | |
| $t$ | time | sec |
| $T$ | natural period | sec |
| $u$ | motion of the support | in. |

## SYMBOLS (Cont.)

| | | |
|---|---|---|
| $\ddot{U}(\omega)$ | Fourier spectrum of $\ddot{u}(t)$ ..... | in./sec |
| $\ddot{U}_c(\omega)$ | Fourier cosine spectrum of $\ddot{u}(t)$ ..... | in./sec |
| $\ddot{U}_s(\omega)$ | Fourier sine spectrum of $\ddot{u}(t)$ ..... | in./sec |
| v | pseudo velocity response ..... | in./sec |
| v | Fourier velocity component ..... | in./sec |
| V | normalized velocity | |
| x | linear displacement in direction of X axis ..... | in. |
| Z | impedance ..... | lb-sec/in. |
| $\delta$ | relative response deflection ..... | in. |
| $\delta_r$ | residual relative response deflection ..... | in. |
| $\zeta$ | fraction of critical damping | |
| $\theta$ | phase angle ..... | degrees |
| $\tau$ | period ..... | sec |
| $\omega$ | forcing frequency-angular ..... | rad/sec |
| $\omega_n$ | undamped natural frequency-angular ..... | rad/sec |
| $\omega_d$ | damped natural frequencies-angular ..... | rad/sec |

# VOLUME II

## I. INTRODUCTION

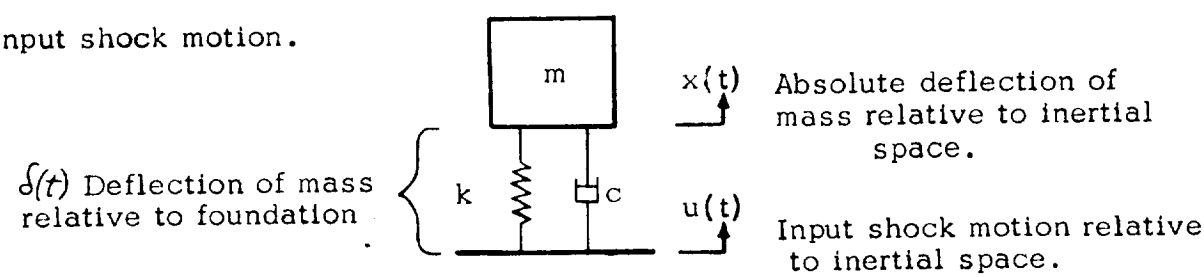
In the development of shock test and design criteria, it is desireable to compare the shock and Fourier spectra which have been obtained from analyses of field measured conditions in the response and frequency domains with corresponding spectra for various forms of idealized shock pulses. The purpose of such comparison is to ascertain whether any simple idealized form of shock pulse can be identified which has similar spectral characteristics to the actual service condition. In general, it is advantageous from a laboratory simulation point of view to associate complicated service shock time-history conditions with simpler idealized forms which may be more feasible to create in the laboratory.

Presented in this report is a compilation of shock and Fourier spectra for a variety of simple and complex idealized shock pulses. These spectra are plotted in a normalized four-coordinate format based on the well known four coordinate vibration nomograph and serve to relate sinusoidal frequency displacement, velocity and acceleration spectral parameters. The normalized spectral plots have logarithmic coordinates, therefore, the shape of the spectra will remain unchanged for adjustments in frequency and amplitude to facillitate correlation with spectra from measured service conditions.

## 2. ANALYSIS IN THE RESPONSE DOMAIN

Analysis to determine the responses of simple single degree-of-freedom systems with negligible mass to shock motions is called analysis in the response domain. The results of such analysis for particular shock inputs are conveniently presented in spectral form as a graph of maximum displacement, velocity or acceleration responses of simple systems plotted as a function of their natural frequency. Such a graph is called by the general term response spectrum. In actual engineering practice, theoretical response spectra are seldom used. Rather, an approximate response plot called the shock spectrum has achieved widespread acceptance and is the subject of current standardization efforts. The distinction between response spectra and shock spectra will be discussed briefly in the following paragraphs.

The simple system used for general analysis of response is the base excited damped single degree-of-freedom system shown below. It is assumed here that the response motion of this system has no effect on the input shock motion.



The motion of the mass may be defined by:

$$\delta(t) = x(t) - u(t) \tag{1}$$

$$\ddot{x}(t) + 2\zeta\omega_n \dot{\delta}(t) + \omega_n^2 \delta(t) = 0 \tag{2}$$

The general solution of Equation (2) provides the deflection response of the mass relative to its support as a function of time:

$$\begin{aligned}\delta(t) = {} & \delta_0 e^{-\zeta\omega_n t}\left(\cos\omega_d t + \frac{\zeta}{\sqrt{1-\zeta^2}}\sin\omega_d t\right) \\ & + \frac{\dot{\delta}_0}{\omega_d} e^{-\zeta\omega_n t}\sin\omega_d t \\ & - \frac{1}{\omega_d}\int_0^t \ddot{u}(\tau)\, e^{-\zeta\omega_n(t-\tau)}\sin\omega_d(t-\tau)\, d\tau\end{aligned} \tag{3}$$

The first derivative of the relative deflection response provides an equation for the velocity response of the mass relative to its support as a function of time:

$$\begin{aligned}\dot{\delta}(t) = {} & -\delta_0\omega_n e^{-\zeta\omega_n t}\sin\omega_d t + \dot{\delta}_0 e^{-\zeta\omega_n t}\left(\cos\omega_d t\right. \\ & \left. - \frac{\zeta}{\sqrt{1-\zeta^2}}\sin\omega_d t\right) - \int_0^t \ddot{u}(\tau)\, e^{-\zeta\omega_n(t-\tau)}\left[\cos\omega_d(t-\tau)\right. \\ & \left. - \frac{\zeta}{\sqrt{1-\zeta^2}}\sin\omega_d(t-\tau)\right] d\tau\end{aligned} \tag{4}$$

The second derivative of Equation (3) gives the response acceleration of the mass relative to its support:

$$\begin{aligned}\ddot{\delta}(t) = {} & -\delta_0\omega_n^2 e^{\zeta\omega_n t}\left(\cos\omega_d t - \frac{\zeta}{\sqrt{1-\zeta^2}}\sin\omega_d t\right) \\ & - \dot{\delta}_0\omega_n e^{\zeta\omega_n t}\left(\frac{2\zeta^2-1}{\sqrt{1-\zeta^2}}\sin\omega_d t - 2\zeta\cos\omega_d t\right) \\ & - \int_0^t \ddot{u}(\tau)\,\omega_n e^{-\zeta\omega_n(t-\tau)}\left[\frac{2\zeta^2-1}{\sqrt{1-\zeta^2}}\sin\omega_d(t-\tau)\right. \\ & \left. - 2\zeta\cos\omega_d(t-\tau)\right] d\tau\end{aligned} \tag{5}$$

The absolute deflection, velocity and acceleration responses of the simple system relative to inertial space can be obtained by combining Equation (1) with Equations (3) to (5). It can be readily seen that at the conclusion of the input shock pulse, the relative and absolute response motions of the system are the same. This response motion after the pulse is over, is termed the residual response. If the maxima of the theoretical damped displacement, velocity or acceleration responses defined by Equations (1) to (5) were plotted as a function of natural frequency, this would constitute defining the effects of shock motions in terms of response spectra.

Primarily because of its common usage as a measure of damage potential, the shock spectrum is based upon the maxima of relative response deflections defined by Equation (3) as a function of natural frequency. The logic for this is that, (1) stress or strain in flexible members is proportional to deflection, and (2) peak values of stress or strain can be related to damage or failure in structural elements.

The shock spectrum is expressed in velocity units by considering the relative response deflection is sinusoidal at the system natural frequency, (which is exactly true for residual response only) and computing the peak velocity as:

$$v_{MAX} = 2\pi f_n \delta_{MAX} \tag{6}$$

The velocity defined by Equation (6) is termed maximum pseudo-velocity to distinguish it from the true relative velocity defined by Equation (4). In general, the pseudo-velocity will be in close agreement with the true relative velocity. However, because of its frequency dependence, the pseudo-velocity will be respectively lower at low frequencies and higher at high frequencies than the true relative velocity.

The shock spectrum is expressed in acceleration units by considering, as above, that the relative response deflection is sinusoidal and computing the peak acceleration as:

$$a_{MAX} = A_g g = (2\pi f_n)^2 \delta_{MAX} = 2\pi f_n \, v_{MAX} \tag{7}$$

The acceleration defined by Equation (7) is called the equivalent static acceleration. This is expressed as a multiple of gravitational units, e.g., 1g, 5g, etc., which if applied as a steady acceleration will produce the same maximum relative deflection response as the input shock. For an undamped system, the absolute response acceleration and the equivalent static acceleration will be identical. This can be seen by comparing Equation (2) with zero damping to Equation (7). With increasing system damping, because of its frequency dependence, the equivalent static acceleration will tend to be lower than the absolute response acceleration at low frequencies. At high frequencies these two parameters will

tend to be in close agreement even for high values of damping. In general, it has become conventional to consider a shock spectrum as undamped unless otherwise specified.

## 2.1 Normalized Four Coordinate Shock Spectrum

The shock spectrum parameters of relative deflection response $\delta$, speudo velocity response $\underline{v}$, and equivalent static acceleration $\underline{a}$ are represented by Equations (6) and (7) as peak sinusoidal quantities of system in free vibration at its natural frequency. This leads to a convenient simultaneous presentation of all these parameters on a four coordinate vibration nomograph.

The four coordinate representation of shock spectra can be made still more convenient for comparison with other spectra and making design calculations by normalizing the shock spectrum parameters with respect to the quantity $\underline{G}\,\underline{g}\,\tau$. This quantity represents the velocity of a square pulse having the same peak acceleration $\underline{G}\,\underline{g}$ and duration $\tau$ as the shock input whose spectrum is to be plotted. Dividing both sides of Equation (6) by $\underline{G}\,\underline{g}\,\tau$, we can define a normalized acceleration parameter $\underline{A}$, as follows:

$$A = \frac{a_{max}}{G g \tau} = 2\pi f_n \left(\frac{v_{max}}{G g \tau}\right) \tag{8}$$

Defining the quantity in parenthesis as the normalized velocity parameter V, and rearranging terms we obtain the expected dimensionless-frequency product relation between normalized acceleration and velocity:

$$A = \frac{A_\tau}{G} = 2\pi (f_n \tau) V \tag{9}$$

The normalized velocity can be related to a normalized deflection parameter by dividing both sides of Equation (7) by the quantity $G g \tau$:

$$V = \frac{v_{max}}{G g \tau} = 2\pi f_n \frac{\delta_{max}}{G g \tau} \tag{10}$$

Multiplying numerator and denominator by $\tau$ we obtain the desired dimensionless-frequency product relation between normalized velocity and deflection:

$$V = \frac{2\pi}{g} (f_n \tau) D \tag{11}$$

where

$$D = \text{Normalized deflection} = \frac{\delta_{max}}{G \tau^2} \tag{12}$$

Combining Equations (11) and (13), we obtain a relation between normalized acceleration and deflection:

$$A = \frac{4\pi^2}{g} (f_n \tau)^2 D \tag{13}$$

Equations (9), (11), (12) and (13) define the normalized acceleration, velocity, deflection and frequency coordinates which are used for plotting the shock spectra presented in this report.

## 2.2 Example of Shock Spectrum Application

As a specific example of the application of the four coordinate shock spectrum, consider the case of a laboratory half sine pulse shock test that is being utilized to determine the shock fragility rating of an undamped critical equipment component whose natural frequency $f_n$ = 100 cps. The critical component fails during a shock input of $Gg$ = 100g and pulse duration $\tau$ = 0.001 sec. What is the component's fragility rating in terms of equivalent static acceleration, pseudo-velocity response and relative deflection response? The dimensionless frequency parameter $f_n \tau$ = (100) (.001) = 0.1. Using the half-sine pulse shock spectrum of Figure 52, we read:

$$A = 0.4$$

$$V = 0.64$$

$$D = 400$$

From which we can compute:

Equivalent static acceleration $a = Gg\,A = (100g)\,(.4) = 40g$

Pseudo-velocity response $v = Gg\,\tau V = (100)\,(386)\,(.001)\,(.64)$
$= 24.7$ in./sec

Relative deflection response $d = G\,\tau^2 D = (100)\,(.001)^2(400) = 0.040$ in.

As a second example, what is the amplitude of a half-sine shock pulse whose duration $\tau$ = 0.010 sec that will produce the same failure, i.e., equivalent static acceleration, as the previous example?

The dimensionless frequency parameter $f_n \tau$ = (100) (.010) = 1.

Now from Figure 52, we read A = 1.7.

Therefore, we compute a = 40g = Gg A

$$Gg = \frac{40g}{1.7} = 23.5g$$

3. Analysis in the Frequency Domain

Analysis to determine the Fourier spectrum or frequency composition of a shock transient is termed analysis in the frequency domain. The Fourier transformation, or equation defining the frequency spectrum, of a shock acceleration time-history designated as $\ddot{u}(t)$ starting at $t = 0$ and ending at $t = \tau$ is:

$$F\left[\ddot{u}(t)\right] = \left[\ddot{U}(\omega)\right] = \int_0^{\tau} \ddot{u}(t)\, e^{-j\omega t}\, dt \tag{15}$$

Equation (15) may be written alternatively in terms of its real and imaginary components as:

$$\left[\ddot{U}(\omega)\right] = \int_0^{\tau} \ddot{u}(t) \cos \omega t\, dt - j \int_0^{\tau} \ddot{u}(t) \sin \omega t\, dt \tag{16}$$

$$\left[\ddot{U}(\omega)\right] = \left[\ddot{U}_c(\omega)\right] + j\left[\ddot{U}_s(\omega)\right] \tag{17}$$

The absolute magnitude of the Fourier transform in Equation (15) is the value used for plotting the Fourier spectrum, and this may be written in terms of its real and imaginary parts as:

$$\left|\ddot{U}(\omega)\right| = \sqrt{\left[U_c(\omega)\right]^2 + \left[U_s(\omega)\right]^2} \tag{18}$$

The phase angle between the absolute magnitude of the Fourier transform and its real component is:

$$\theta(\omega) = \arctan \frac{[\ddot{U}_s(\omega)]}{[\ddot{U}_c(\omega)]} \tag{19}$$

A convenient relation exists between the Fourier spectrum and the residual undamped response shock spectrum for a given shock input motion. From Equations (3) and (4) the relative deflection response $\delta_r(\tau)$ and relative velocity response $\dot{\delta}_r(\tau)$ at the end of a shock input for an undamped system initially at rest will be a free vibration at the system undamped natural frequency $\omega_n$, as follows:

$$\delta_r(\tau) = -\frac{1}{\omega_n}\int_0^\tau \ddot{u}(\tau)\, \sin \omega_n (t-\tau)\, d\tau$$

and

$$= -\frac{1}{\omega_n}\int_0^\tau \ddot{u}(\tau) \sin \omega_n t \cos \omega_n \tau\, d\tau + \frac{1}{\omega}\int_0^\tau \ddot{u}(\tau) \cos \omega_n t \sin \omega_n \tau\, d\tau \tag{20}$$

$$\dot{\delta}_r(\tau) = -\int_0^\tau \ddot{u}(\tau) \cos \omega_n (t-\tau)\, d\tau$$

$$= -\int_0^\tau \ddot{u}(\tau) \cos \omega_n t \cos \omega_n \tau\, d\tau - \int_0^\tau \ddot{u}(\tau) \sin \omega_n t \sin \omega_n \tau\, d\tau \tag{21}$$

Combining Equations (16), (17), (20) and (21), we obtain the following equations defining the relative deflection and velocity at the end of the pulse:

$$\delta_r(\tau) = -\frac{1}{\omega_n}[\ddot{U}_c(\omega)] \sin \omega_n \tau - \frac{1}{\omega_n}[\ddot{U}_s(\omega)] \cos \omega_n \tau \tag{22}$$

and

$$\dot{\delta}_r(\tau) = -[\ddot{U}_c(\omega)] \cos \omega_n \tau + [\ddot{U}_s(\omega)] \sin \omega_n \tau \tag{23}$$

Considering Equations (22) and (23) as a set of initial conditions, an equation defining the maximum residual sinusoidal response amplitude is readily obtained as:

$$(\delta_r)_{max} = \sqrt{[\delta_r(\tau)]^2 + \left[\frac{\dot{\delta}_r(\tau)}{\omega_n}\right]^2}$$

$$= \frac{1}{\omega_n}\sqrt{[\dot{U}_c(\omega_n)]^2 + [\dot{U}_s(\omega_n)]^2} = \frac{[\dot{U}(\omega_n)]}{\omega_n} \tag{24}$$

Since the residual vibration is sinusoidal, it is convenient to rewrite Equation (24) as:

$$\omega_n (\delta_r)_{MAX} = (\dot{\delta}_r)_{MAX} = [\dot{U}(\omega_n)] \tag{25}$$

From Equation (25) it can be seen that the maximum values plotted in a residual velocity (response) shock spectrum for an undamped system are identical to the Fourier spectrum for a shock acceleration input. This relationship between the residual shock spectrum and the Fourier spectrum for a given shock acceleration input is noted on each of the spectrum plots presented in this report.

### 3.1 Normalized Four Coordinate Fourier Spectrum

The frequency components of a Fourier spectrum are sinusoidal quantities, hence they can be interchangeably expressed in units of displacement, velocity or acceleration as follows:

$$a_{max} = 2\pi f \; v_{max} = (2\pi f)^2 d_{max} \tag{26}$$

$$v_{max} = 2\pi f \; d_{max} \tag{27}$$

It is convenient for purposes of simultaneous plotting of shock and Fourier spectra to normalize the components defined by Equations (26) and (27) with respect to the quantity $\underline{G}\,\underline{g}\,\tau$. This quantity represents the velocity of a square wave shock pulse which in the limit will envelope any simple pulse with peak acceleration $\underline{G}\,\underline{g}$ and duration $\tau$. The quantity $\underline{G}\,\underline{g}\,\tau$ also represents the zeroth frequency component for the Fourier spectrum of a square wave acceleration pulse, as can be seen by setting $\omega = 0$ in Equation (15). Dividing Equations (26) and (27) by the quantity $\underline{G}\,\underline{g}\,\tau$ and rearranging terms, a set of normalized acceleration velocity and displacement parameters analagous to those defined previously for the shock spectrum are obtained as follows:

$$A = \frac{a_{max}}{Gg} = 2\pi(f\tau)V = \frac{4\pi^2}{g}(f\tau)^2 D \tag{28}$$

$$V = \frac{v_{max}}{Gg\tau} = \frac{2\pi}{g}(f\tau)D \tag{29}$$

$$D = \frac{d_{max}}{G\tau^2} \tag{30}$$

Inasmuch as the normalized shock and Fourier spectrum parameters have been made numerically identical, the desired objective of using a single graph to depict both the residual shock spectrum and the Fourier spectrum, has been achieved. This is noted in the plots of Fourier spectra presented herein.

4. Compilation of Shock and Fourier Spectra

The following pages present a compilation of shock and Fourier spectra for a variety of simple and complex shock acceleration pulses. The purpose of these spectral plots is to permit comparison with similar spectra computed from measured service conditions and thereby facillitate work on

the development of shock test and design criteria. The spectra are grouped with three pages for each of the shock acceleration pulses included in this compilation as follows:

Shock and Fourier Spectra

(a) Shock Spectrum (undamped).

(b) Fourier Spectrum (also represents undamped residual shock spectrum).

Damped Shock Spectra

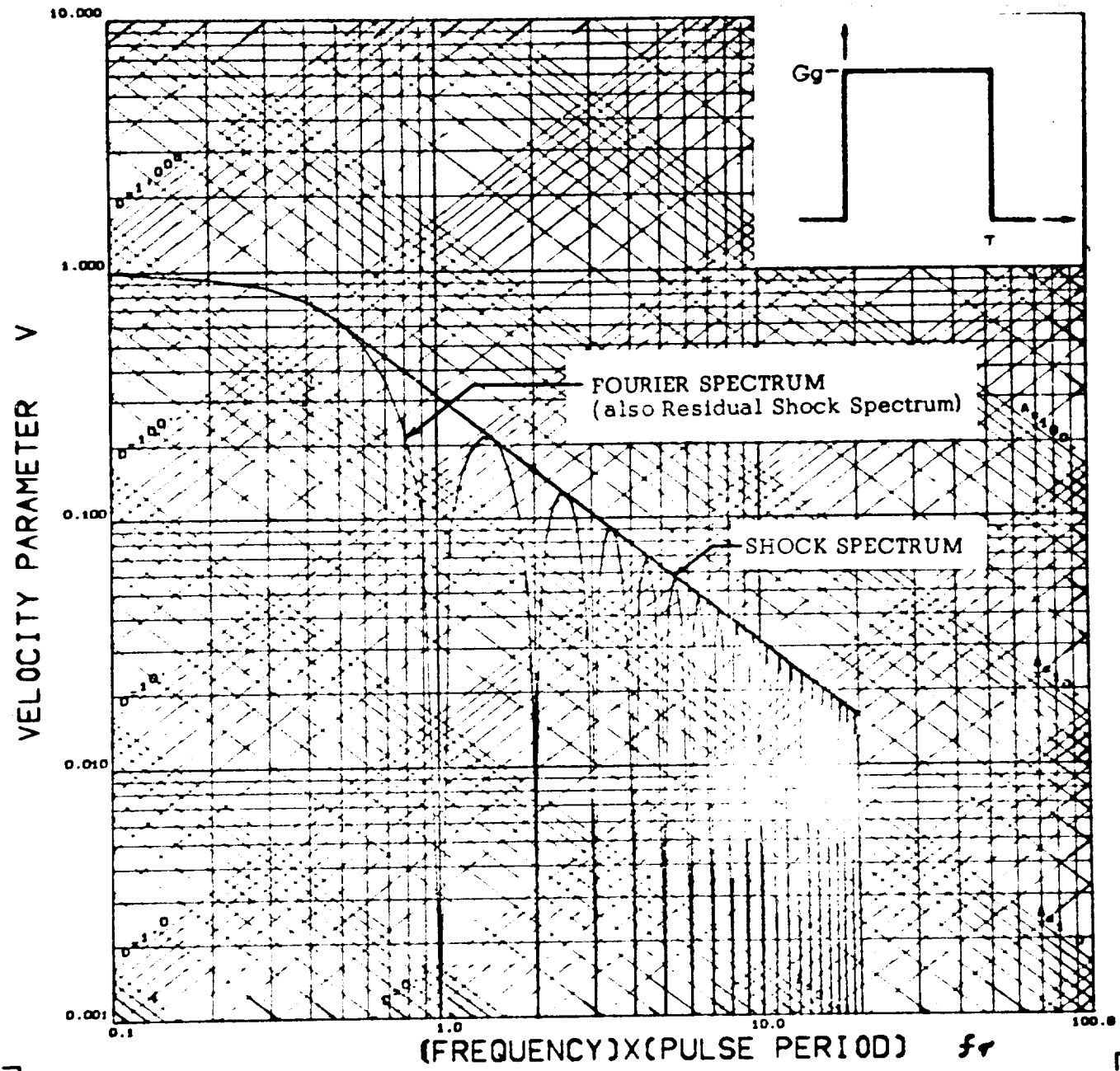
(a) $c/c_c = 0$

(b) $c/c_c = 0.05$

(c) $c/c_c = 0.10$

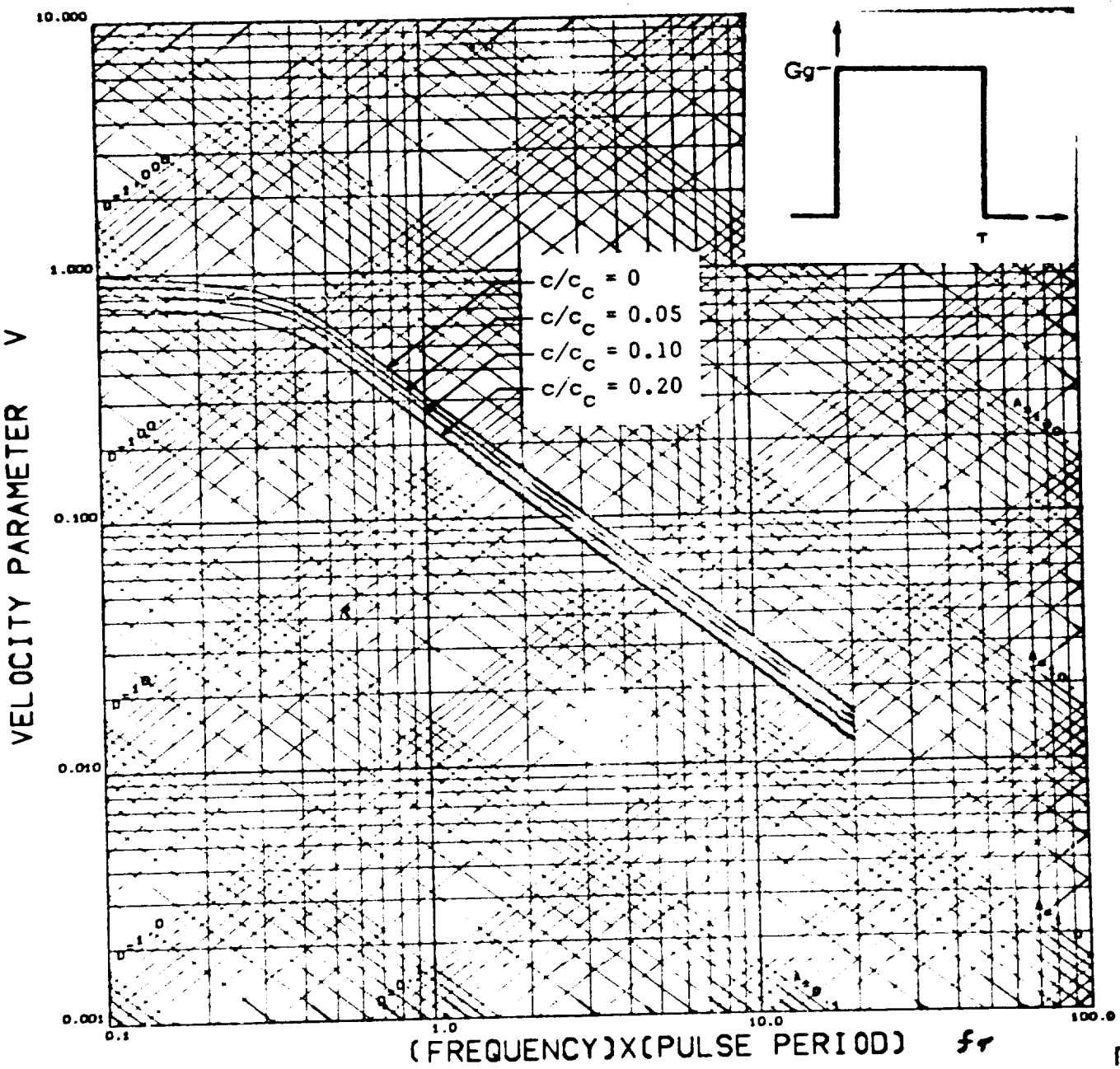
(d) $c/c_c = 0.20$

Fourier Phase Spectrum




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G_\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-1 Fourier and Shock Spectra for a Rectangular Acceleration Pulse




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-2 Damped Shock Spectra for a Rectangular Acceleration Pulse

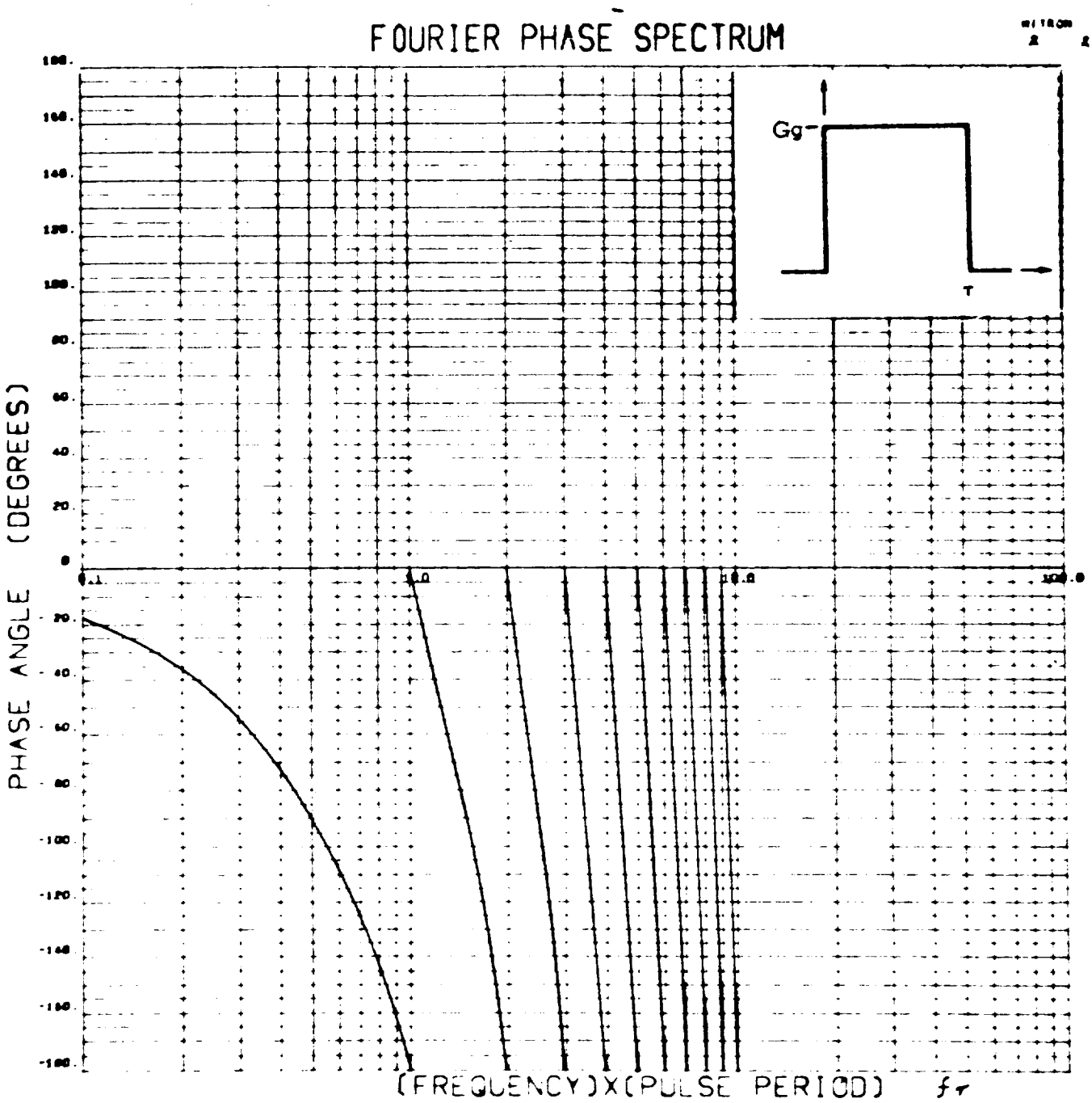
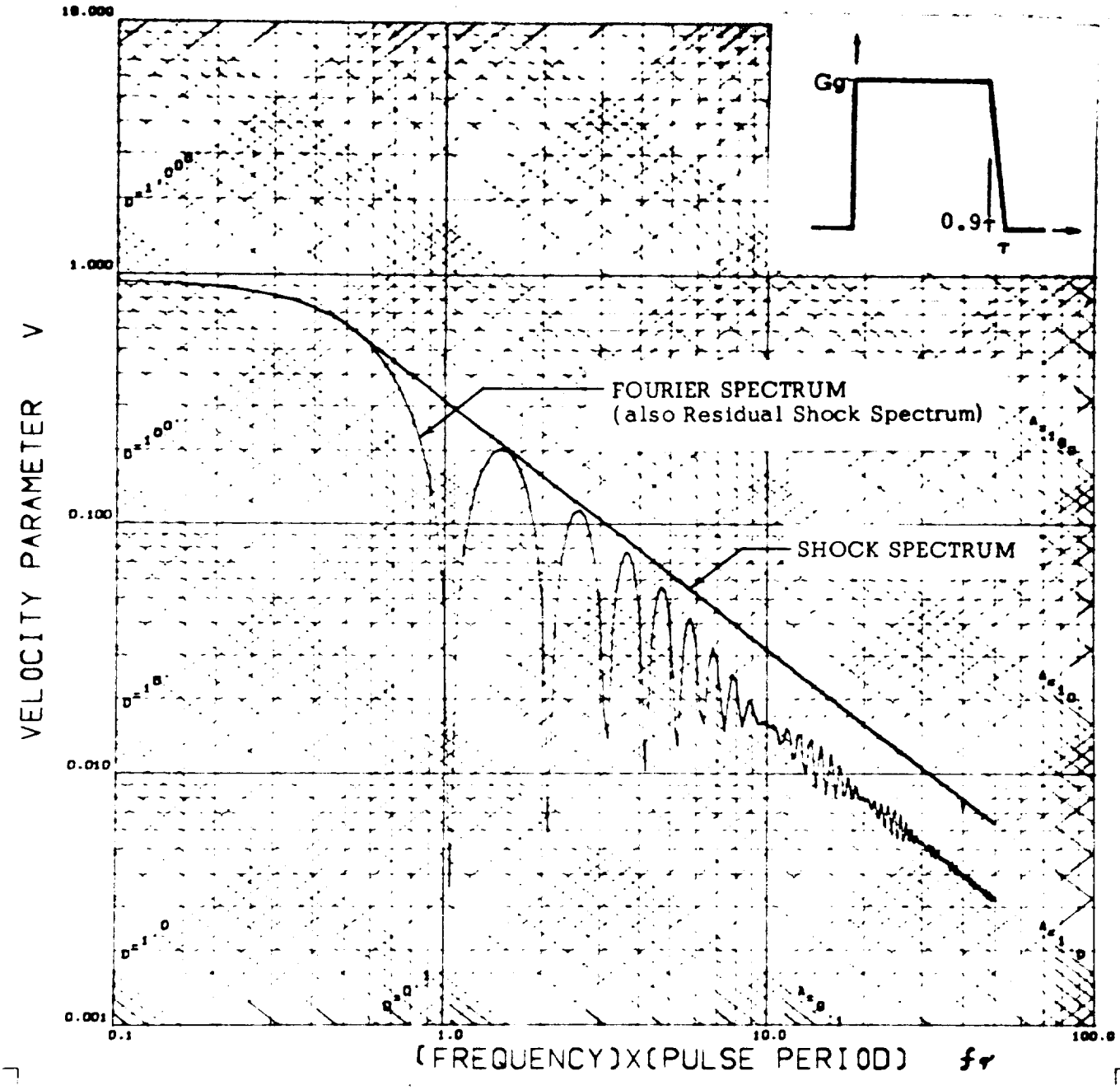
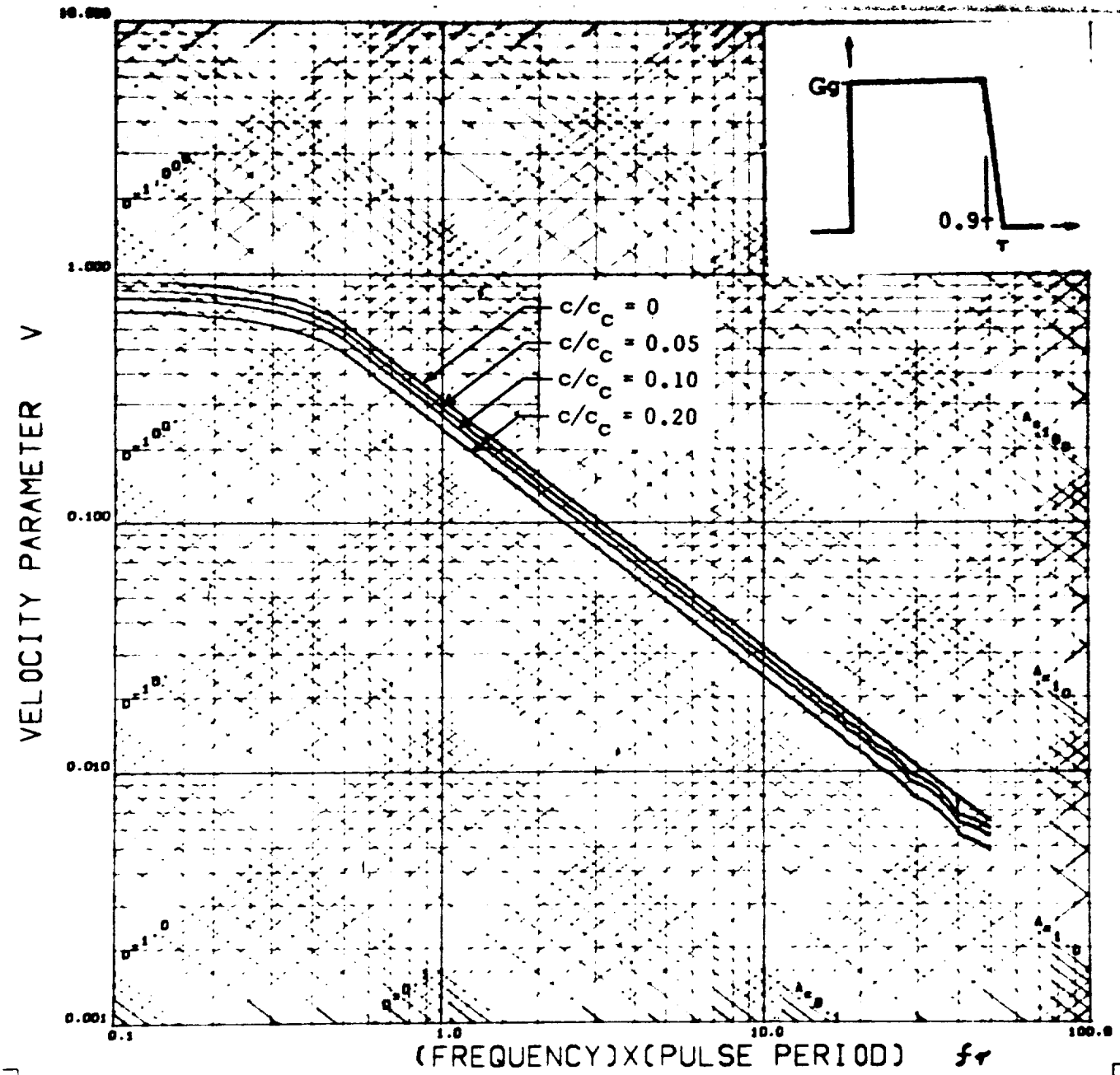



FIGURE II-3 Fourier Phase Spectrum for a Rectangular Acceleration Pulse




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-4 Fourier and Shock Spectra for a Trapezoidal Acceleration Pulse with Step Rise and Constant-Slope Decay. Decay Time = 0.1 τ




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-5 Damped Shock Spectra for a Trapezoidal Acceleration Pulse with Step Rise and Constant-Slope Decay. Decay Time = 0.1τ

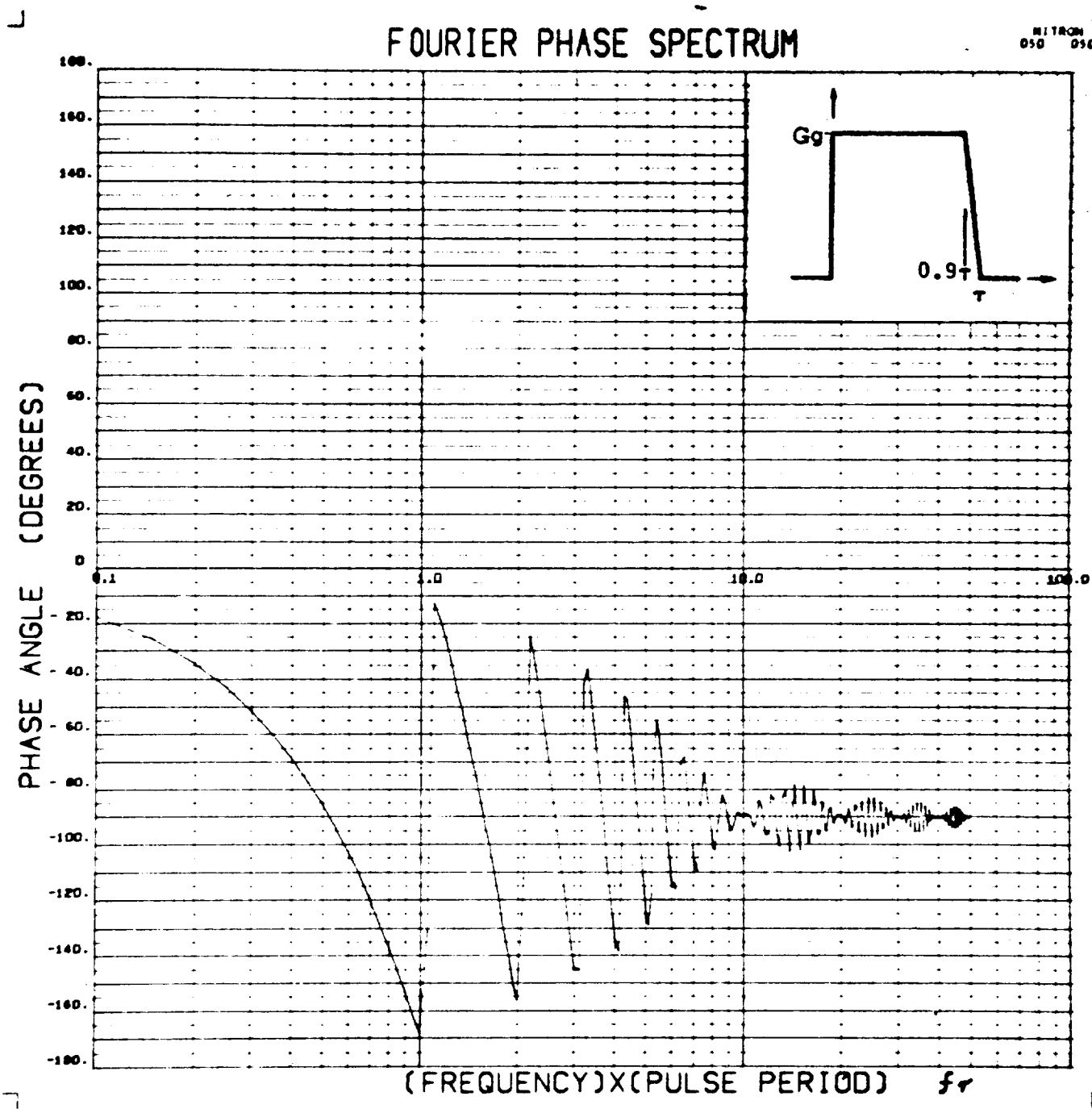
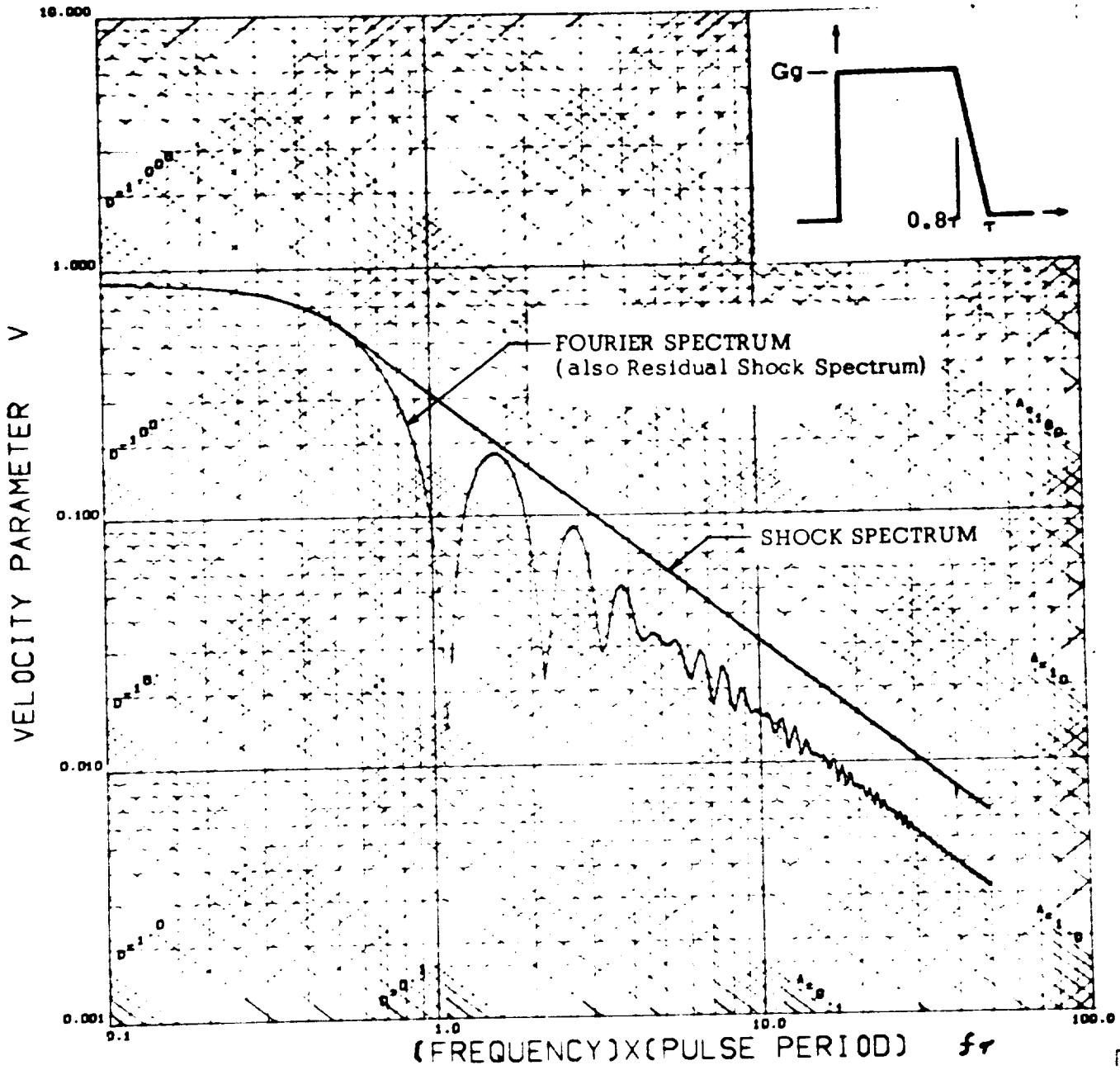
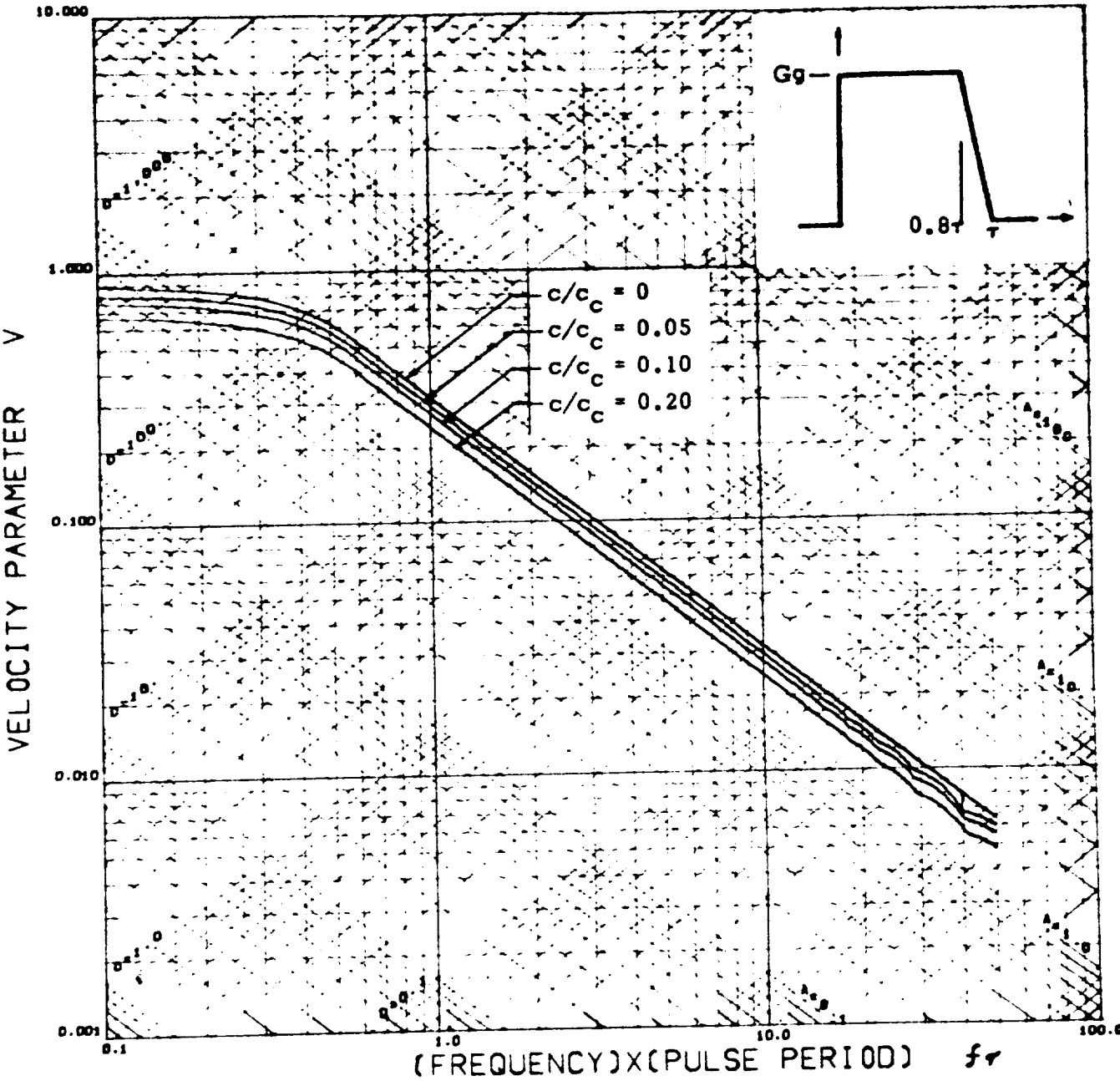



FIGURE II-6 Fourier Phase Spectrum for a Trapezoidal Acceleration Pulse with Step Rise and Constant-Slope Decay. Decay Time = 0.1 τ




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-7 Fourier and Shock Spectra for a Trapezoidal Acceleration Pulse with Step Rise and Constant-Slope Decay. Decay Time = 0.2τ




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

TABLE II-8 Damped Shock Spectra for a Trapezoidal Acceleration Pulse with Step Rise and Constant-Slope Decay. Decay Time = 0.2 τ

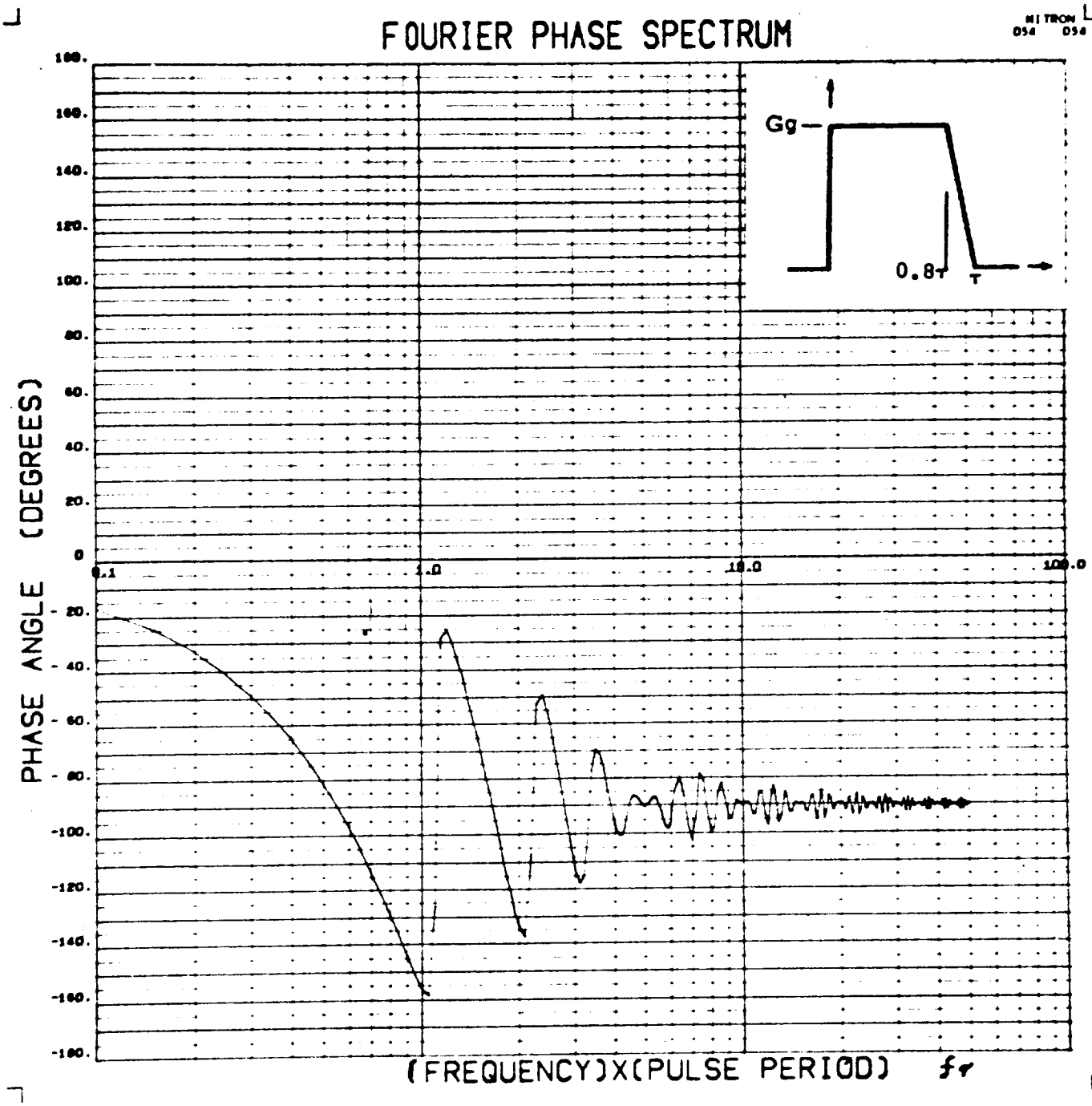
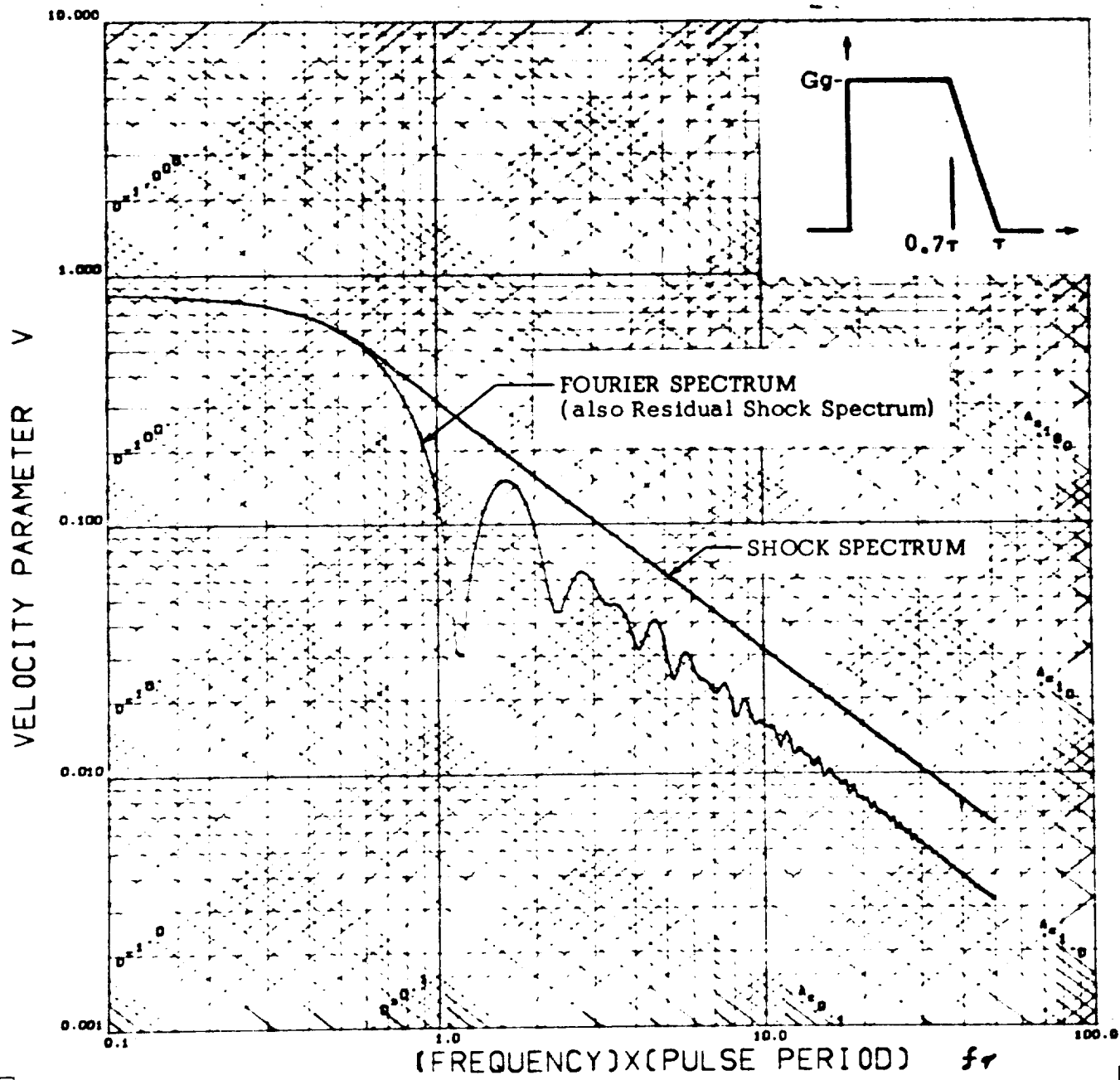
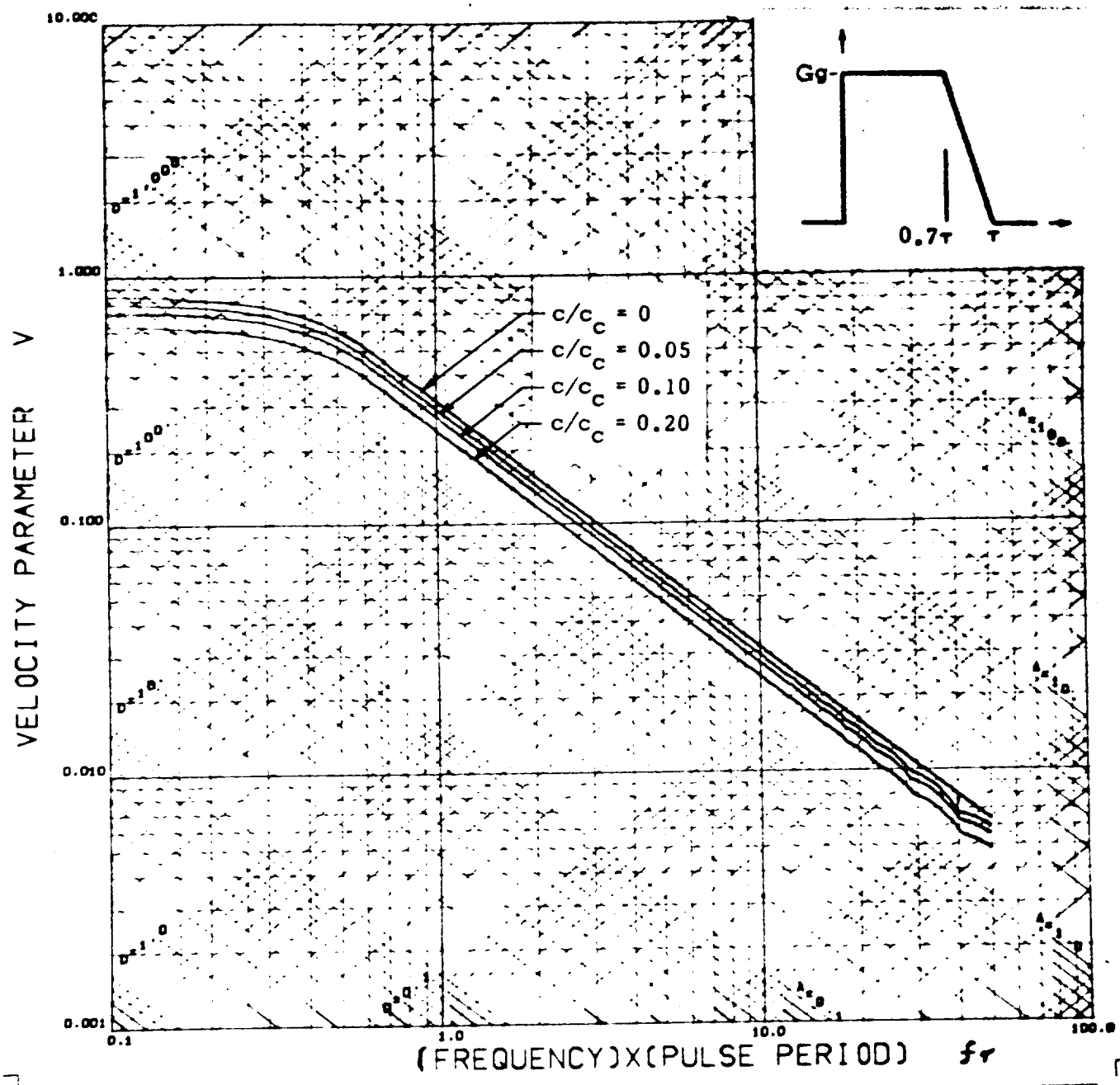



FIGURE II-9 Fourier Phase Spectrum for a Trapezoidal Acceleration Pulse with Step Rise and Constant-Slope Decay. Decay Time = 0.2 τ




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-10 Fourier and Shock Spectra for a Trapezoidal Acceleration Pulse with Step Rise and Constant-Slope Decay. Decay Time = 0.3 τ




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-11 Damped Shock Spectra for a Trapezoidal Acceleration Pulse with Step Rise and Constant-Slope Decay. Decay Time = 0.3 τ

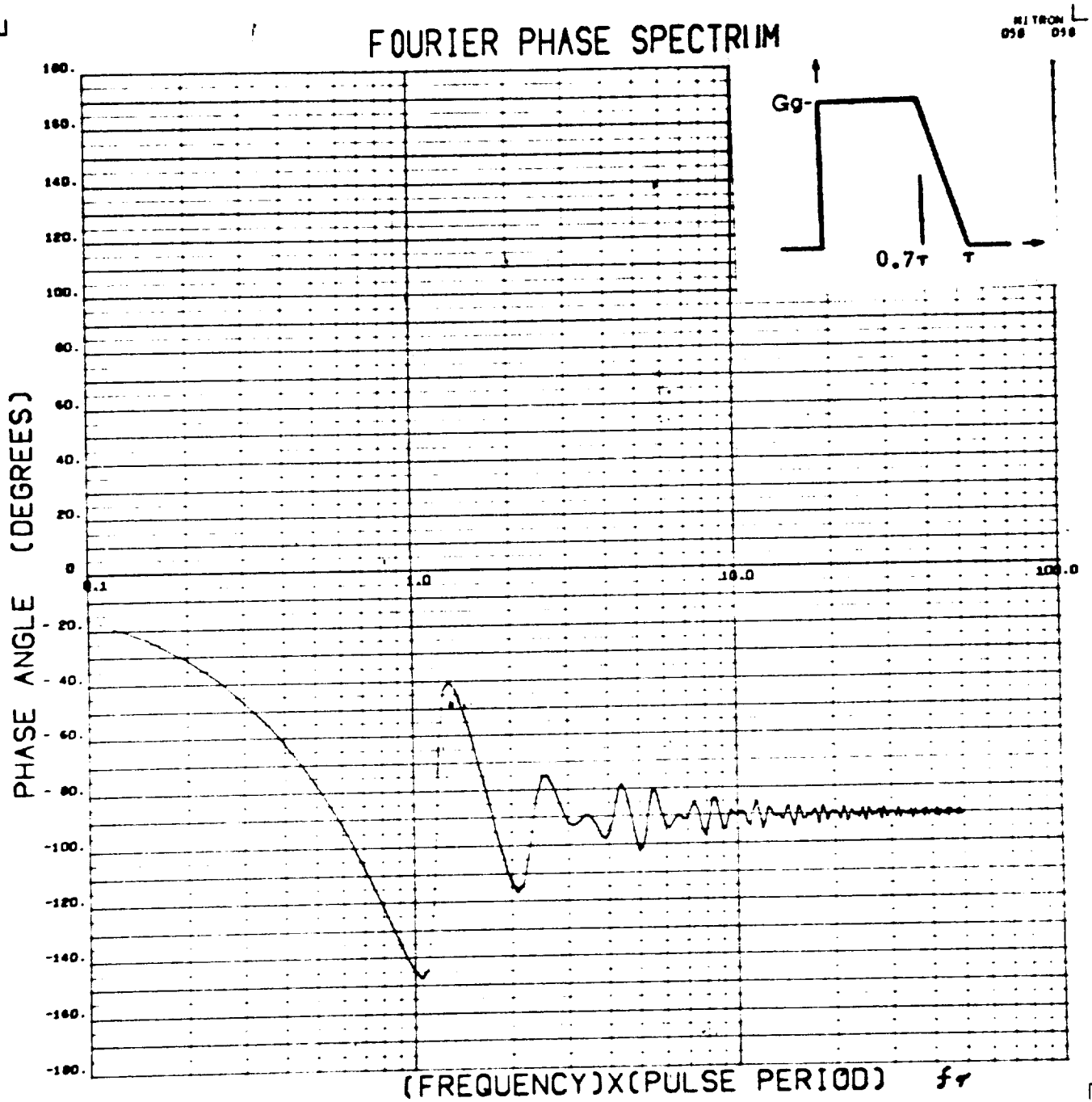
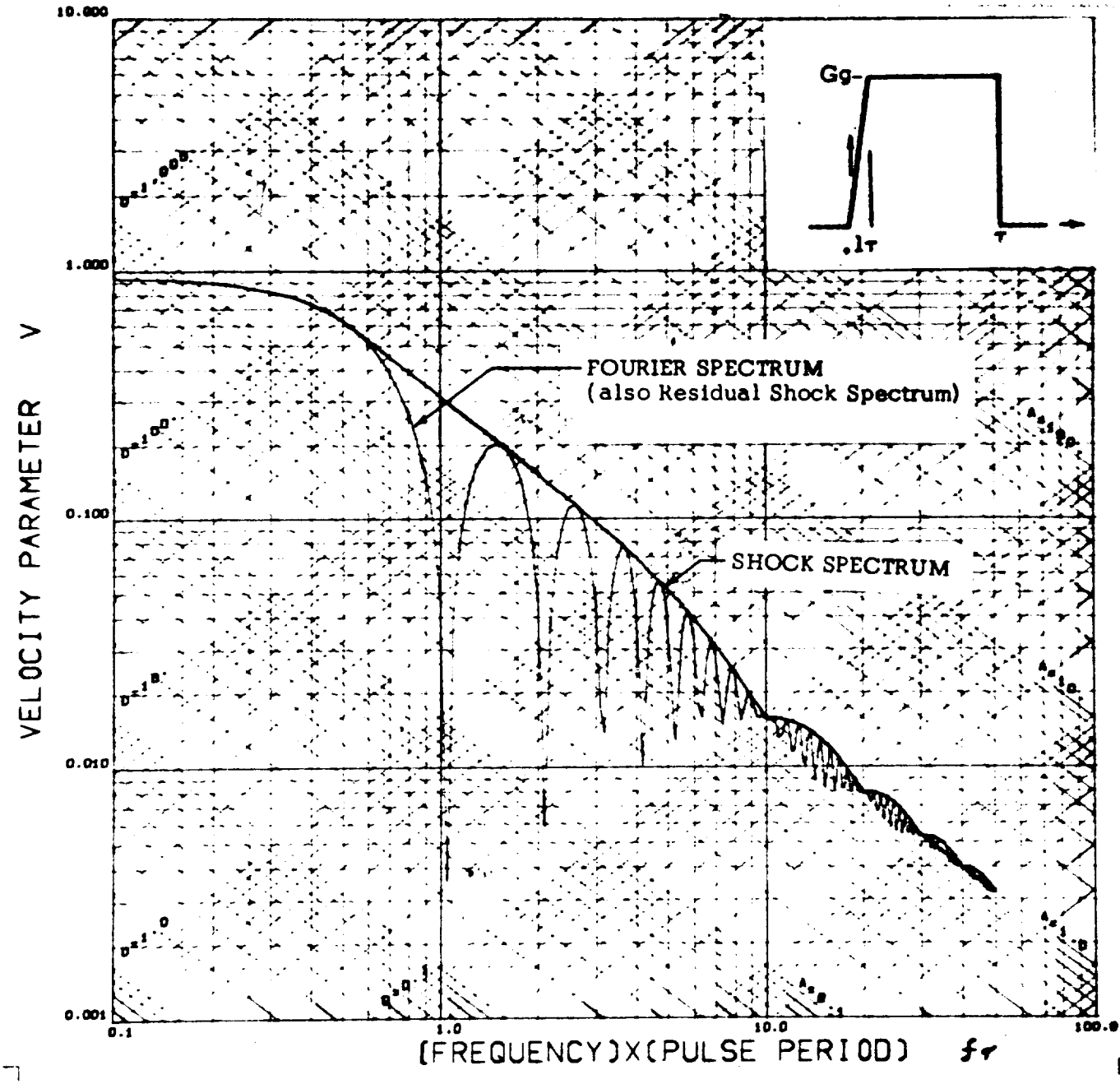
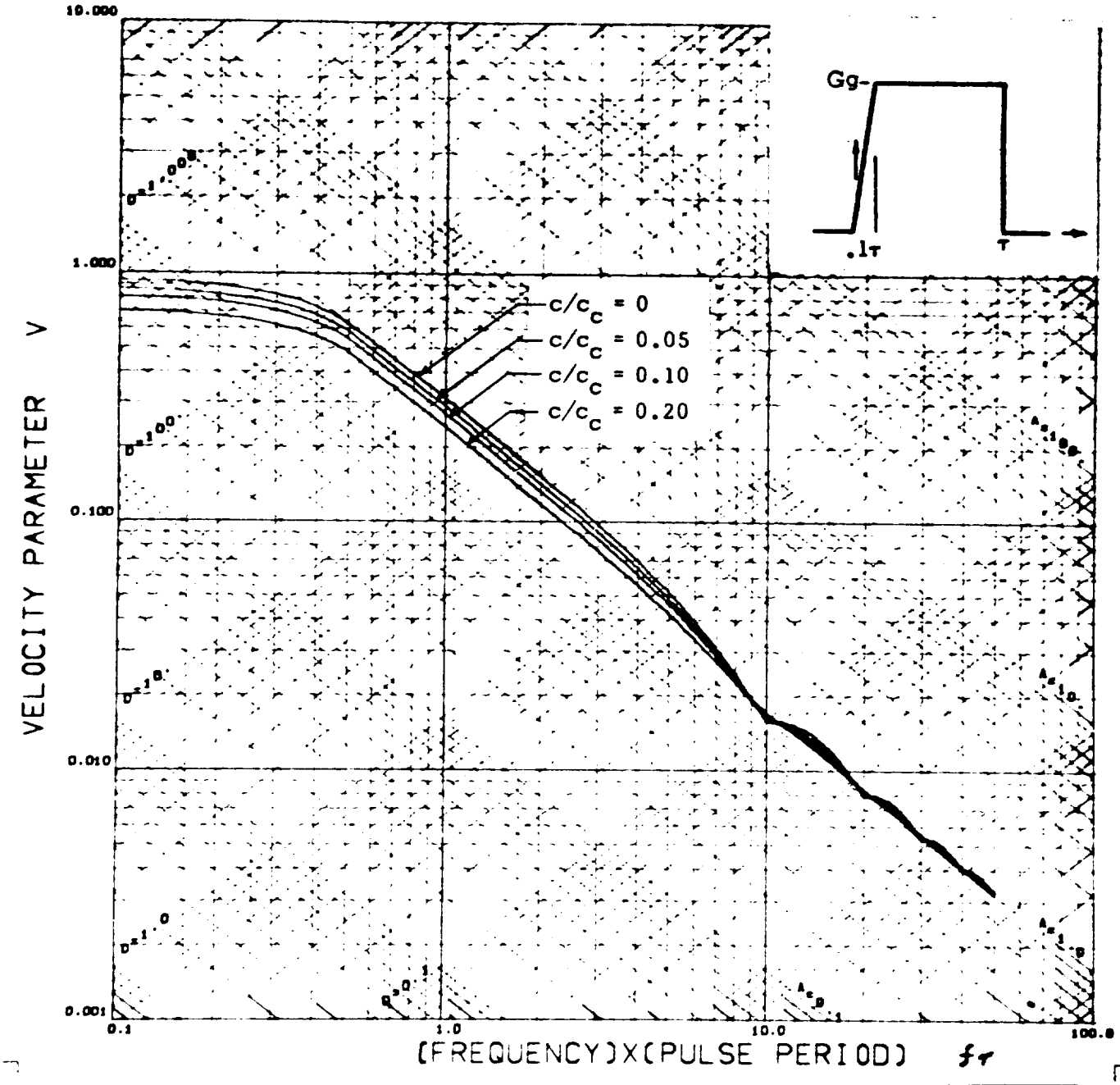



FIGURE II-12 Fourier Phase Spectrum for a Trapezoidal Acceleration Pulse with Step Rise and Constant-Slope Decay. Decay Time = 0.3 τ




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-13 Fourier and Shock Spectra for a Trapezoidal Acceleration Pulse with Constant-Slope Rise and Vertical Decay. Rise Time = 0.1 τ




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-14 Damped Shock Spectra for a Trapezoidal Acceleration Pulse with a Constant-Slope Rise and Vertical Decay. Rise Time = 0.1 τ

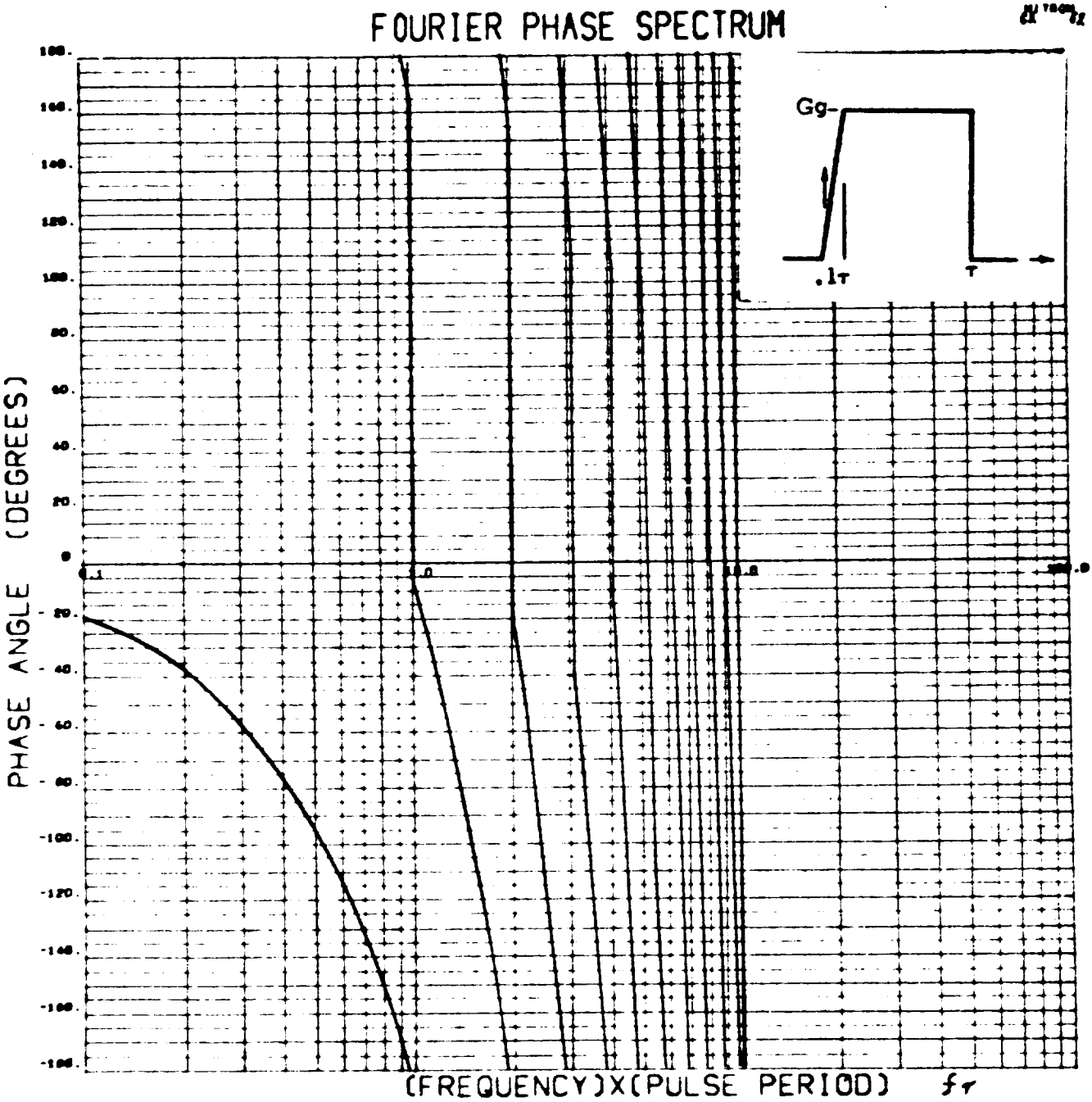
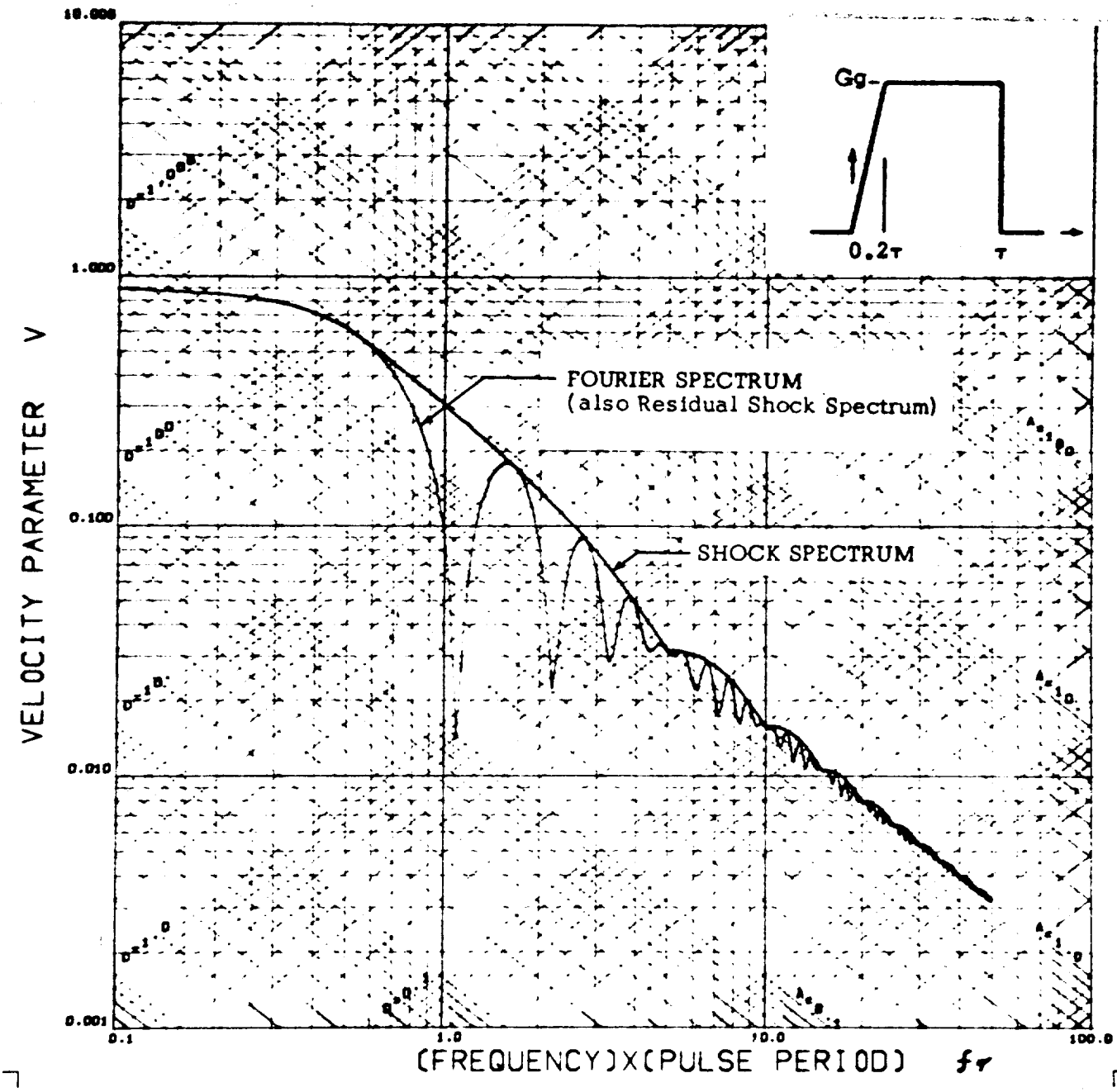
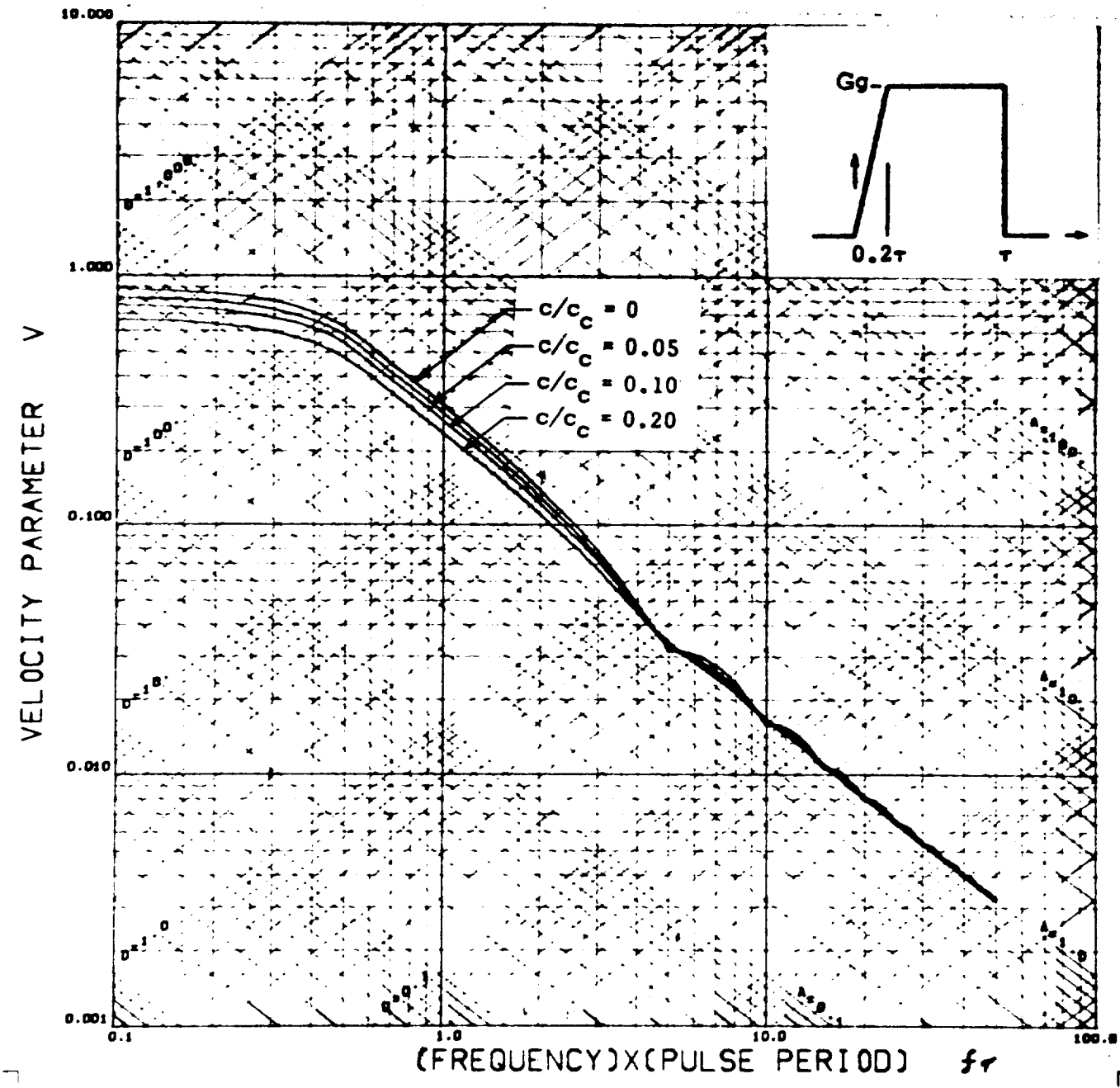



FIGURE II-15 Fourier Phase Spectrum for a Trapezoidal Acceleration Pulse with Constant-Slope Rise and Vertical Decay. Rise Time = 0.1 τ




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)^s$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-16 Fourier and Shock Spectra for a Trapezoidal Acceleration Pulse with Constant-Slope Rise and Vertical Decay. Rise Time = 0.2 τ




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-17 Damped Shock Spectra for a Trapezoidal Acceleration Pulse with Constant-Slope Rise and Vertical Decay. Rise Time = 0.2 τ

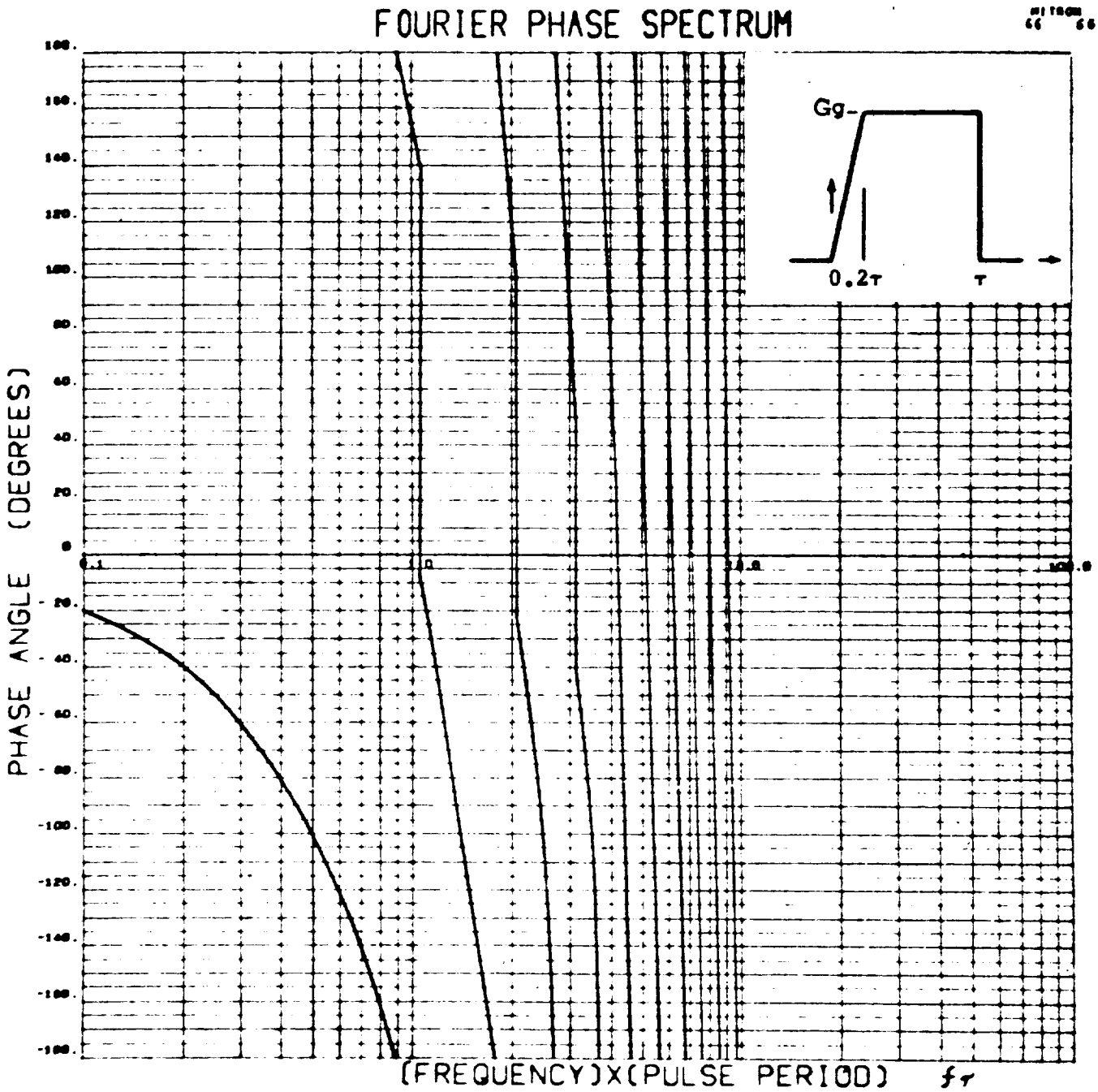
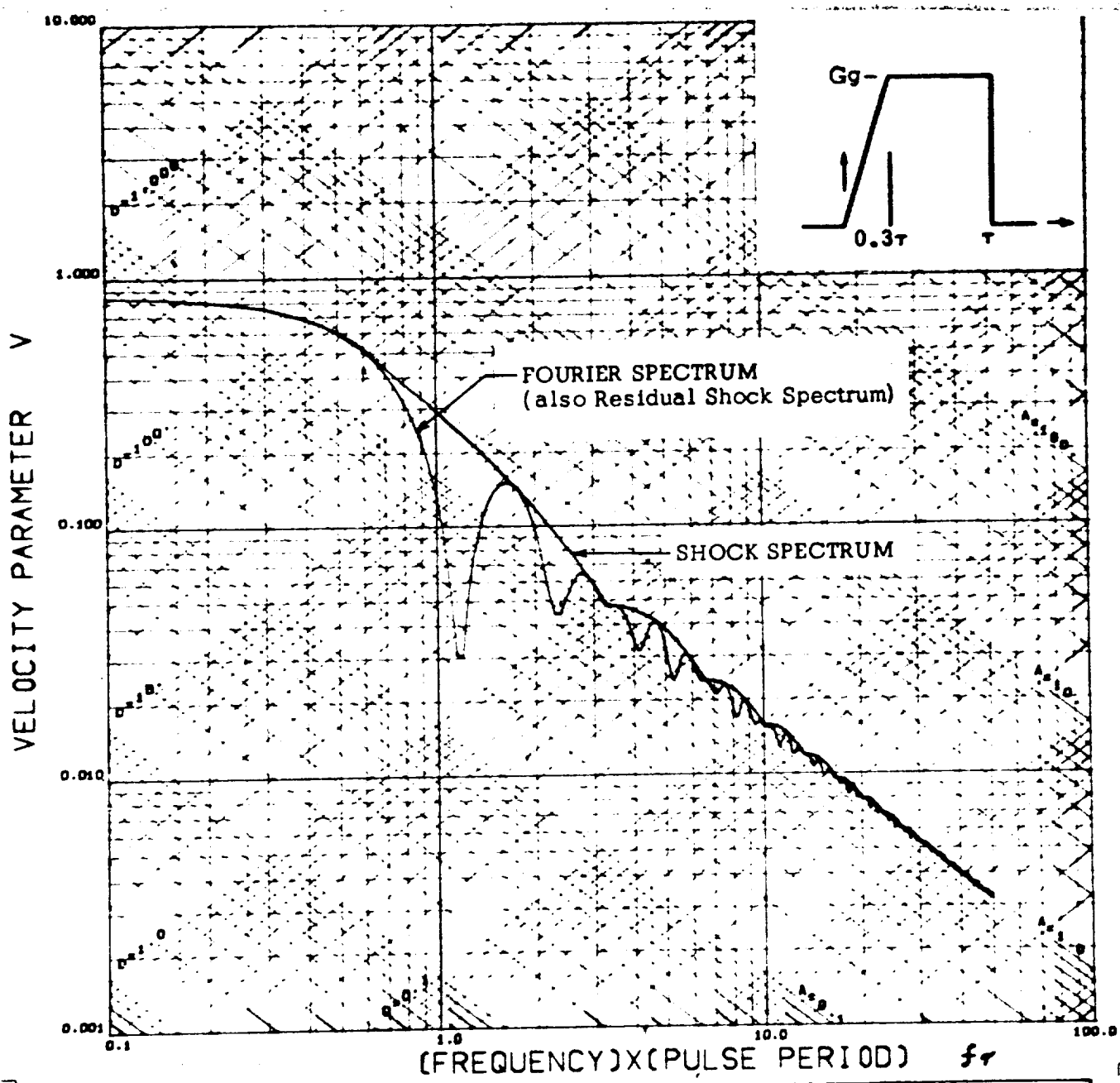
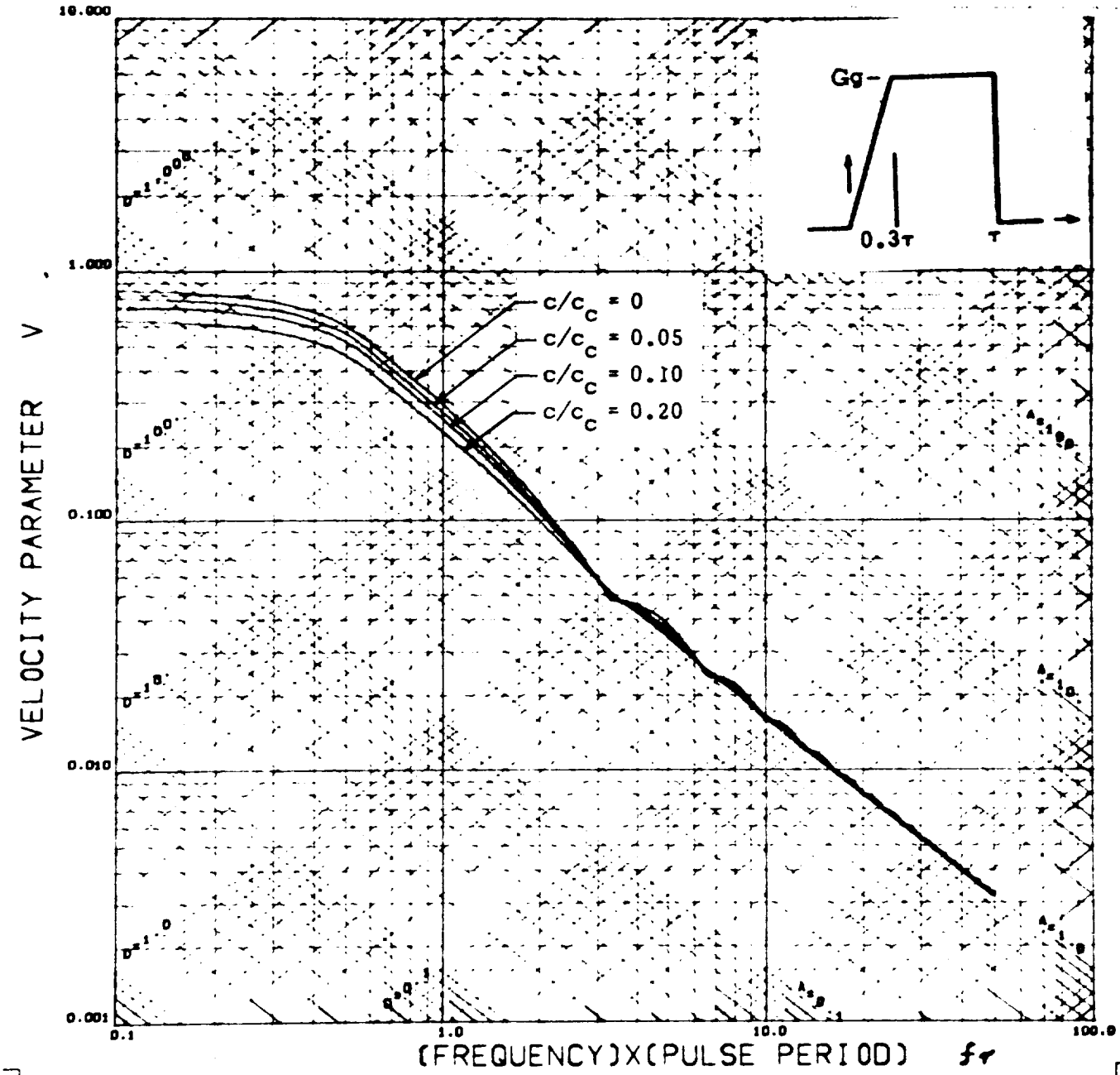



FIGURE II-18 Fourier Phase Spectrum for a Trapezoidal Acceleration Pulse with Constant-Slope Rise and Vertical Decay. Rise Time = 0.2 τ




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-19 Fourier and Shock Spectra for a Trapezoidal Acceleration Pulse with Constant-Slope Rise and Vertical Decay. Rise Time = 0.3 τ




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-20 Damped Shock Spectra for a Trapezoidal Acceleration Pulse with Constant-Slope Rise and Vertical Decay. Rise Time = 0.3 τ

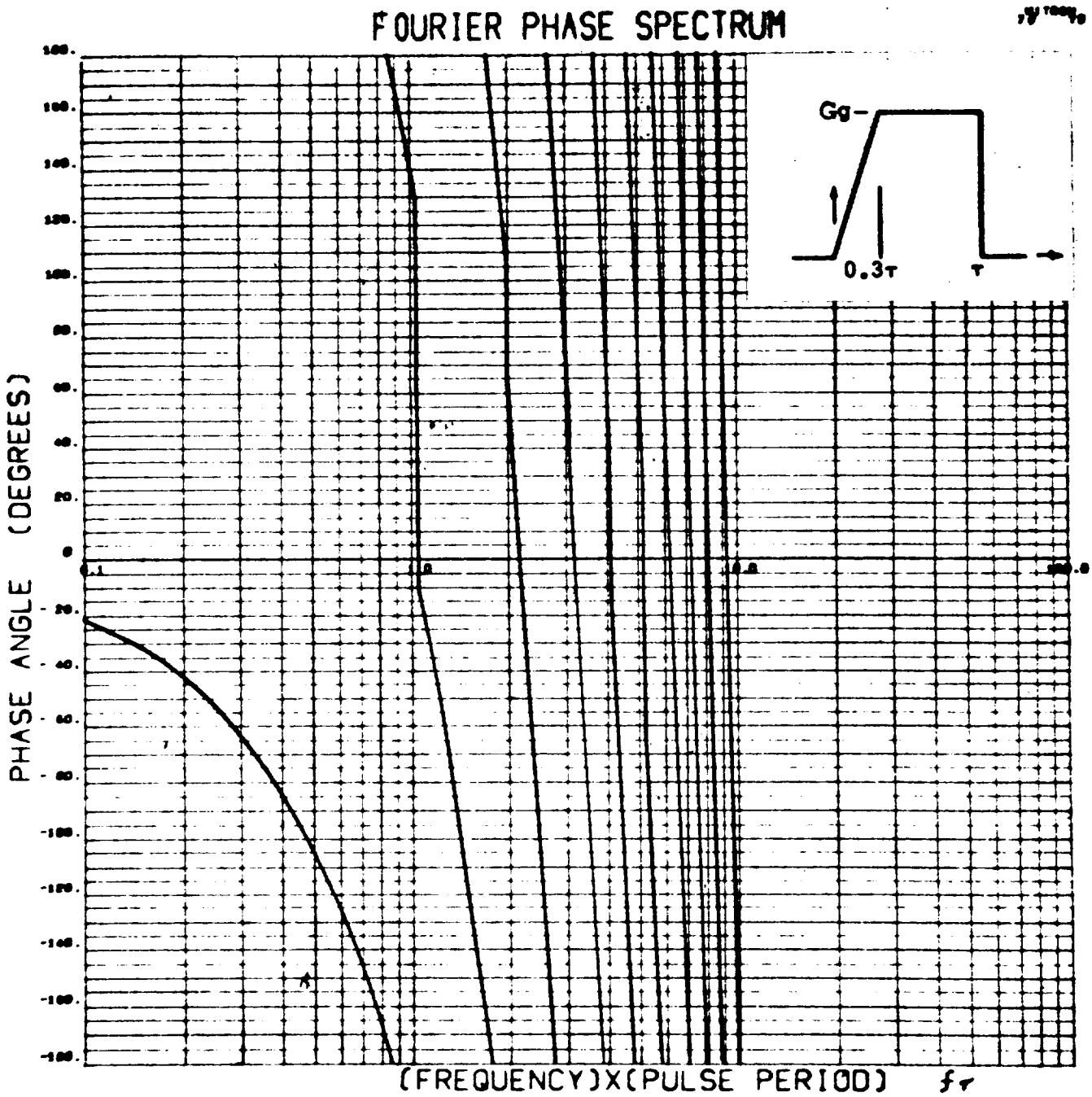
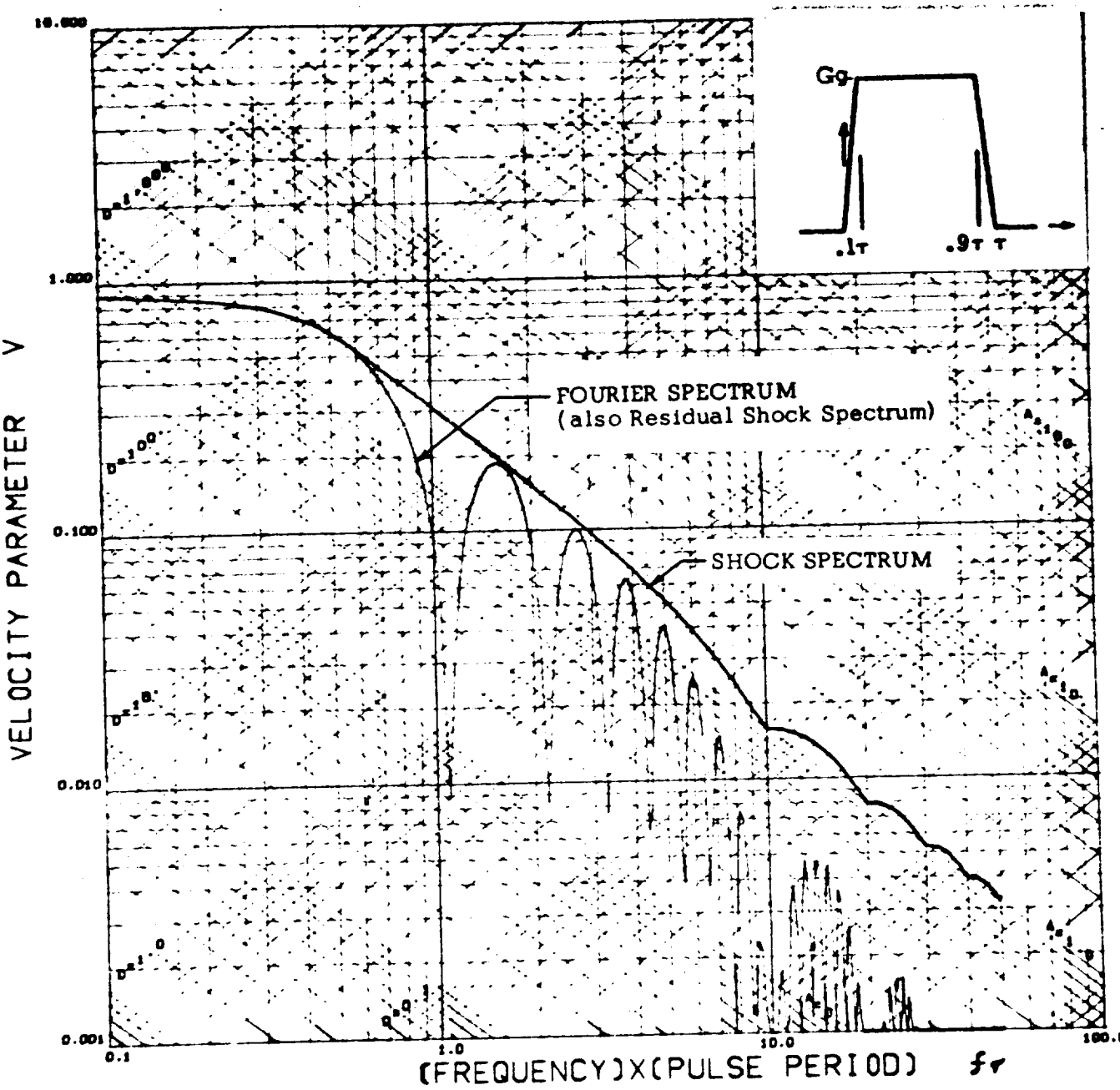
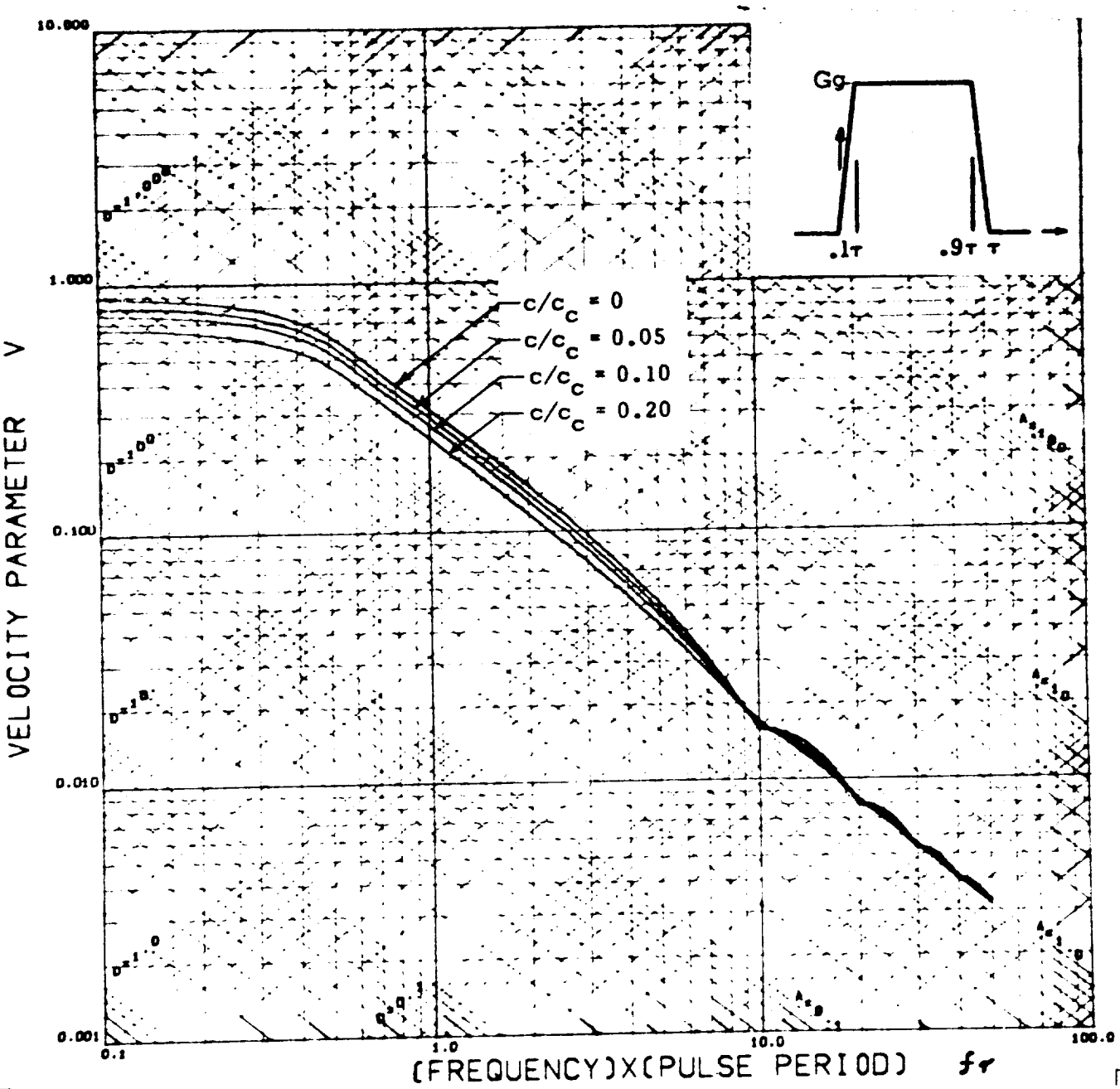



FIGURE II-21 Fourier Phase Spectrum for a Trapezoidal Acceleration Pulse with Constant-Slope Rise and Vertical Decay. Rise Time = 0.3 τ




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-22 Fourier and Shock Spectra for a Constant-Slope Symmetrical Acceleration Pulse. Rise Time = Decay Time = 0.1 τ




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-23 Damped Shock Spectra for a Constant-Slope Symmetrical Acceleration Pulse. Rise Time = Decay Time = 0.1 τ

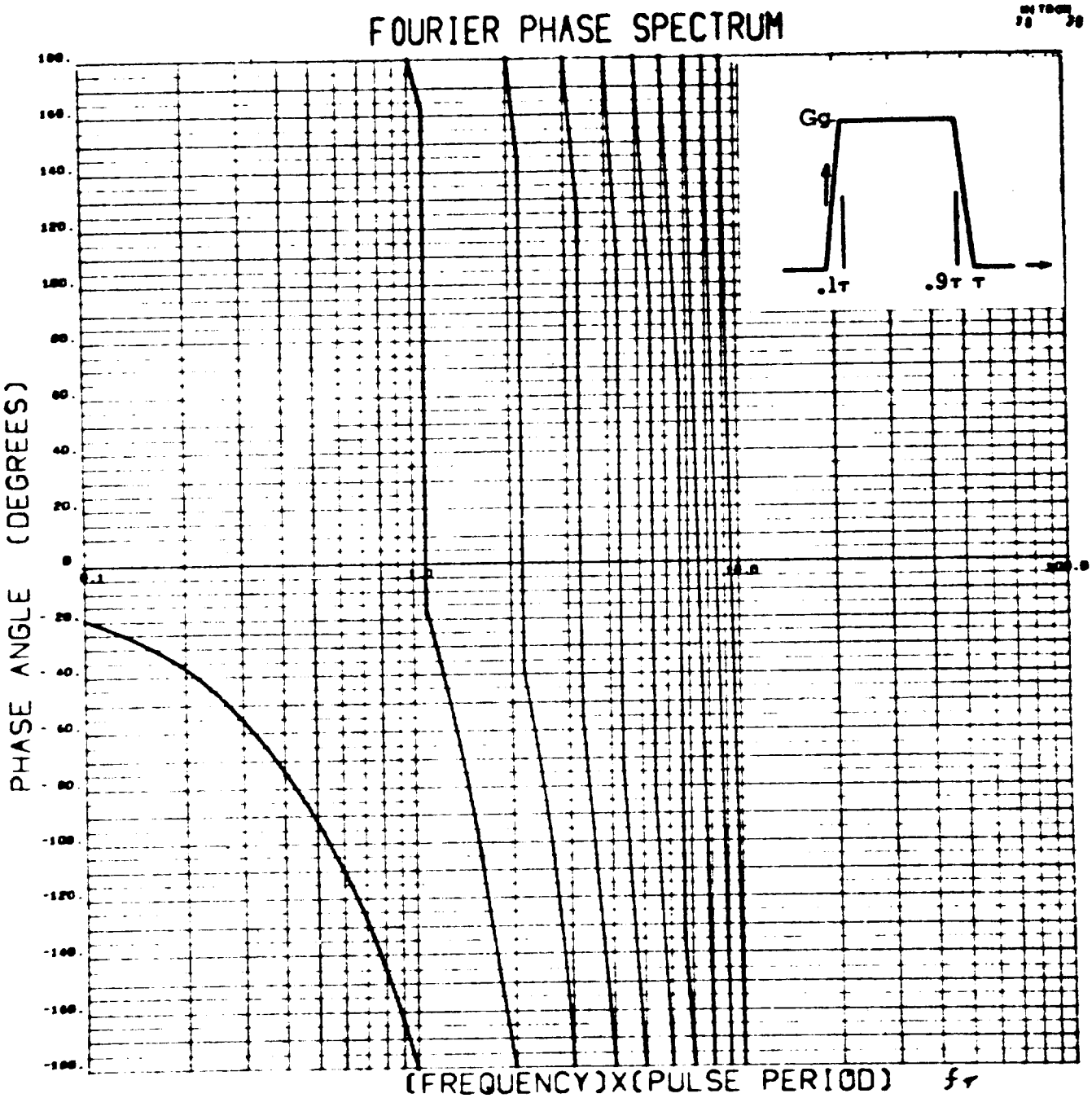
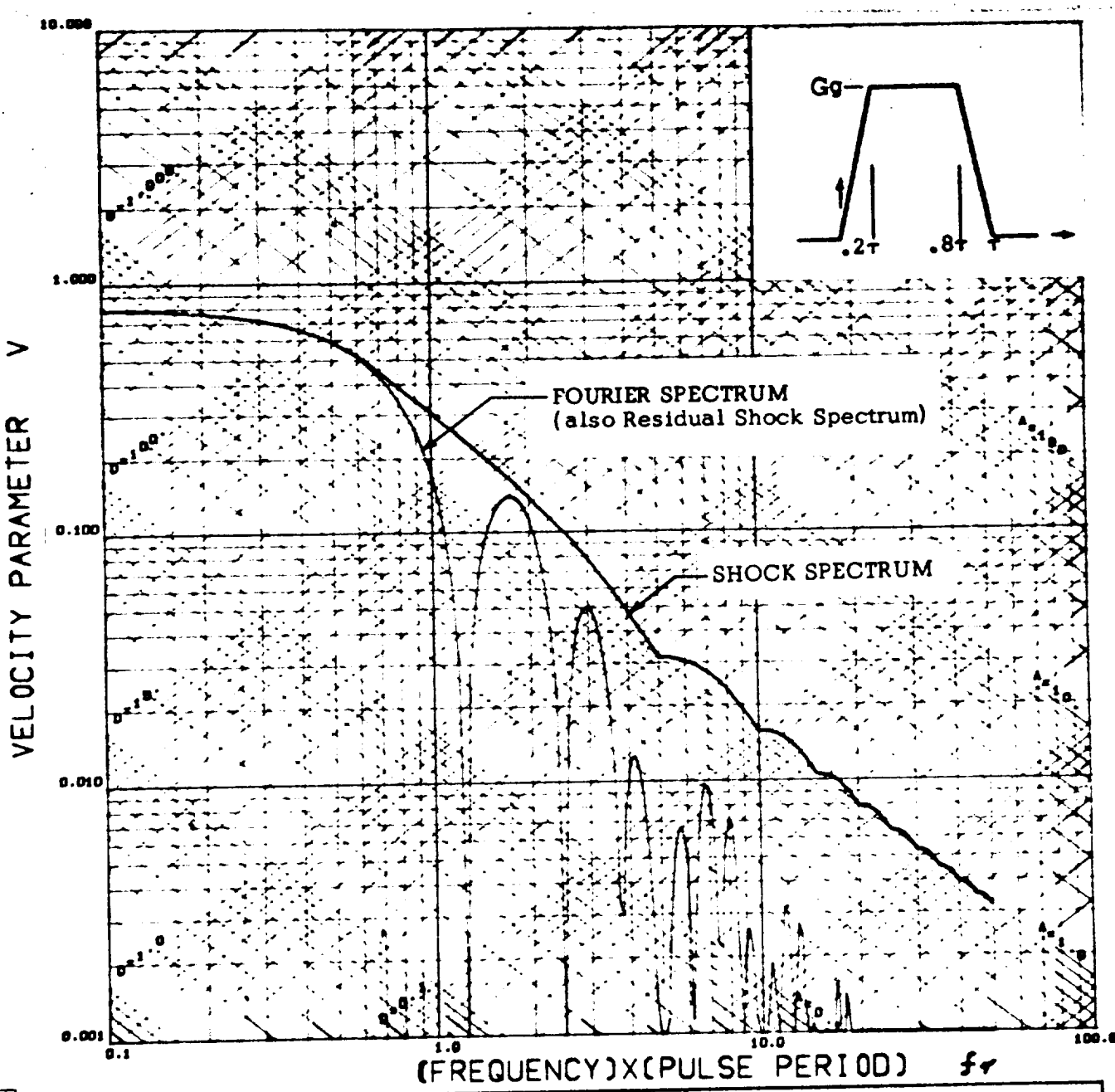
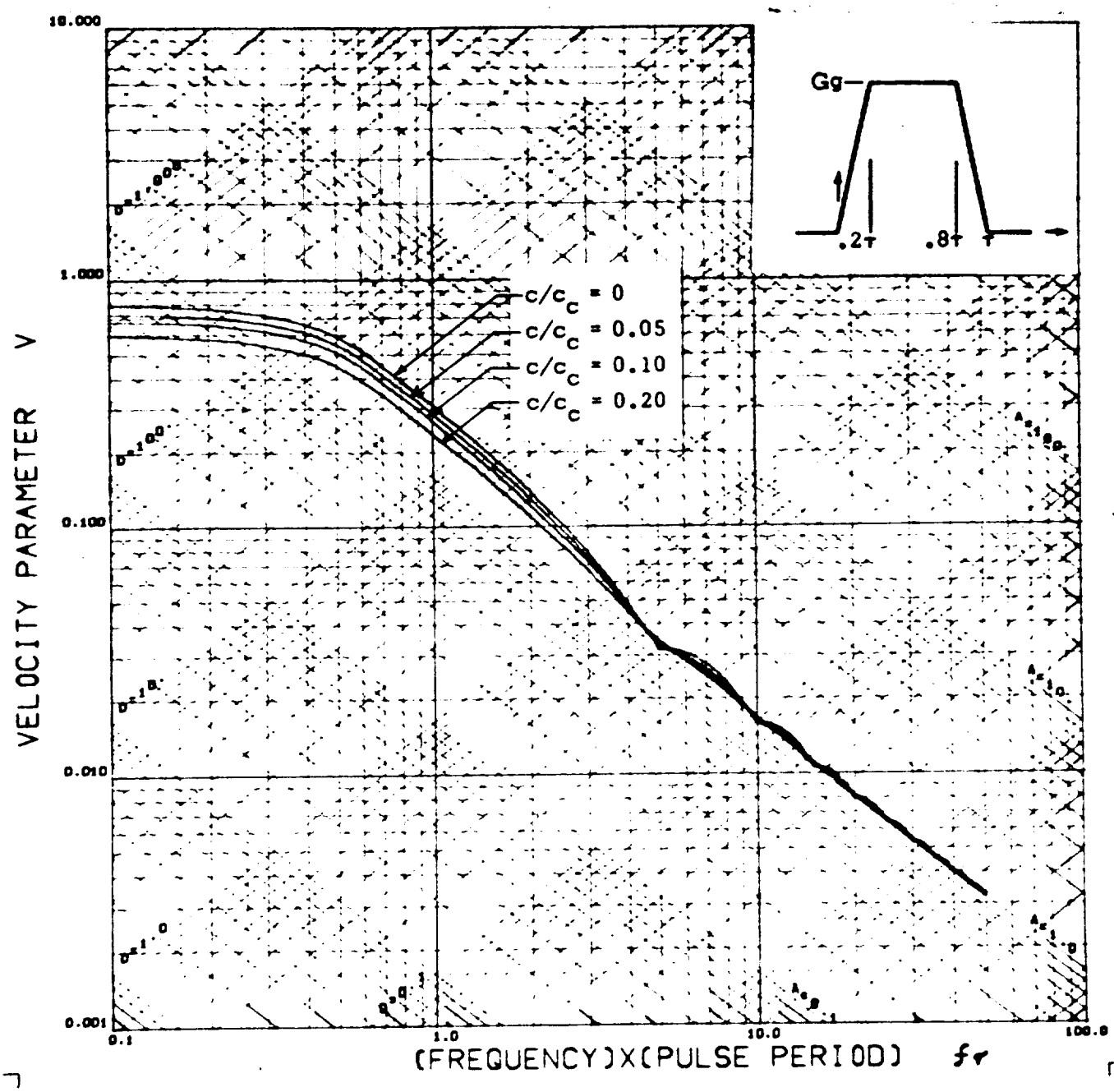



FIGURE II-24 Fourier Phase Spectrum for a Constant-Slope Symmetrical Acceleration Pulse. Rise Time = Decay Time = 0.1 τ




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-25 Fourier and Shock Spectra for a Constant-Slope Symmetrical Acceleration Pulse. Rise Time = Decay Time = 0.2 τ




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-26 Damped Shock Spectra for a Constant-Slope Symmetrical Acceleration Pulse. Rise Time = Decay Time = 0.2 τ

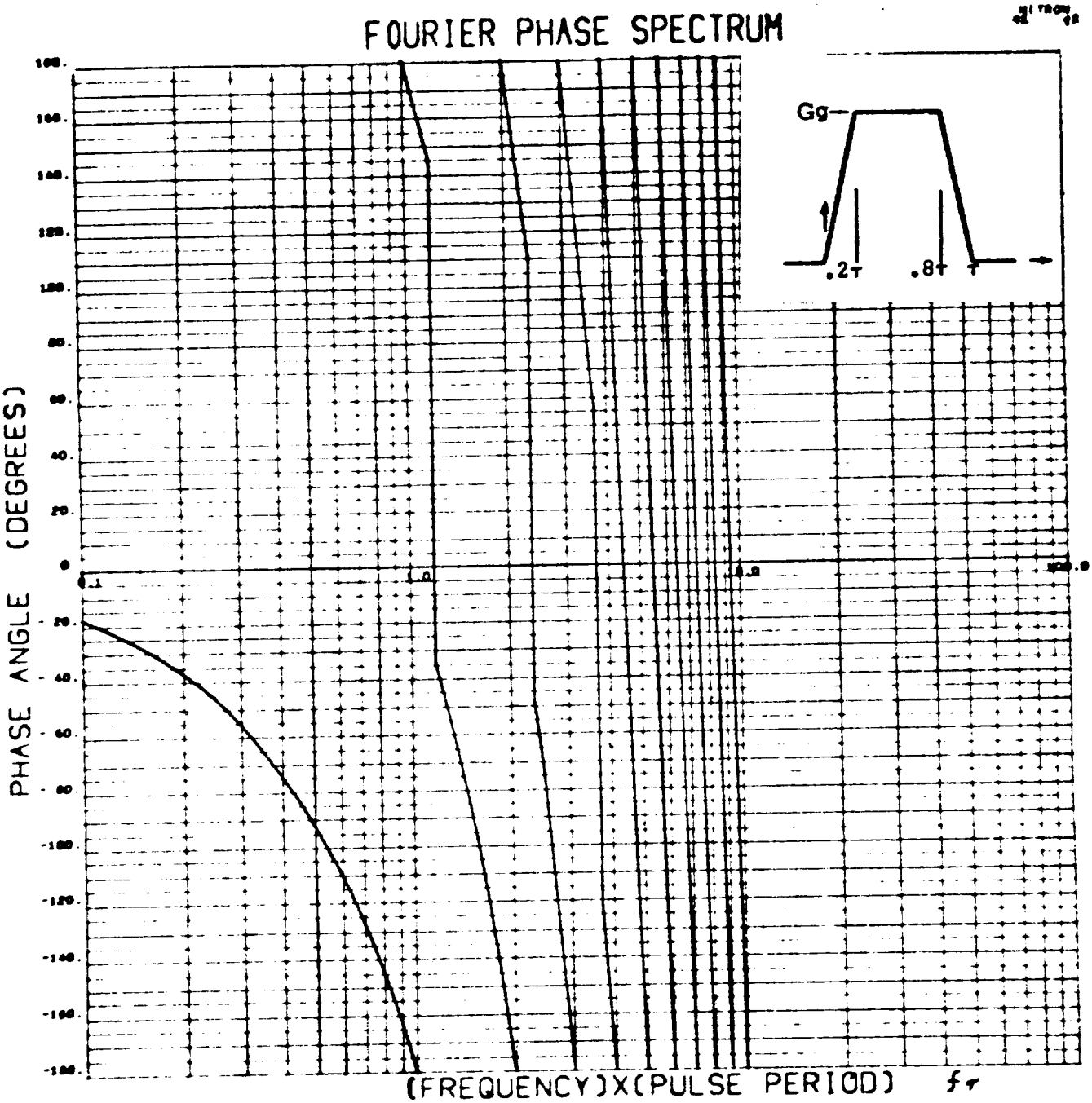
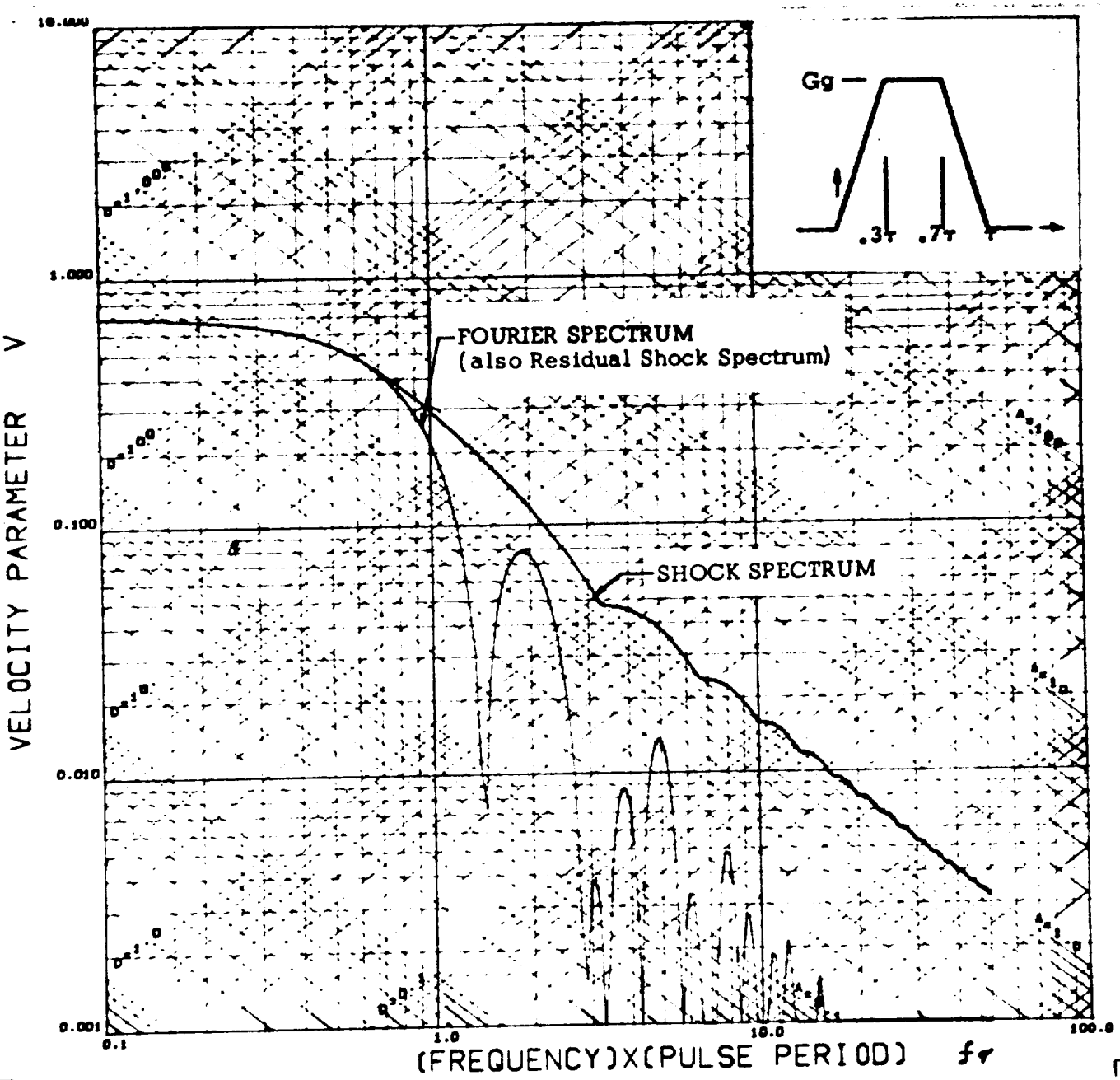
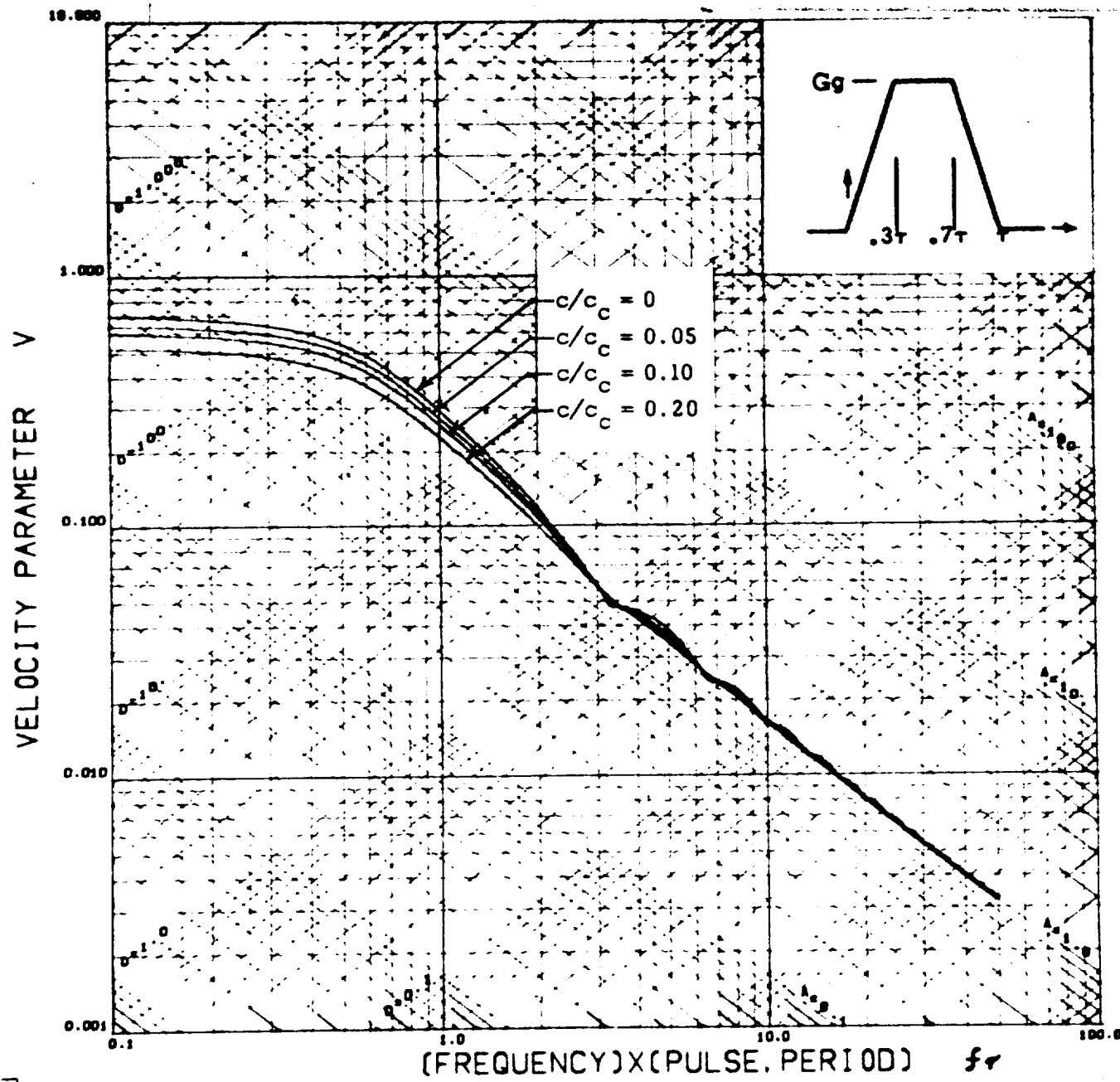



FIGURE II-27 Fourier Phase Spectrum for a Constant-Slope Symmetrical Acceleration Pulse. Rise Time = Decay Time = 0.2 τ




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-28 Fourier and Shock Spectra for a Constant-Slope Symmetrical Acceleration Pulse. Rise Time = Decay Time = 0.3 τ




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-29 Damped Shock Spectra for a Constant-Slope Symmetrical Acceleration Pulse. Rise Time= Decay Time = 0.3 τ

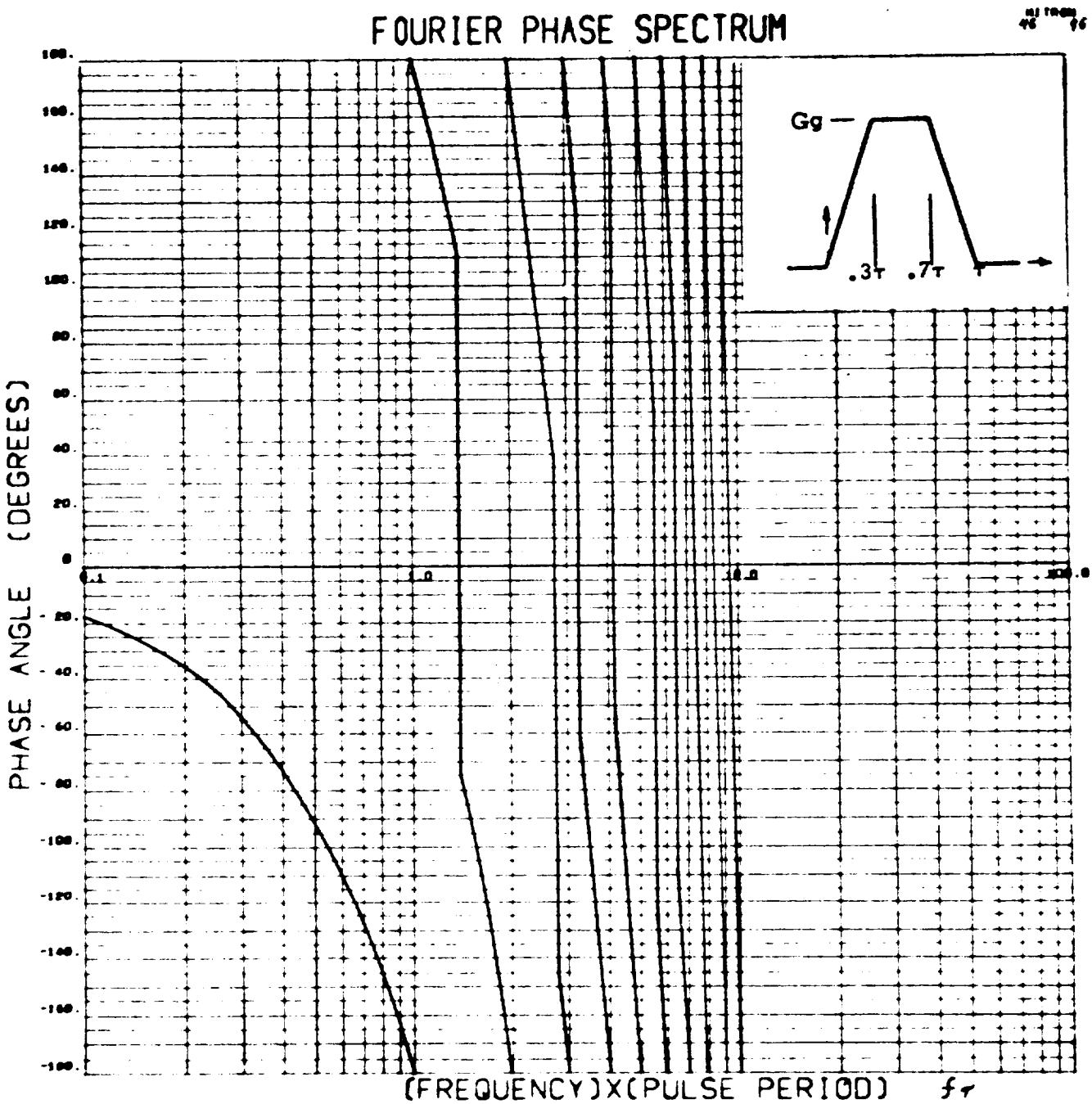
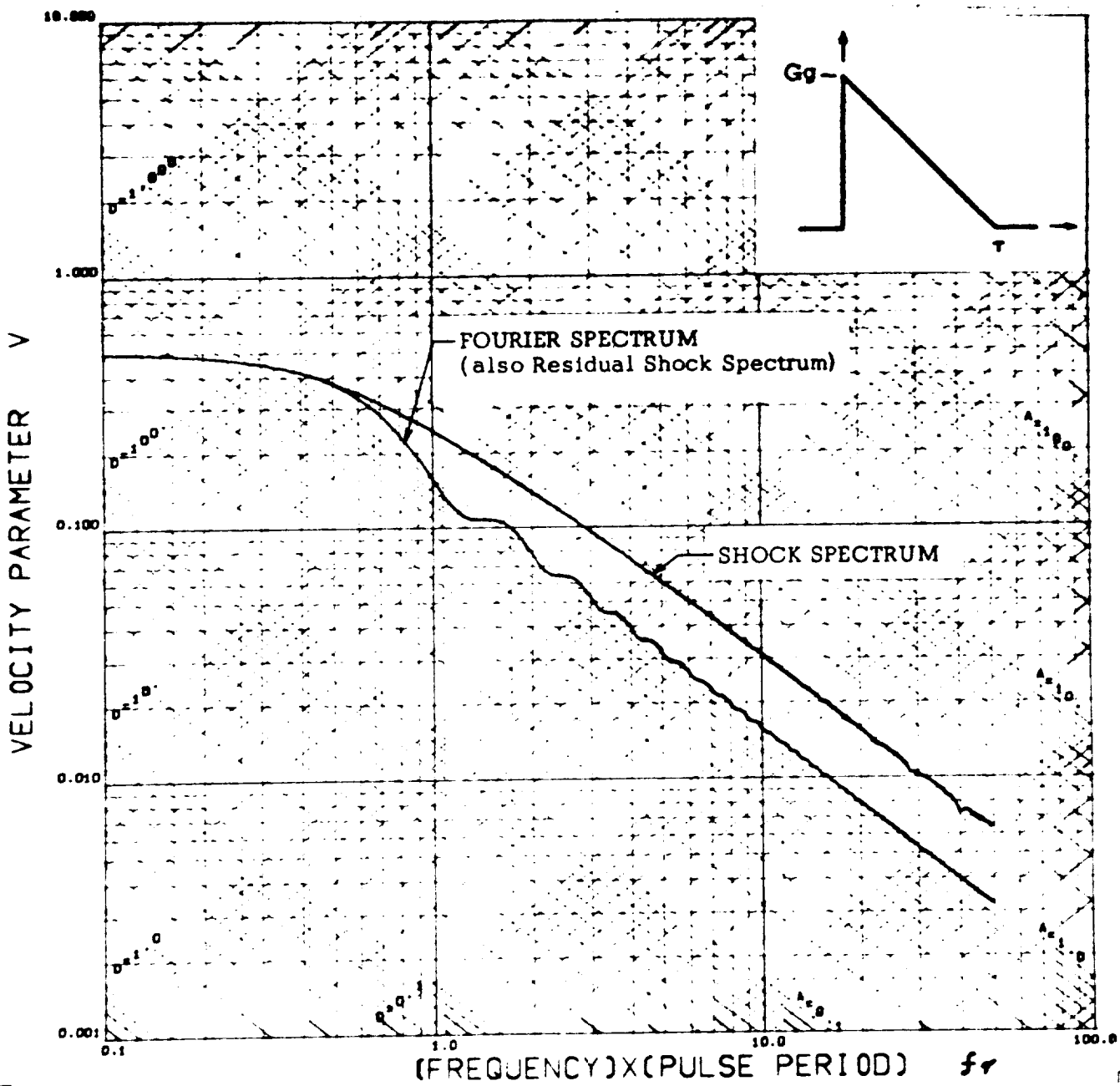
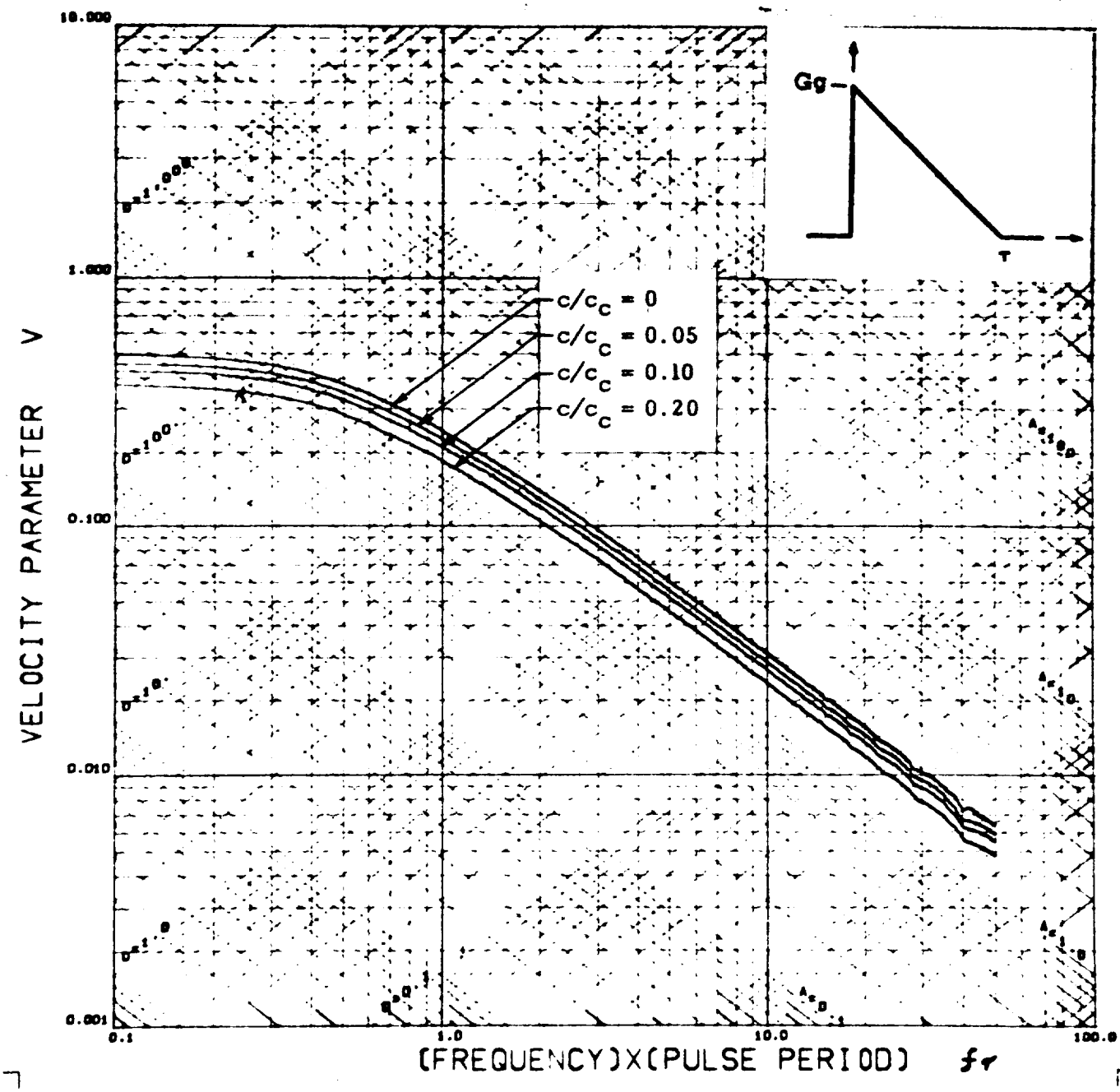



FIGURE II-30 Fourier Phase Spectrum for a Constant-Slope Symmetrical Acceleration Pulse. Rise Time = Decay Time = 0.3 τ




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-31 Fourier and Shock Spectra for a Triangular Acceleration Pulse with Step Rise.




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-32 Damped Shock Spectra for a Triangular Acceleration Pulse with Step Rise.

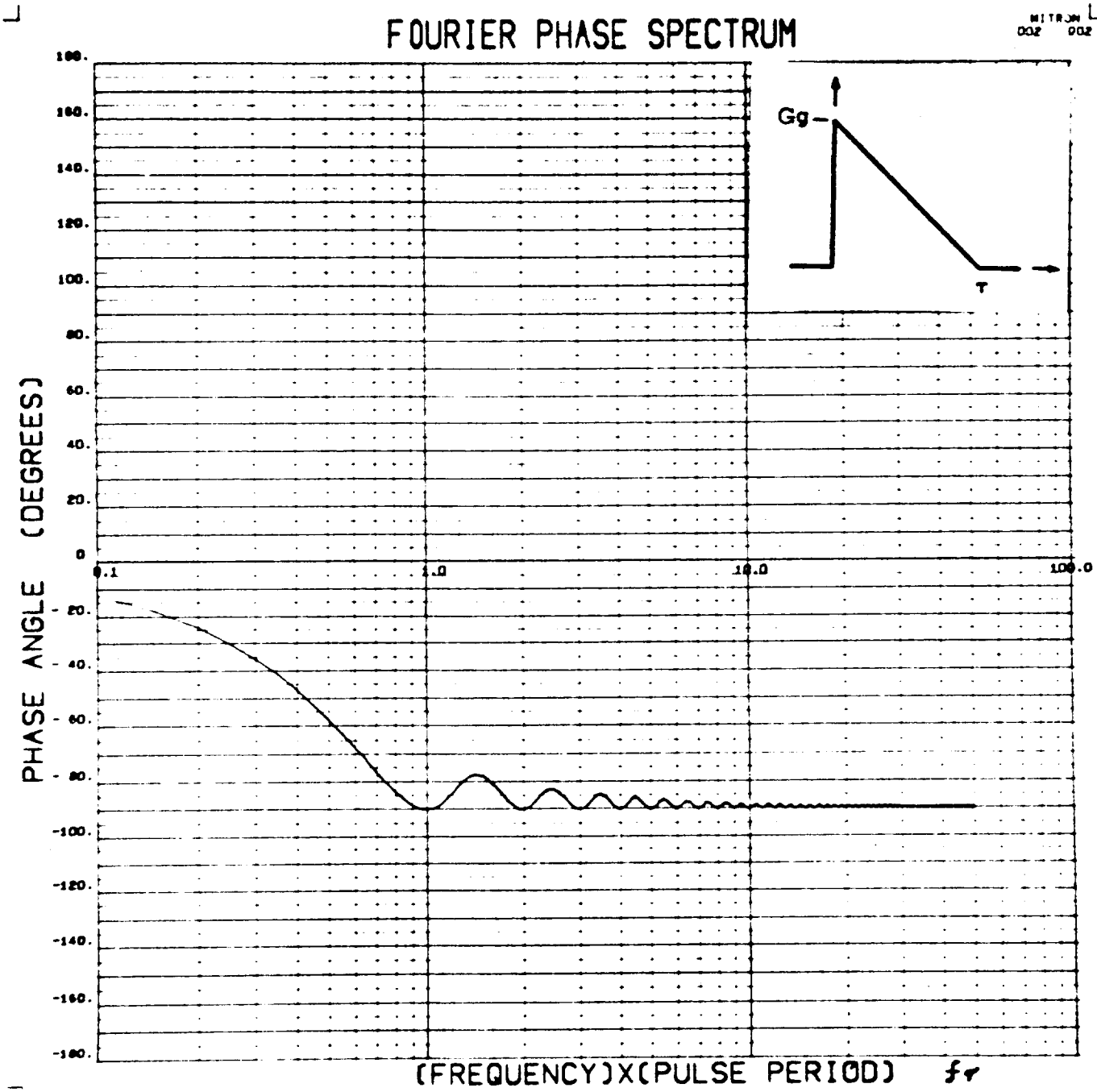
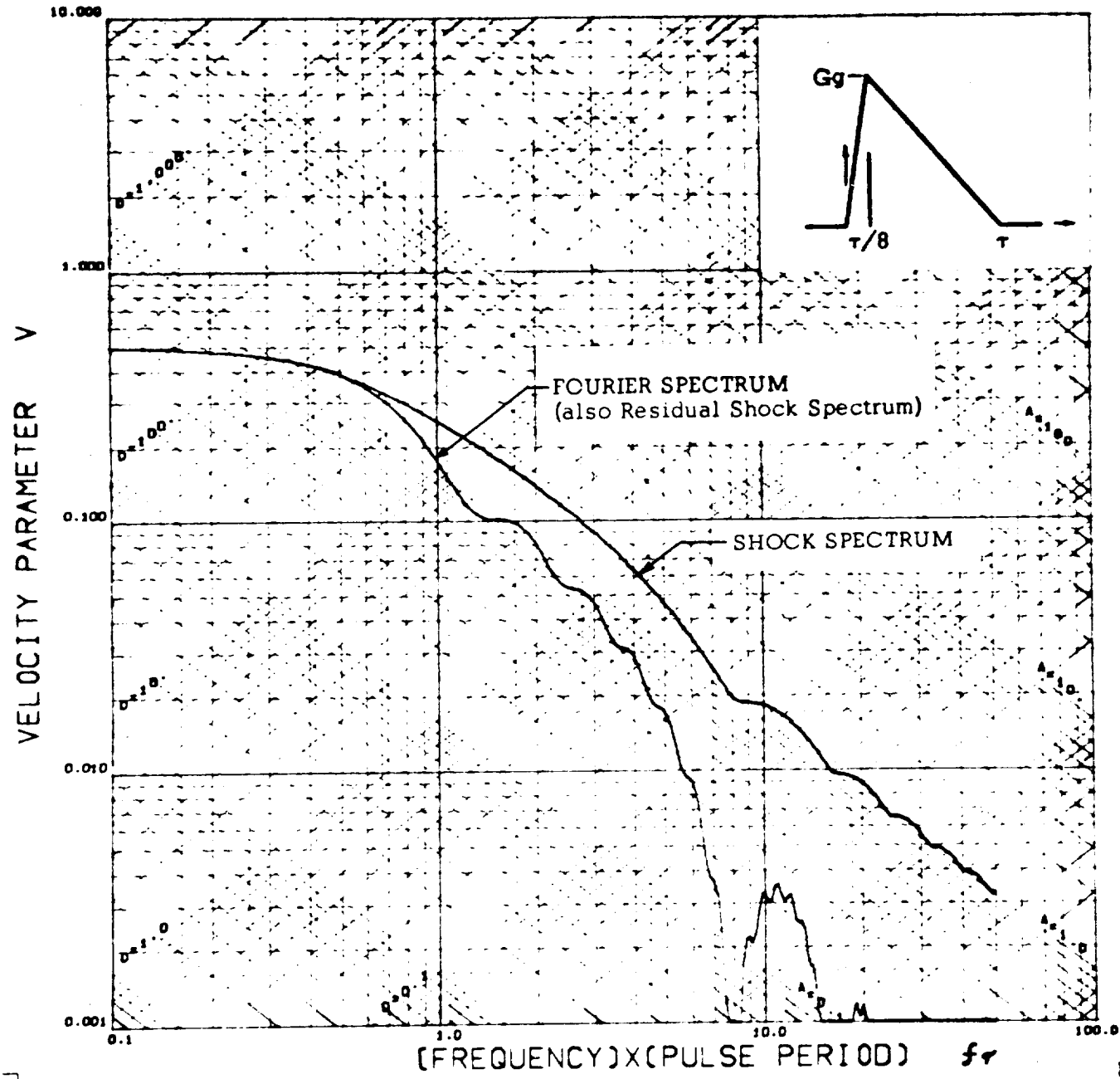
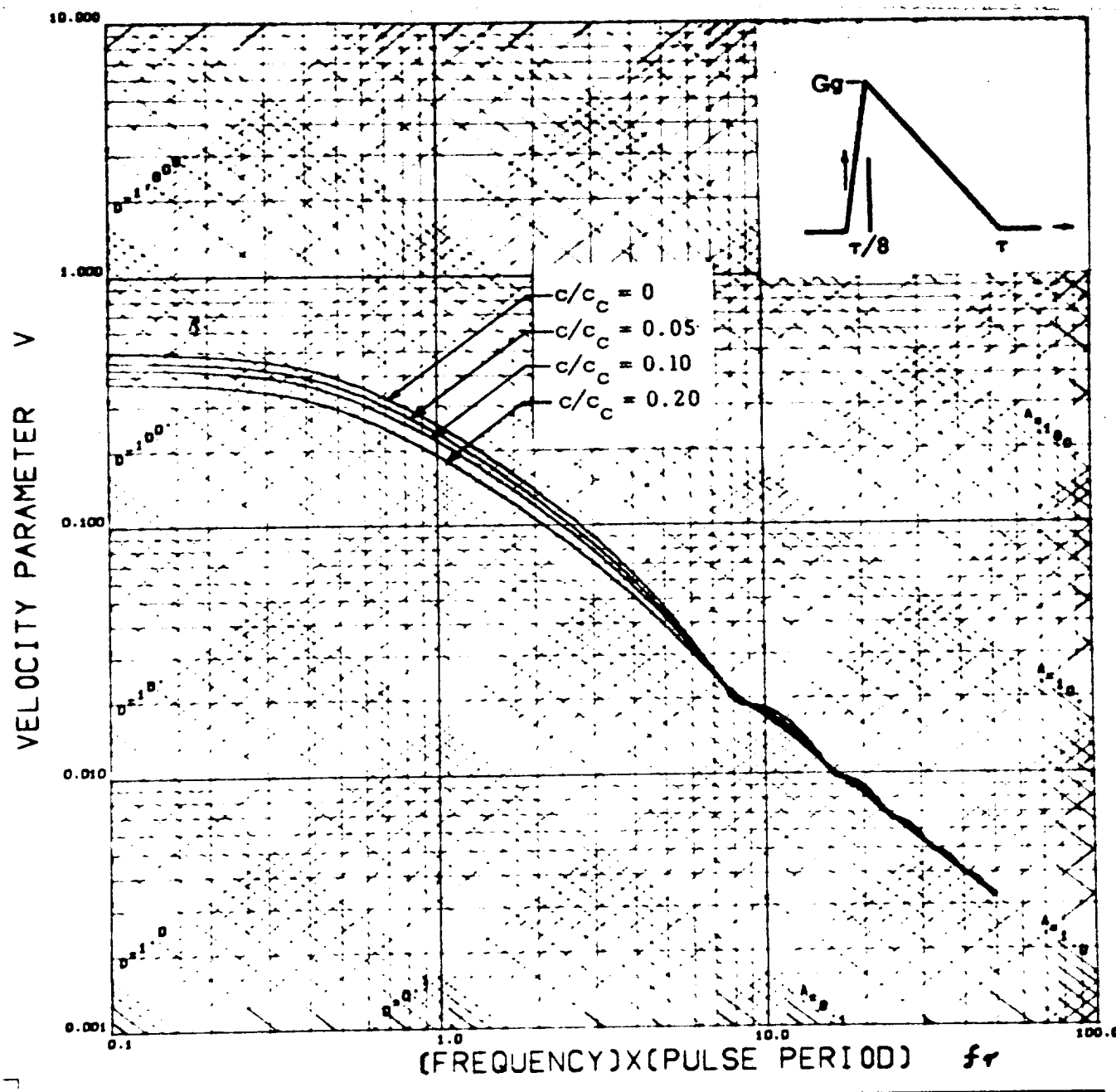



FIGURE II-33 Fourier Phase Spectrum for a Triangular Acceleration Pulse with Step Rise.




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-34 Fourier and Shock Spectra for a Triangular Acceleration Pulse with Rise Time = τ/8




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-35 Damped Shock Spectra for a Triangular Acceleration Pulse with Rise Time = $\tau/8$

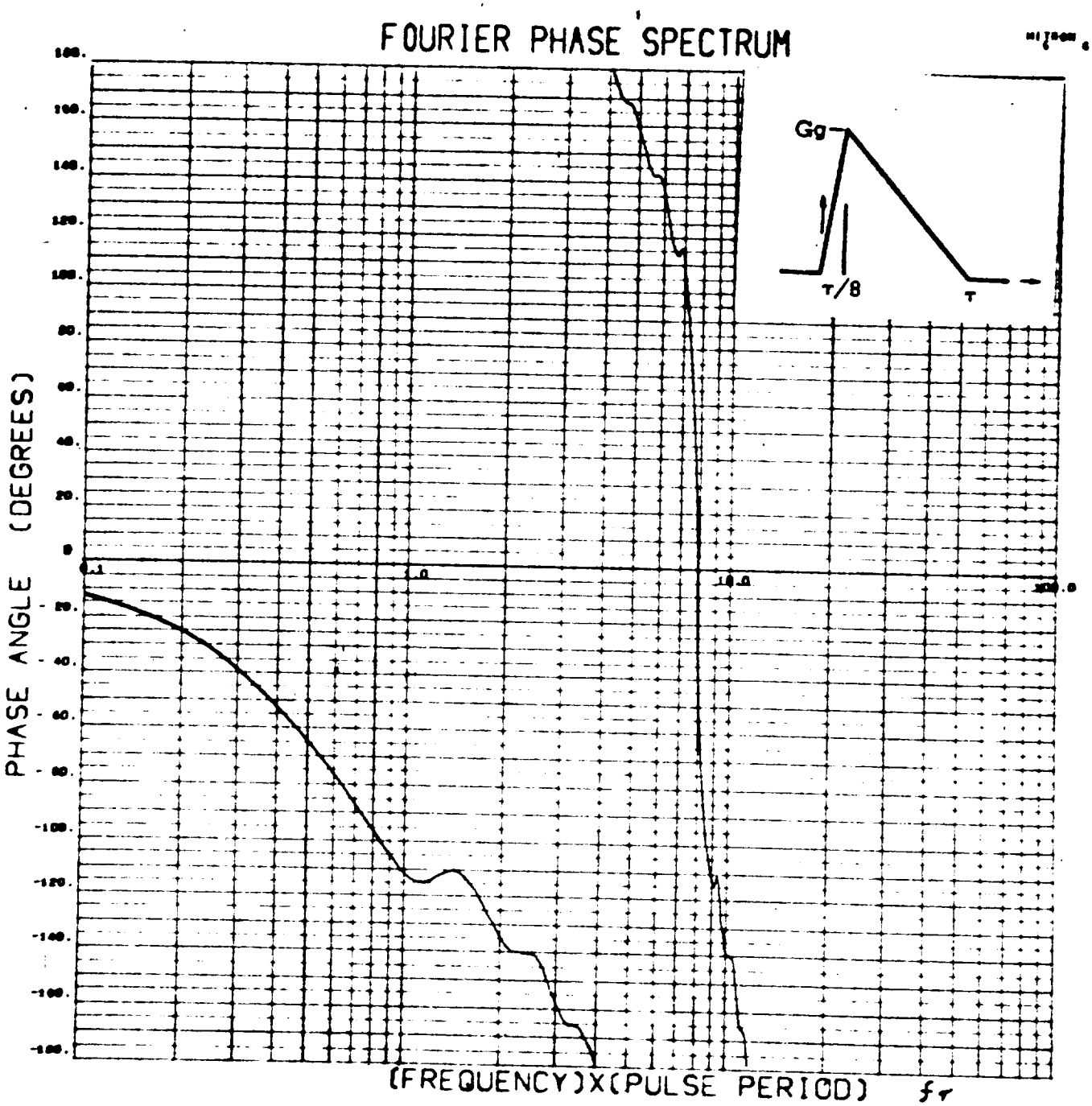
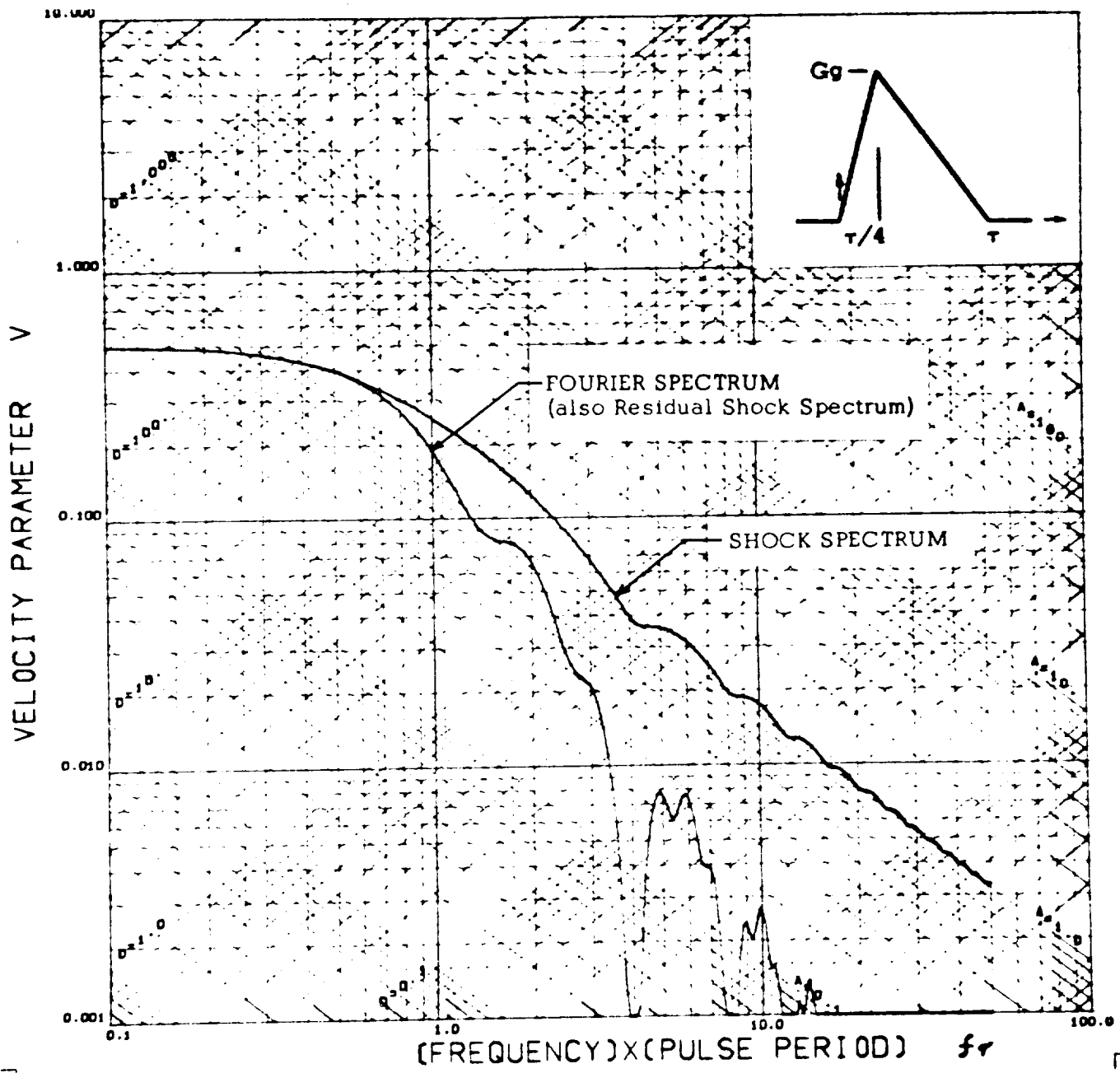
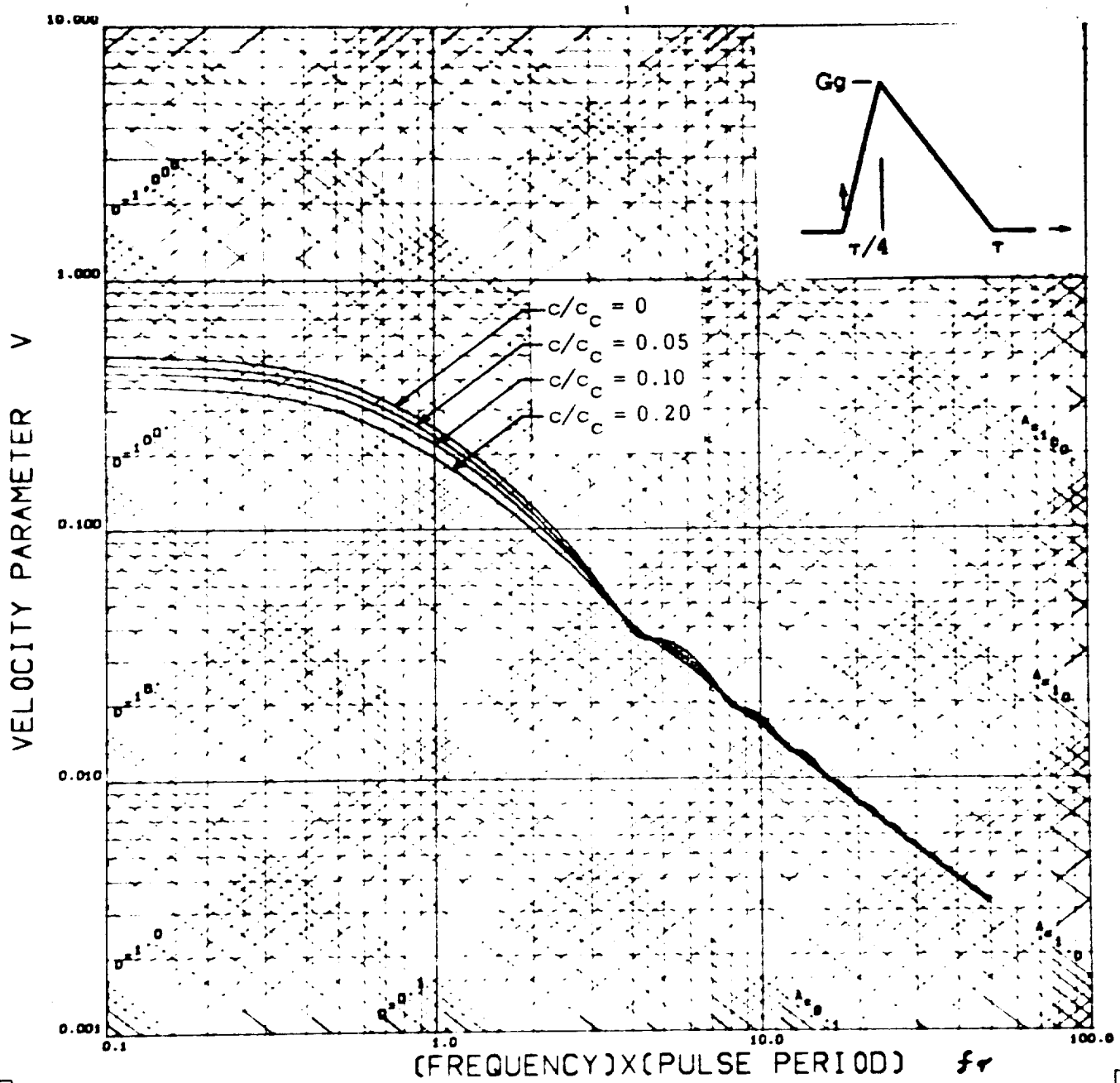



FIGURE II -36 Fourier Phase Spectrum for a Triangular Acceleration Pulse with Rise Time = τ/8




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-37 Fourier and Shock Spectra for a Triangular Acceleration Pulse with Rise Time = $\tau/4$




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-38 Damped Shock Spectra for a Triangular Acceleration Pulse with Rise Time = $\tau/4$

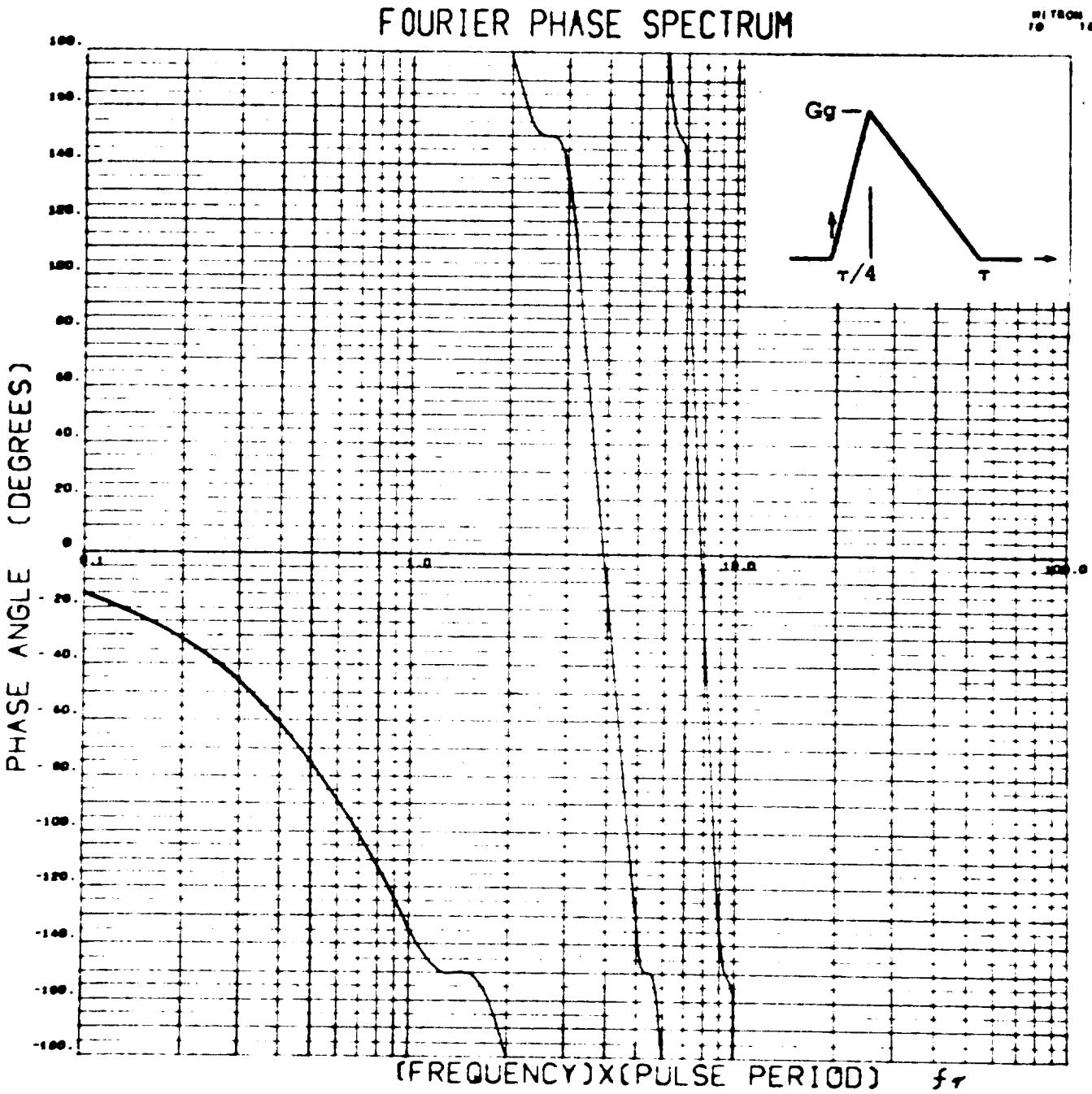
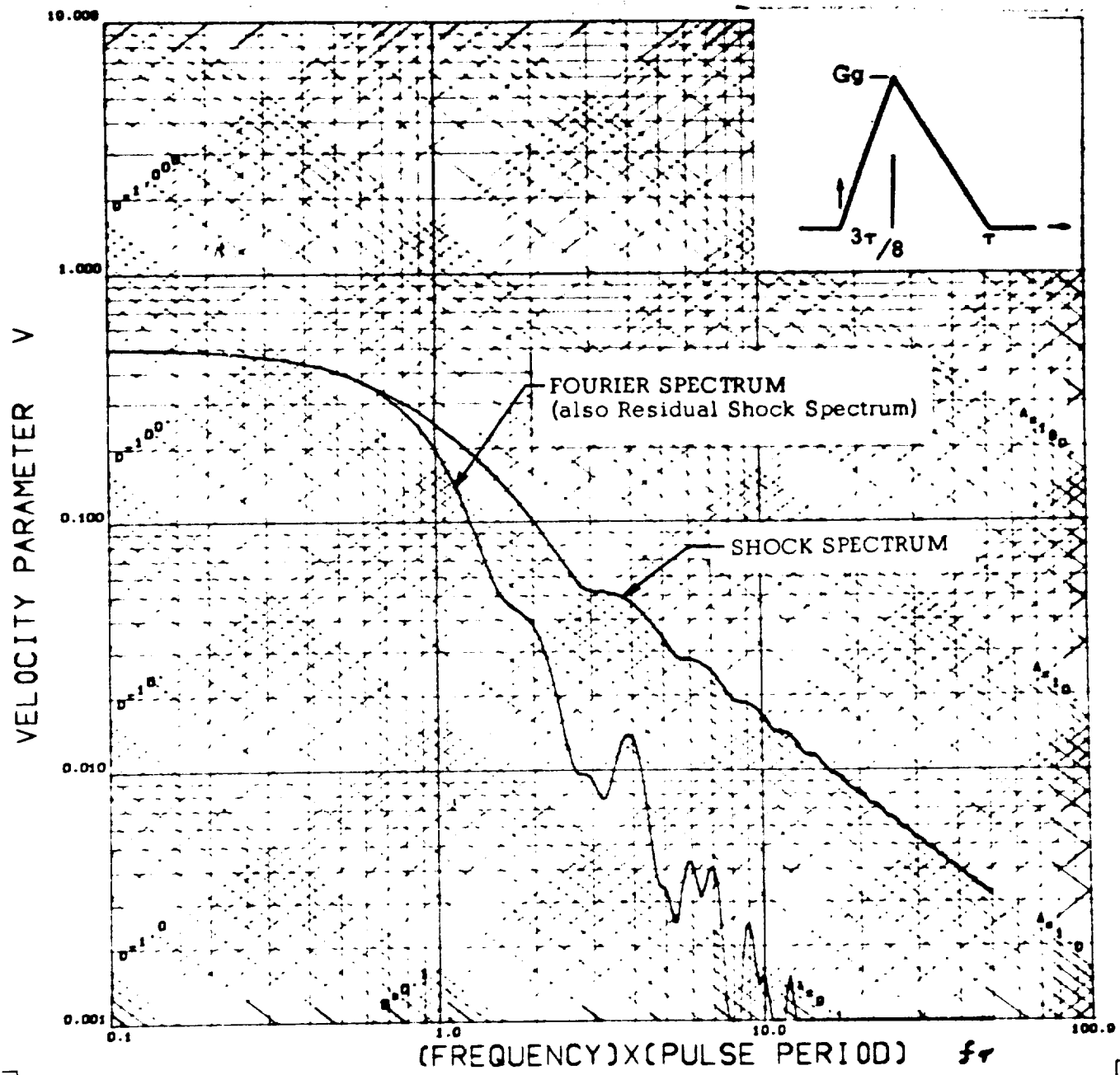
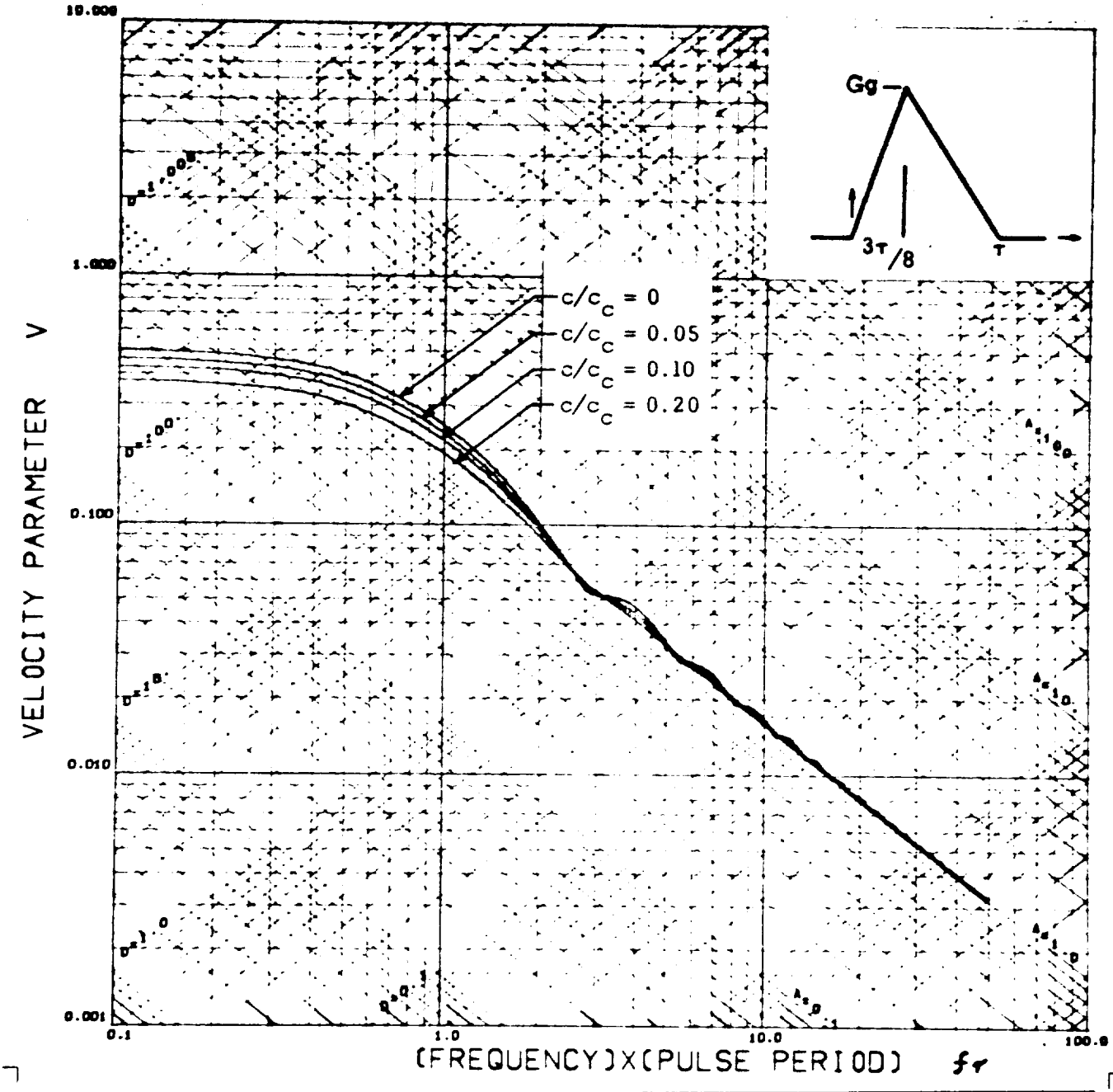



FIGURE II-39 Fourier Phase Spectrum for a Triangular Acceleration Pulse with Rise Time = $\tau/4$




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-4b Fourier and Shock Spectra for a Triangular Acceleration Pulse with Rise Time = $3\tau/8$




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-41 Damped Shock Spectra for a Triangular Acceleration Pulse with Rise Time = 3τ/8

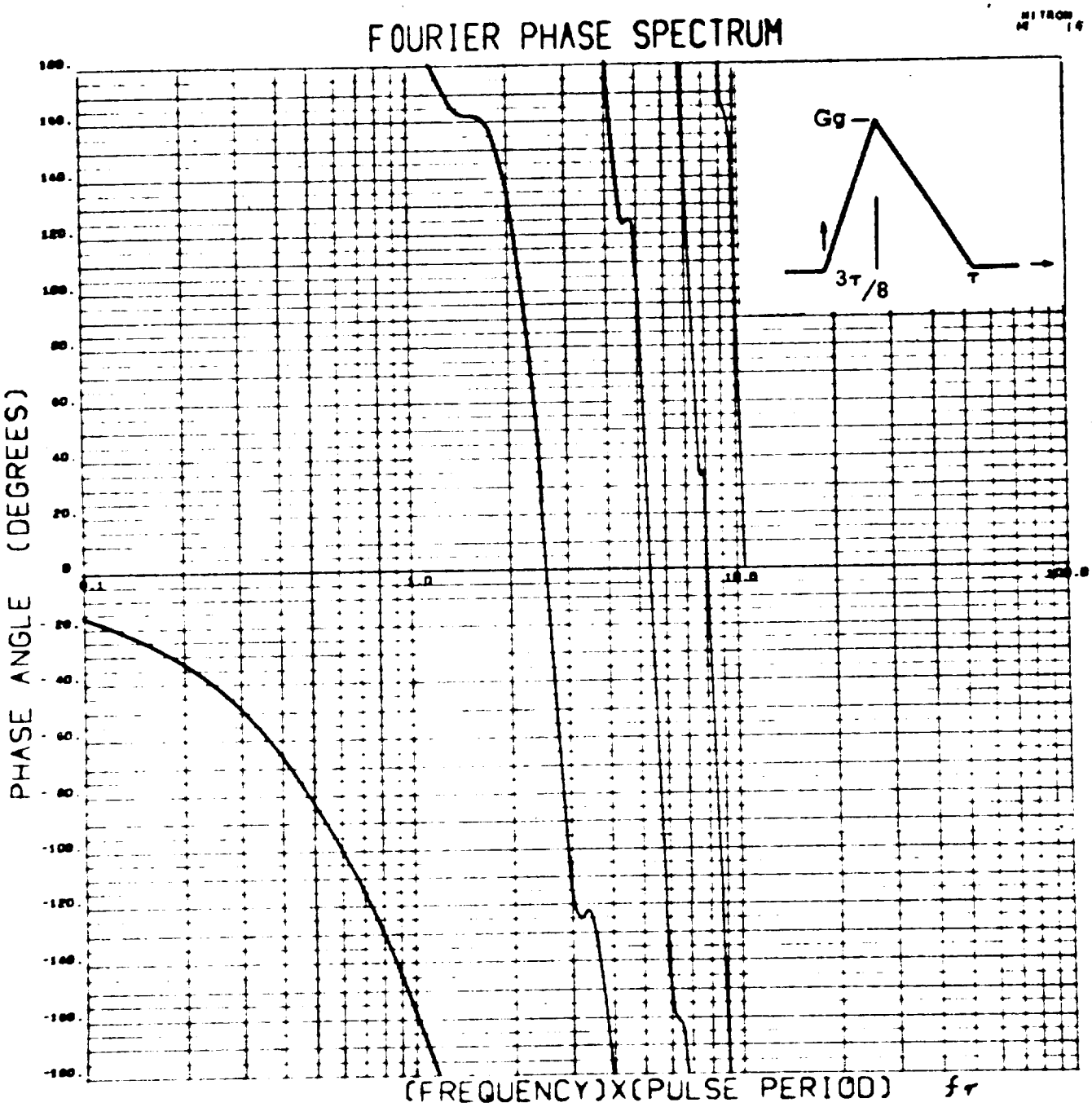
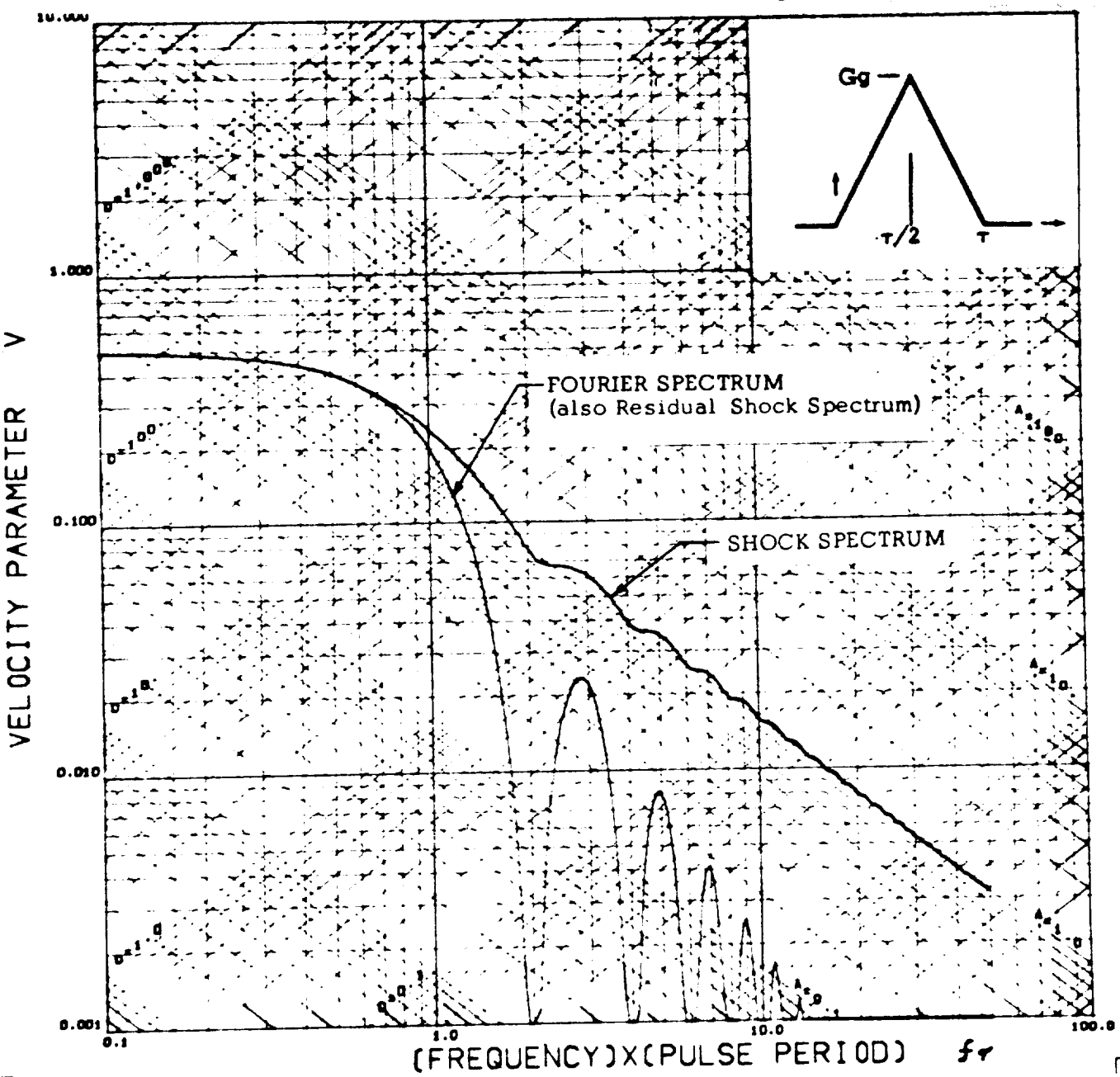
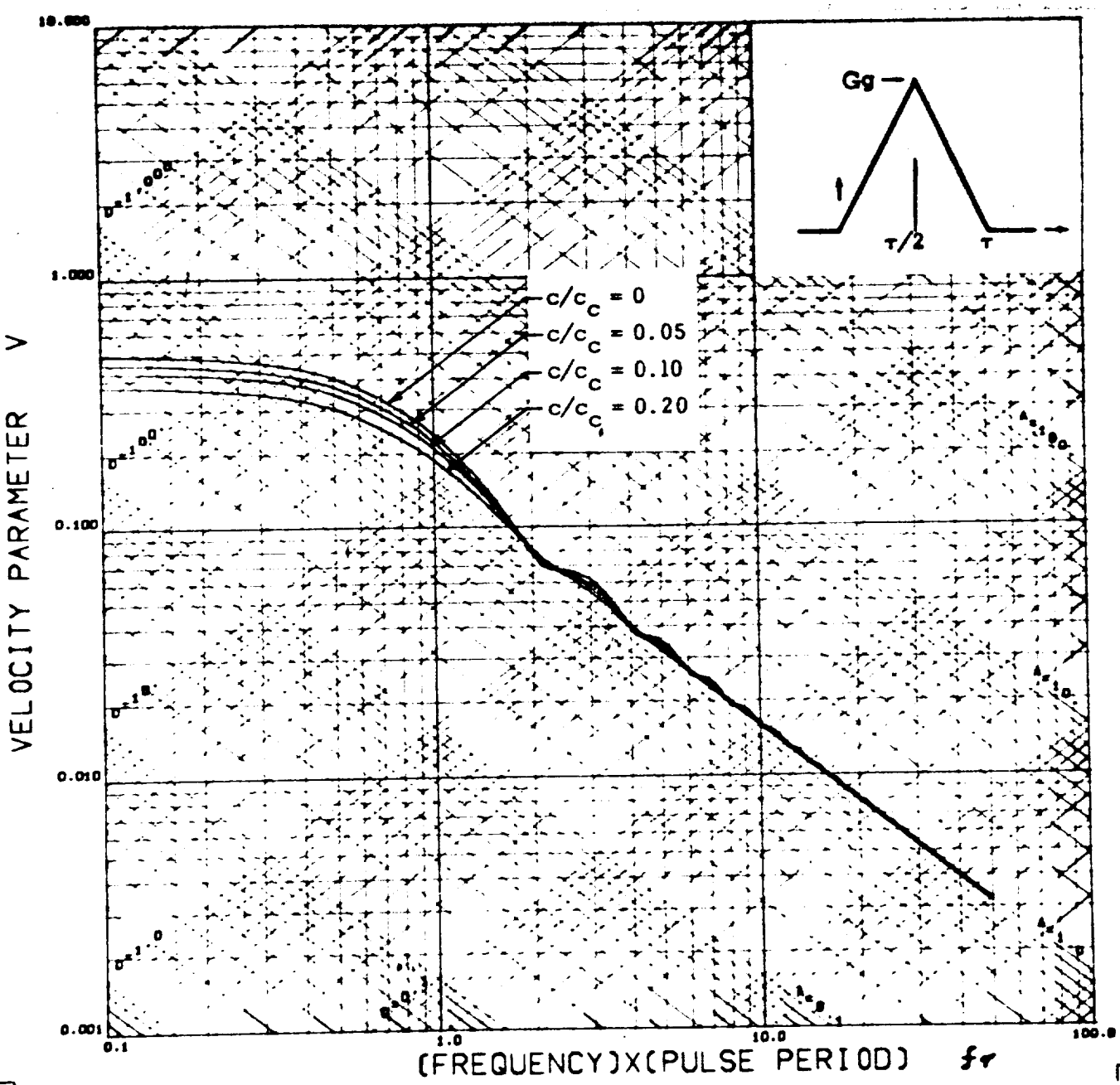



FIGURE II-42 Fourier Phase Spectrum for a Triangular Acceleration Pulse with Rise Time = 3τ/8




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-43 Fourier and Shock Spectra for a Triangular Acceleration Pulse with Rise Time = τ/2




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-44 Damped Shock Spectra for a Triangular Acceleration Pulse with Rise Time = $\tau/2$

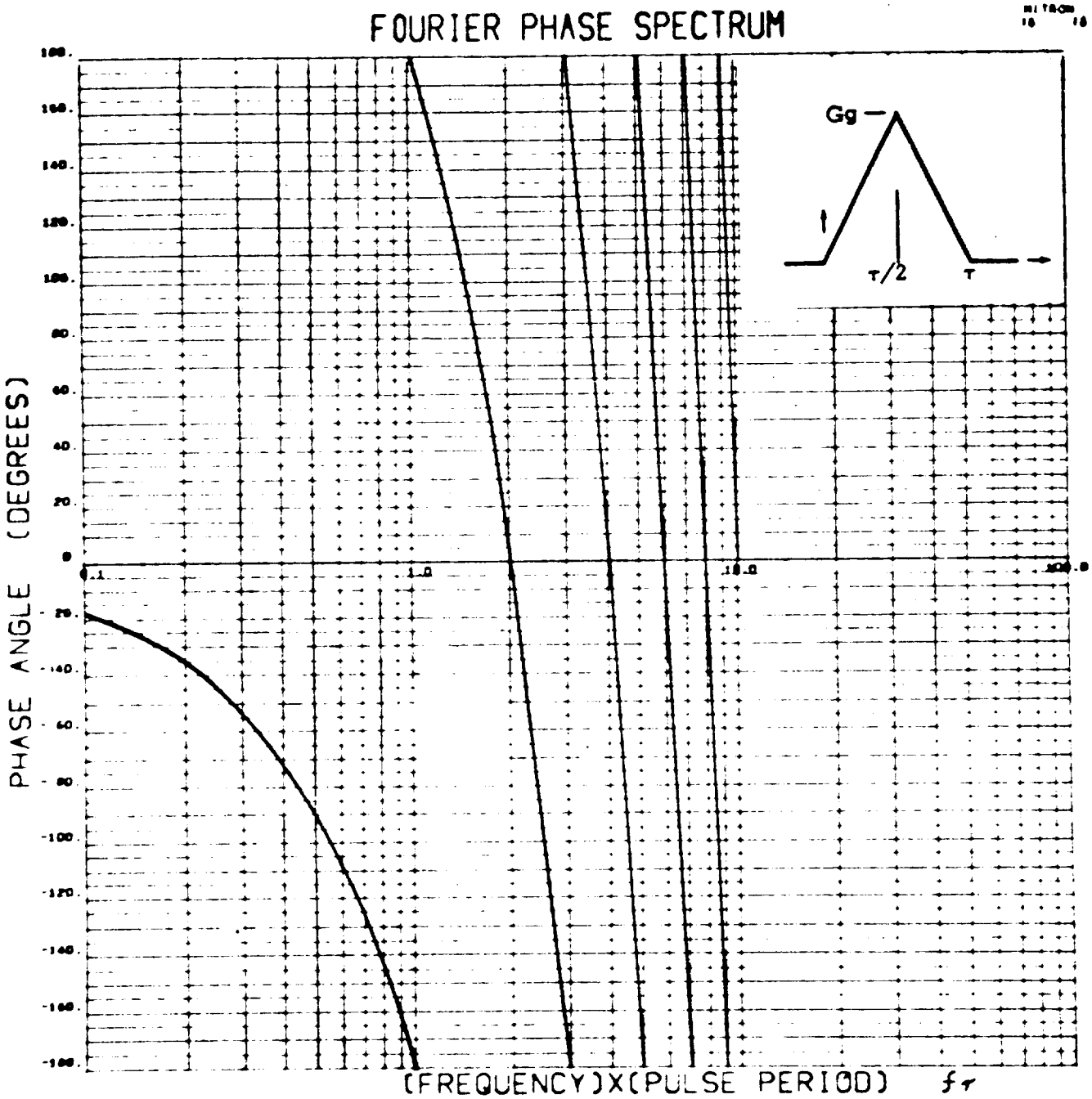
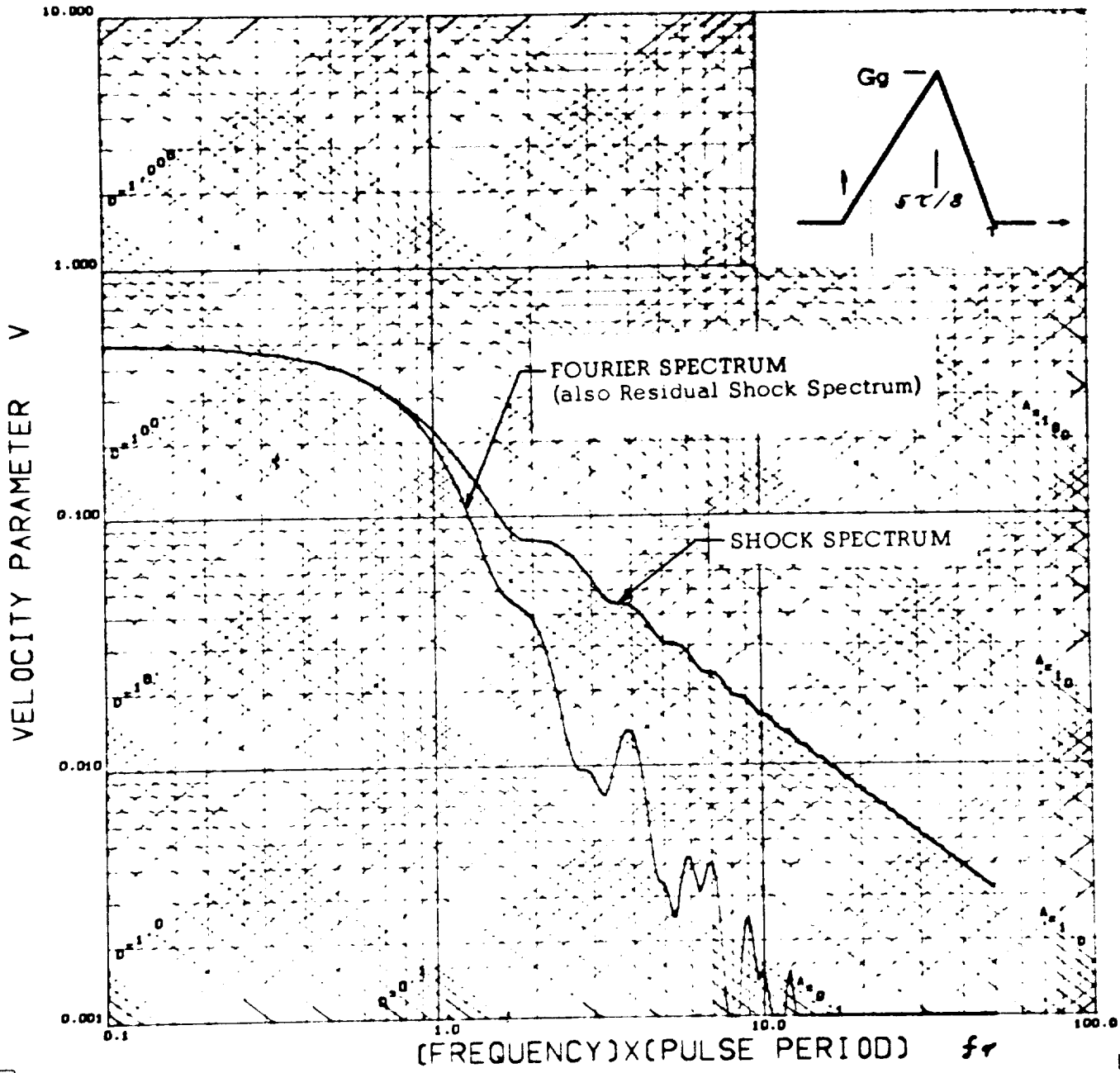
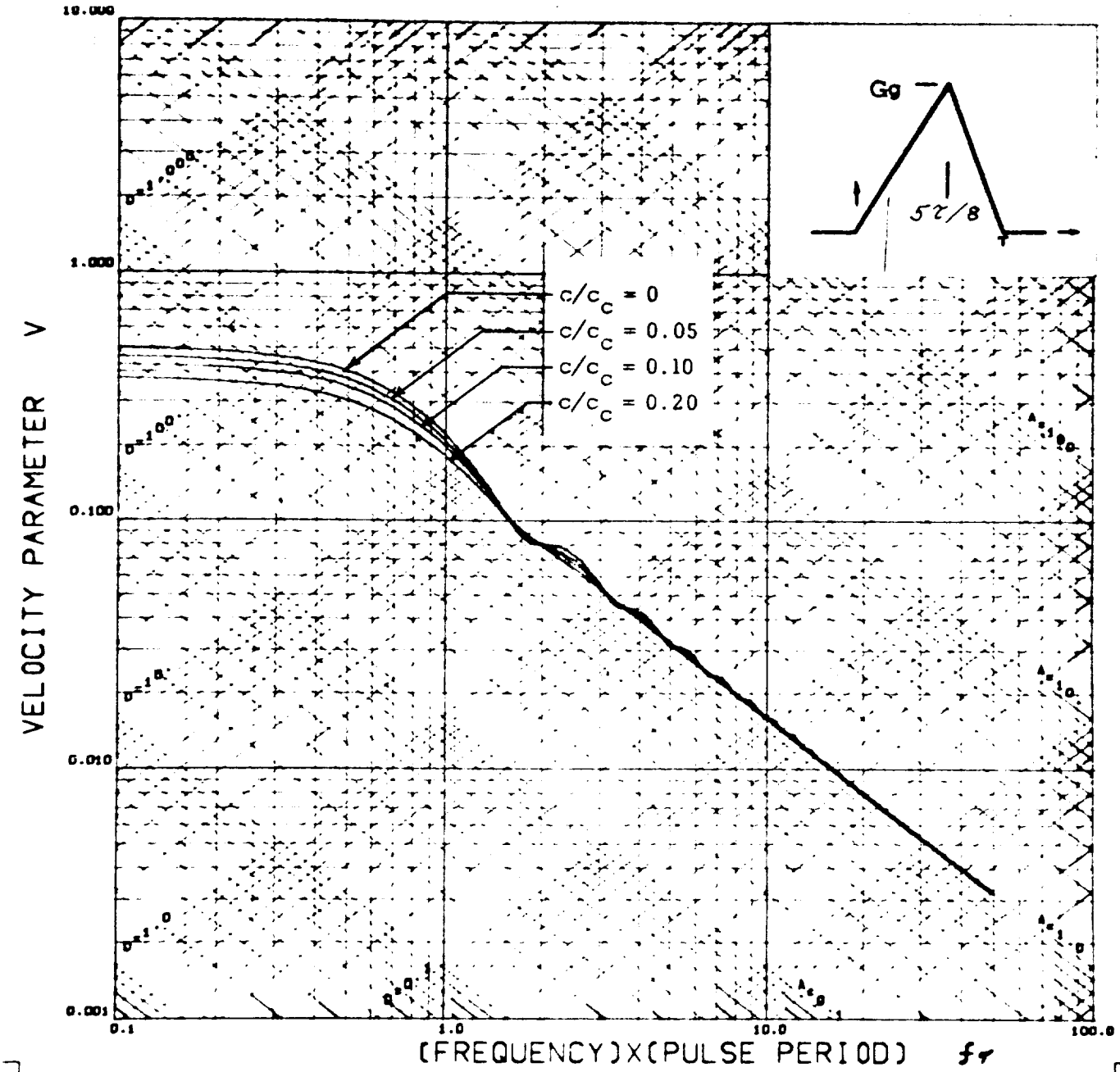



FIGURE II-45 Fourier Phase Spectrum for a Triangular Acceleration Pulse with Rise Time = $\tau/2$




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-46 Fourier and Shock Spectra for a Triangular Acceleration Pulse with Rise Time = $5\tau/8$




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-47 Damped Shock Spectra for a Triangular Acceleration Pulse with Rise Time = $5\tau/8$

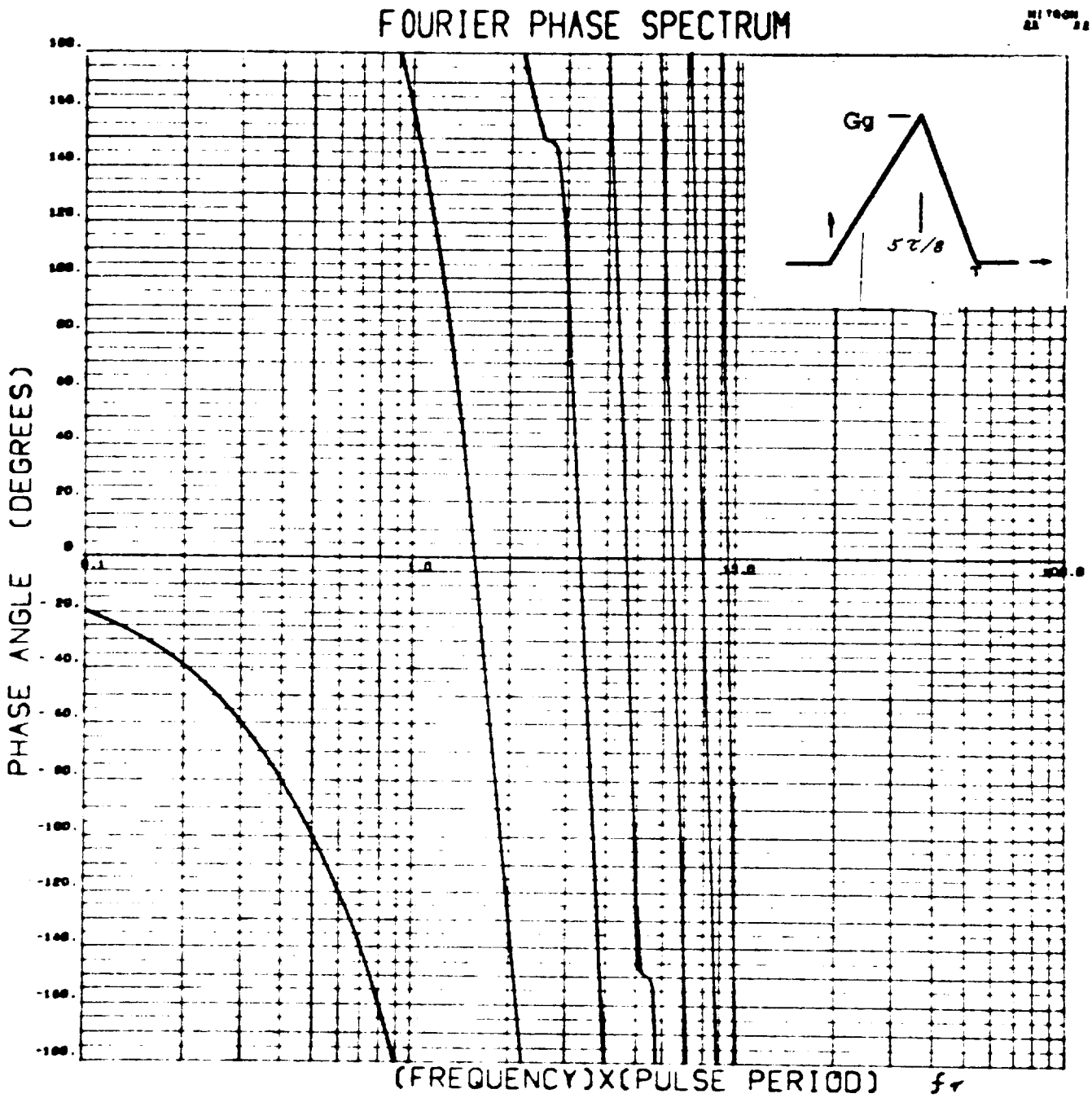
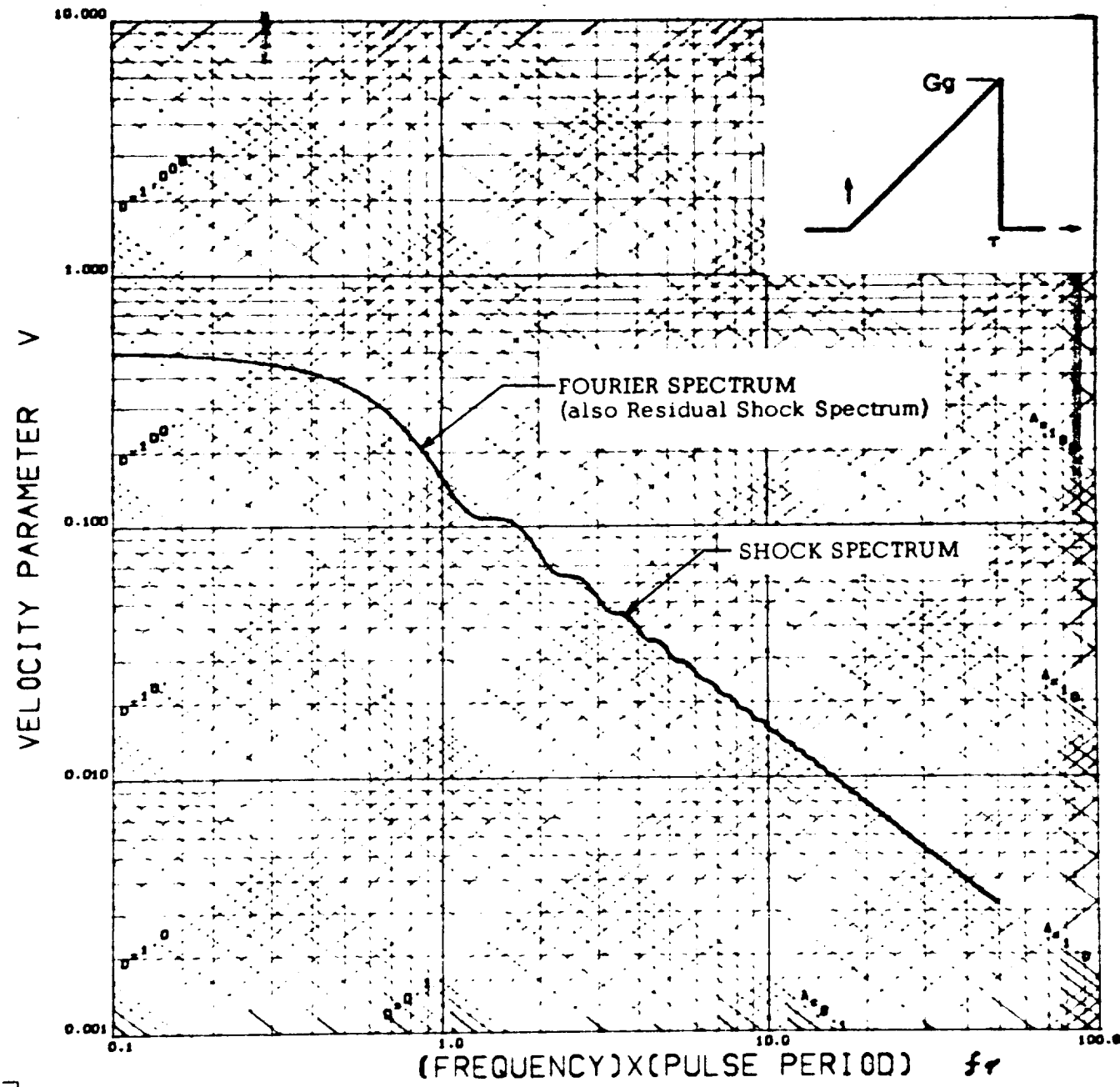
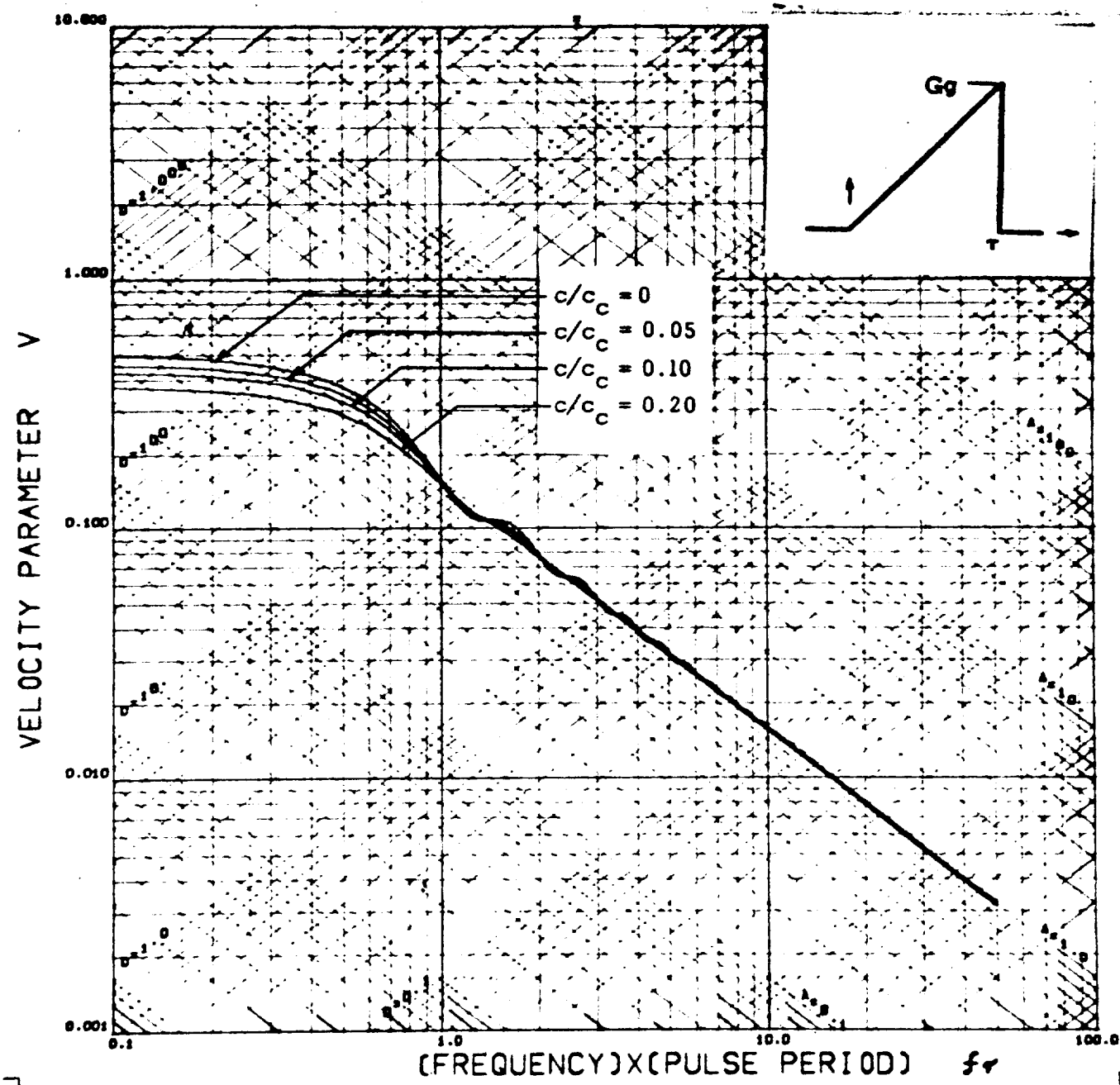



FIGURE II-48 Fourier Phase Spectrum for a Triangular Acceleration Pulse with Rise Time = 5τ/8




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-49 Fourier and Shock Spectra for a Triangular Acceleration Pulse with Rise Time = τ




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-50 Damped Shock Spectra for a Triangular Acceleration Pulse with Rise Time = τ

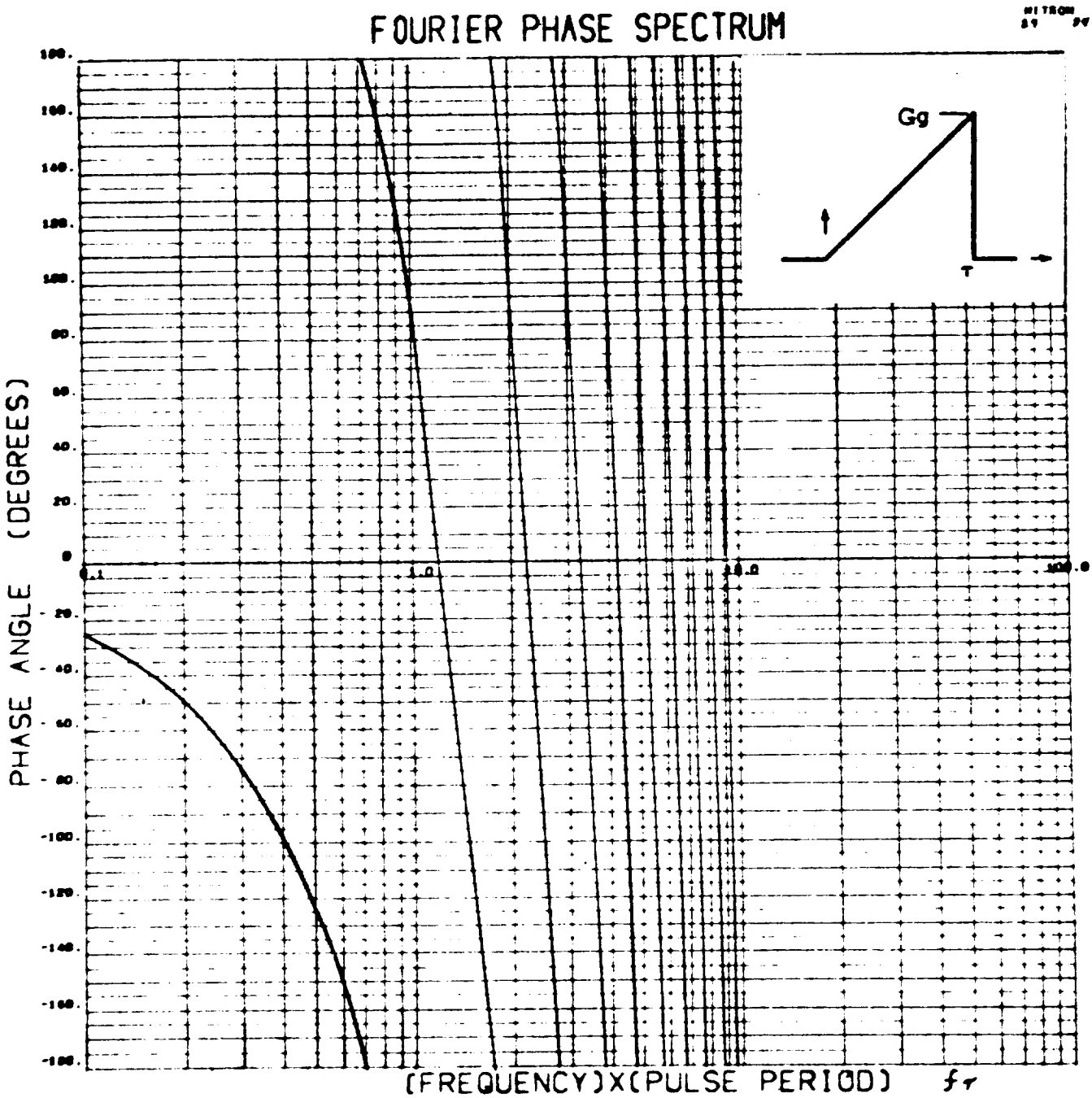
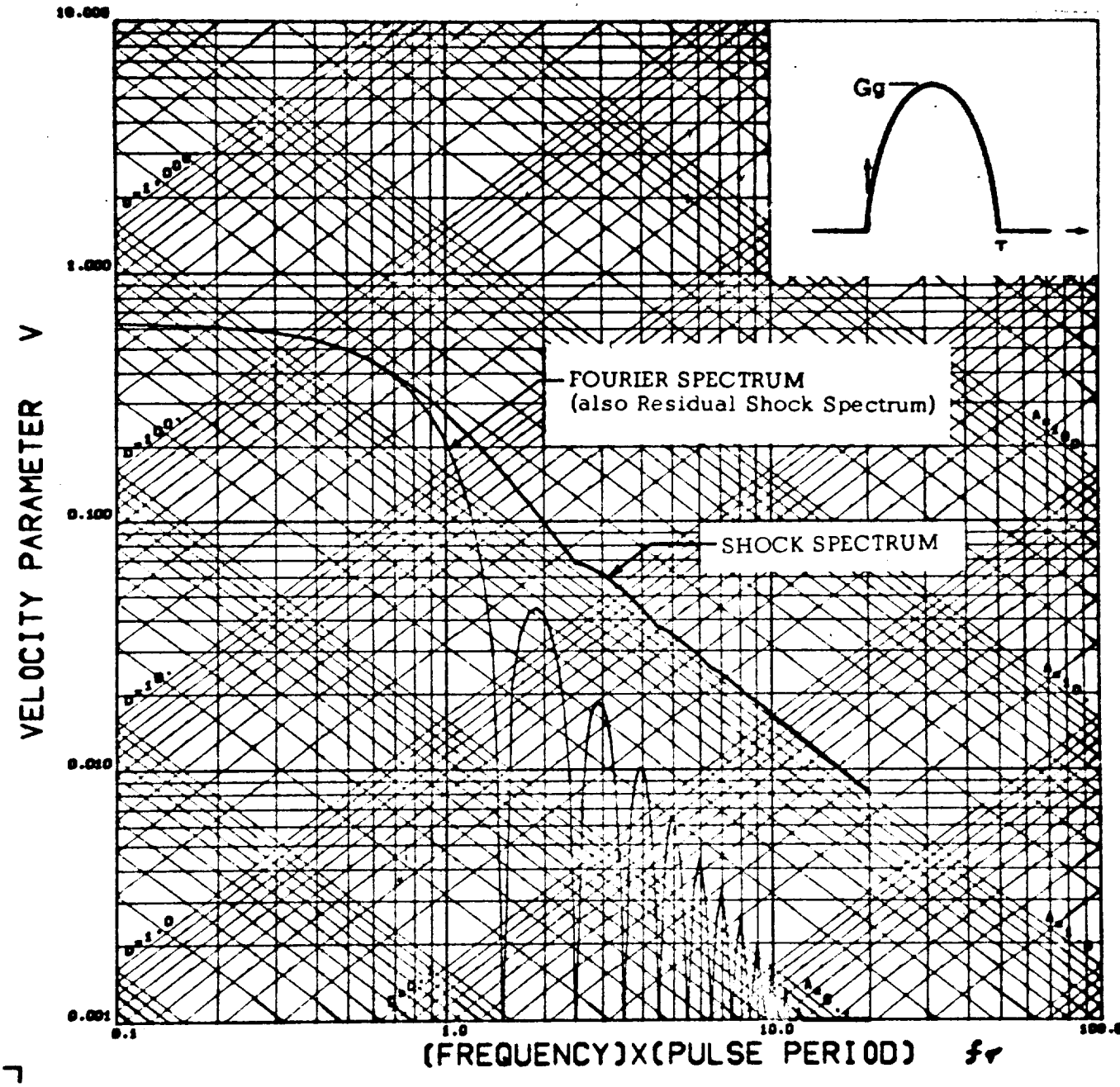
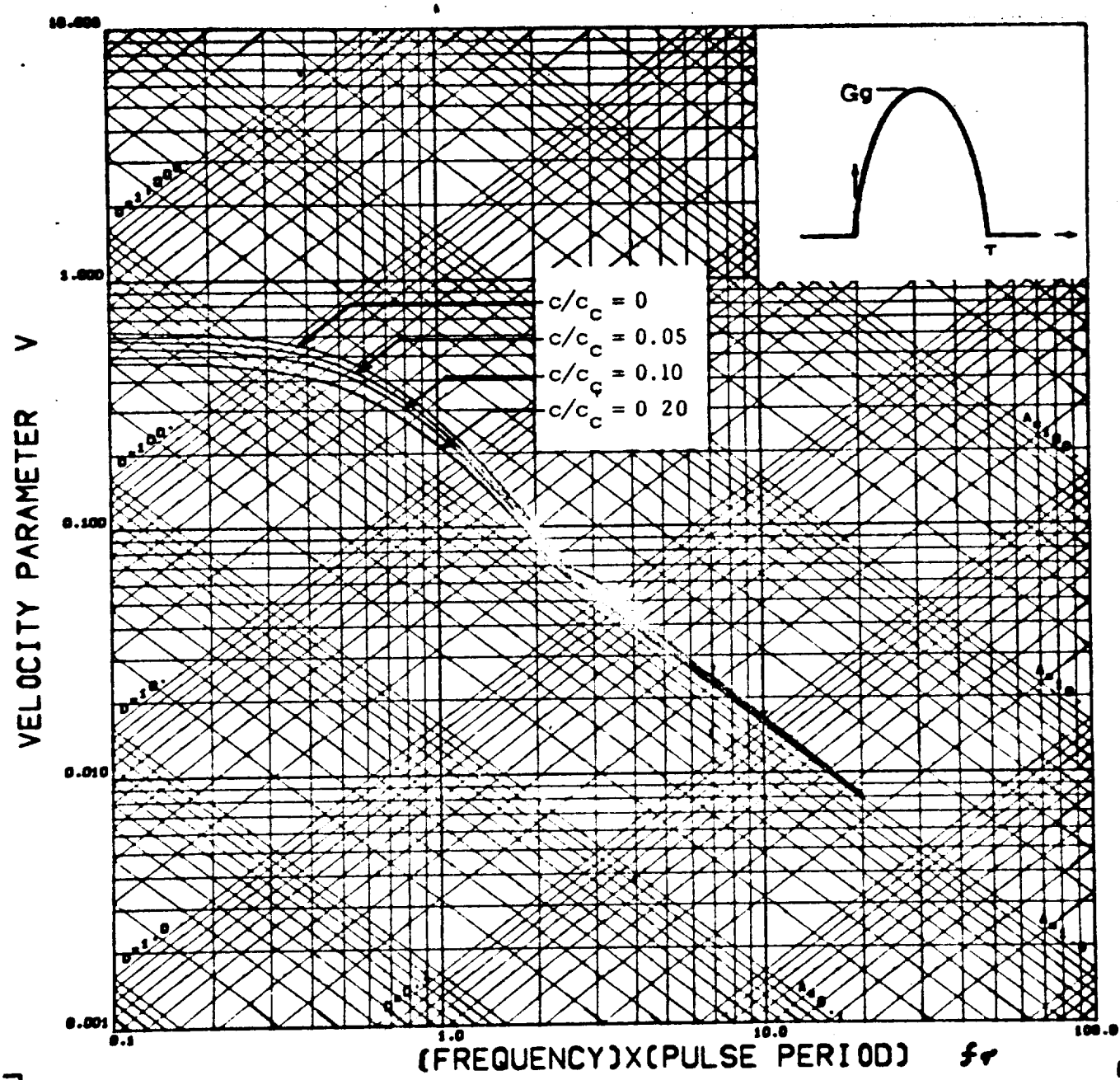



FIGURE II-51 Fourier Phase Spectrum for a Triangular Acceleration Pulse with Rise Time = $\tau$




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-52 Fourier and Shock Spectra for a Half-Cycle Sine Acceleration Pulse




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-53 Damped Shock Spectra for a Half-Cycle Sine Acceleration Pulse

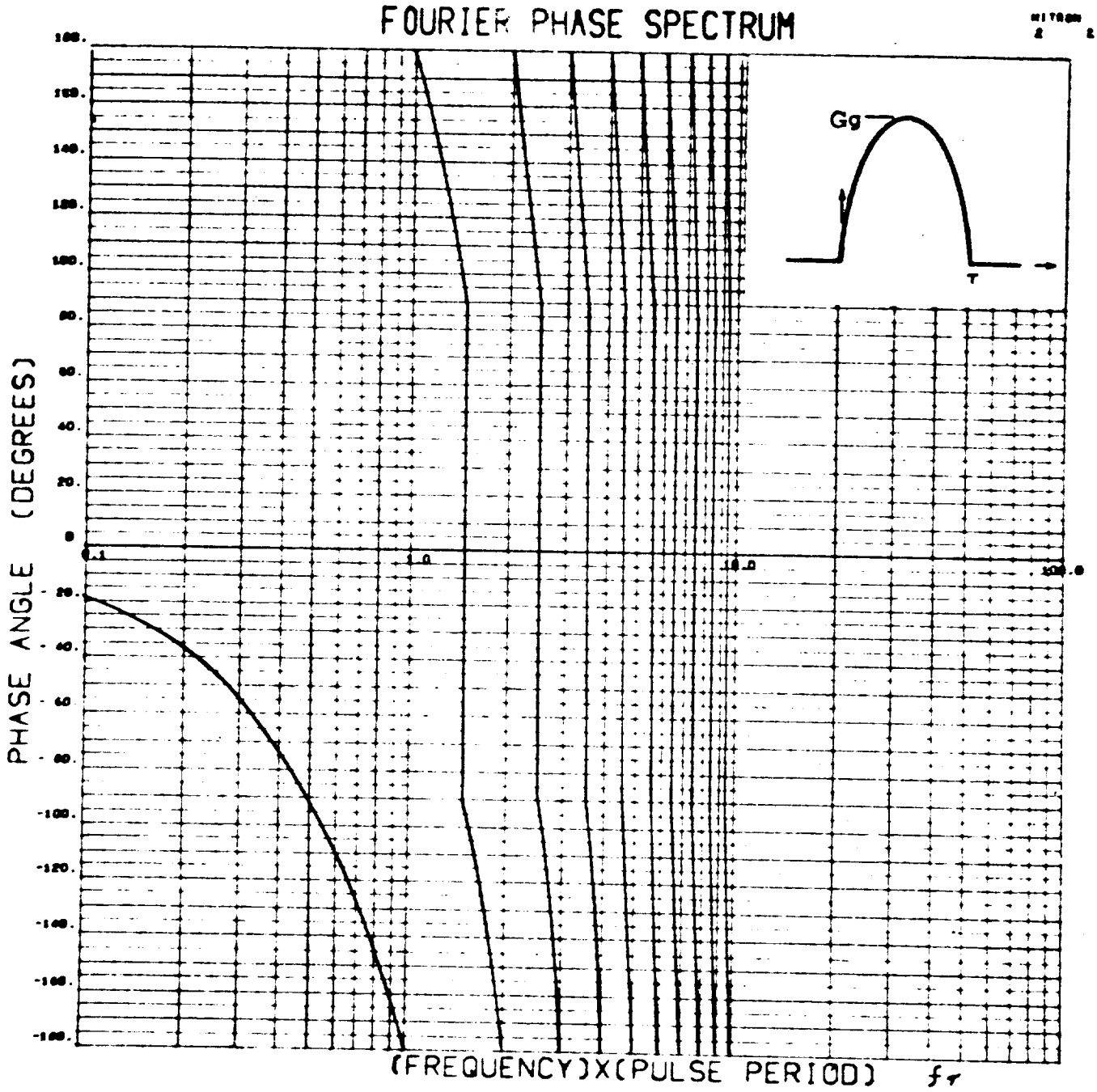
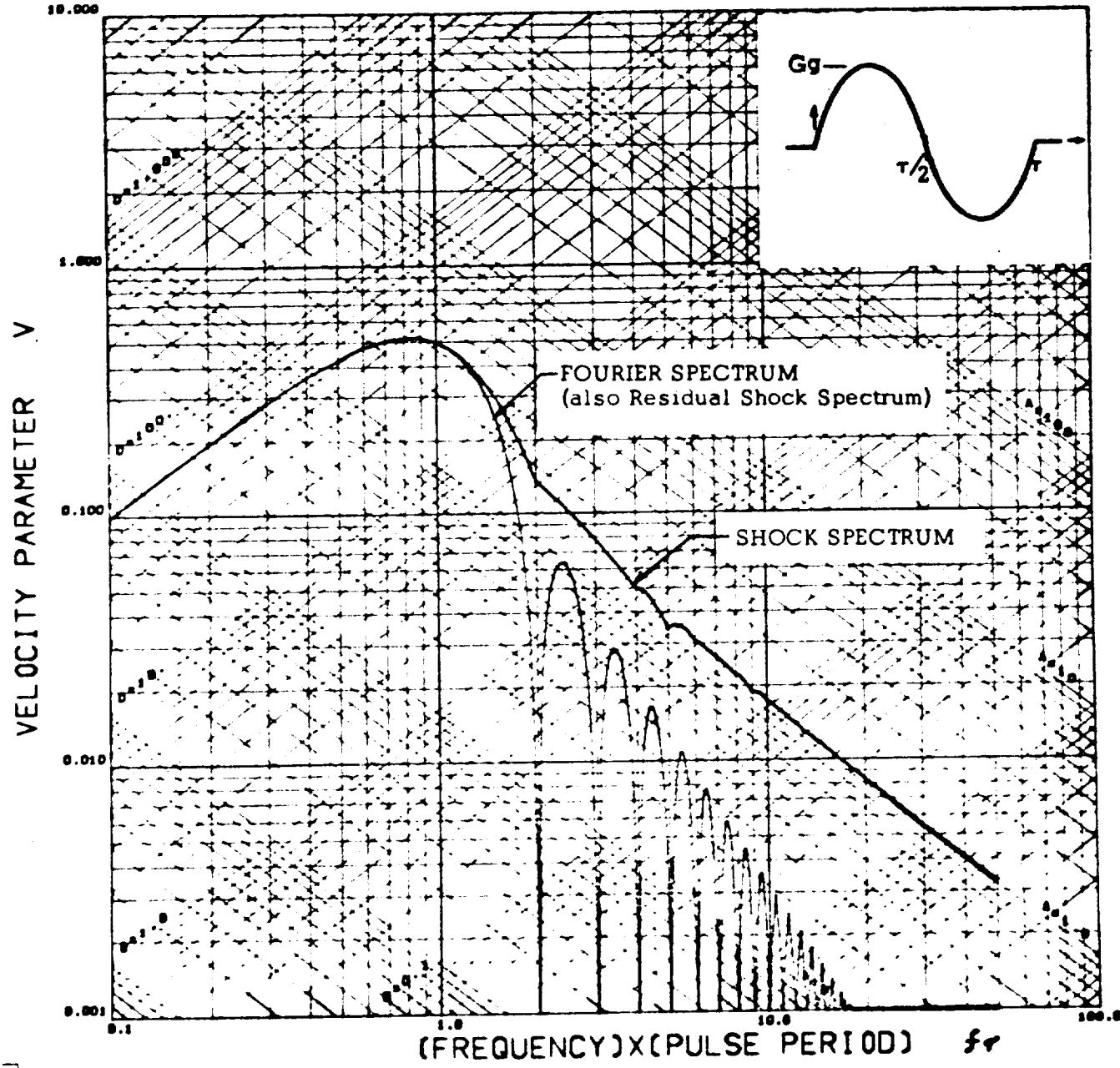
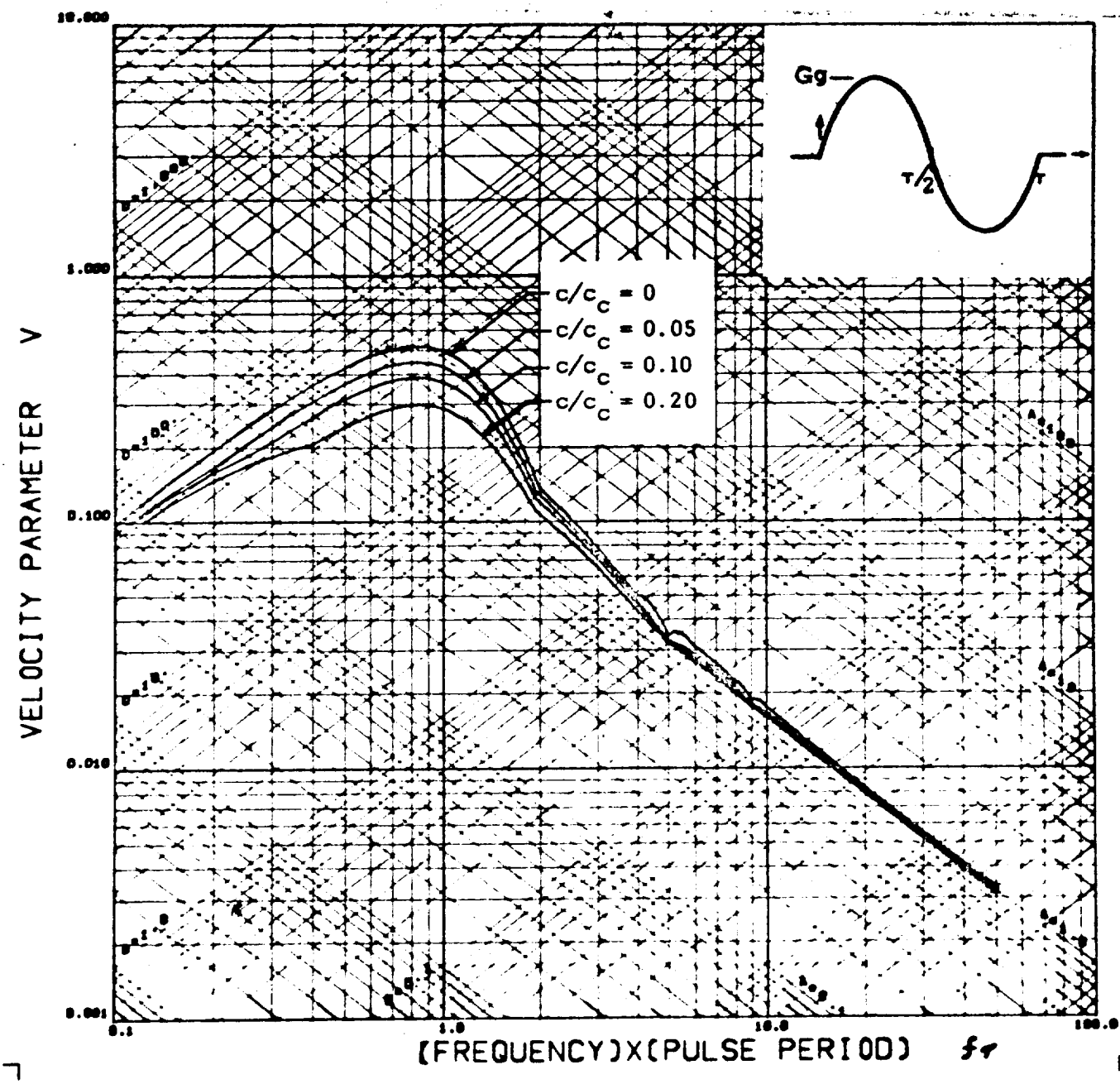



FIGURE II-54 Fourier Phase Spectrum for a Half-Cycle Sine Acceleration Pulse




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-55 Fourier and Shock Spectra for a Full-Cycle Sine Acceleration Pulse




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-56 Damped Shock Spectra for a Full-Cycle Sine Acceleration Pulse

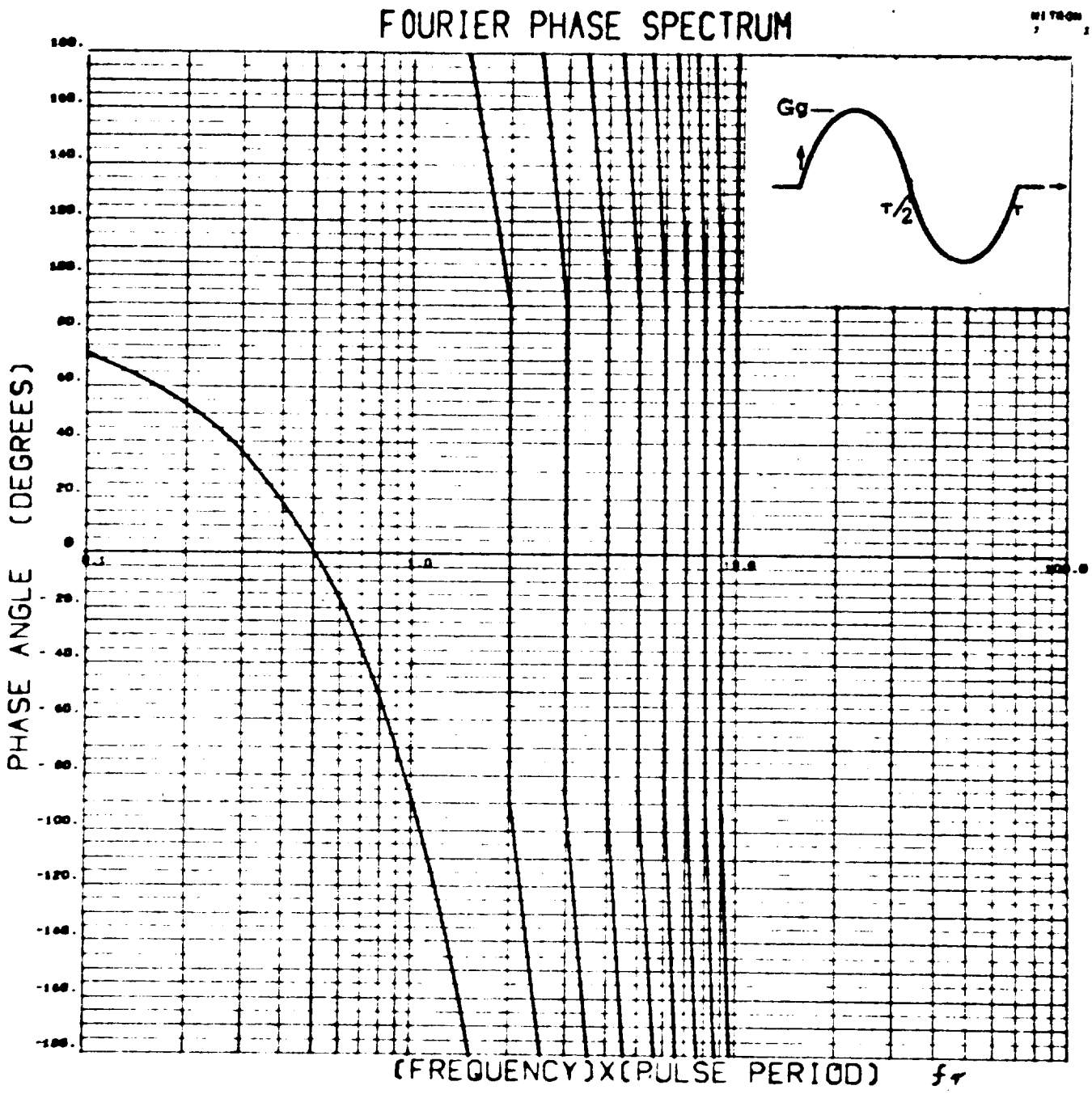
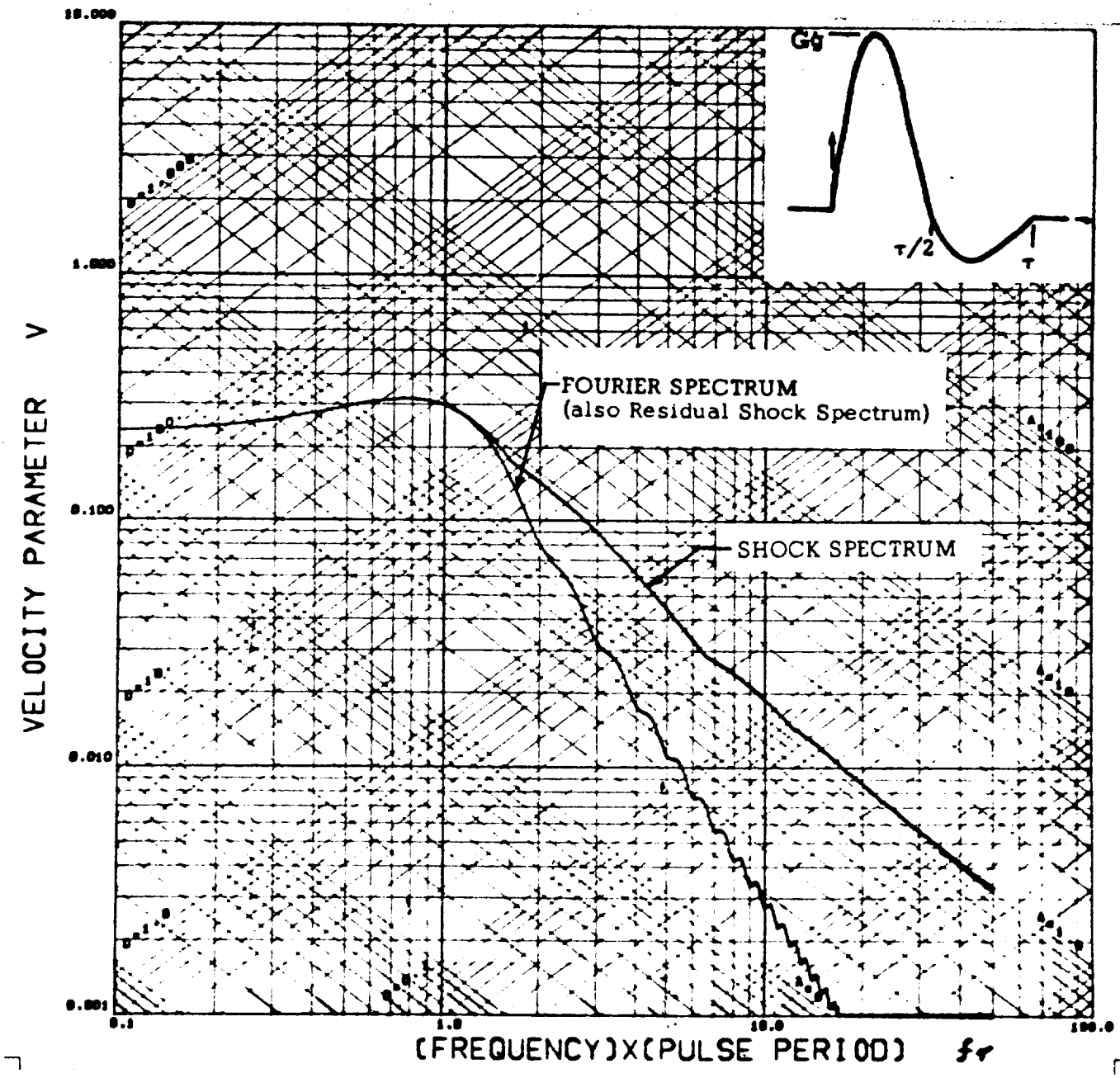
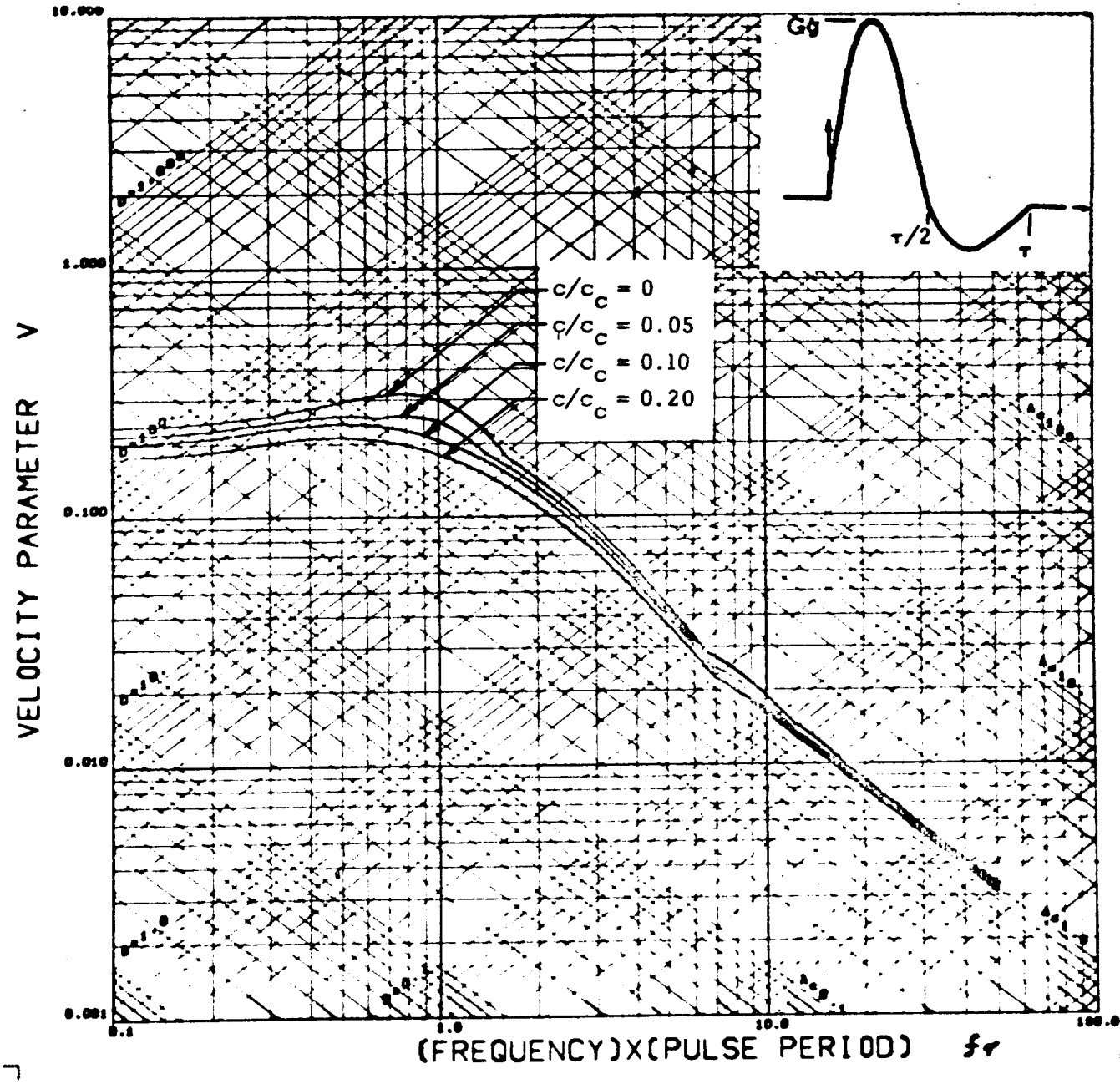



FIGURE II-57 Fourier Phase Spectrum for a Full-Cycle Sine Acceleration Pulse




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-58 Fourier and Shock Spectra for a Decaying Sinusoidal Acceleration Pulse with One Cycle and Amplitude Ratio = 1/16




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-59 Damped Shock Spectra for a Decaying Sinusoidal Acceleration Pulse with One Cycle and Amplitude Ratio = 1/16

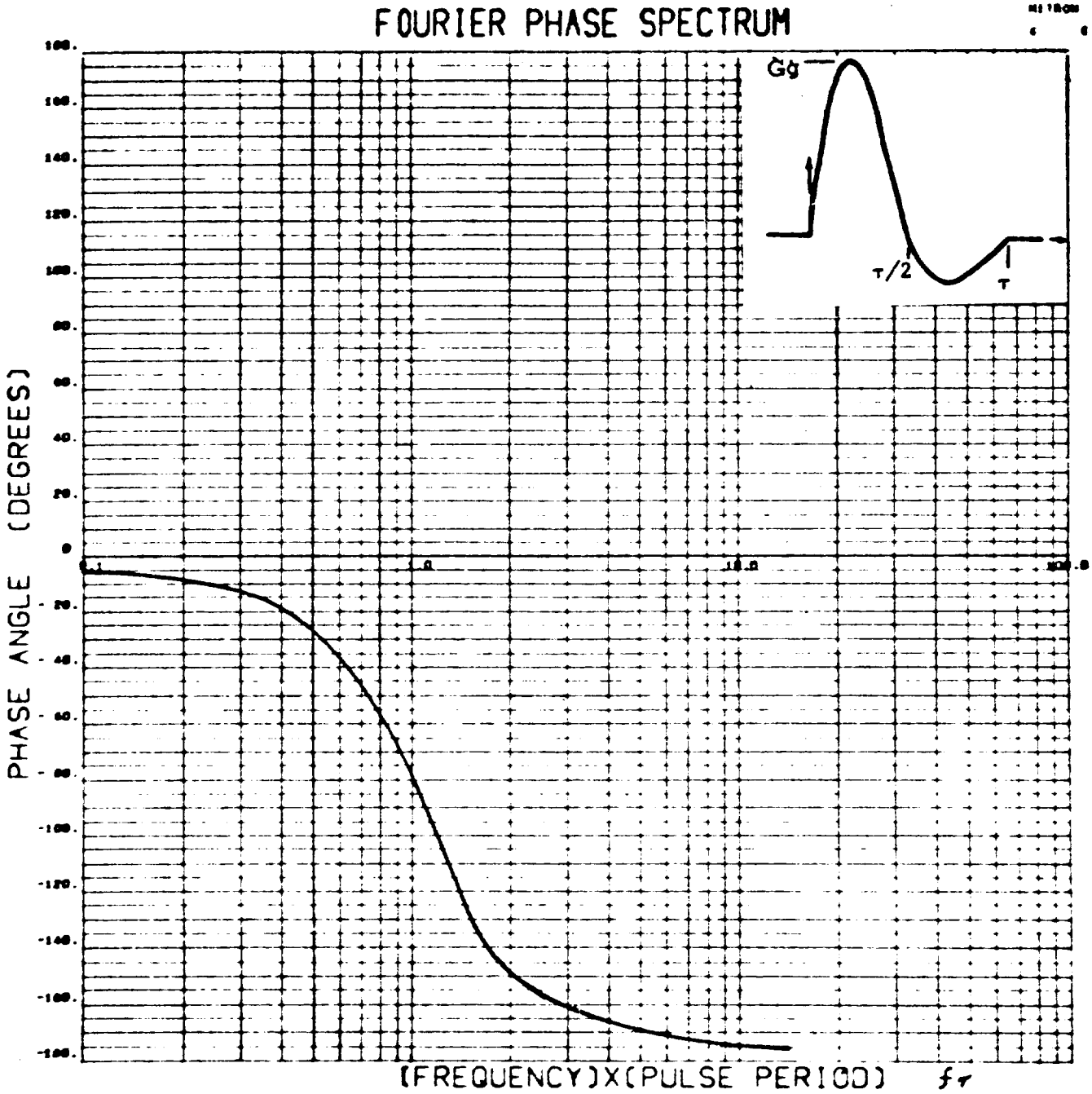
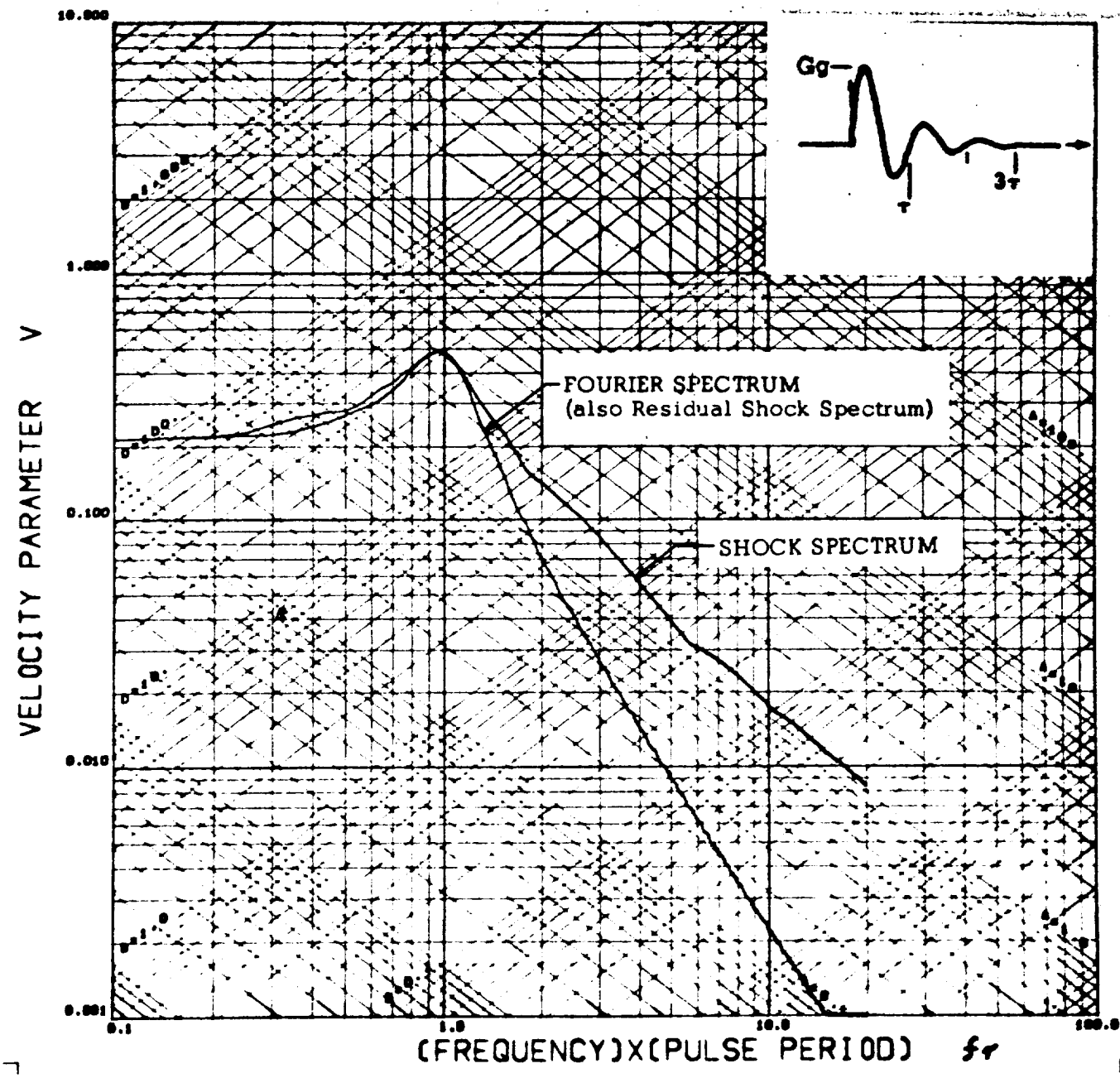
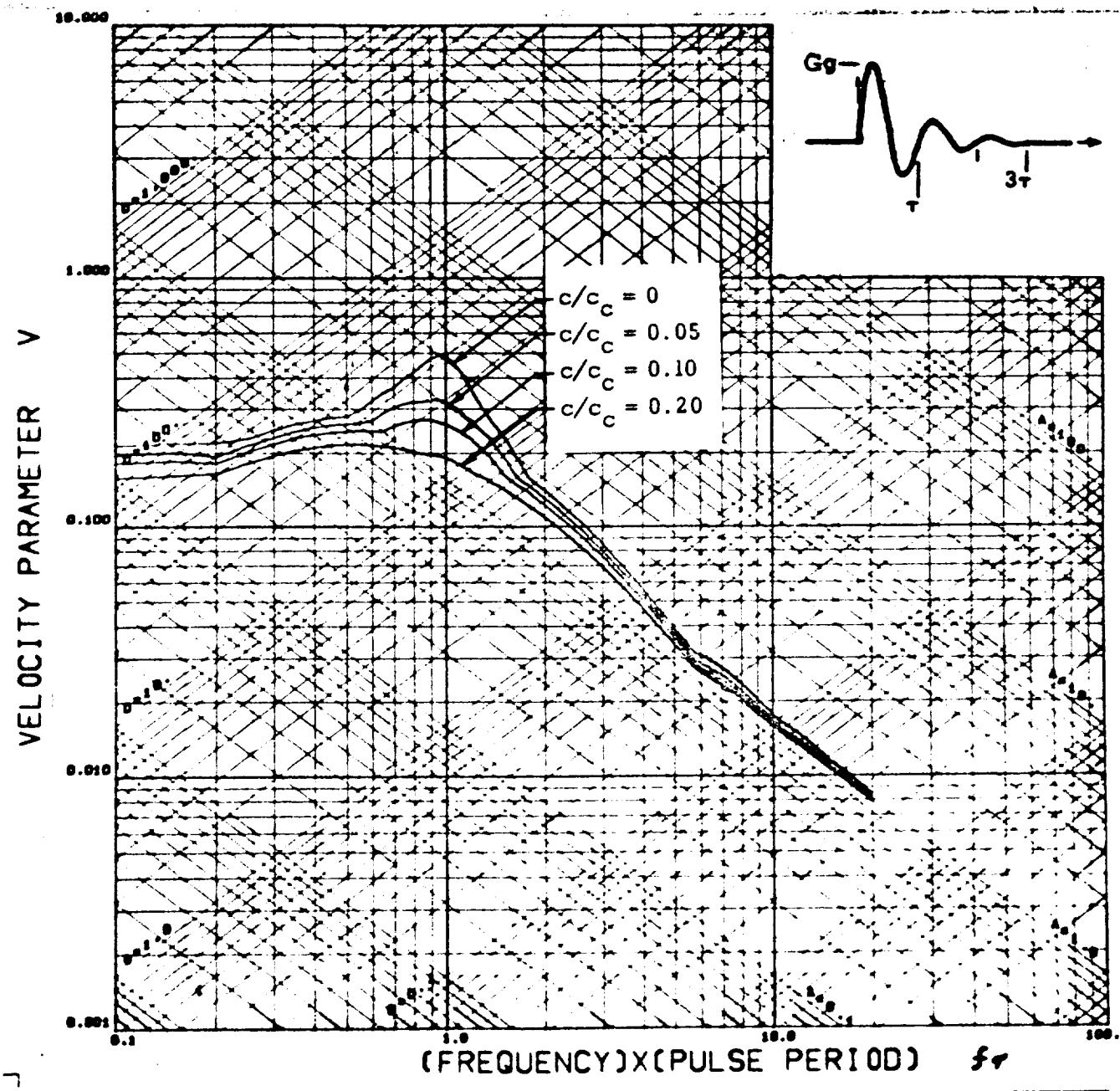



FIGURE II-60 Fourier Phase Spectrum for a Decaying Sinusoidal Acceleration Pulse with One Cycle and Amplitude Ratio = 1/16




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-61 Fourier and Shock Spectra for a Decaying Sinusoidal Acceleration Pulse with Three Cycles and Amplitude Ratio = 1/4




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-62 Damped Shock Spectra for a Decaying Sinusoidal Acceleration Pulse with Three Cycles and Amplitude Ratio = 1/4

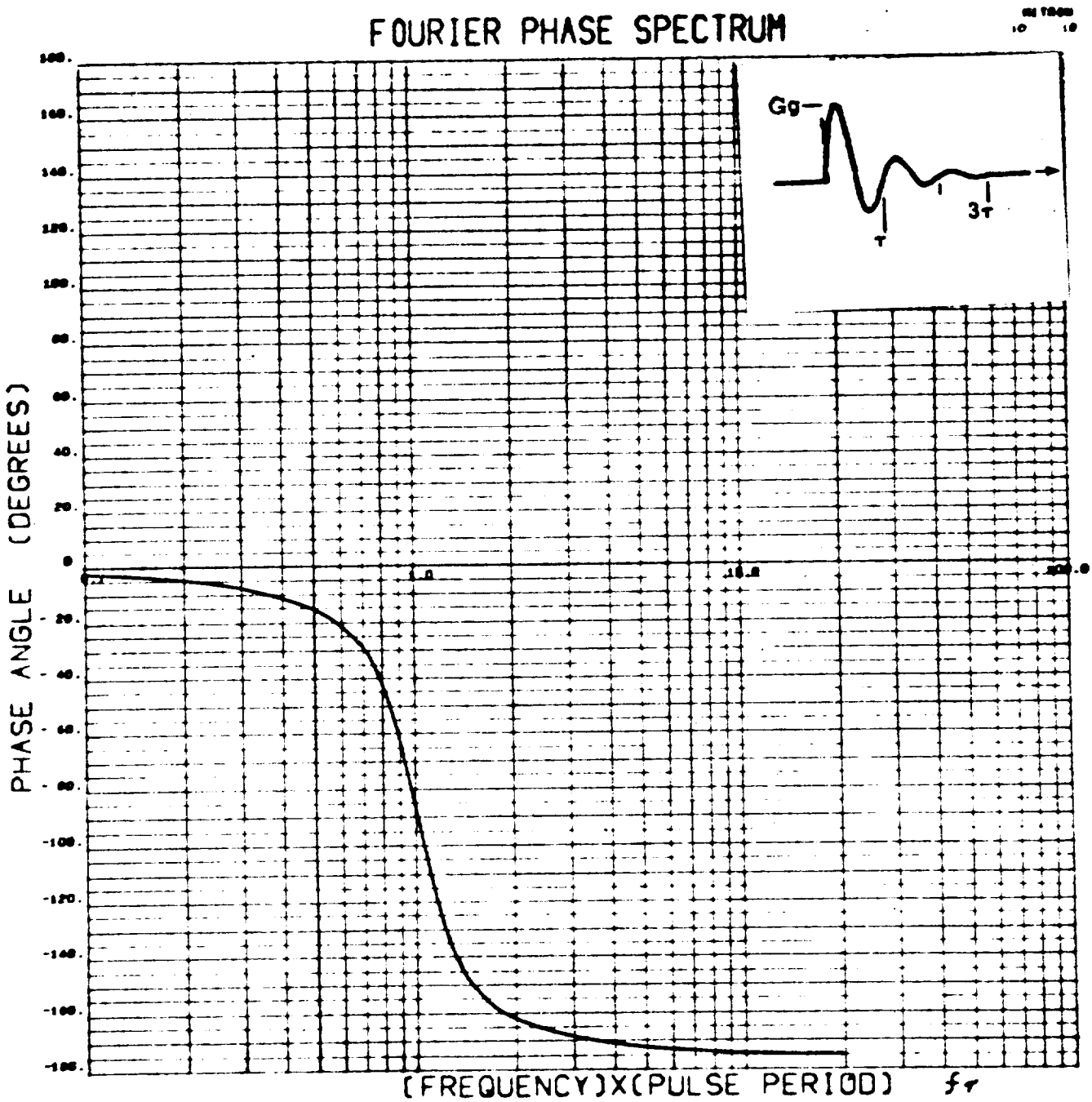
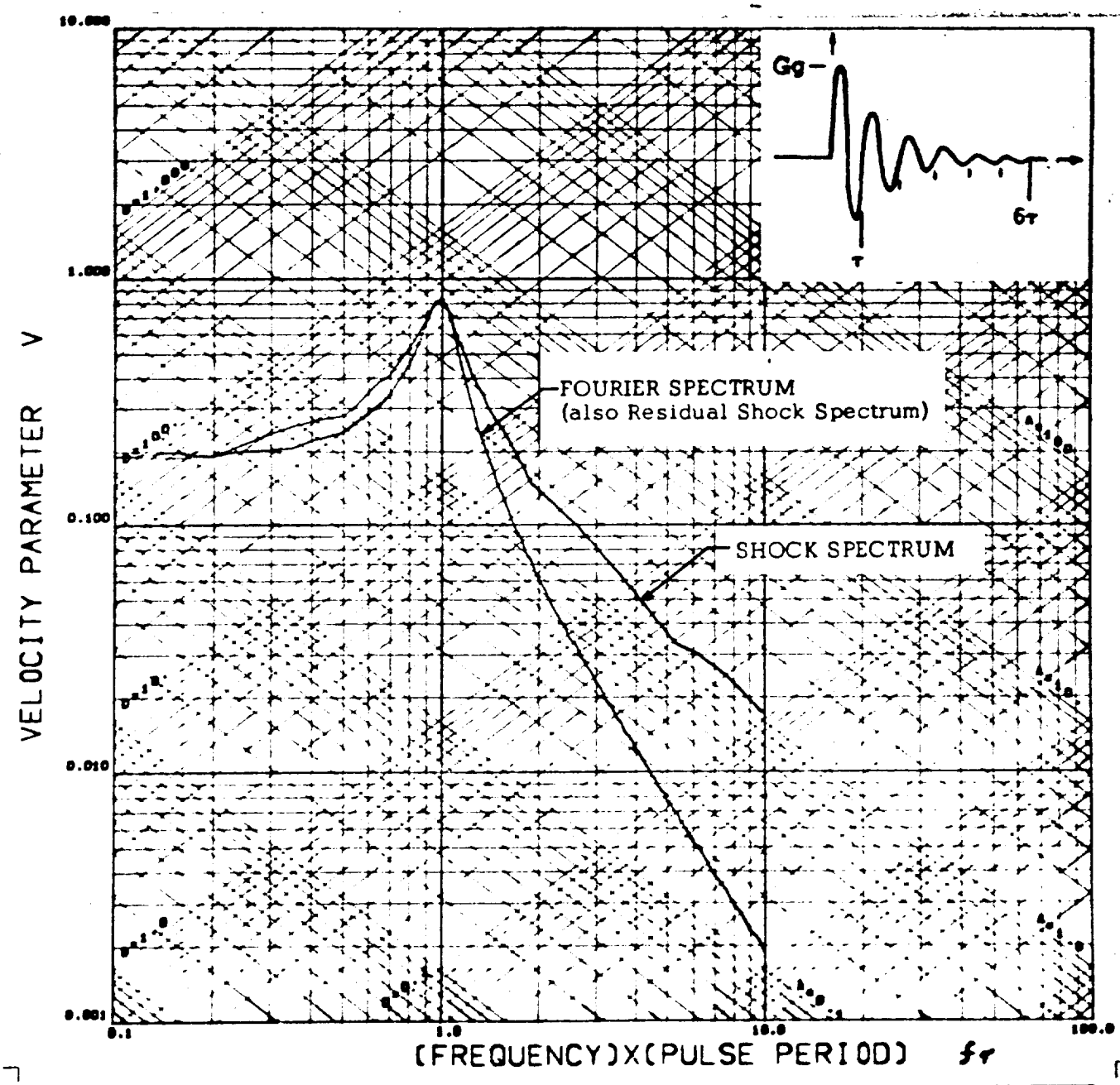
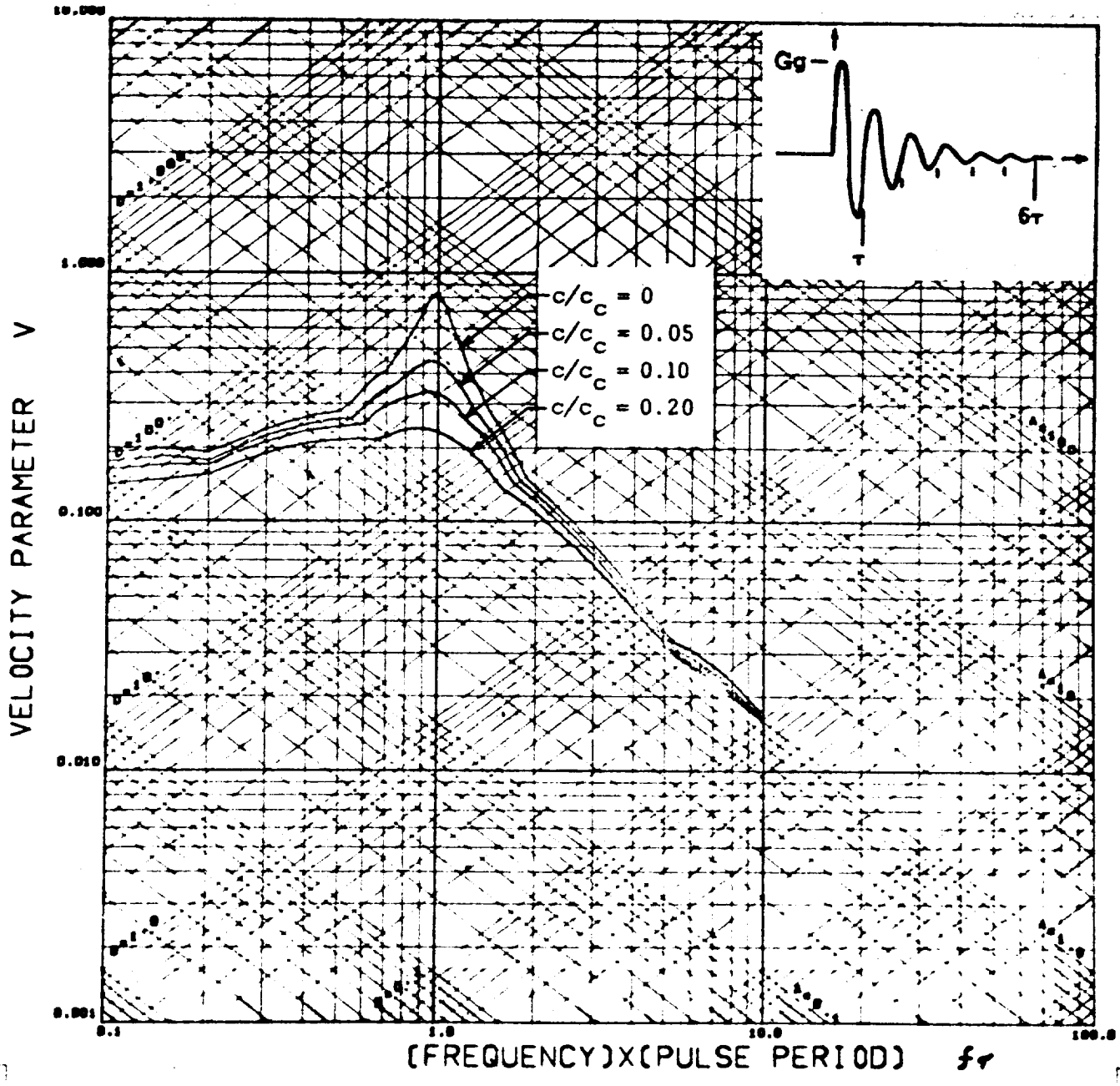



FIGURE II-63 Fourier Phase Spectrum for a Decaying Sinusoidal Acceleration Pulse with Three Cycles and Amplitude Ratio = 1/4




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-64 Fourier and Shock Spectra for a Decaying Sinusoidal Acceleration Pulse with Six Cycles and Amplitude Ratio = 1/2




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-65 Damped Shock Spectra for a Decaying Sinusoidal Acceleration Pulse with Six Cycles and Amplitude Ratio = 1/2

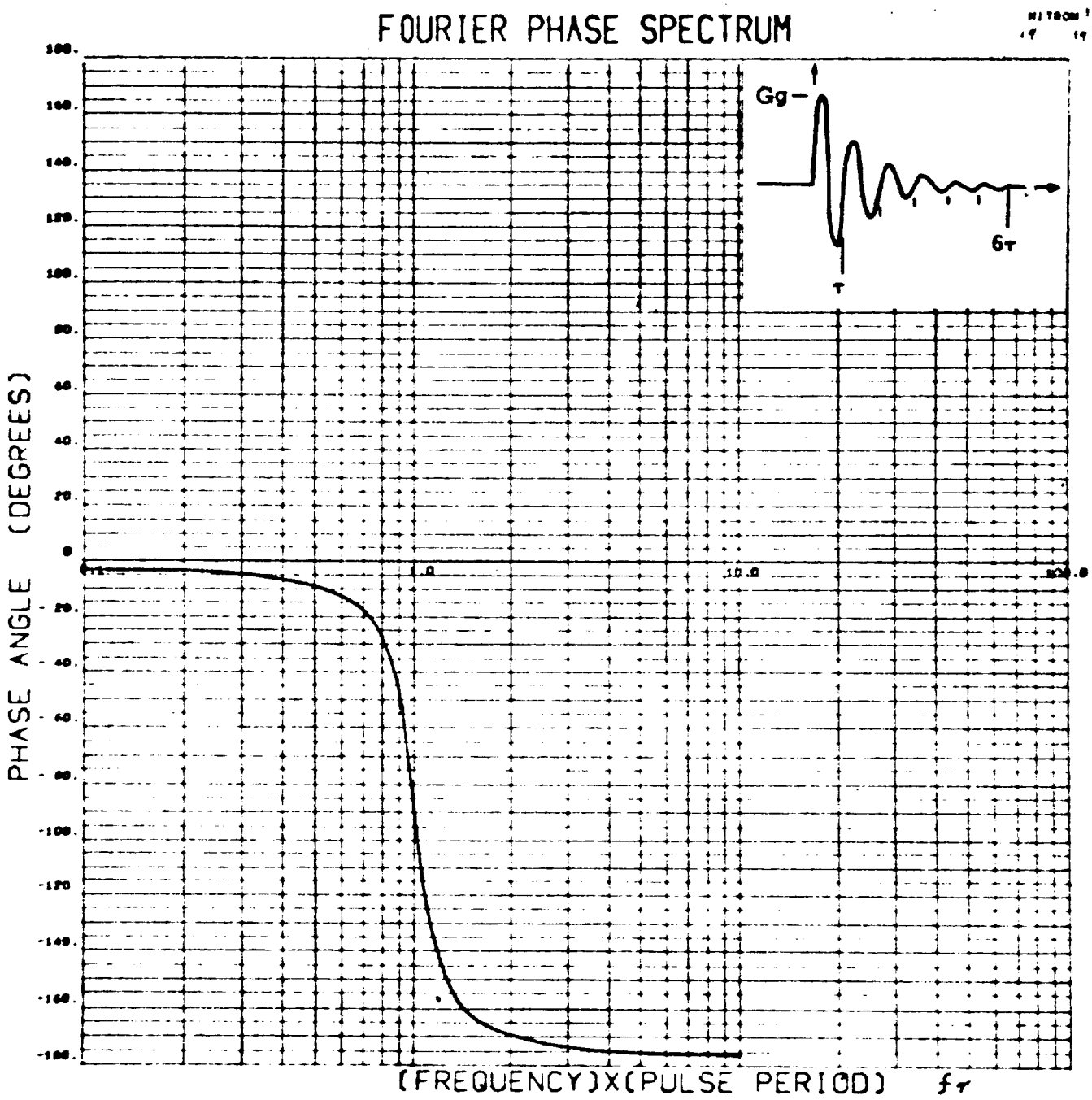
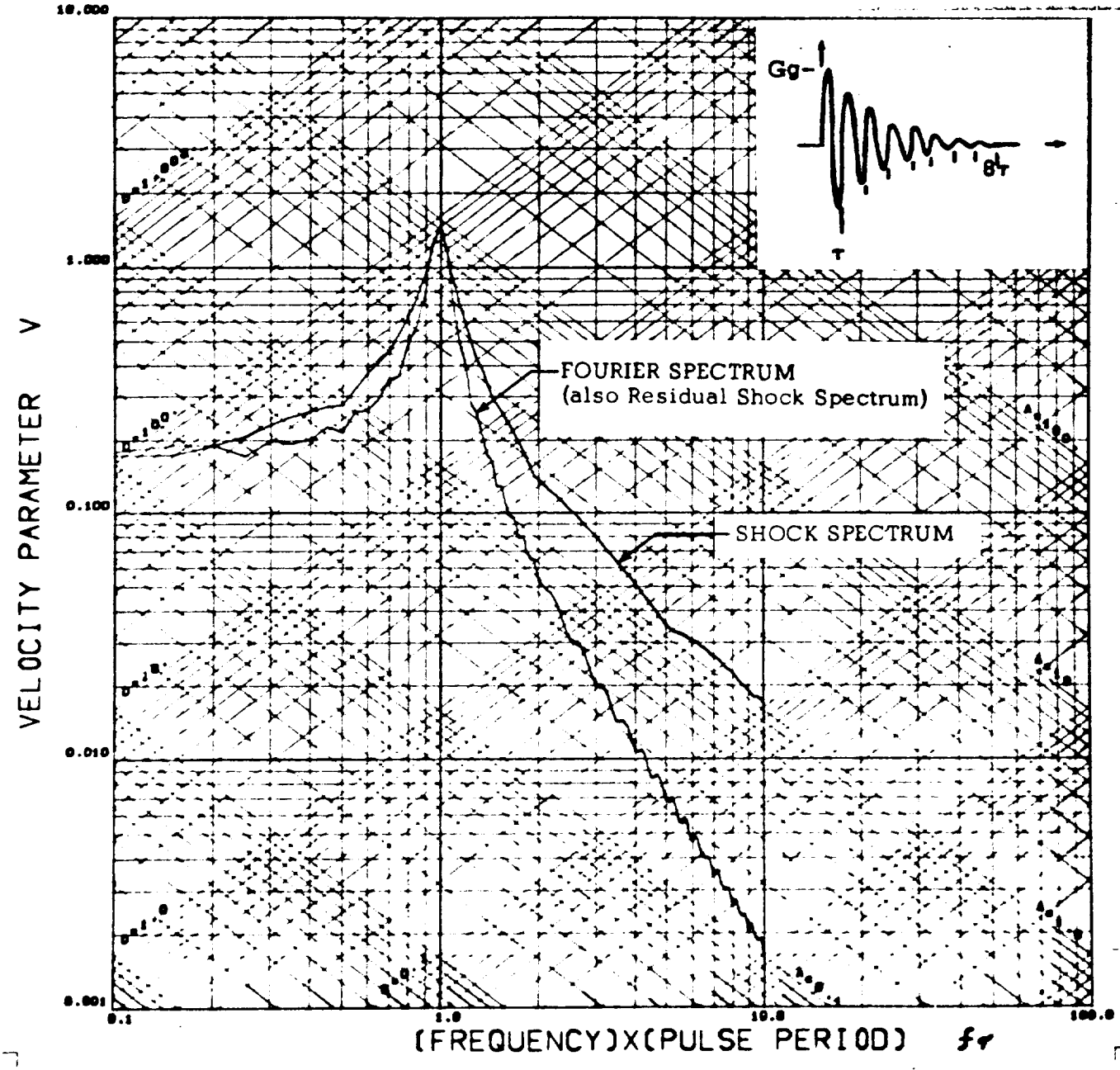
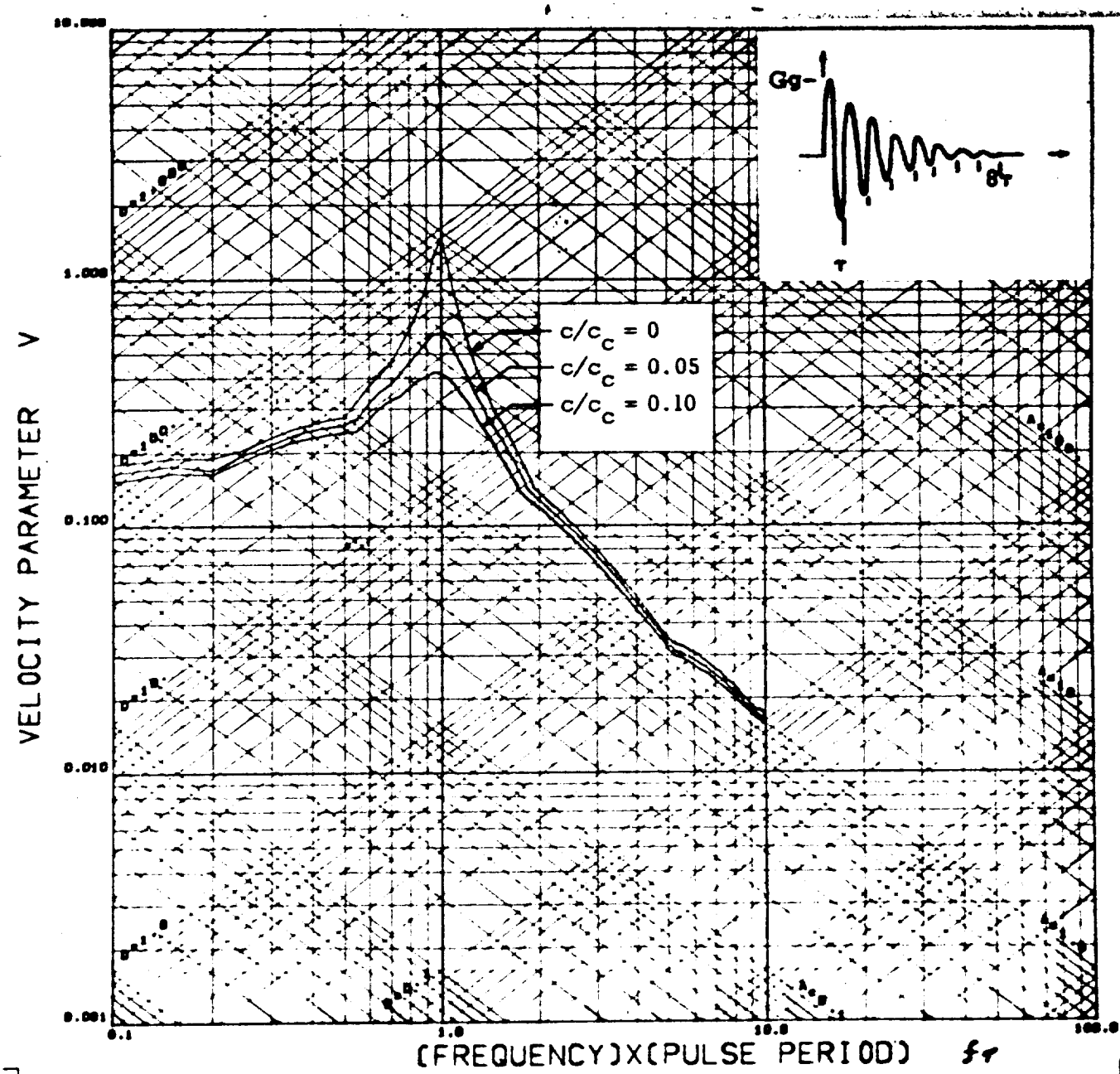



FIGURE II-66 Fourier Phase Spectrum for a Decaying Sinusoidal Acceleration Pulse with Six Cycles and Amplitude Ratio = 1/2




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-67 Fourier and Shock Spectra for a Decaying Sinusoidal Acceleration Pulse with Eight Cycles and Amplitude Ratio = $1/\sqrt{2}$




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-68 Damped Shock Spectra for a Decaying Sinusoidal Acceleration Pulse with Eight Cycles and Amplitude Ratio = $1/\sqrt{2}$

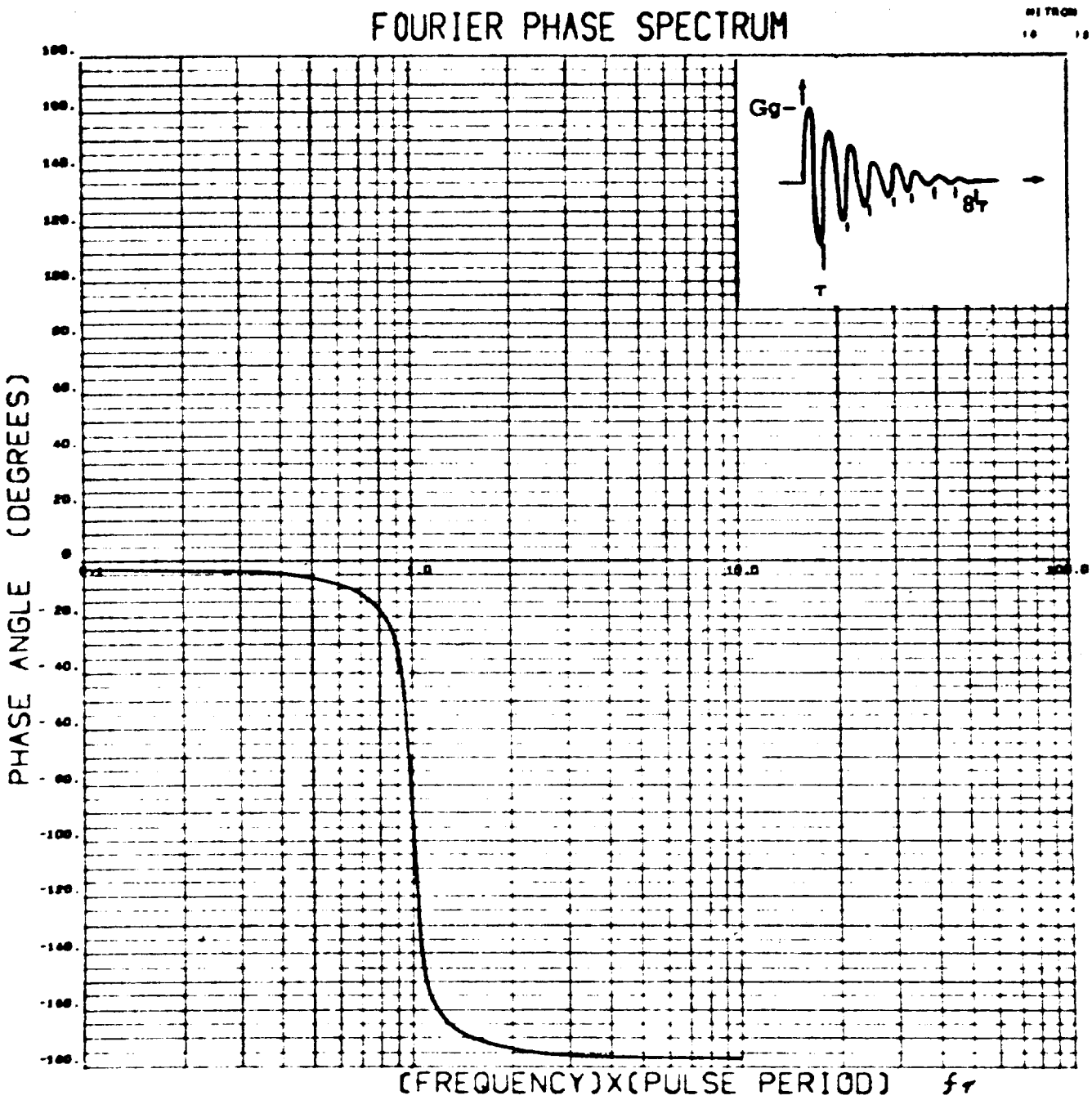
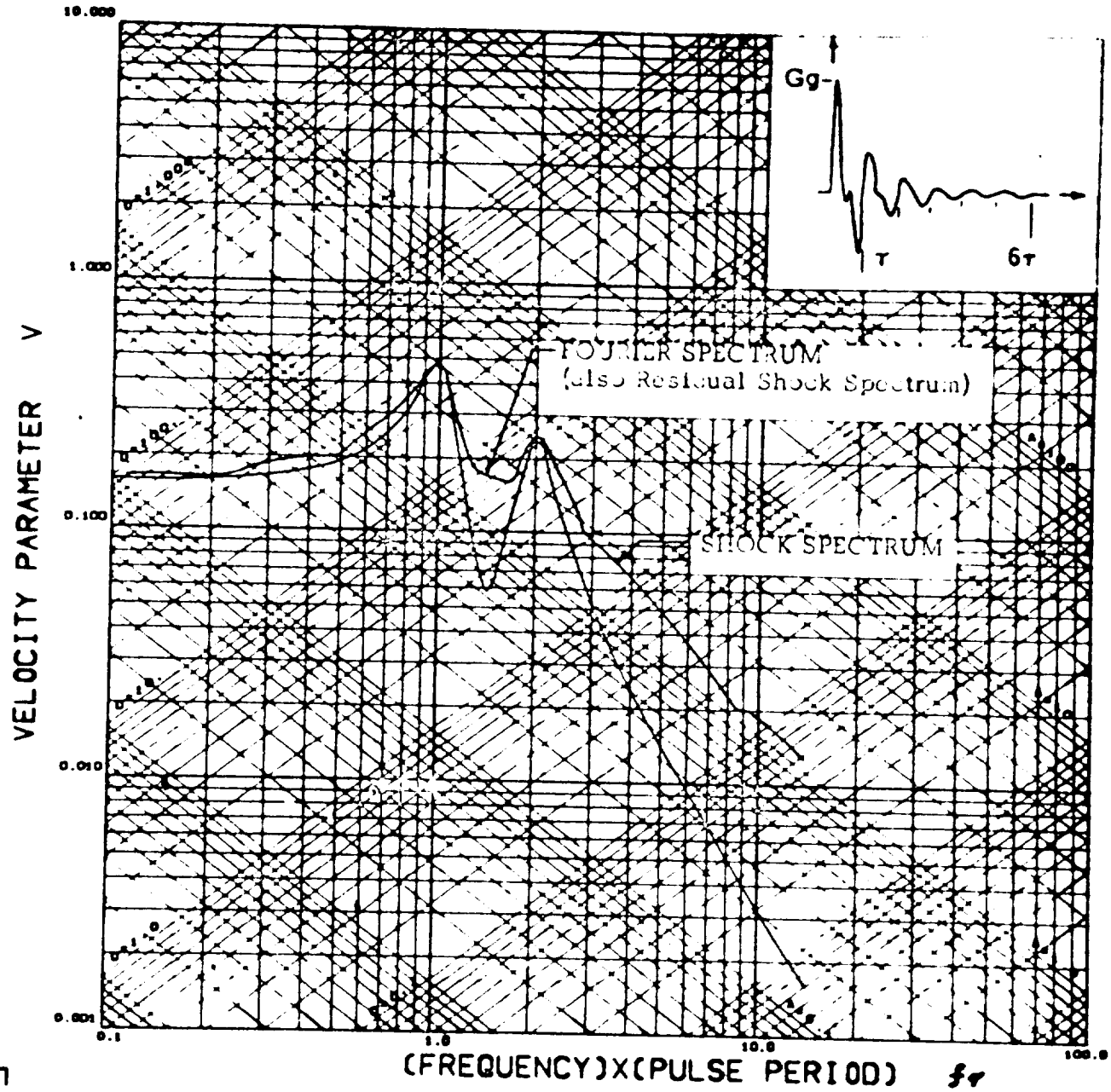
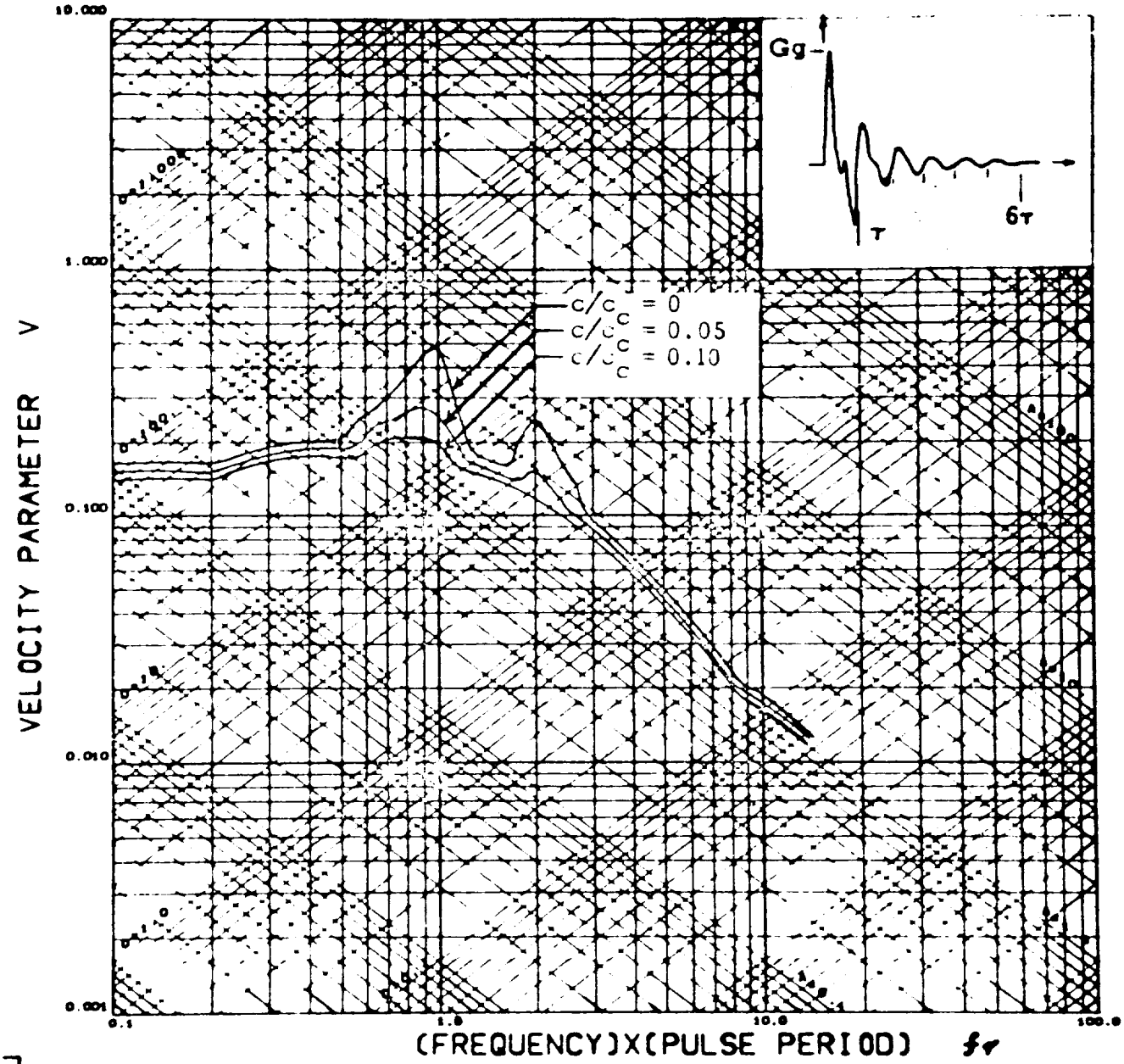



FIGURE II-69 Fourier Phase Spectrum for a Decaying Sinusoidal Acceleration Pulse with Eight Cycles and Amplitude Ratio = $1/\sqrt{2}$




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-70 Fourier and Shock Spectra for a Decaying Sinusoidal Acceleration Pulse with Two Superimposed Frequencies of Frequency Ratio = 1:2, Decay Ratios = 1/2 and Component Amplitudes = 0.561 Gg.




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-71 Damped Shock Spectra for a Decaying Sinusoidal Acceleration Pulse with Two Superimposed Frequencies of Frequency Ratio = 1:2, Decay Ratios = 1/2 and Component Amplitudes = 0.561 Gg.

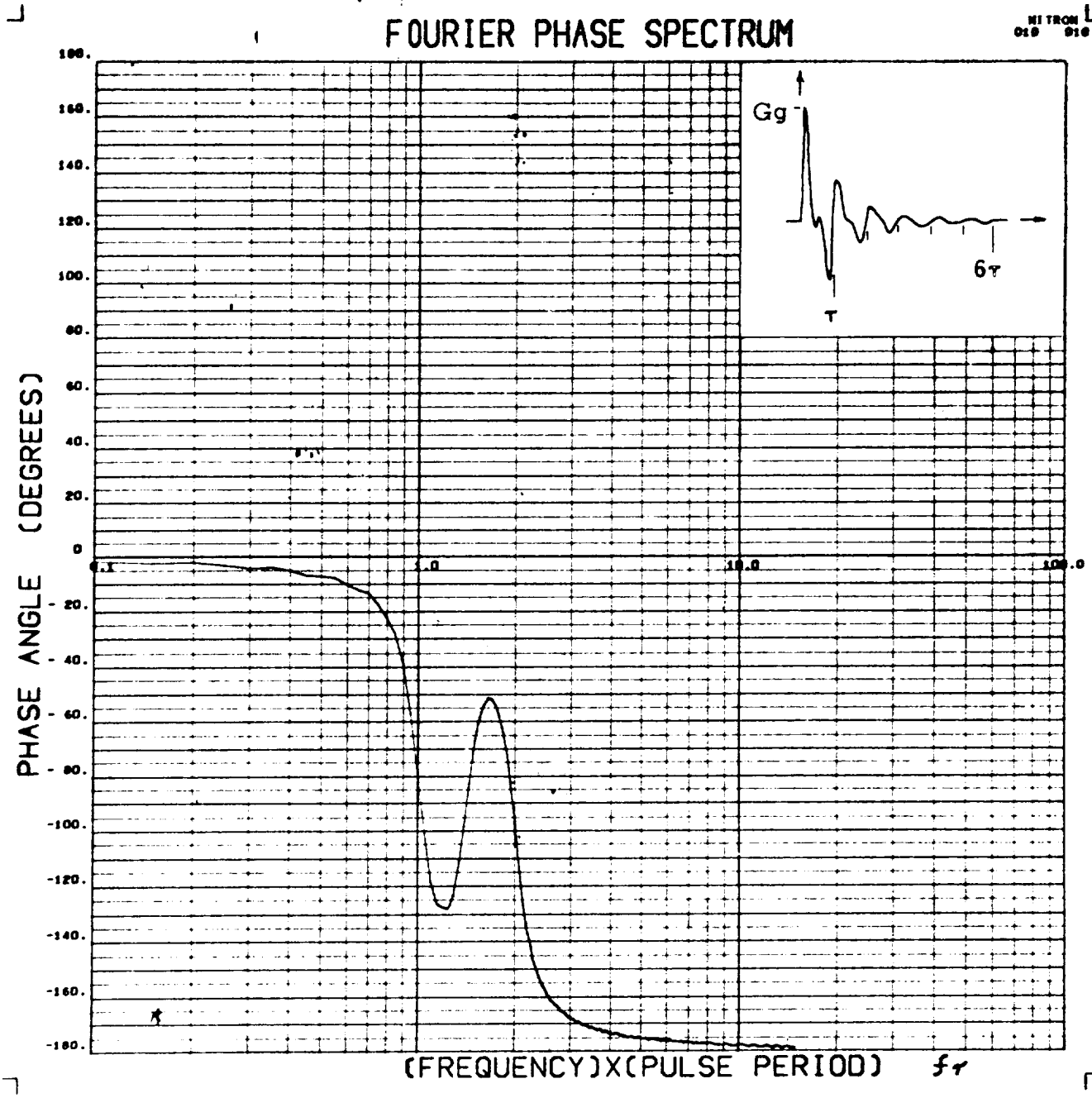
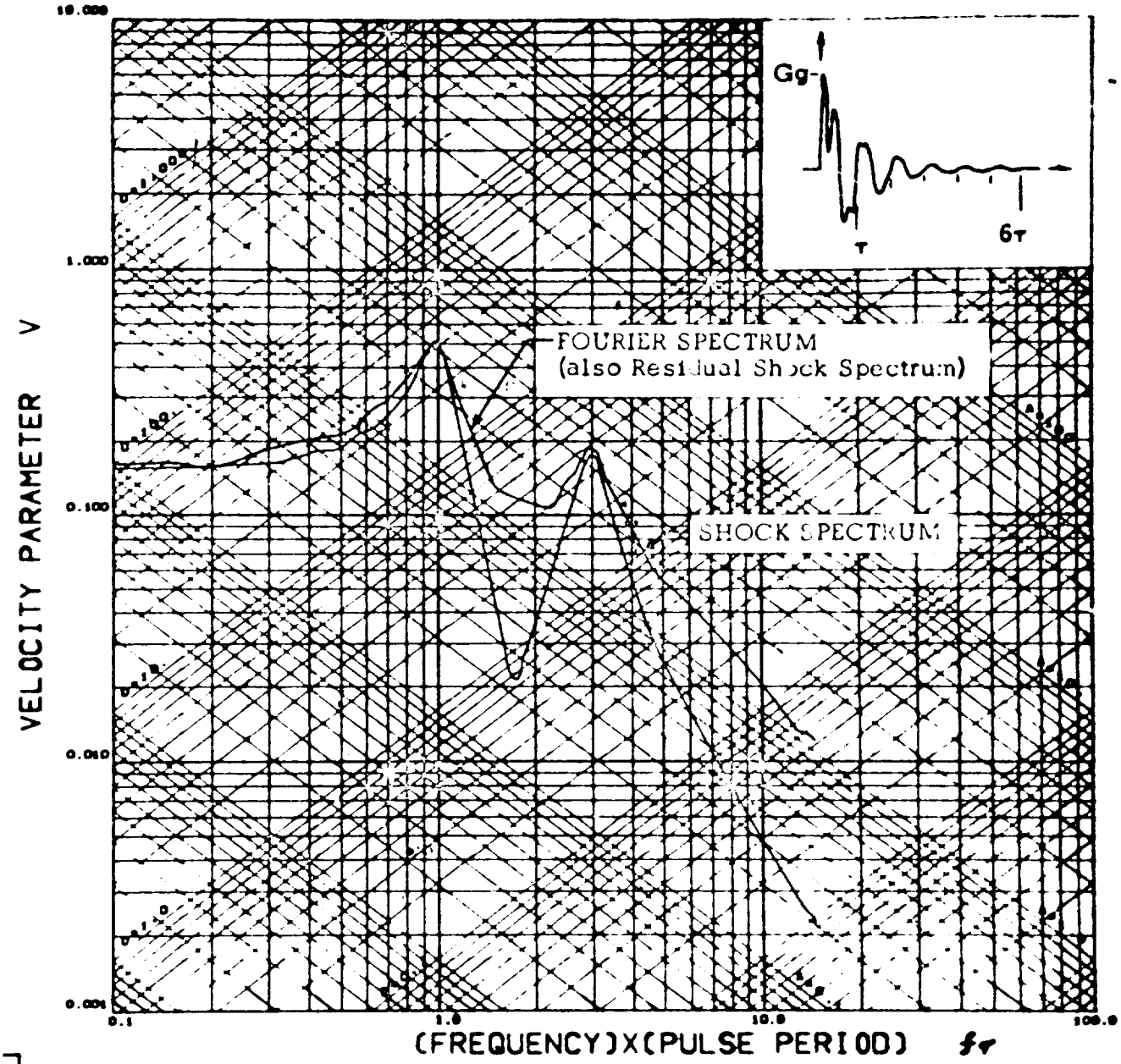
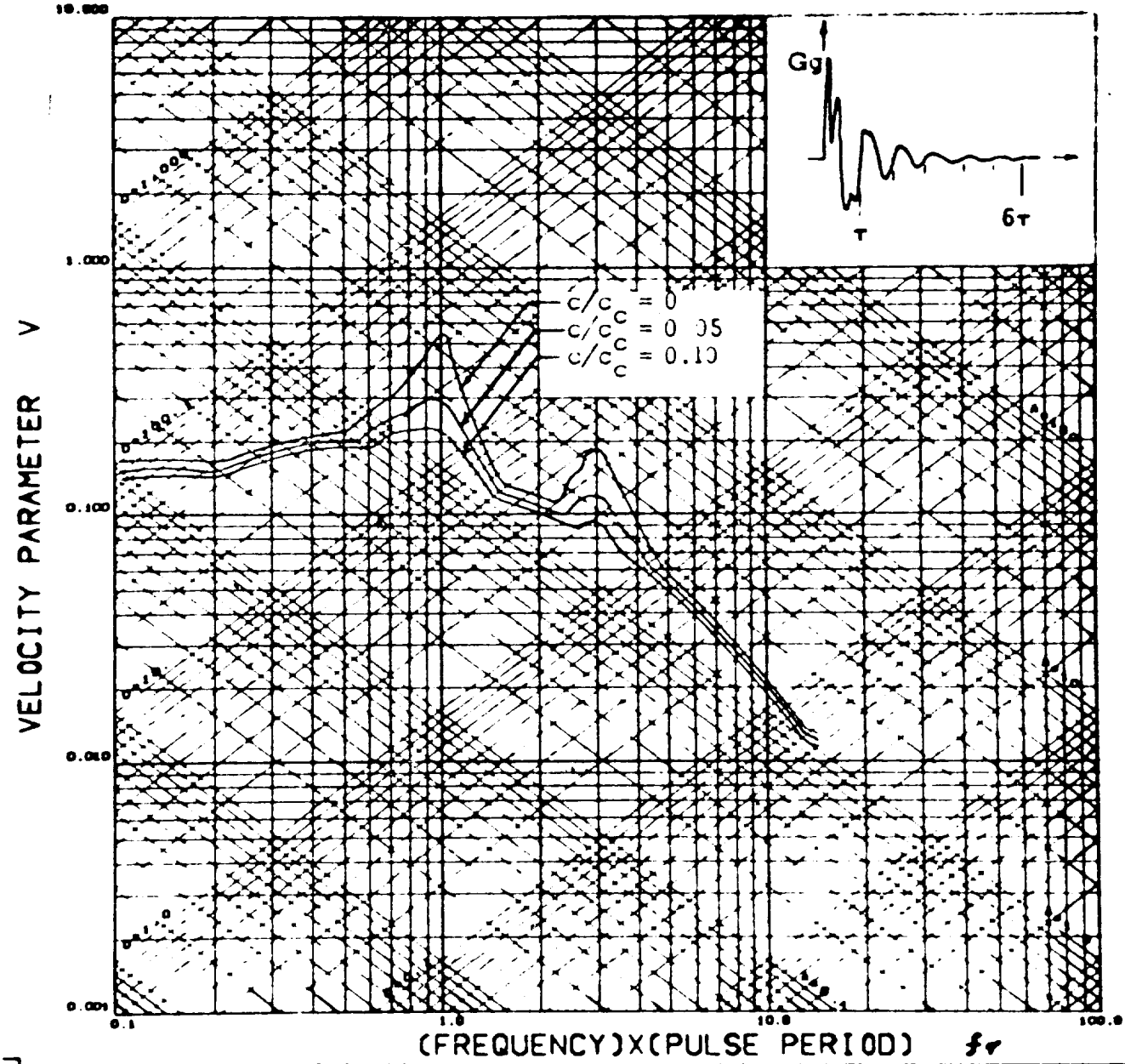



FIGURE II -72 Fourier Phase Spectrum for a Decaying Sinusoidal Acceleration Pulse with Two Superimposed Frequencies of Frequency Ratio = 1:2, Decay Ratios = 1/2 and Component Amplitudes = 0.561 Gg.




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in/sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-73 Fourier and Shock Spectra for a Decaying Sinusoidal Acceleration Pulse with Two Superimposed Frequencies of Frequency Ratio = 1:3, Decay Ratios = 1/2 and Component Amplitudes = 0.638 Gg.




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-74 Damped Shock Spectra for a Decaying Sinusoidal Acceleration Pulse with Two Superimposed Frequencies of Frequency Ratio = 1:3, Decay Ratios = 1/2 and Component Amplitudes = 0.638 Gg.

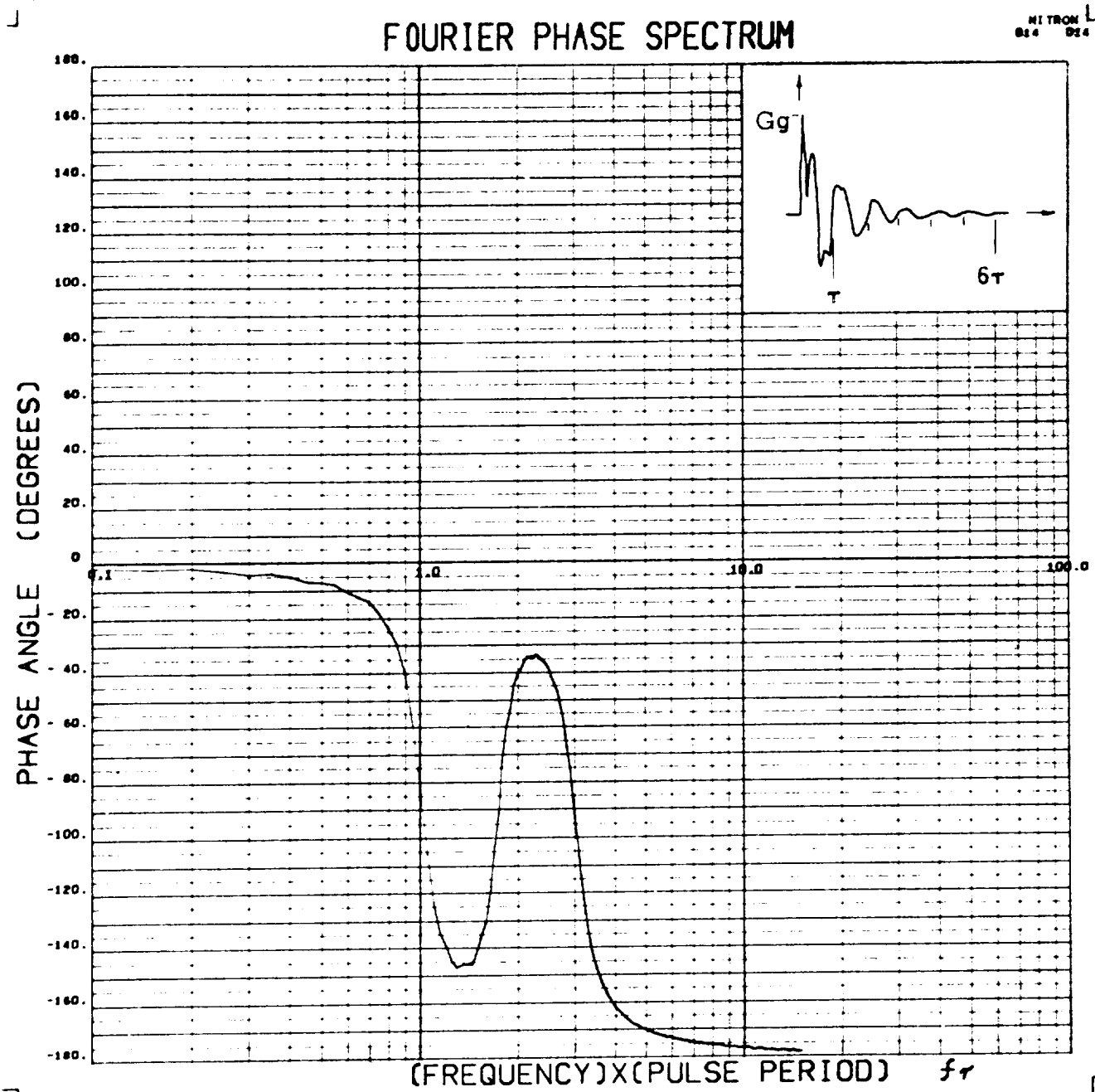
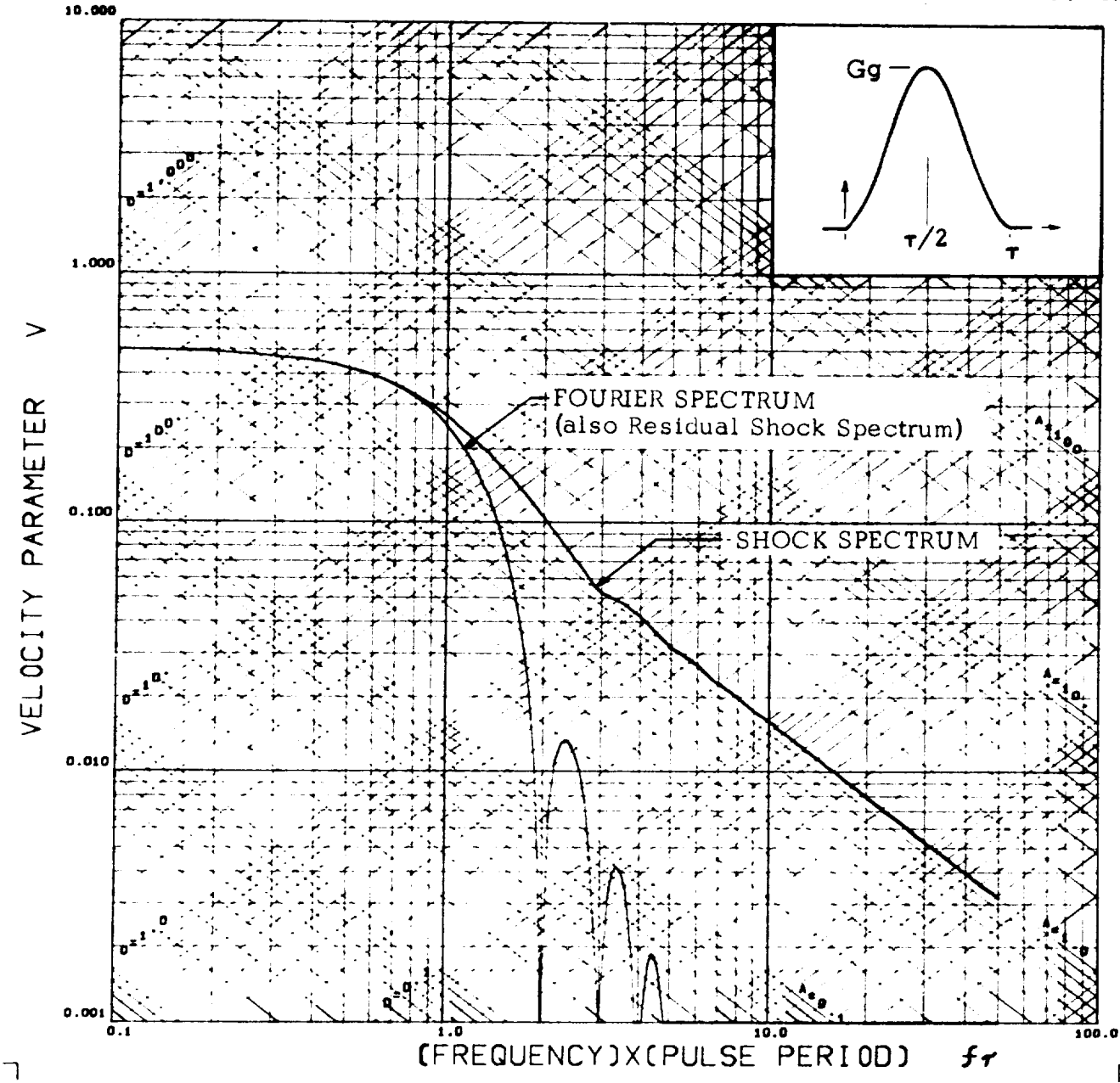
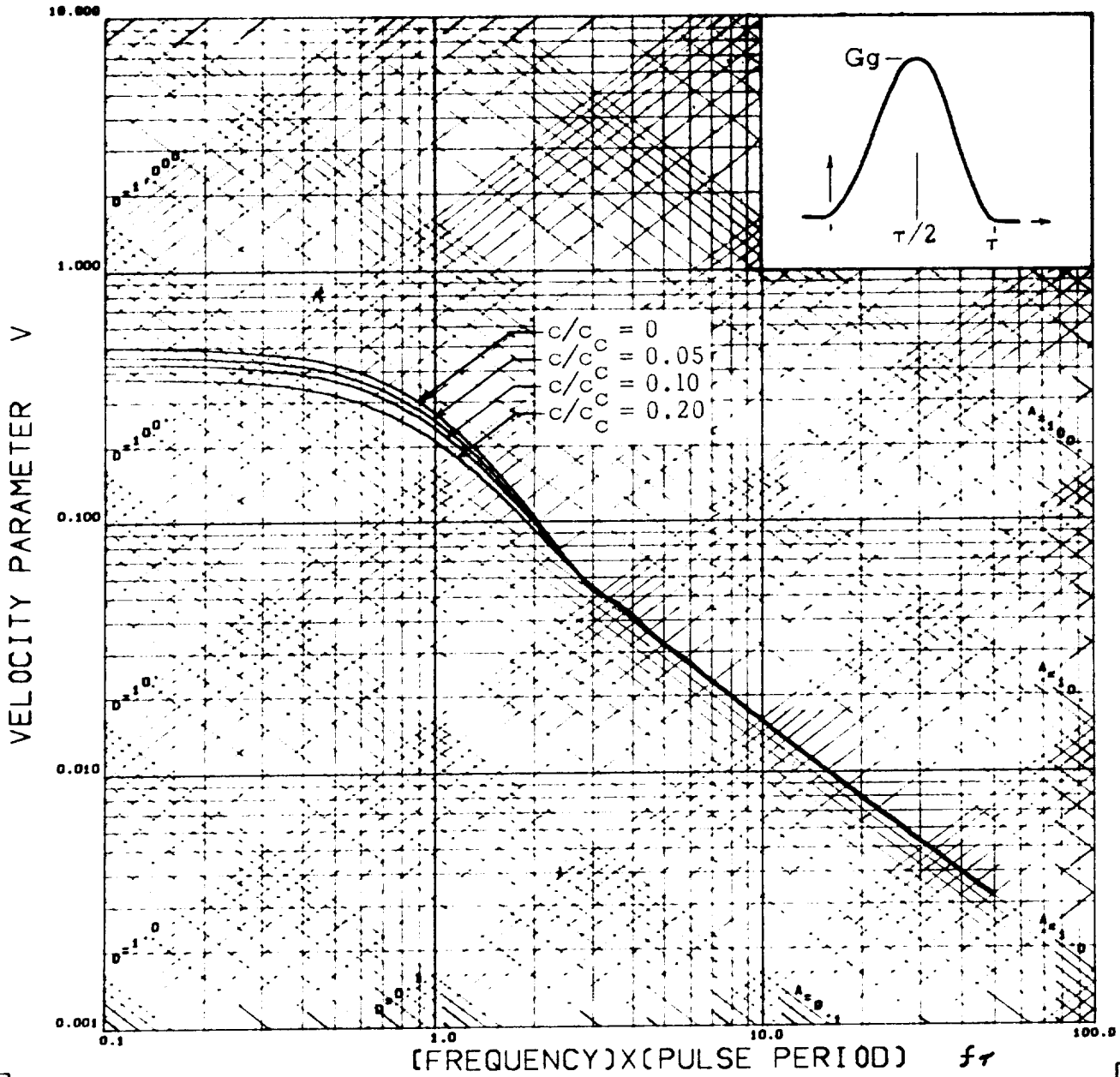



FIGURE II-75 Fourier Phase Spectrum for a Decaying Sinusoidal Acceleration Pulse with Two Superimposed Frequencies of Frequency Ratio = 1:3, Decay Ratios = 1/2 and Component Amplitudes = 0.638 Gg.




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-76 Fourier and Shock Spectra for a Full-Cycle Versed-Sine Acceleration Pulse.




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-77 Damped Shock Spectra for a Full-Cycle Versed-Sine Acceleration Pulse

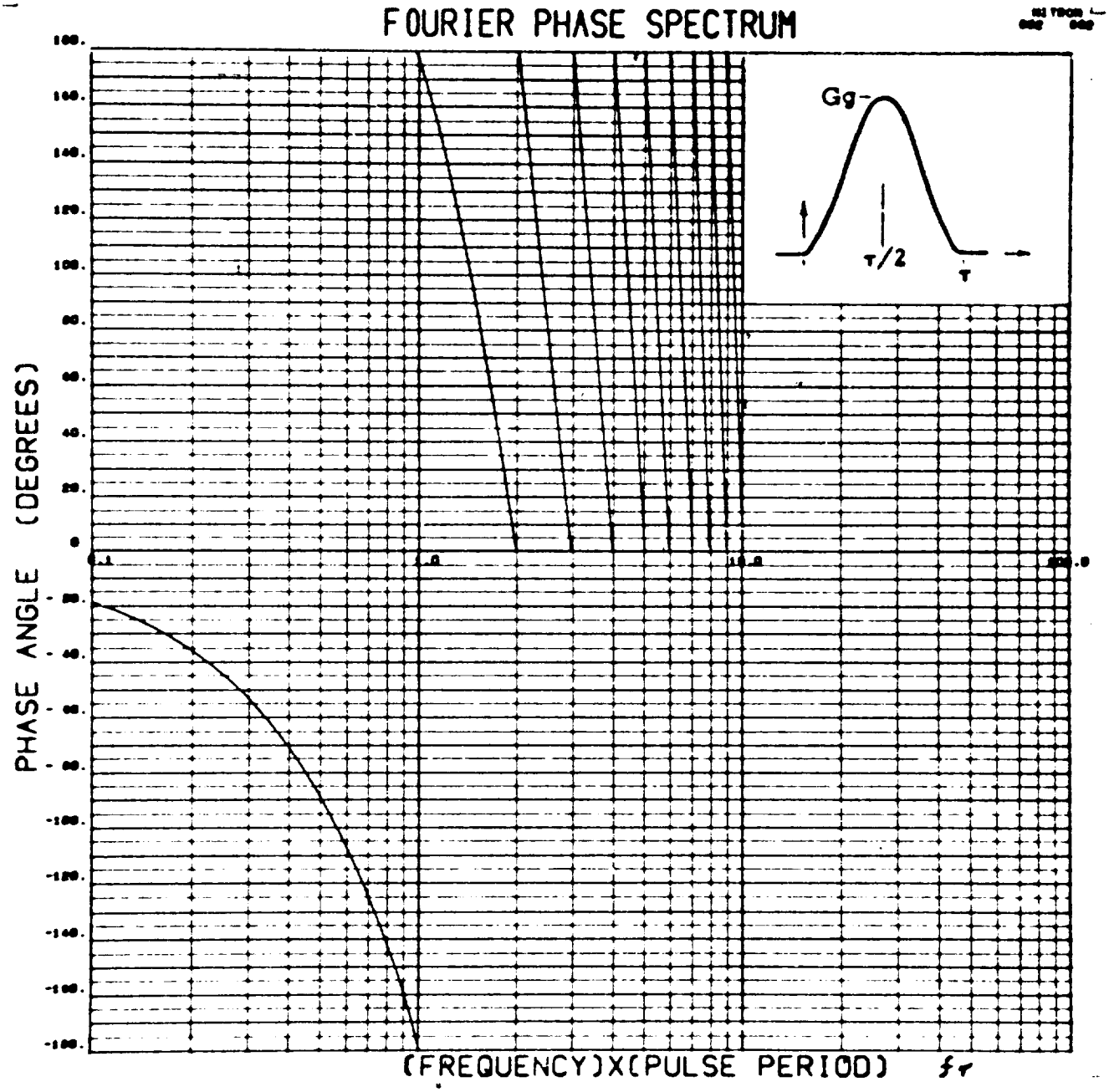
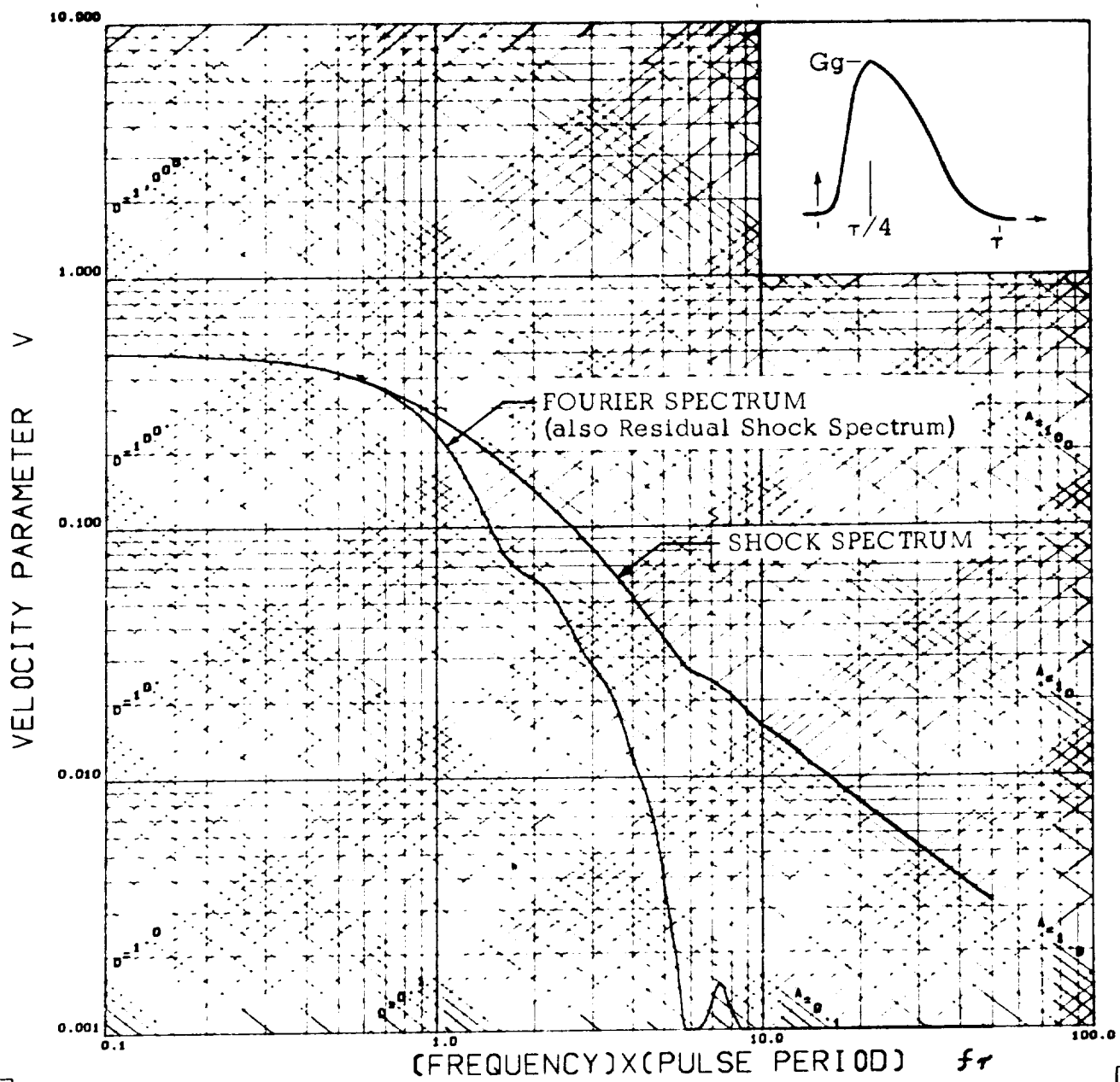
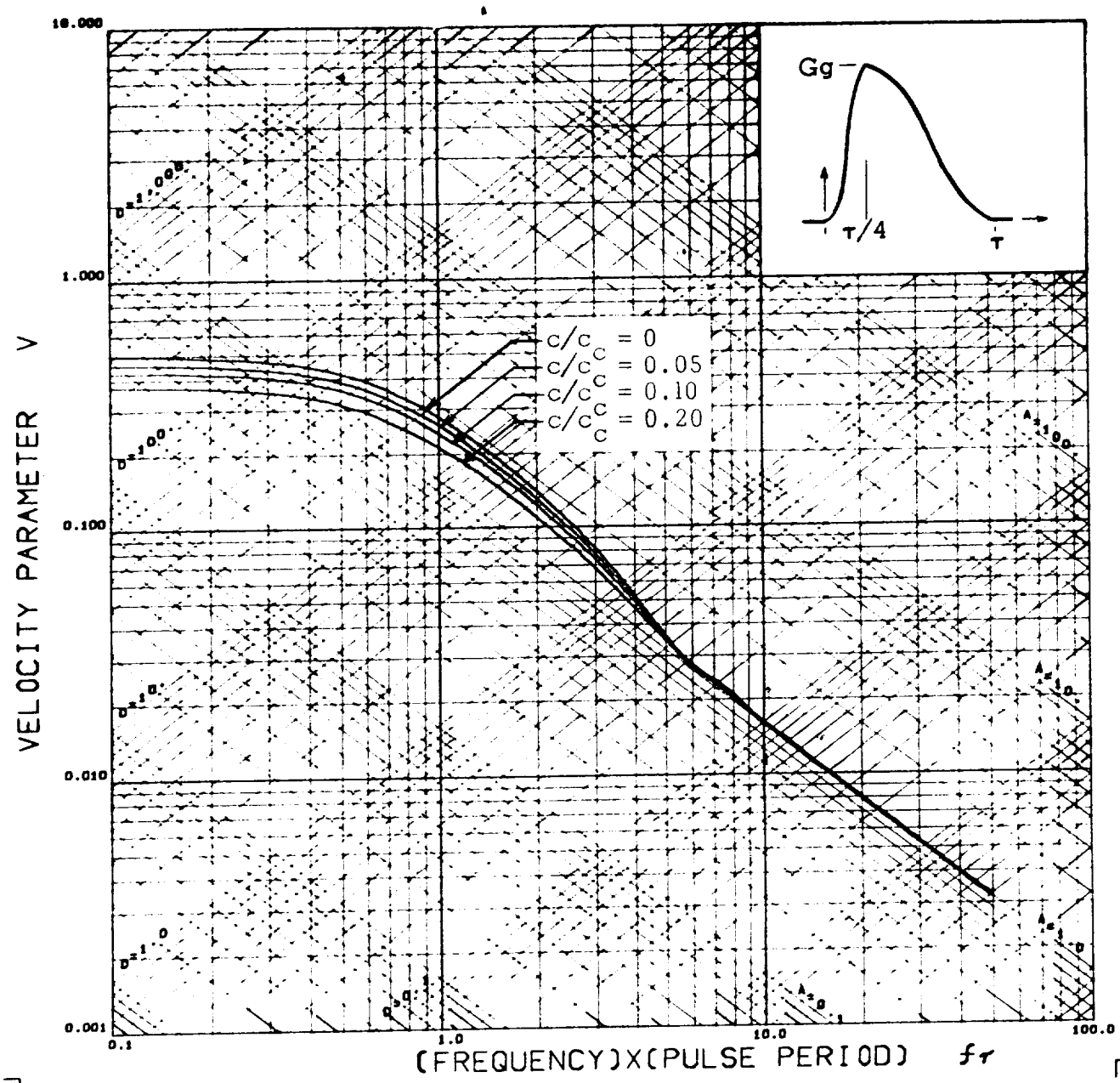



FIGURE II-78 Fourier Phase Spectrum for a Full-Cycle Versed-Sine Acceleration Pulse




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-79 Fourier and Shock Spectra for a Skewed-Verse-Sine Acceleration Pulse. Rise Time = τ/4




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-80 Damped Shock Spectra for a Skewed-Verse-Sine Acceleration Pulse. Rise Time = $\tau/4$

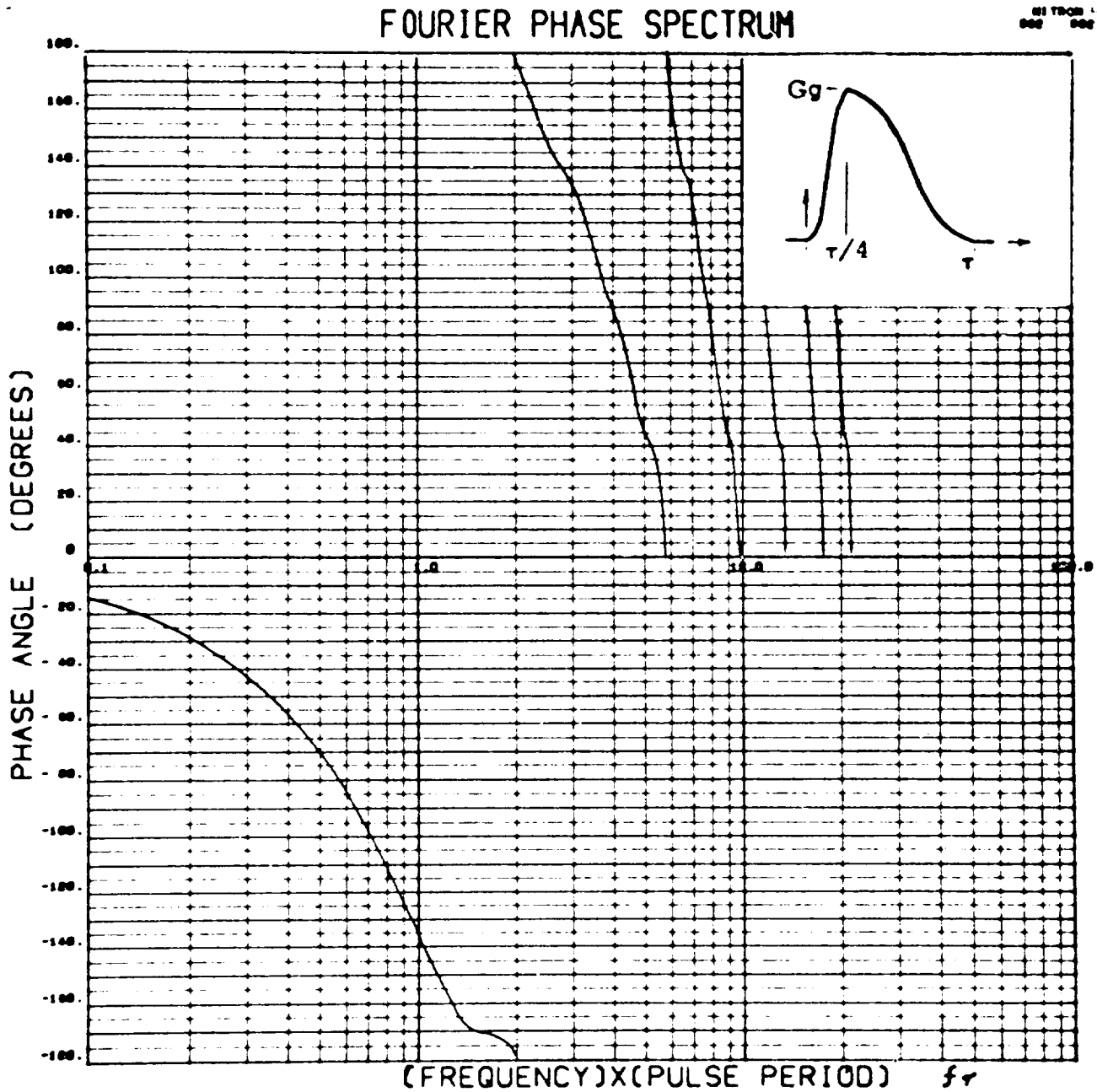
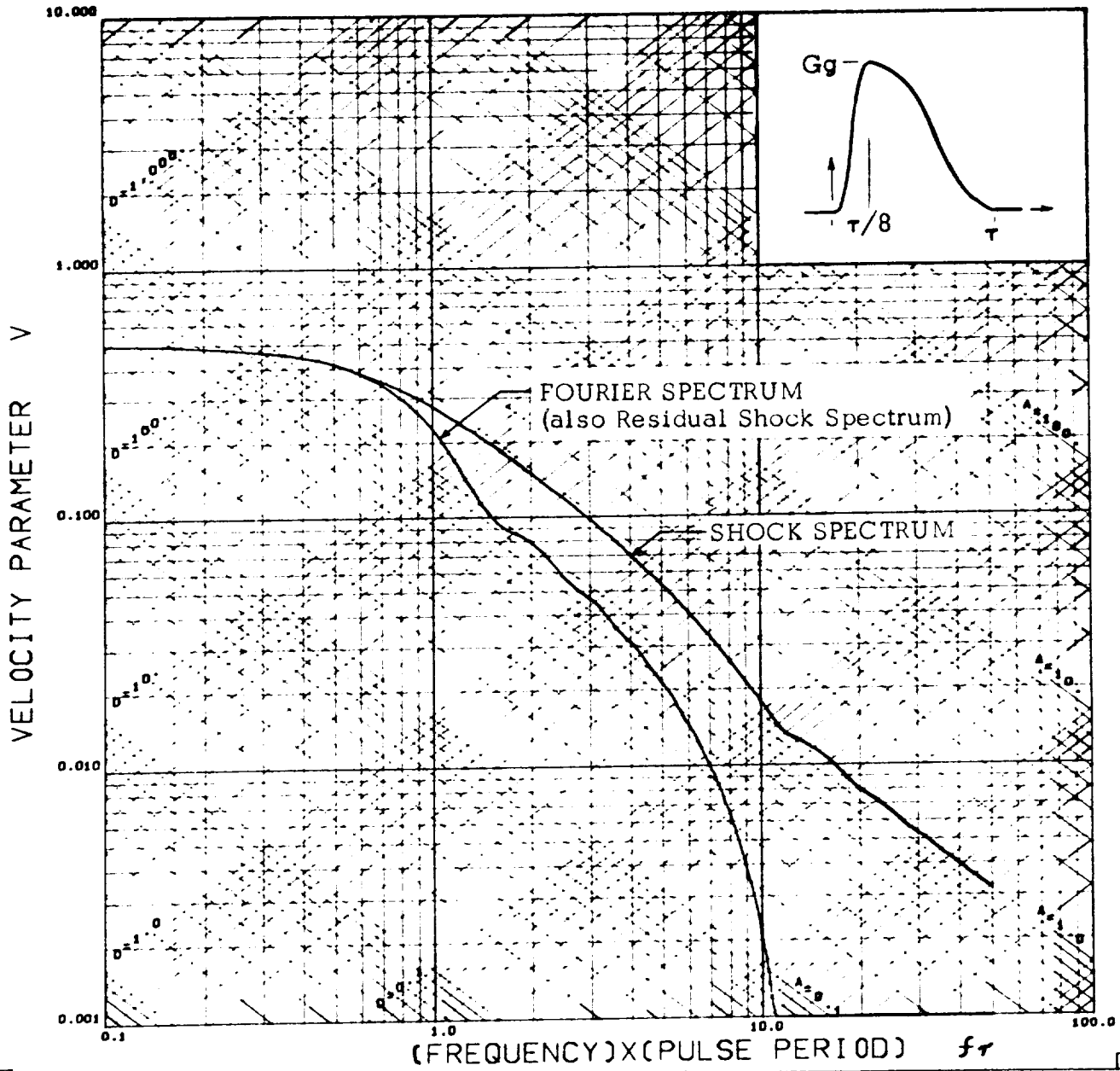
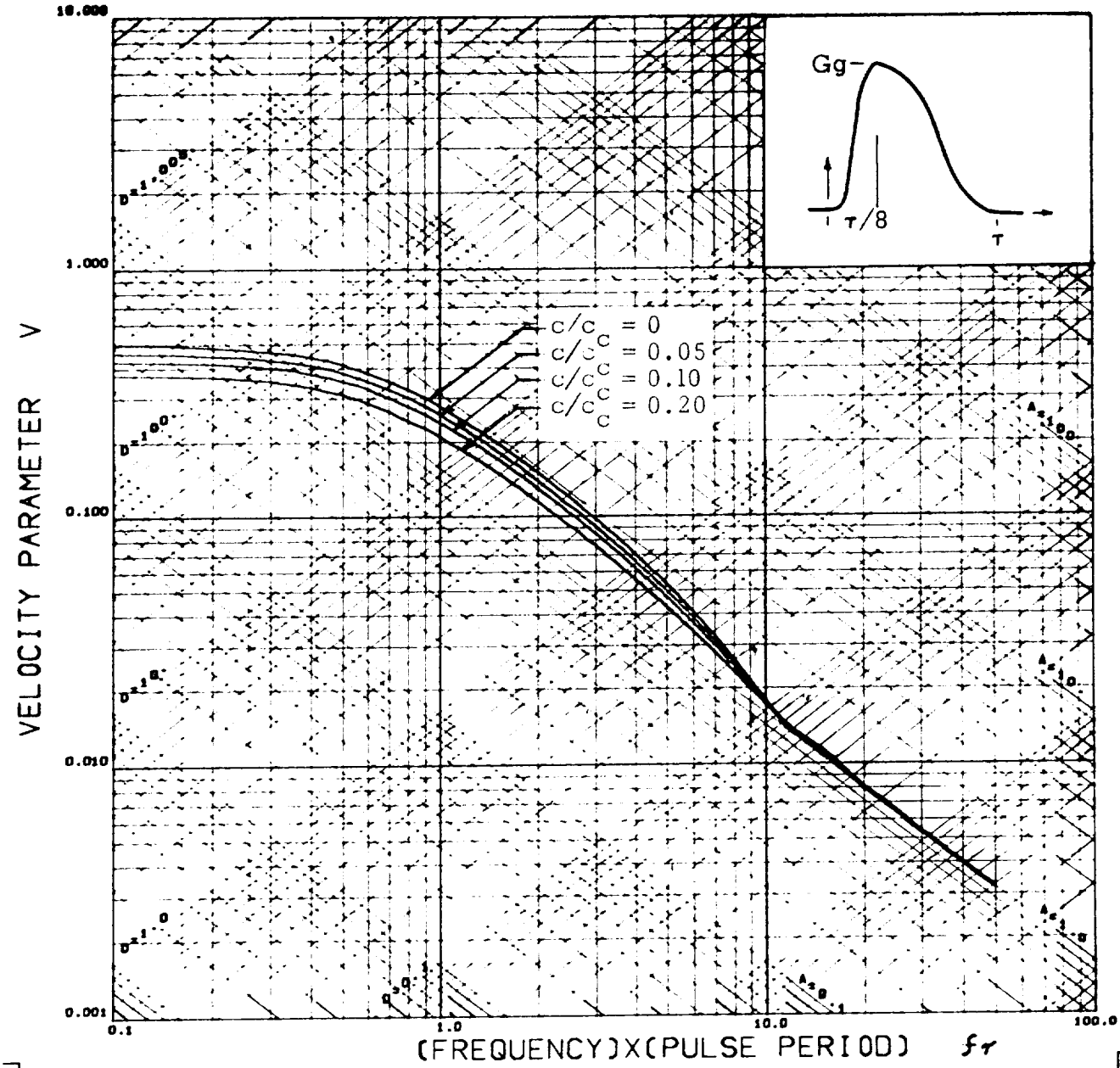



FIGURE II-81 Fourier Phase Spectrum for a Skewed-Verse-Sine Acceleration Pulse. Rise Time = τ/4




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-82 Fourier and Shock Spectra for a Skewed-Verse-Sine Acceleration Pulse. Rise Time = τ/8




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-83 Damped Shock Spectra for a Skewed-Verse-Sine Acceleration Pulse. Rise Time = $\tau/8$

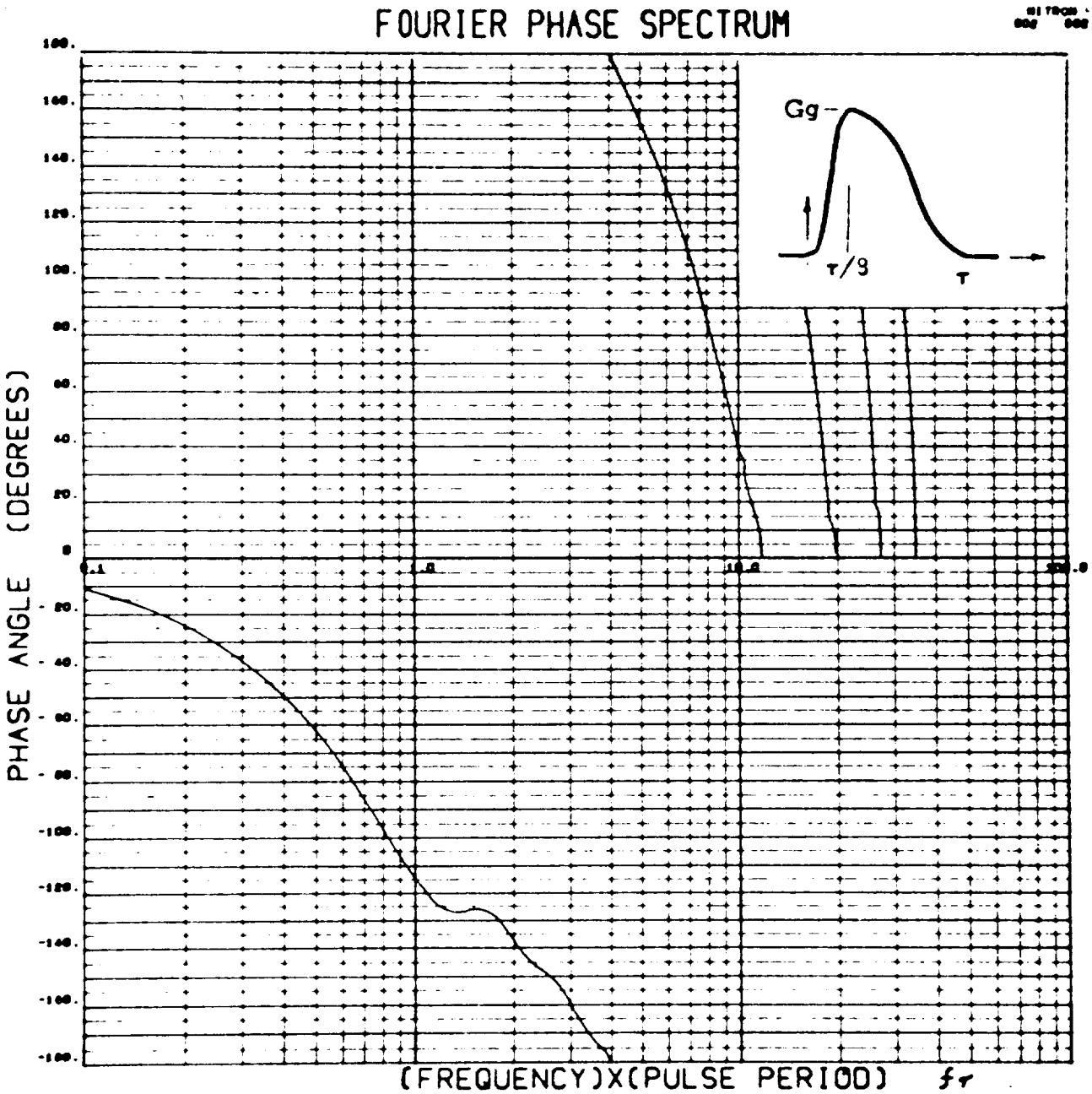
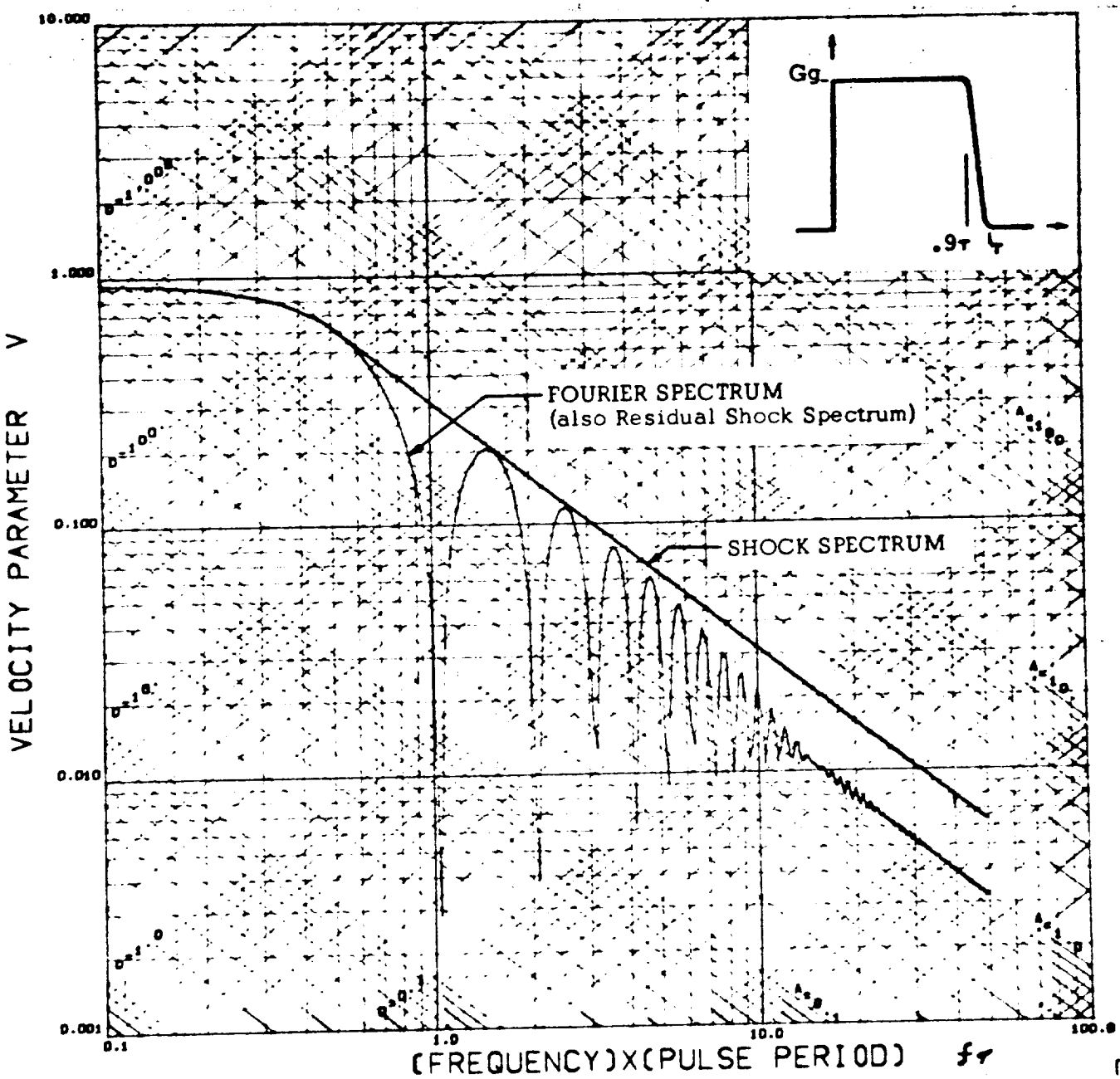
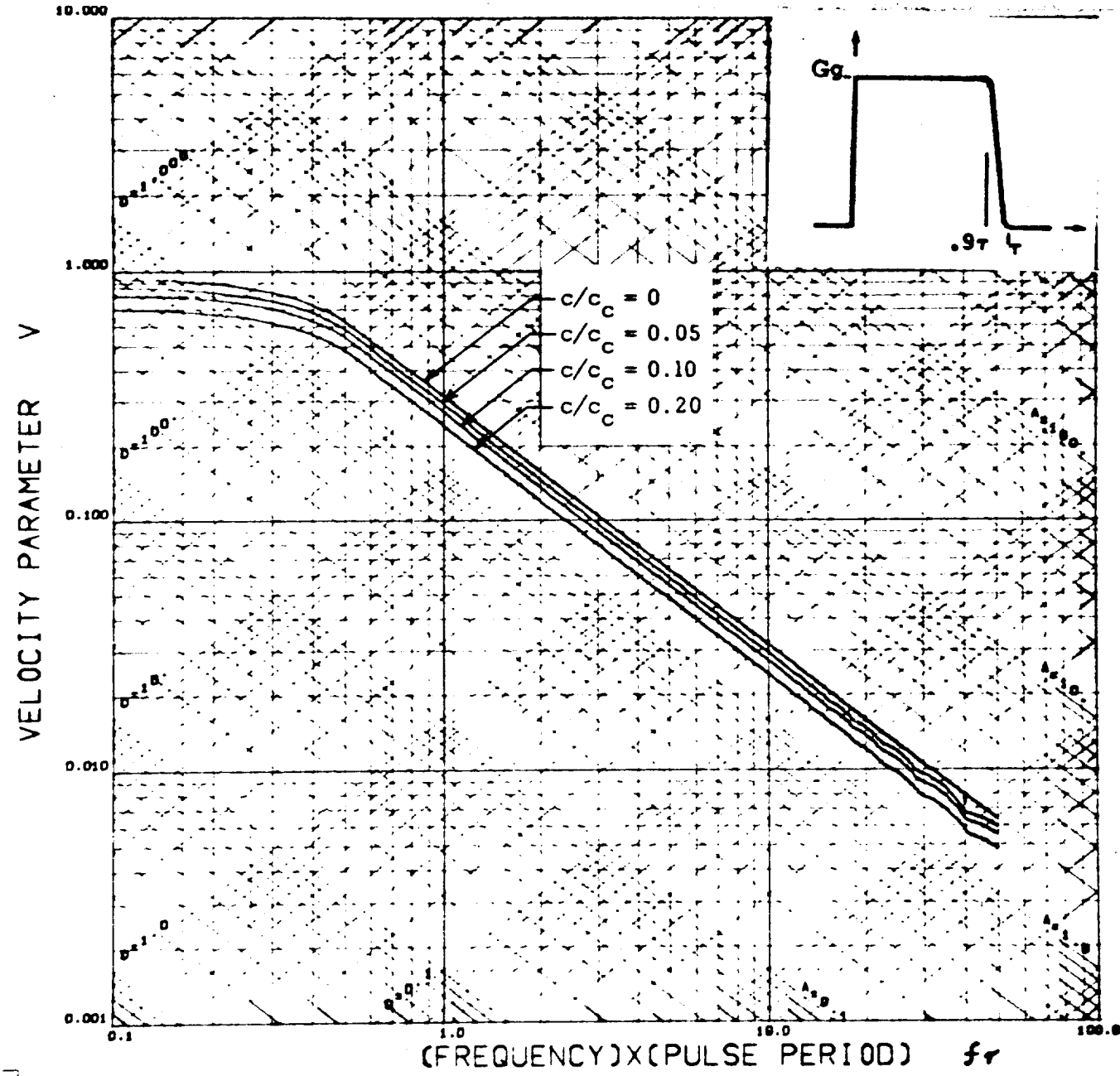



FIGURE II-84 Fourier Phase Spectrum for a Skewed-Verse-Sine Acceleration Pulse. Rise Time = τ/8




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-85 Fourier and Shock Spectra for a Step Acceleration Pulse With Versed-Sine Decay. Decay Time = 0.1τ




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-86 Damped Shock Spectra for a Step Acceleration Pulse With Versed-Sine Decay. Decay Time - 0.1τ

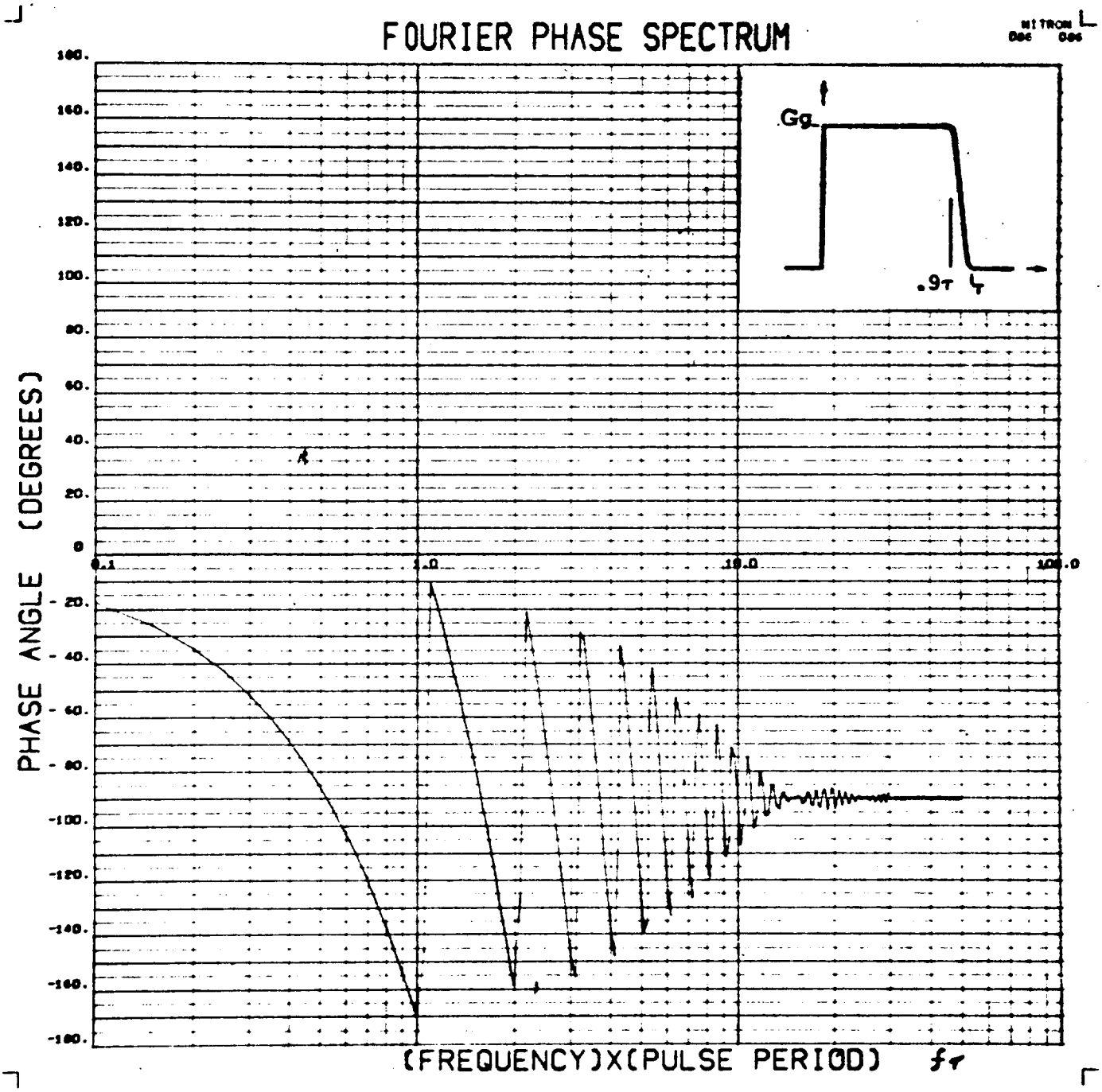
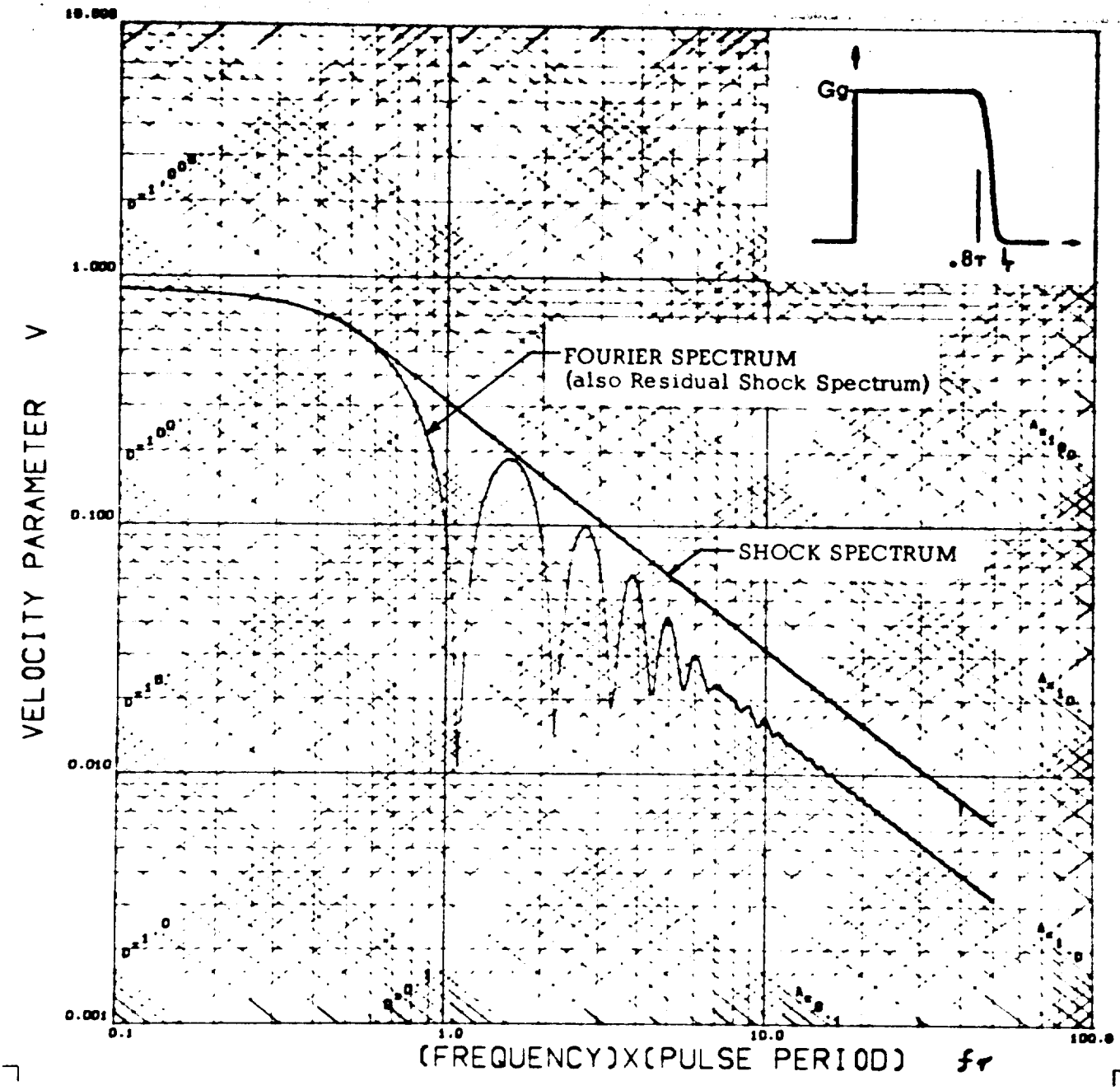
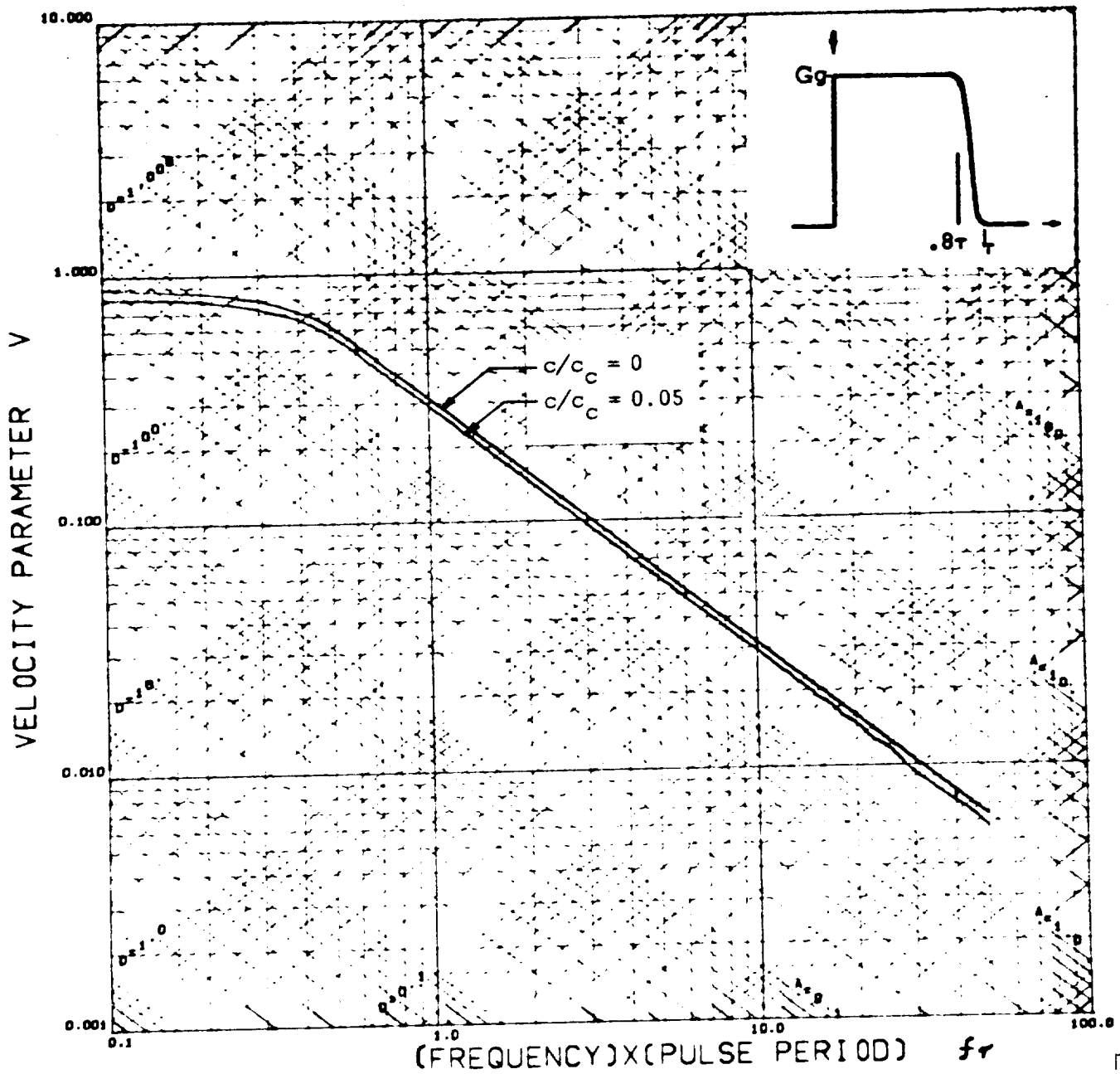



FIGURE II-87 Fourier Phase Spectrum for a Step Acceleration Pulse With Versed-Sine Decay. Decay Time = 0.1τ




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-88 Fourier and Shock Spectra for a Step Acceleration Pulse With Versed-Sine Decay. Decay Time = 0.2 τ




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-89 Damped Shock Spectra for a Step Acceleration Pulse With Versed-Sine Decay. Decay Time = 0.2 τ

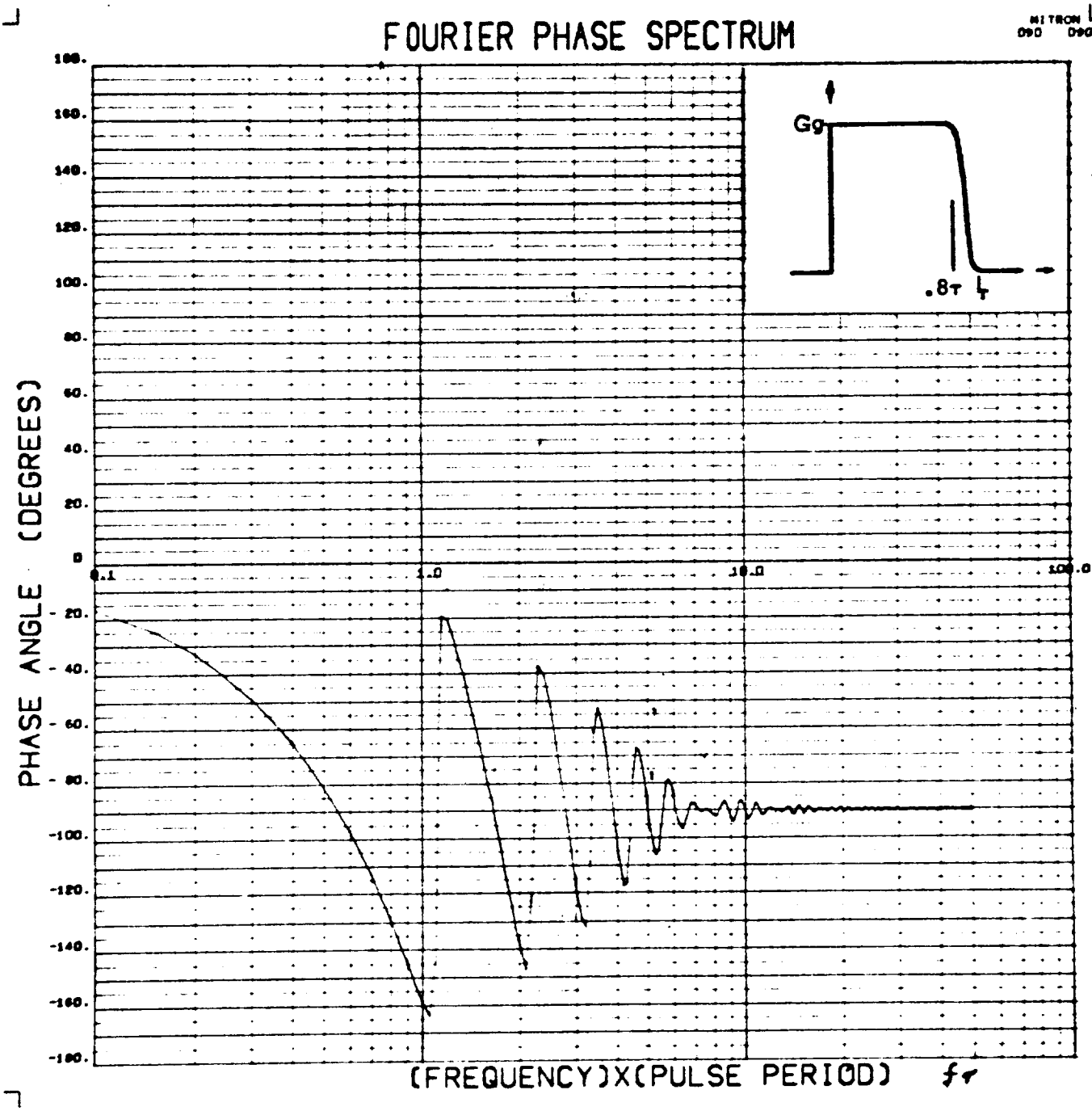
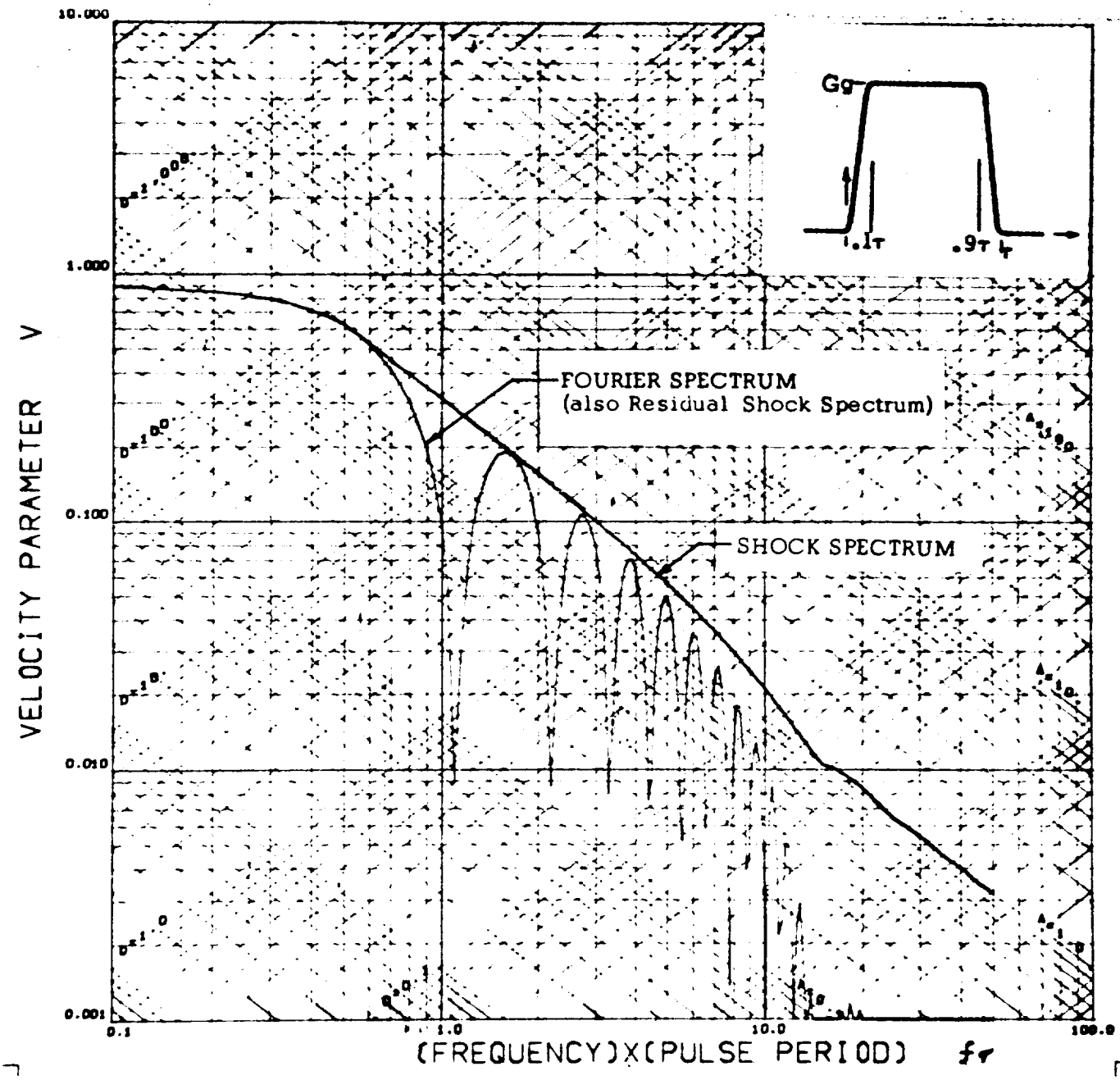
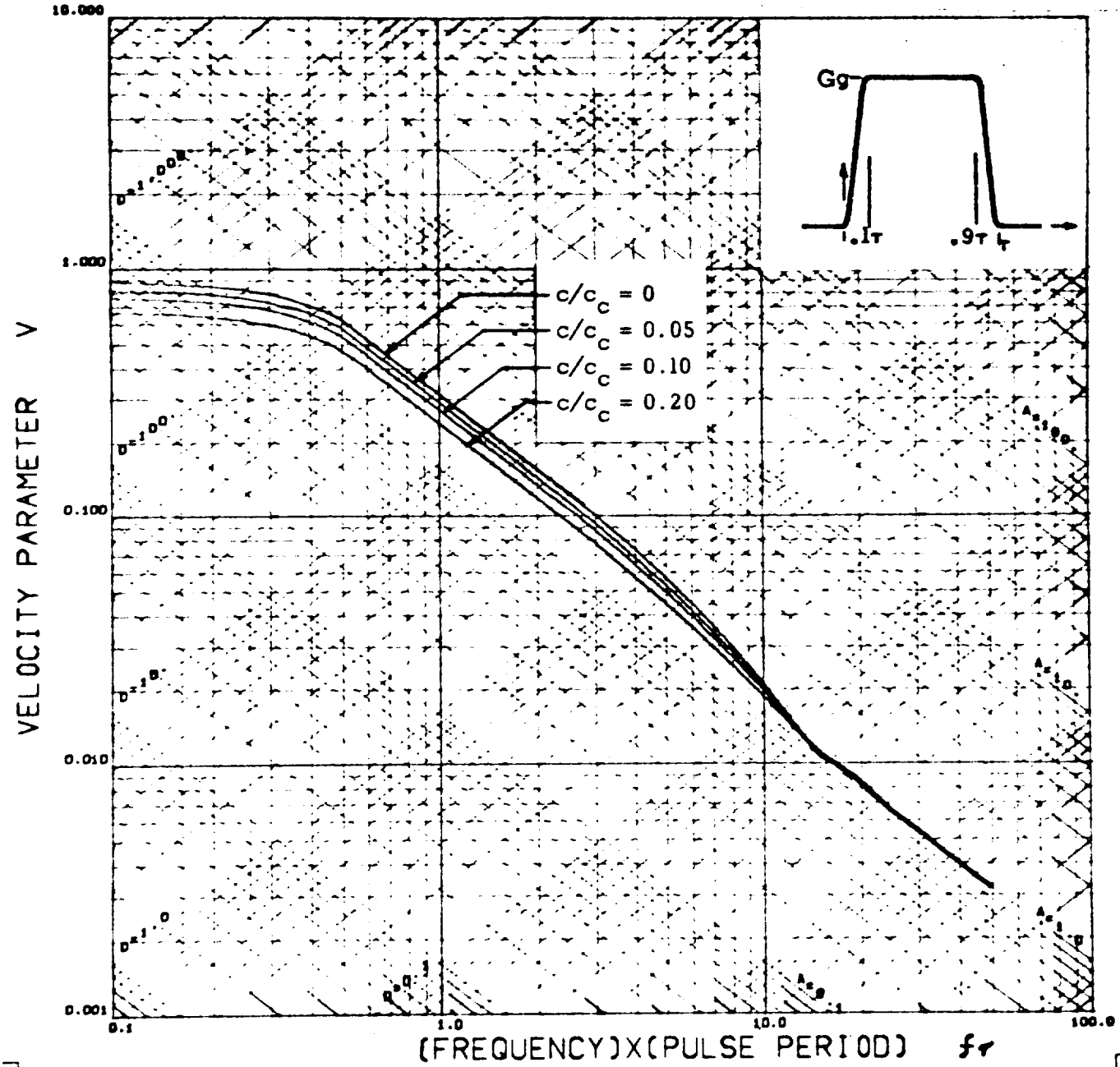



FIGURE II-90 Fourier Phase Spectrum for a Step Acceleration Pulse With Versed-Sine Decay. Decay Time = 0.2 τ




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE 11-91 Fourier and Shock Spectra for a Versed-Sine Symmetrical Acceleration Pulse with Dwell. Rise Time = Decay Time = 0.1τ




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE 11-92 Damped Shock Spectra for a Versed-Sine Symmetrical Acceleration Pulse with Dwell. Rise Time = Decay Time = 0.1τ

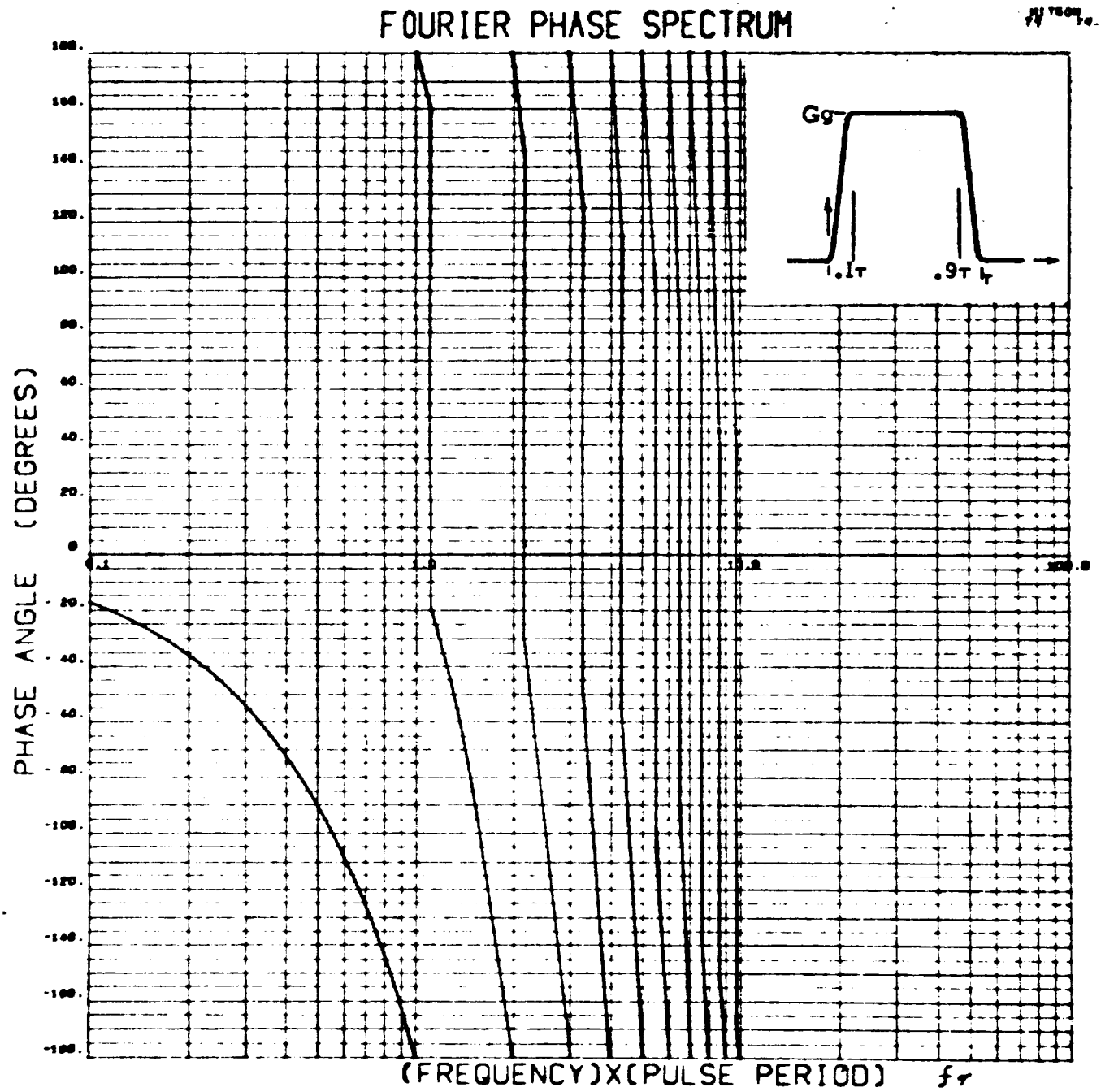
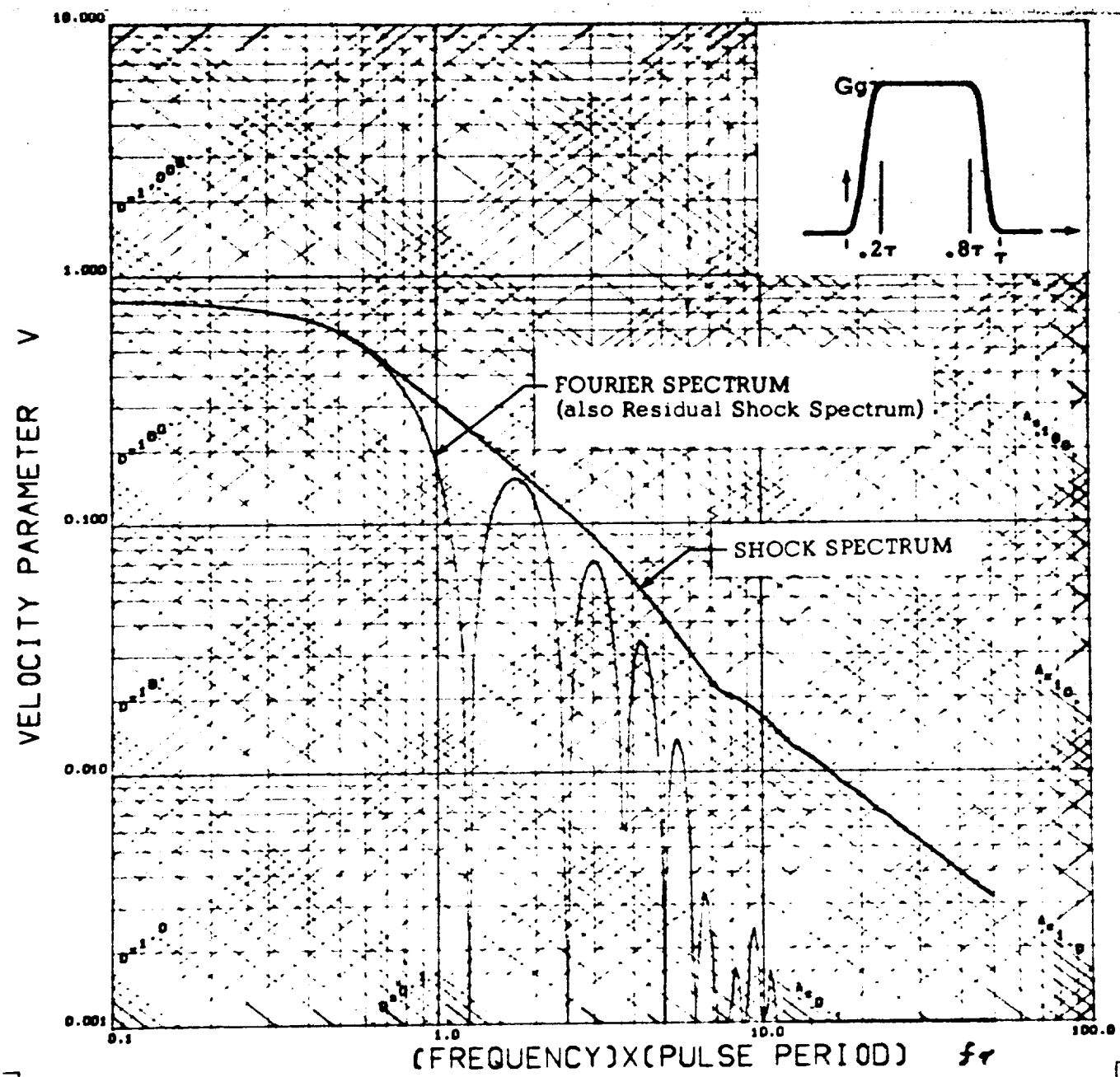
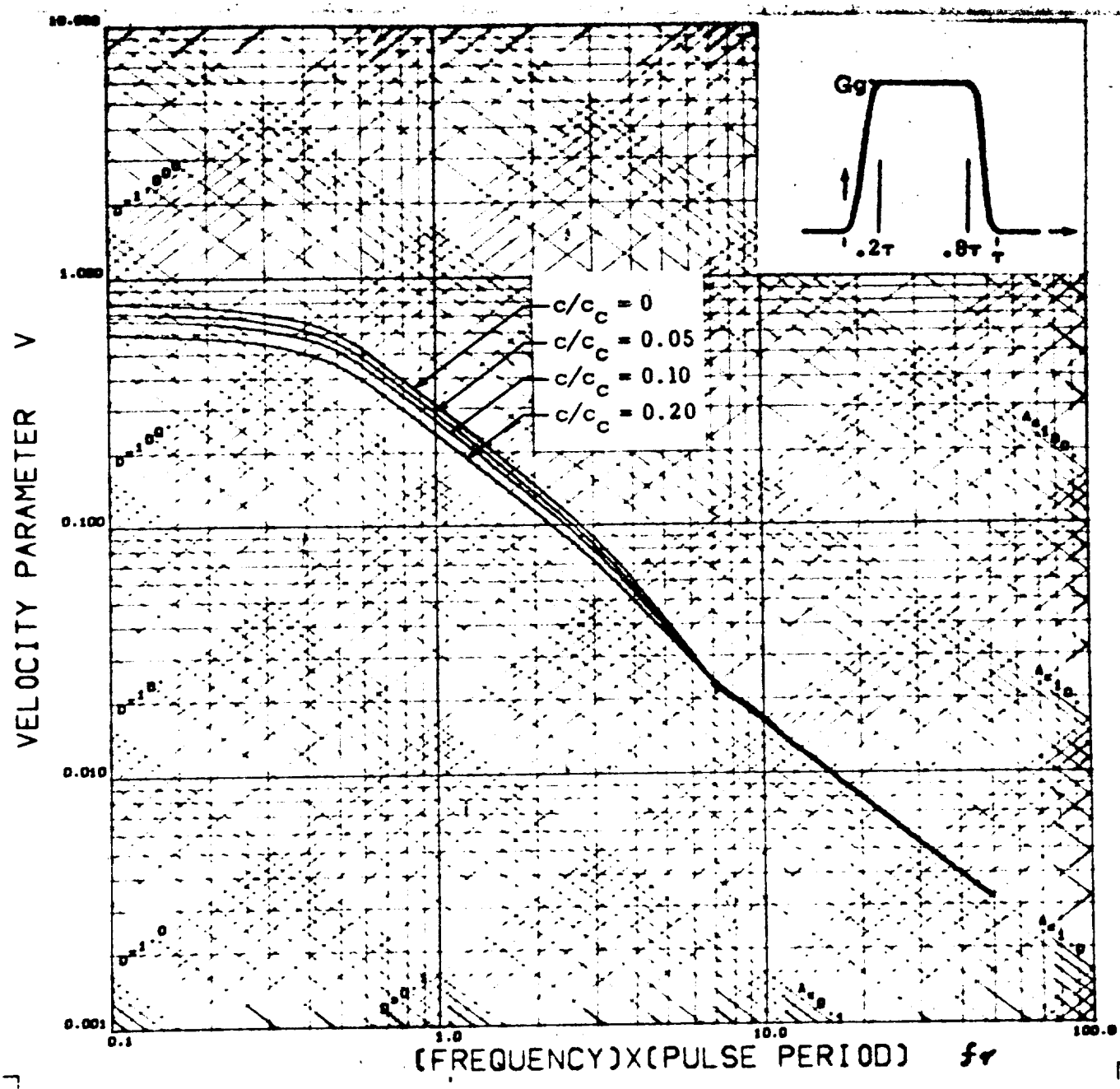



FIGURE 11-93 Fourier Phase Spectrum for a Versed-Sine Symmetrical Acceleration Pulse with Dwell. Rise Time = Decay Time = 0.1τ




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE 11-94 Fourier and Shock Spectra for a Versed-Sine Symmetrical Acceleration Pulse with Dwell. Rise Time = Decay Time = 0.2τ




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE 11-95 Damped Shock Spectra for a Versed-Sine Symmetrical Acceleration Pulse with Dwell. Rise Time = Decay Time = 0.2τ

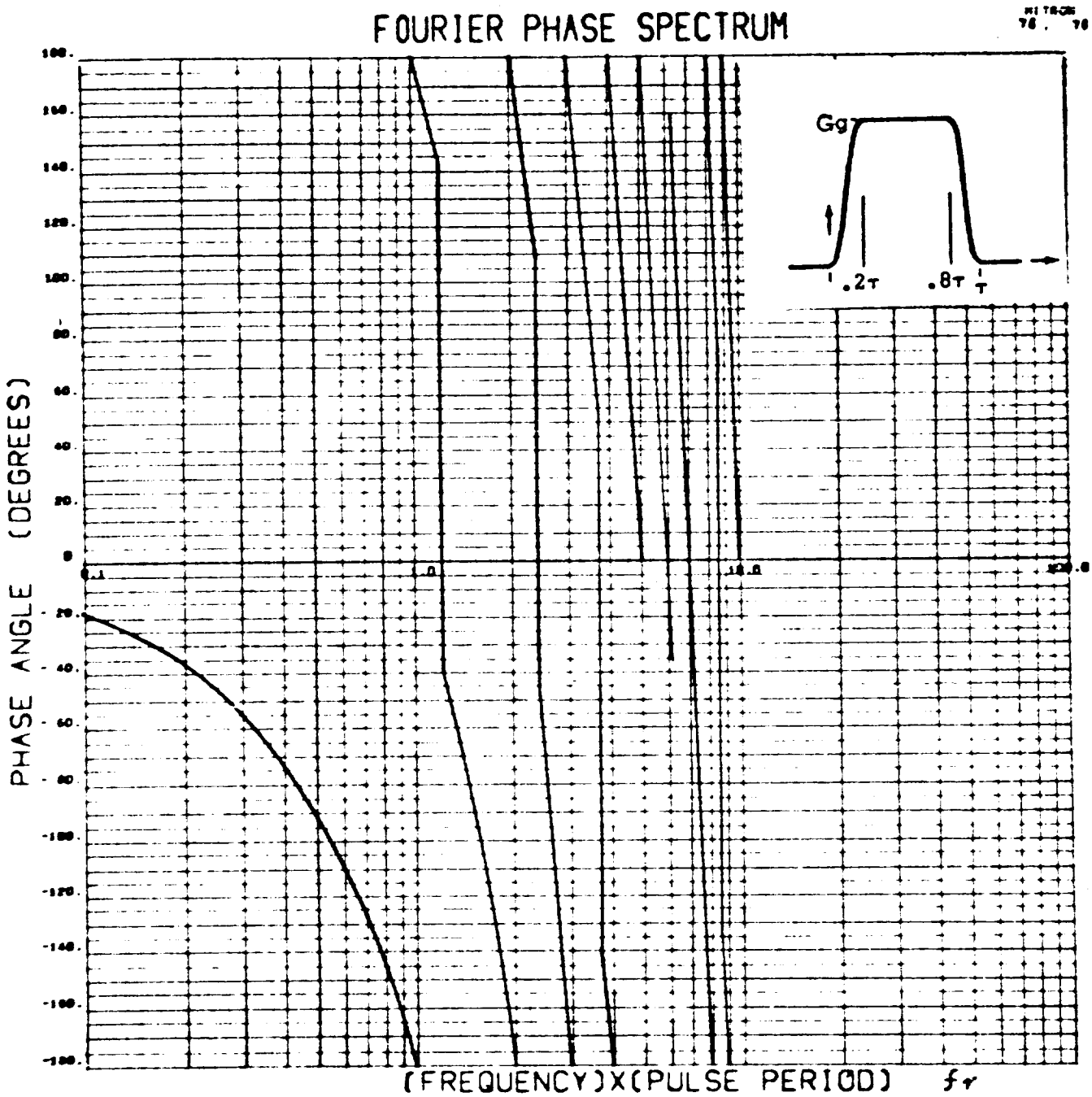
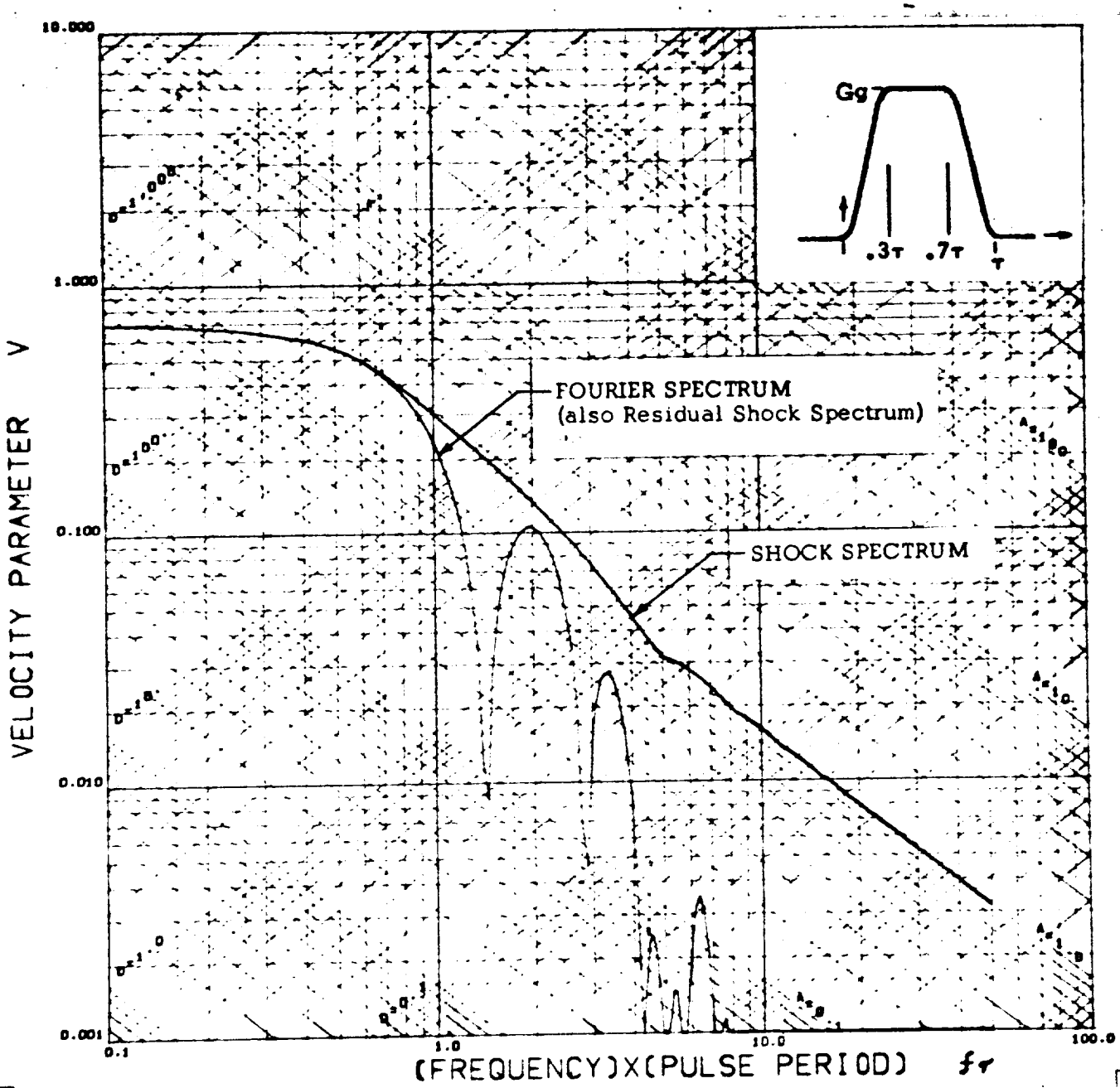
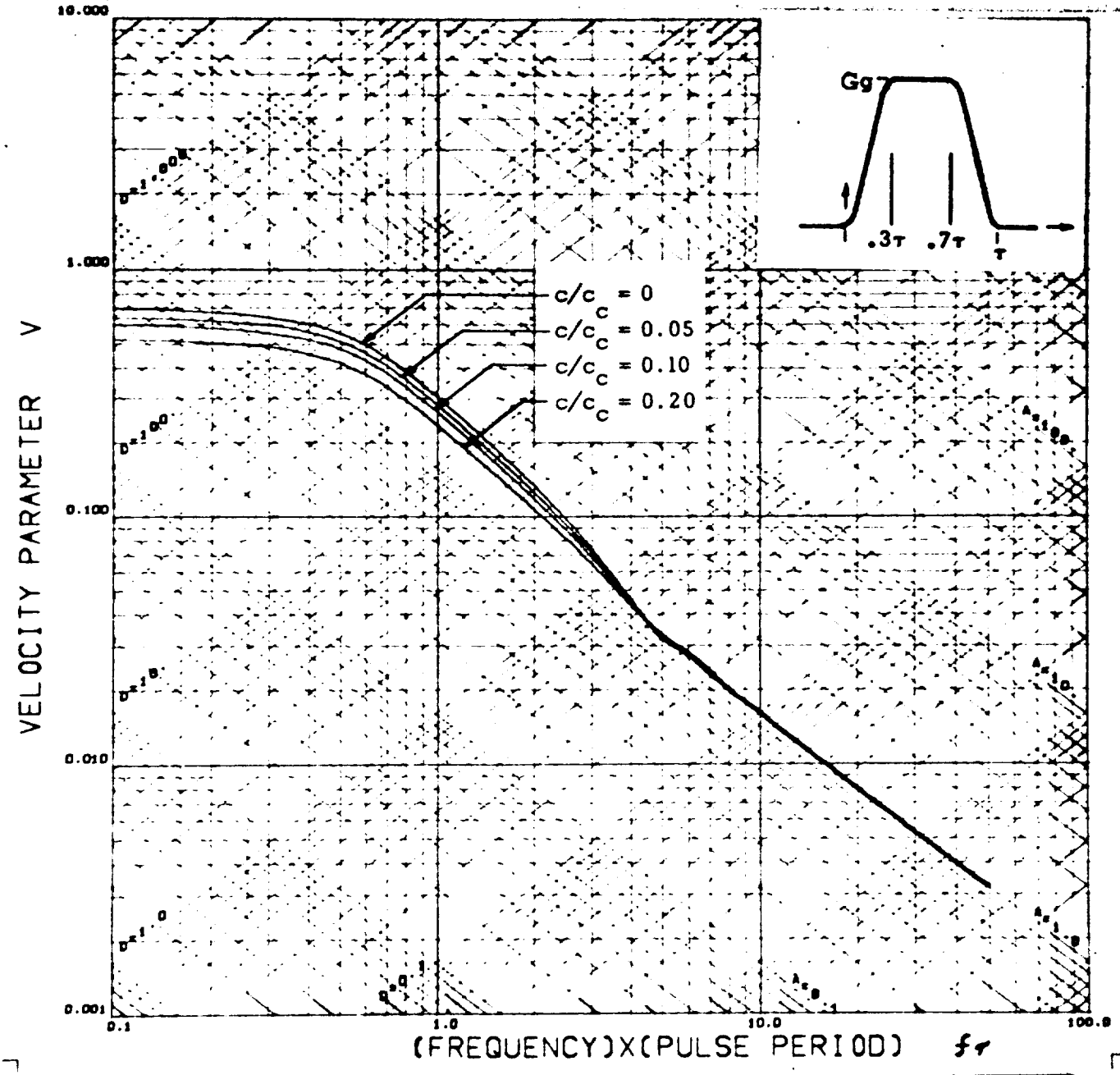



FIGURE 11-96 Fourier Phase Spectrum for a Versed-Sine Symmetrical Acceleration Pulse with Dwell. Rise Time = Decay Time = 0.2τ




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE 11-97 Fourier and Shock Spectra for a Versed-Sine Symmetrical Acceleration Pulse with Dwell. Rise Time = Decay Time = 0.3τ




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE 11-98 Damped Shock Spectra for a Versed-Sine Symmetrical Acceleration Pulse with Dwell. Rise Time = Decay Time = 0.3 τ

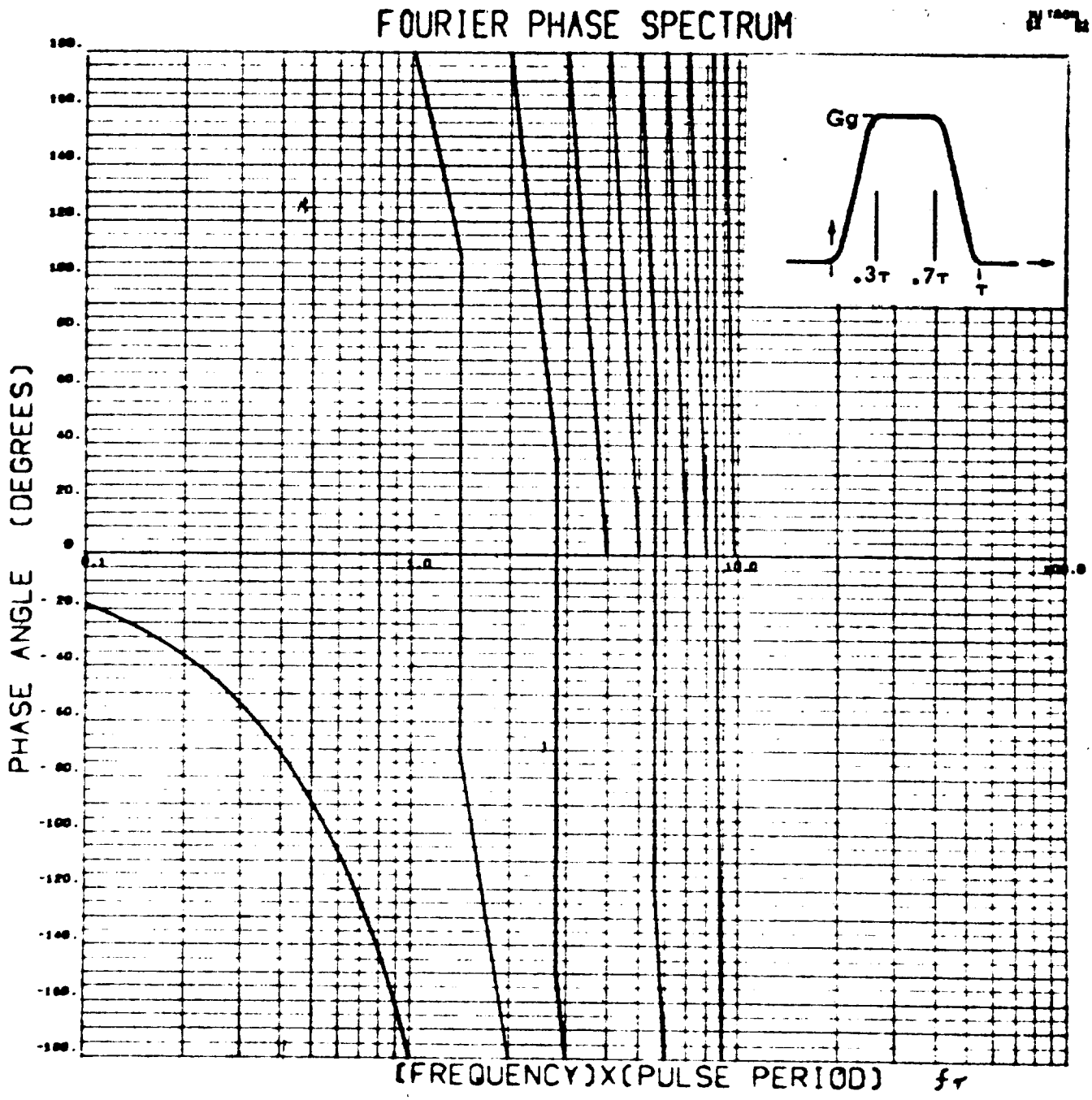
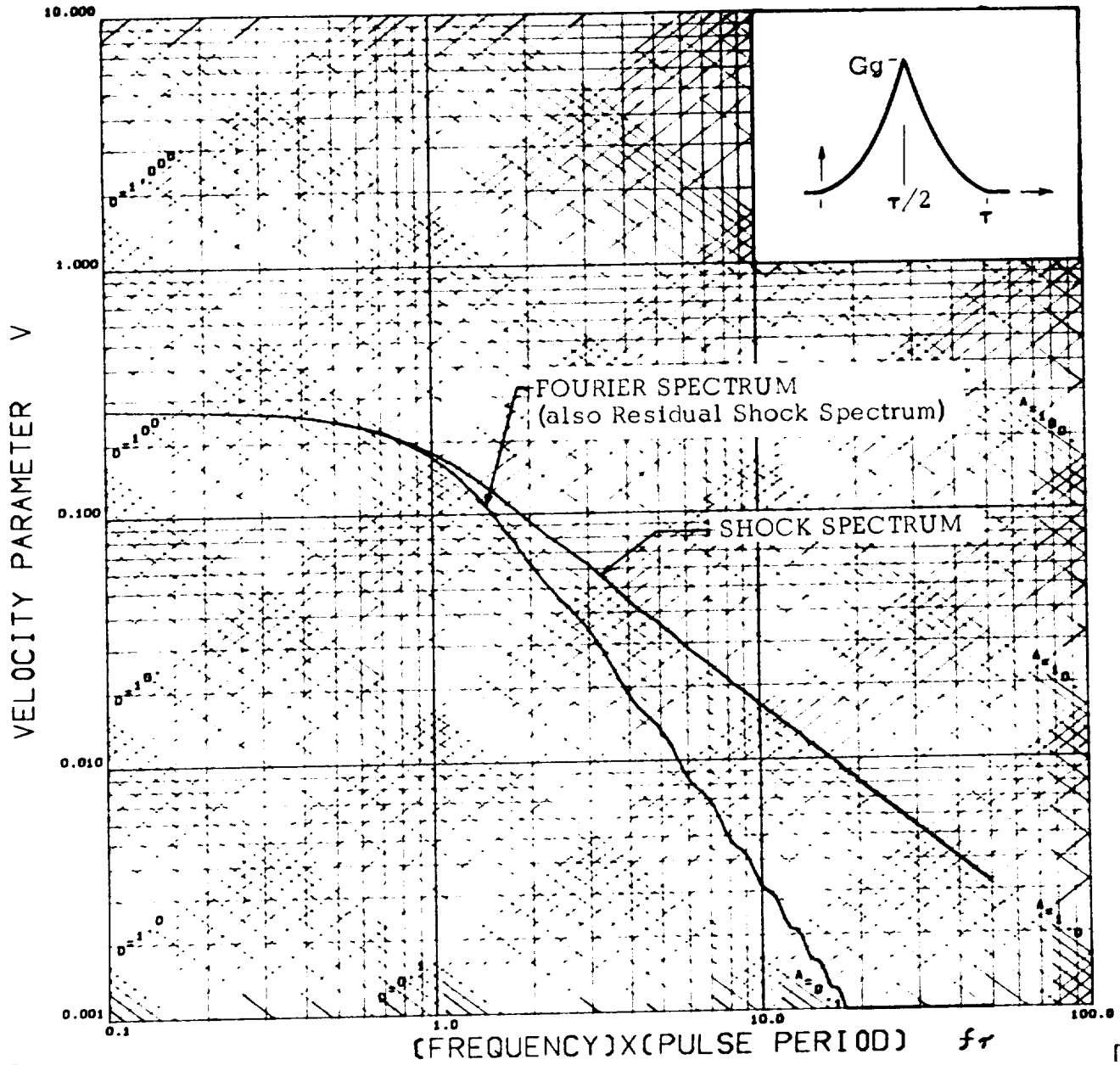
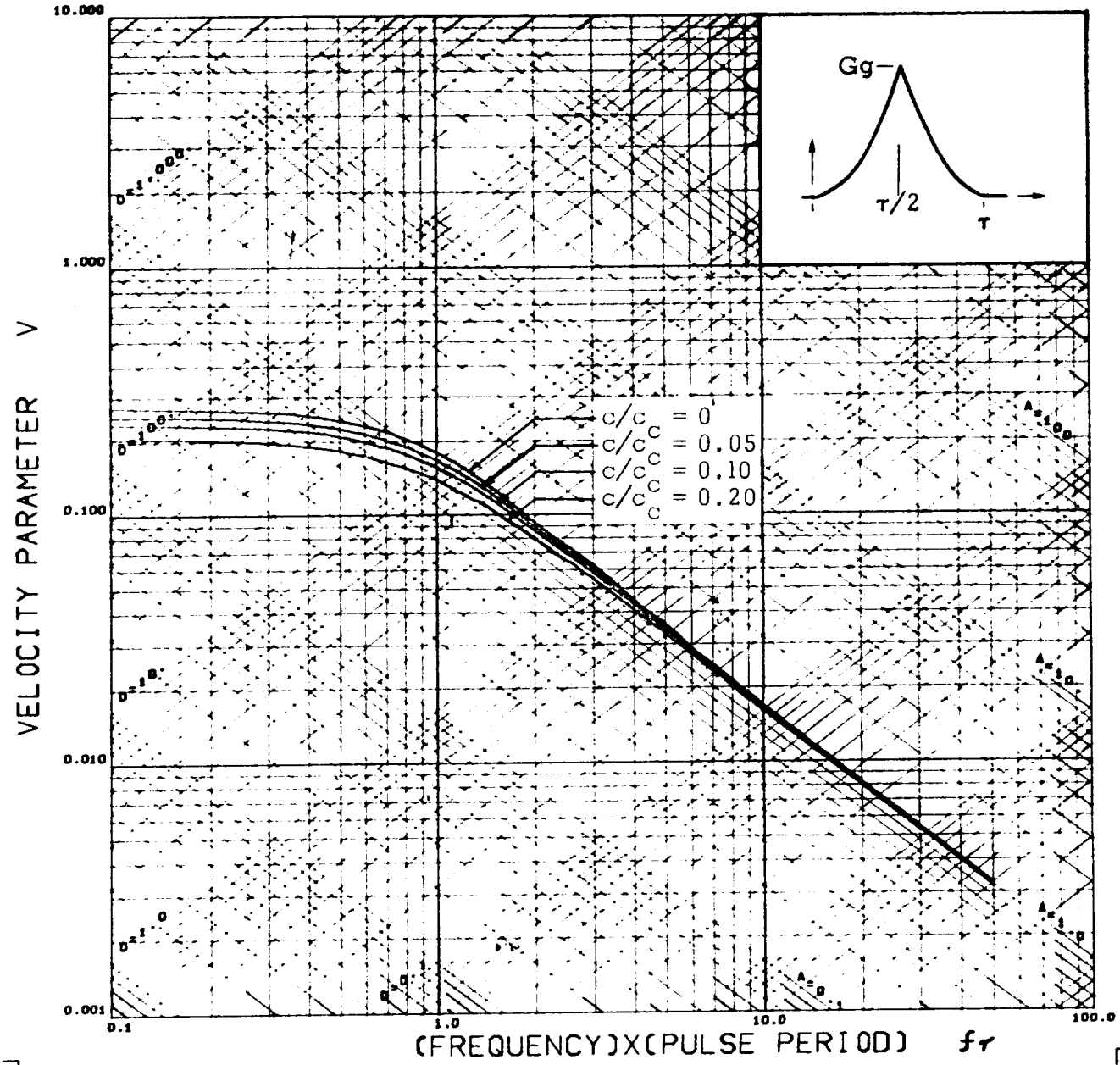



FIGURE 11-99 Fourier Phase Spectrum for a Versed-Sine Symmetrical Acceleration Pulse with Dwell. Rise Time = Decay Time = 0.3τ




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-100 Fourier and Shock Spectra for an Exponential Symmetrical Acceleration Pulse. Rise and Decay of $e^{\pi}$




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity component |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-101 Damped Shock Spectra for an Exponential Symmetrical Acceleration Pulse. Rise and Decay of $e^{\pi t}$

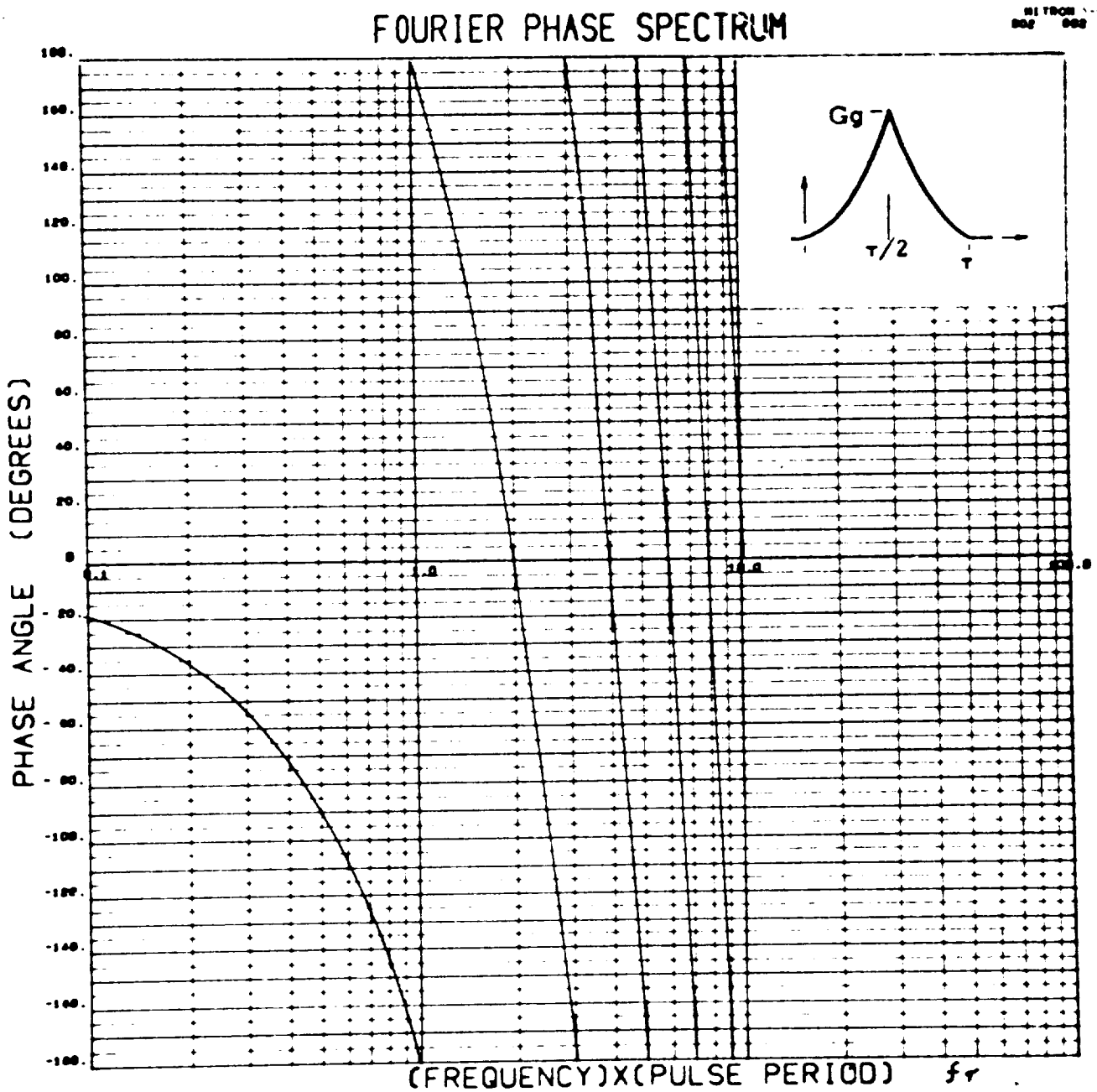
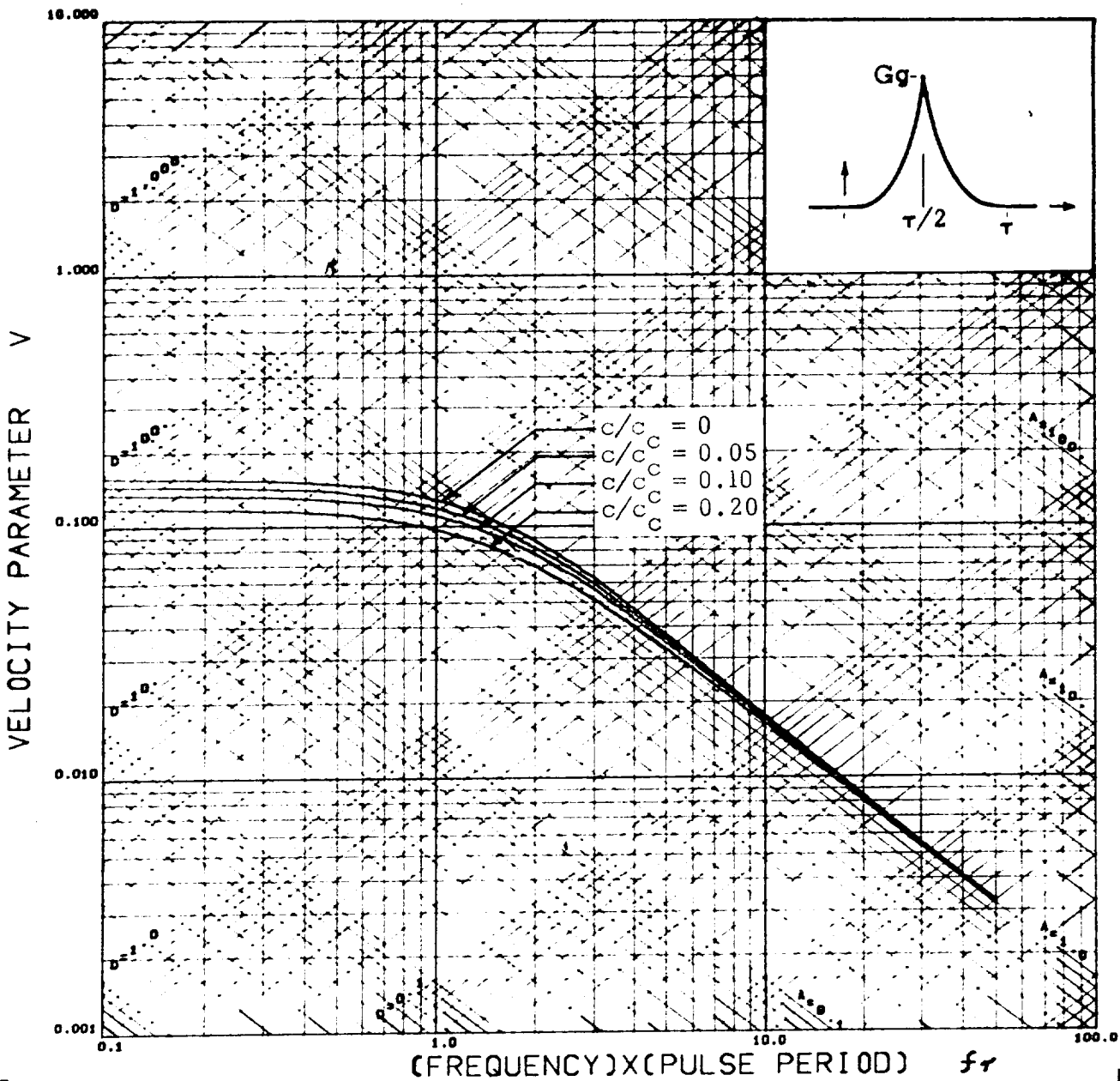
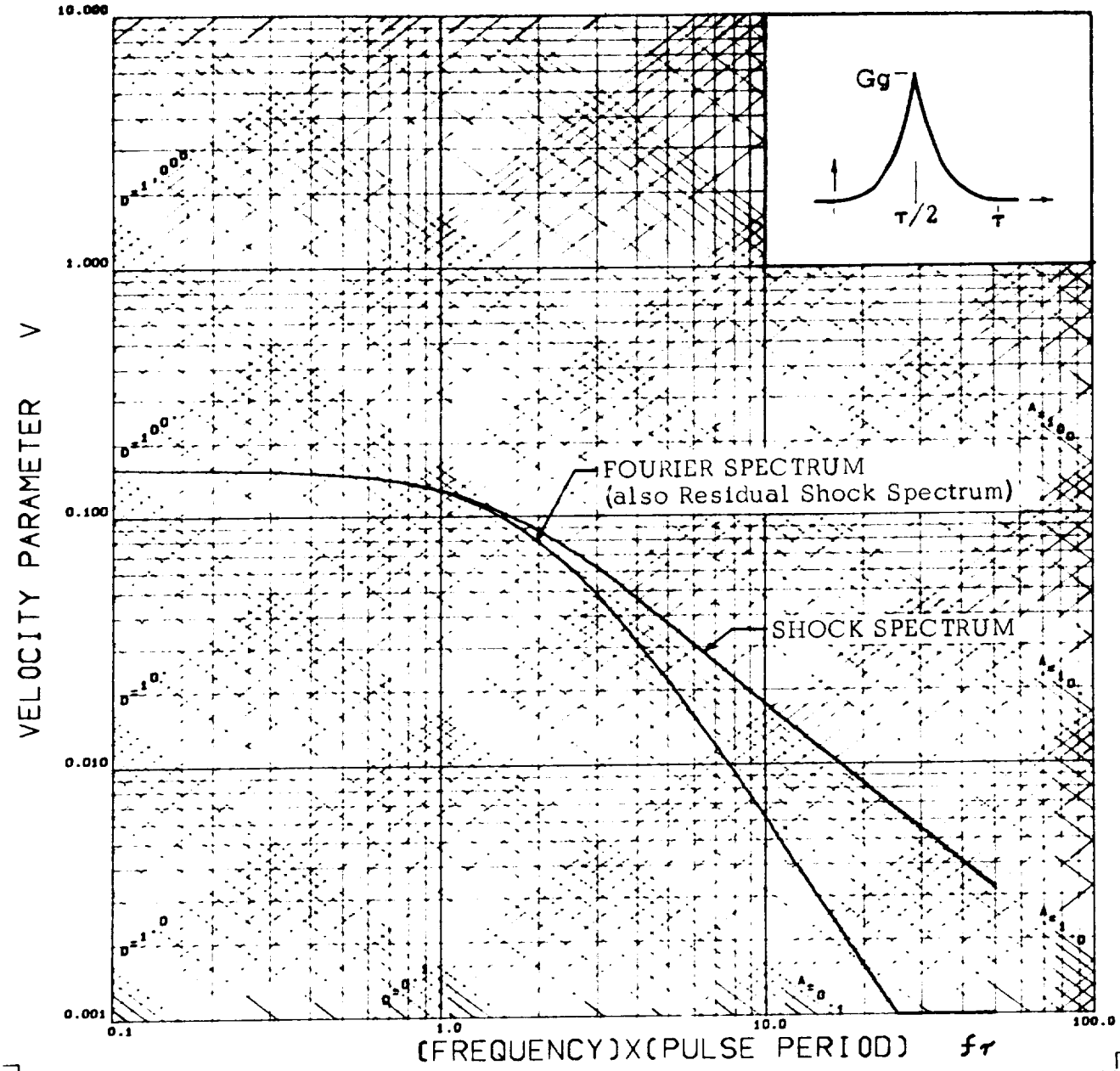



FIGURE II-102 Fourier Phase Spectrum for an Exponential Symmetrical Acceleration Pulse. Rise and Decay of $e^{\pi}$




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-104 Damped Shock Spectra for an Exponential Symmetrical Acceleration Pulse. Rise and Decay of $e^{2\pi}$




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in/sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-103 Fourier and Shock Spectra for an Exponential Symmetrical Acceleration Pulse. Rise and Decay of $e^{2\pi}$

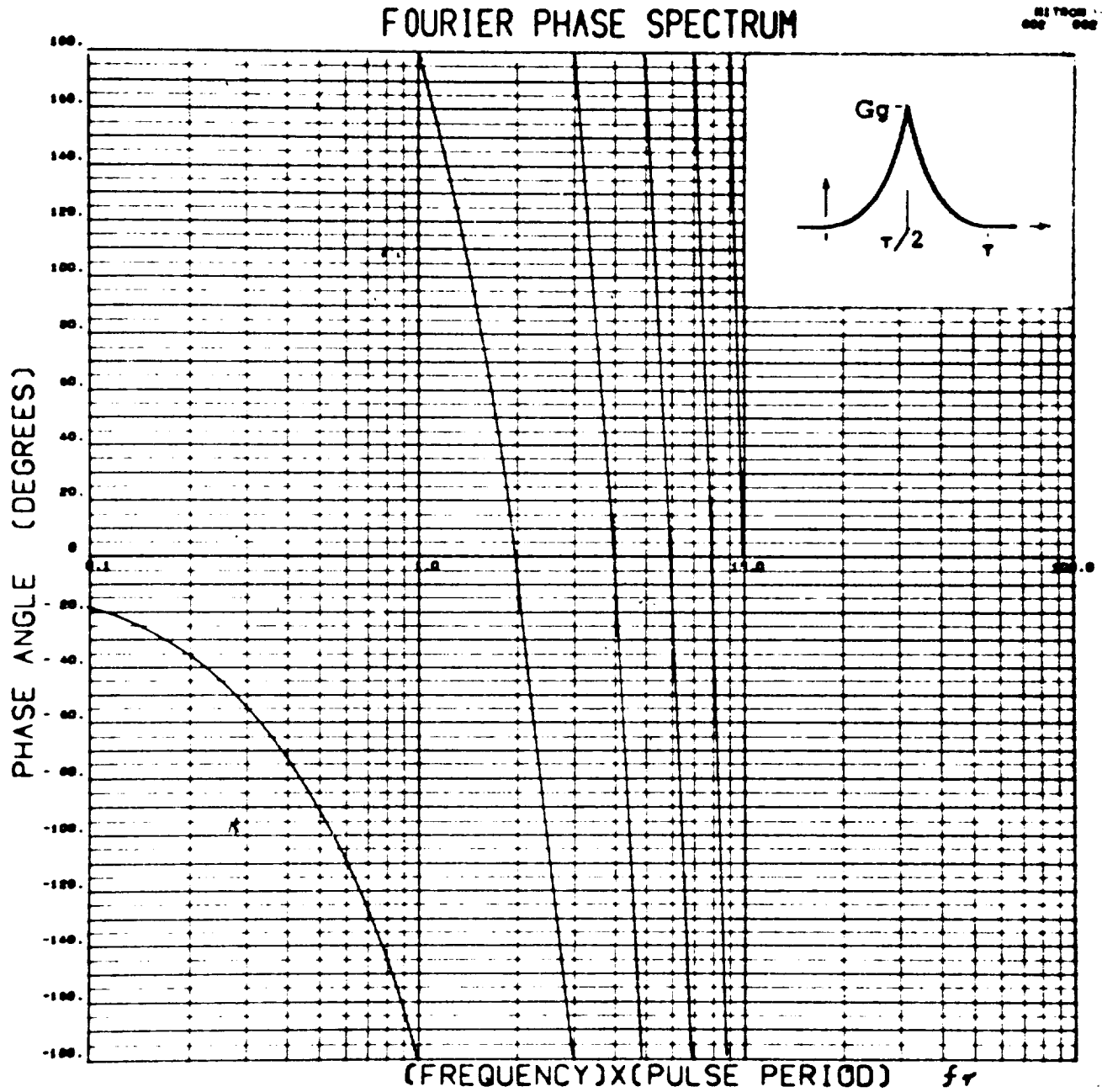
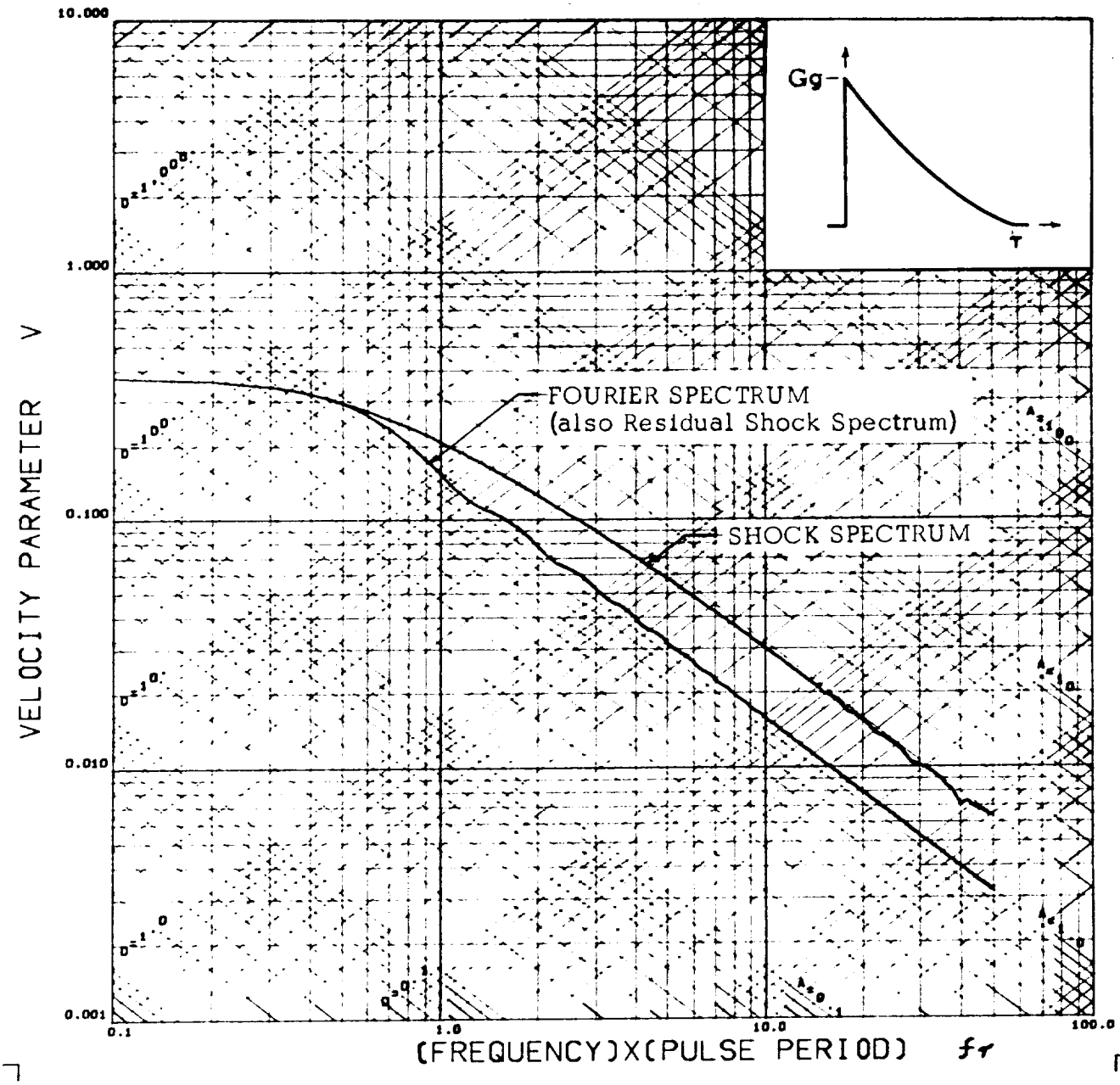
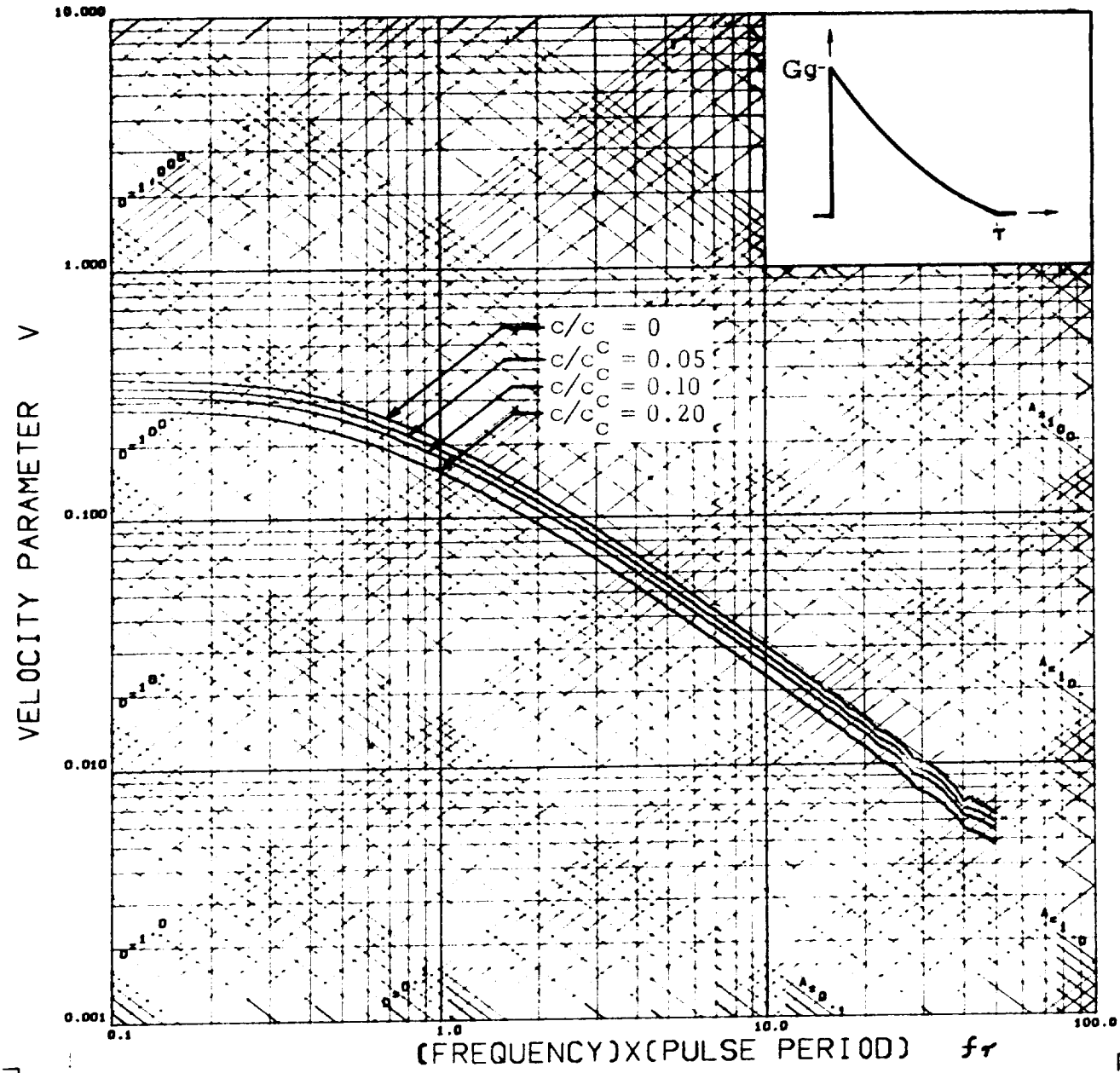



FIGURE II-105 Fourier Phase Spectrum for an Exponential Symmetrical Acceleration Pulse. Rise and Decay of $e^{2\pi}$




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-106 Fourier and Shock Spectra for a Blast Acceleration Pulse with Step Rise and Decay of $e^{\pi/2}$




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-107 Damped Shock Spectra for a Blast Acceleration Pulse with Step Rise and Decay of $e^{\pi/2}$

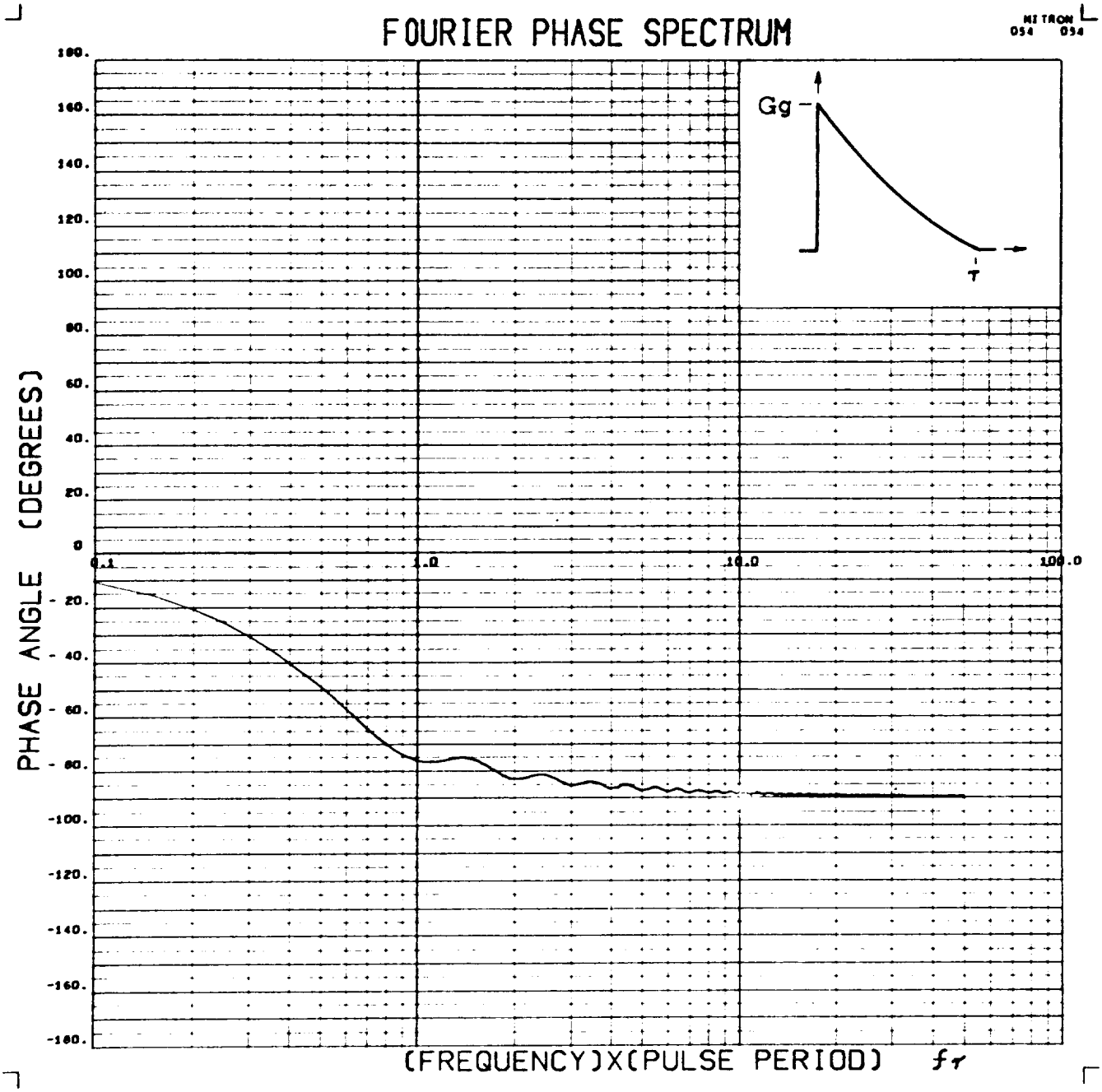
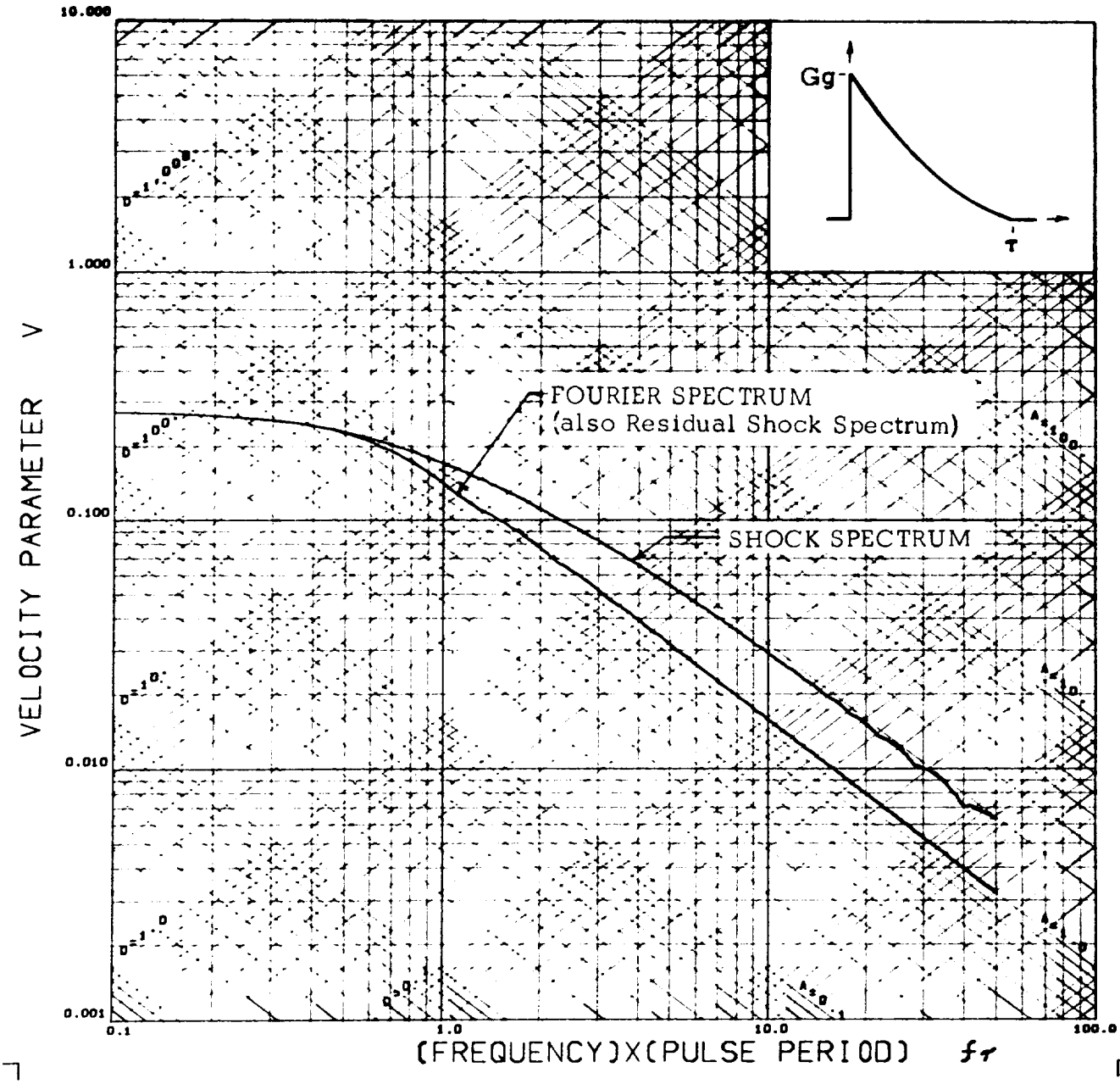
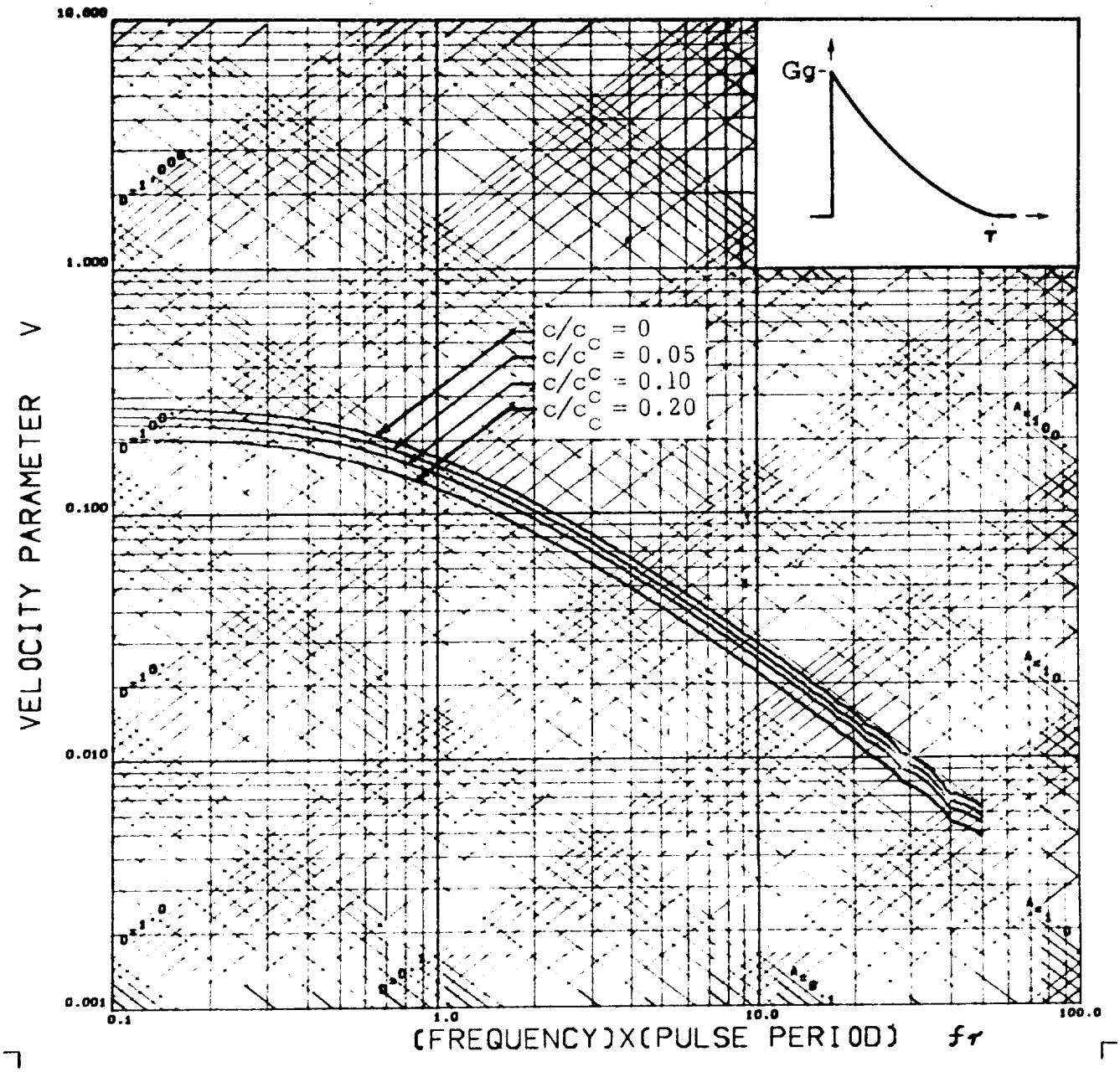



FIGURE II-108 Fourier Phase Spectrum for a Blast Acceleration Pulse with Step Rise and Decay of $e^{\pi/2}$




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-109 Fourier and Shock Spectra for a Blast Acceleration Pulse with Step Rise and Decay of $e^{\pi}$




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-110 Damped Shock Spectra for a Blast Acceleration Pulse with Step Rise and Decay of $e^{\pi}$

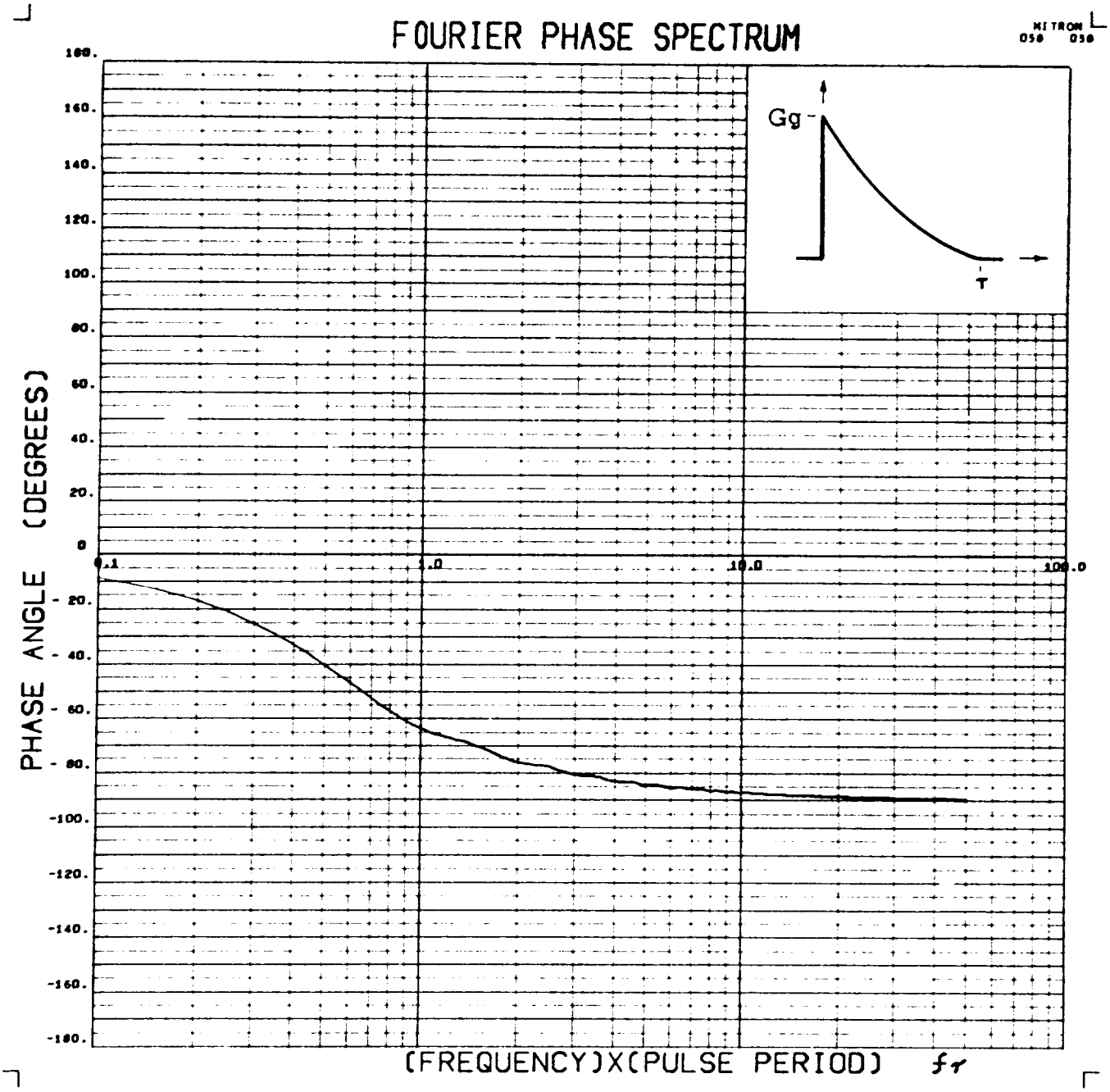
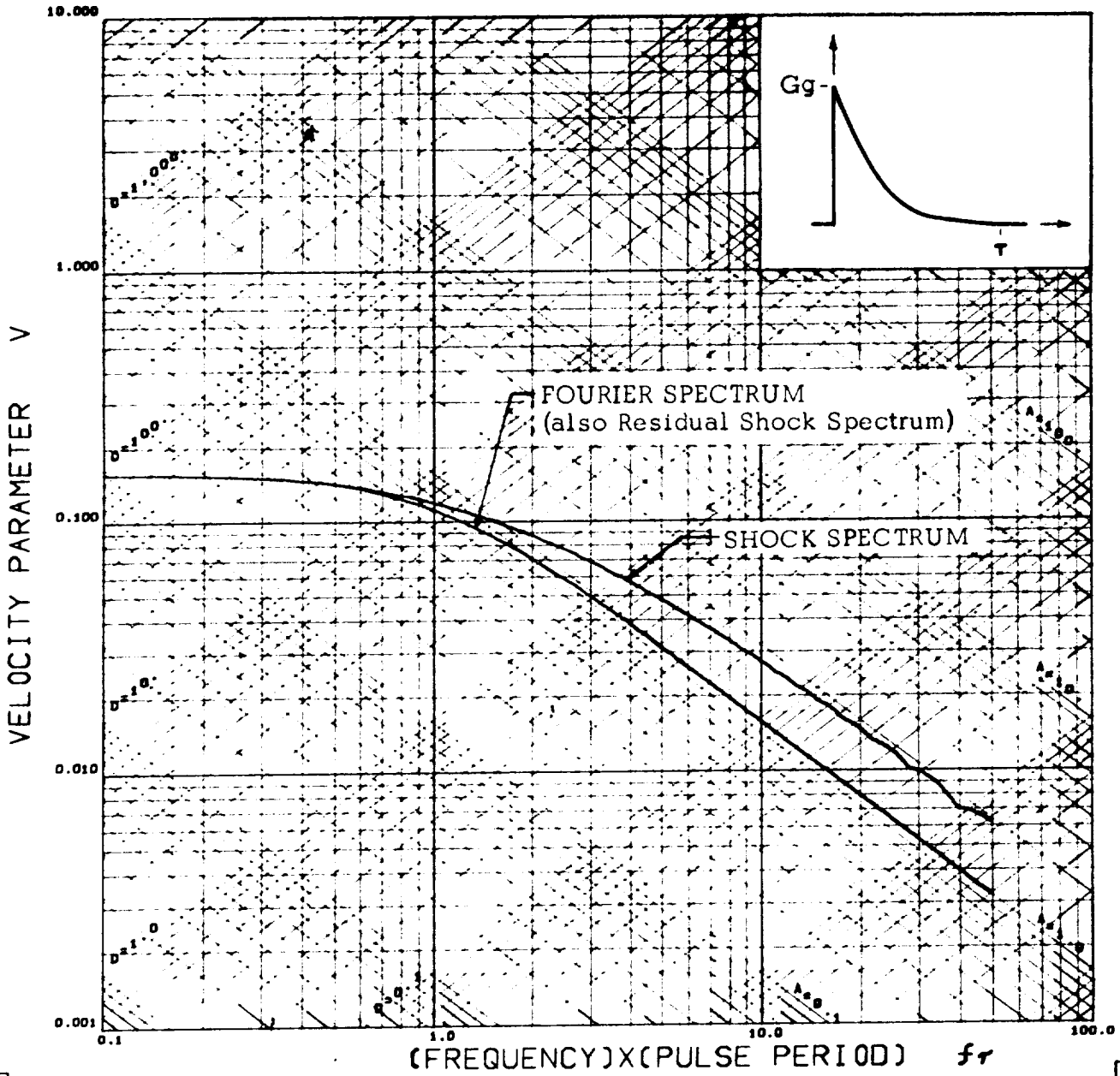
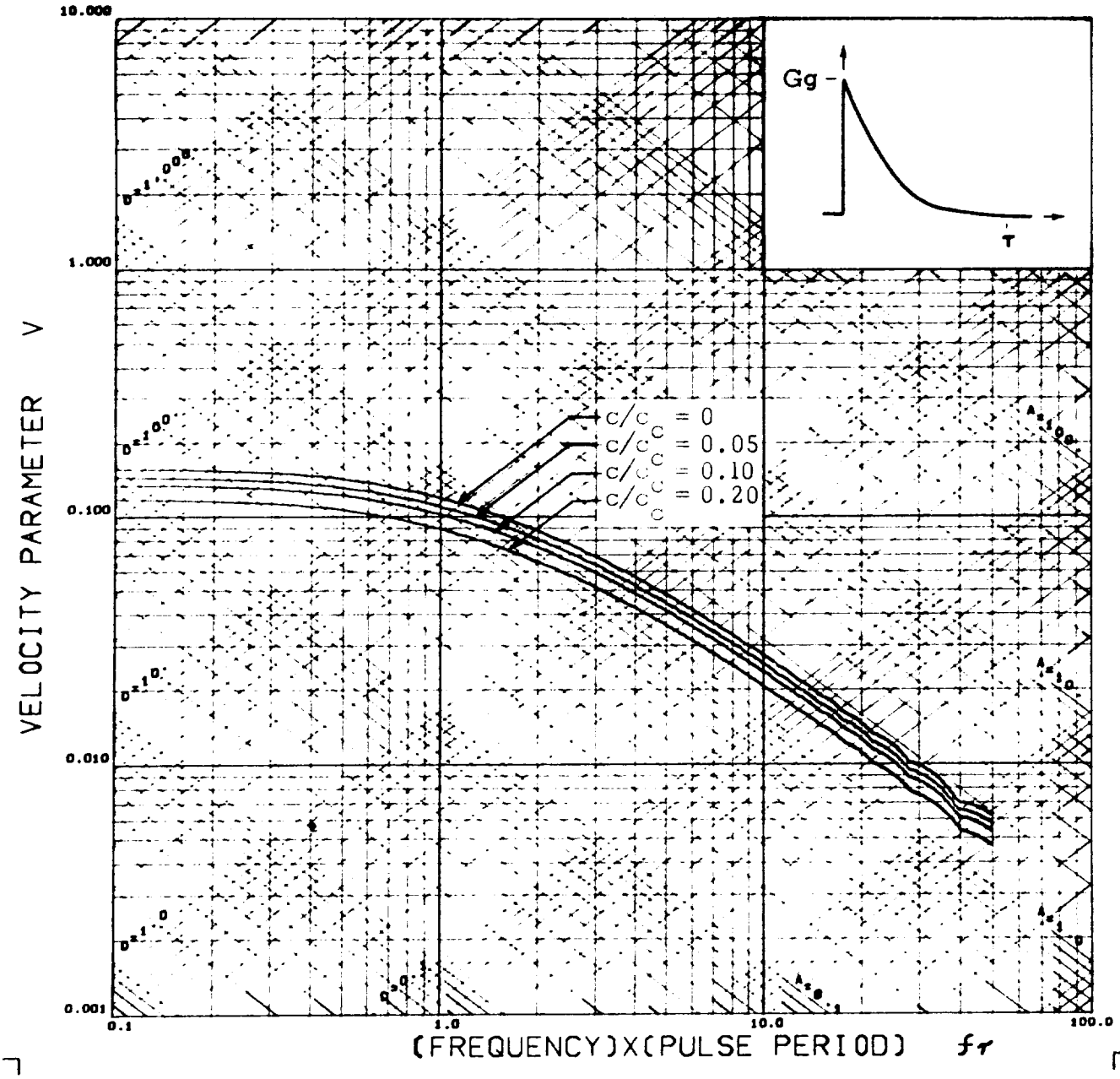



FIGURE II-111 Fourier Phase Spectrum for a Blast Acceleration Pulse with Step Rise and Decay of $e^{\pi}$




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-112 Fourier and Shock Spectra for a Blast Acceleration Pulse with Step Rise and Decay of $e^{2\pi}$




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-113 Damped Shock Spectra for a Blast Acceleration Pulse with Step Rise and Decay of $e^{2\pi}$

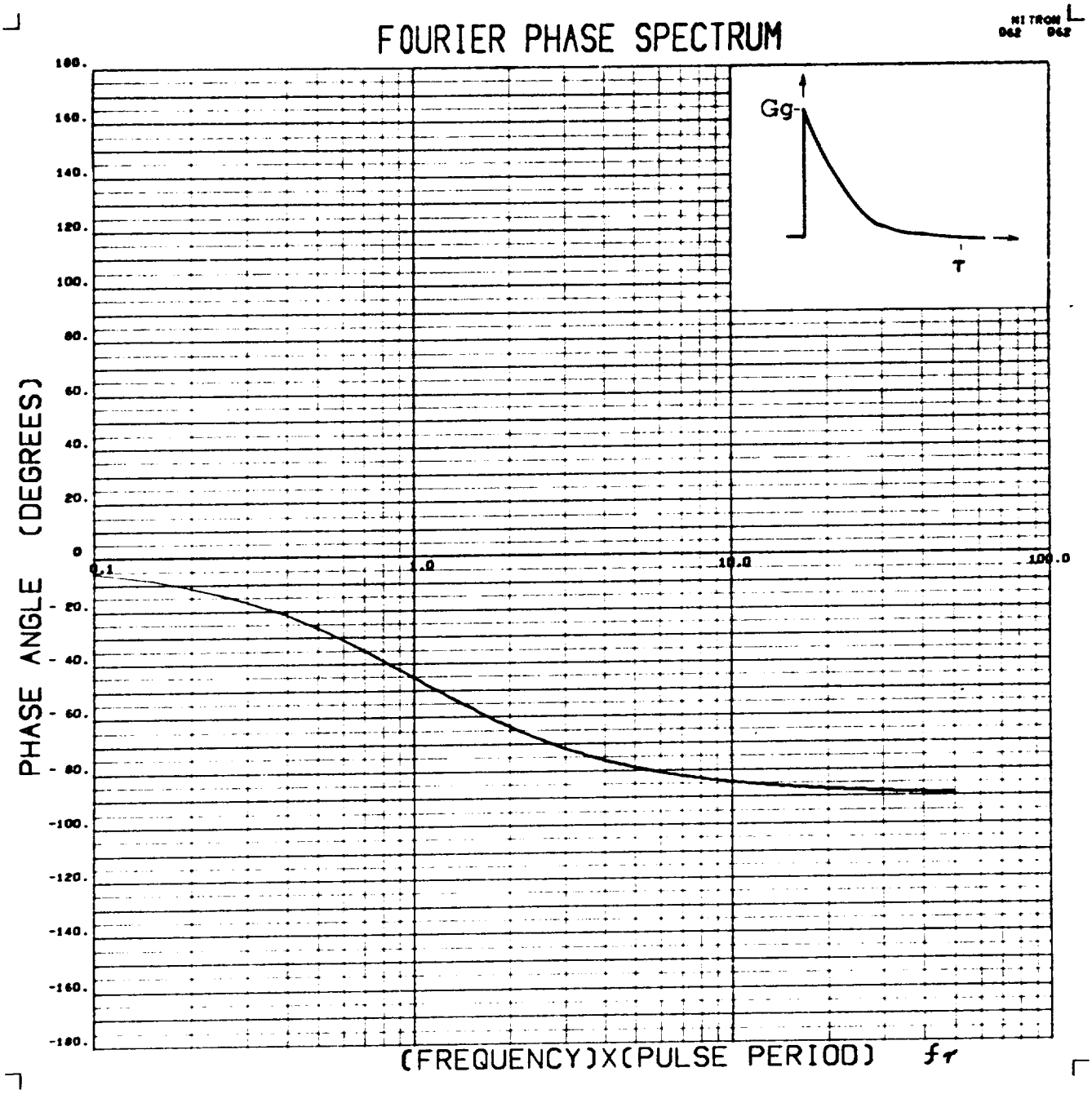
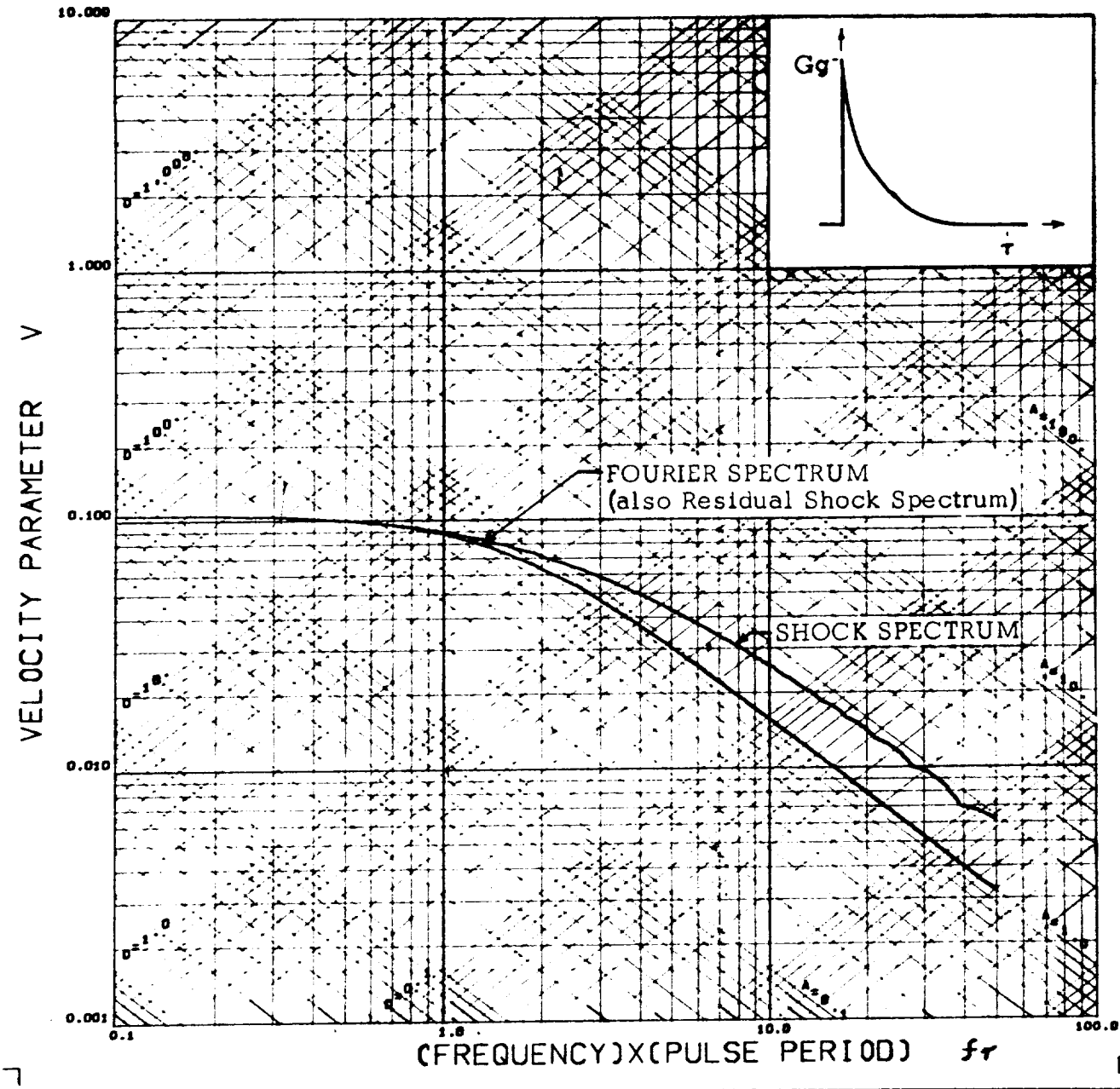
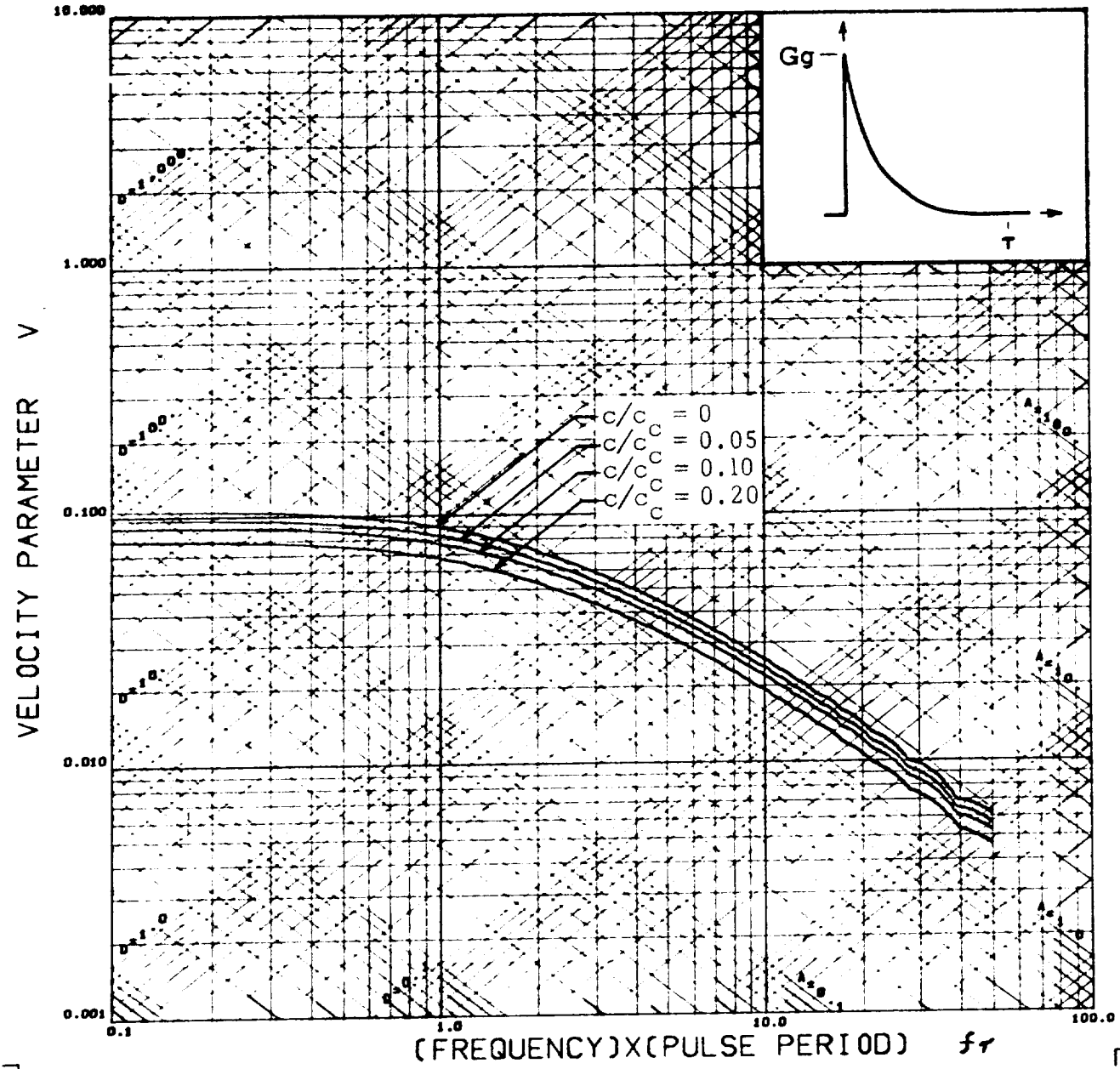



FIGURE II-114 Fourier Phase Spectrum for a Blast Acceleration Pulse with Step Rise and Decay of $e^{2\pi}$




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in/sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-115 Fourier and Shock Spectra for a Blast Acceleration Pulse with Step Rise and Decay of $e^{3\pi}$




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-116 Damped Shock Spectra for a Blast Acceleration Pulse with Step Rise and Decay of $e^{3\pi}$

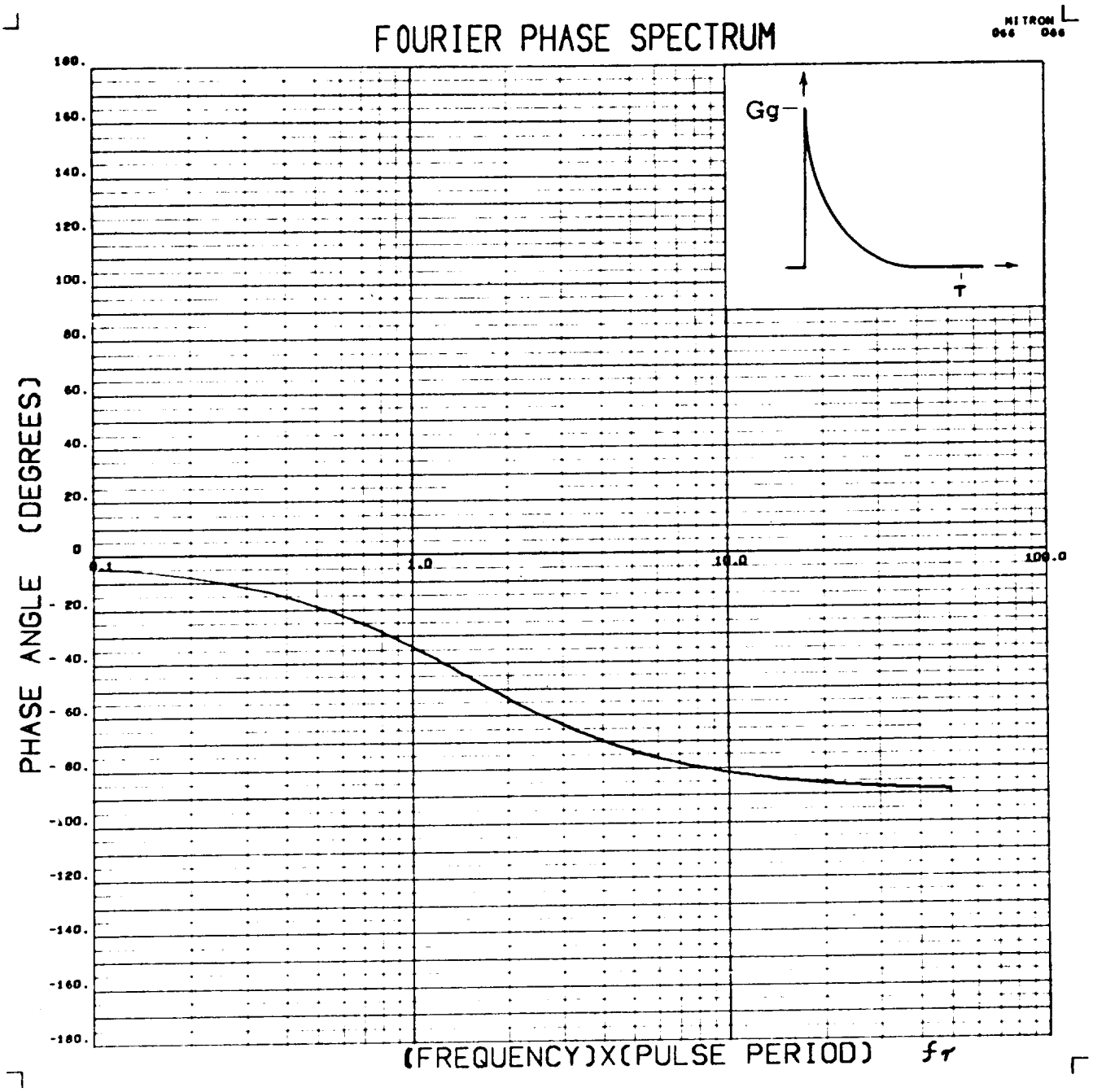
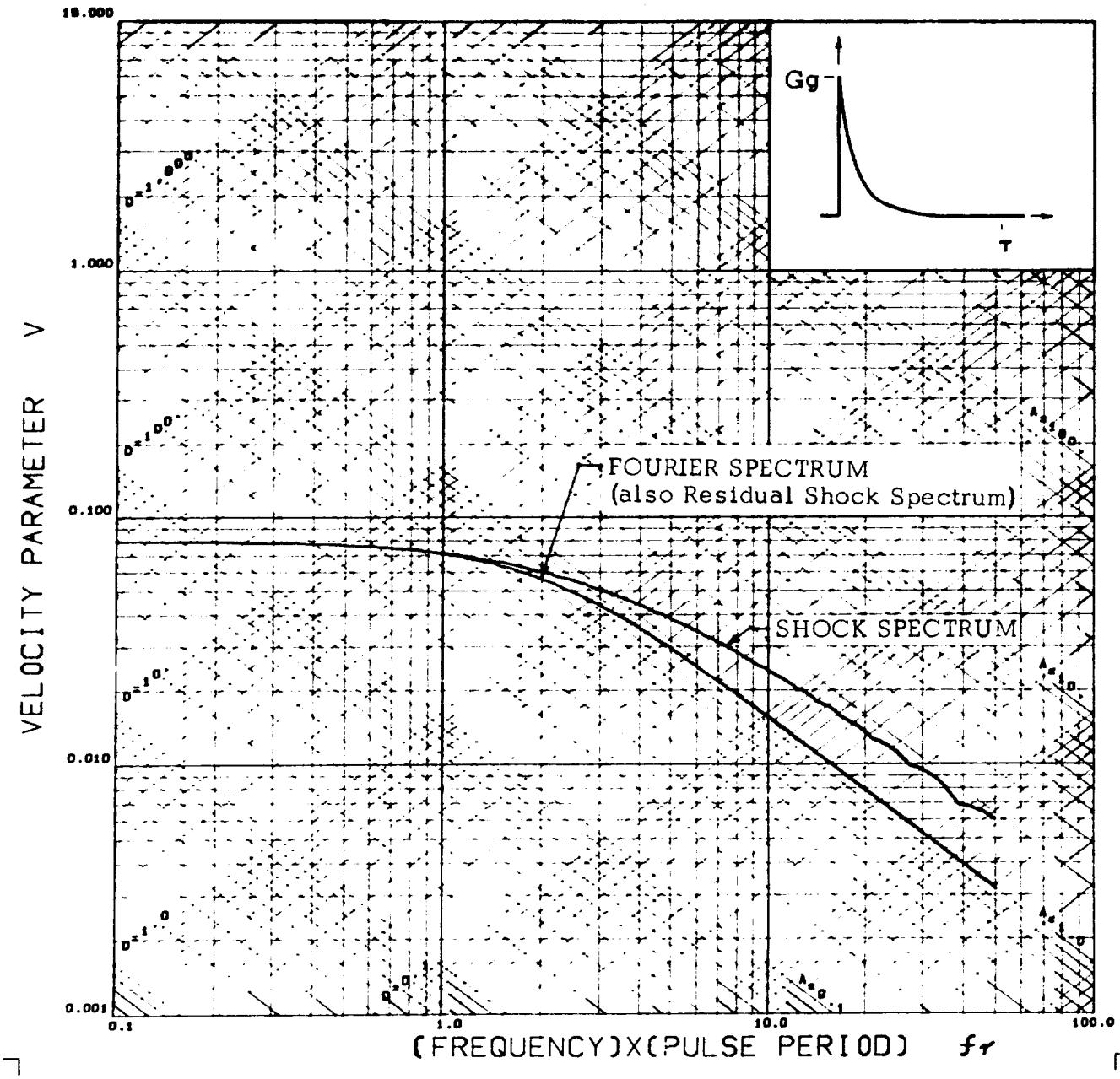
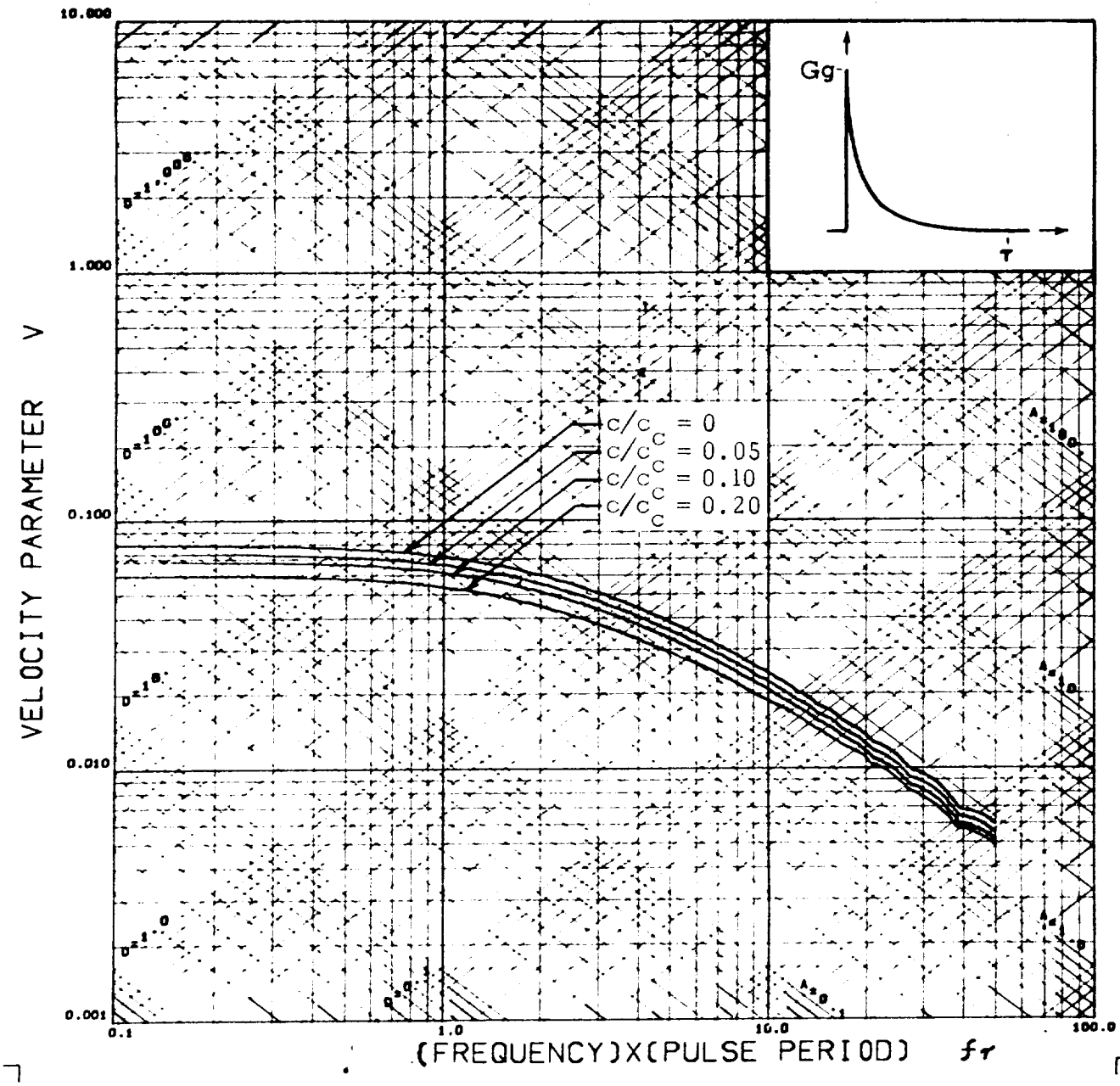



FIGURE II-117 Fourier Phase Spectrum for a Blast Acceleration Pulse with Step Rise and Decay of $e^{3\pi}$




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-118 Fourier and Shock Spectra for a Blast Acceleration Pulse with Step Rise and Decay of $e^{4\pi}$




| PARAMETER | FOURIER SPECTRUM | SHOCK SPECTRUM |
|---|---|---|
| $d = (G\tau^2)\cdot(D)$ in. | deflection component | relative deflection response |
| $v = (Gg\tau)\cdot(V)$ in./sec | velocity component | pseudo velocity response |
| $a = (Gg)\cdot(A)$ in./sec$^2$ | acceleration component | absolute acceleration response |

FIGURE II-119 Damped Shock Spectra for a Blast Acceleration Pulse with Step Rise and Decay of $e^{4\pi}$

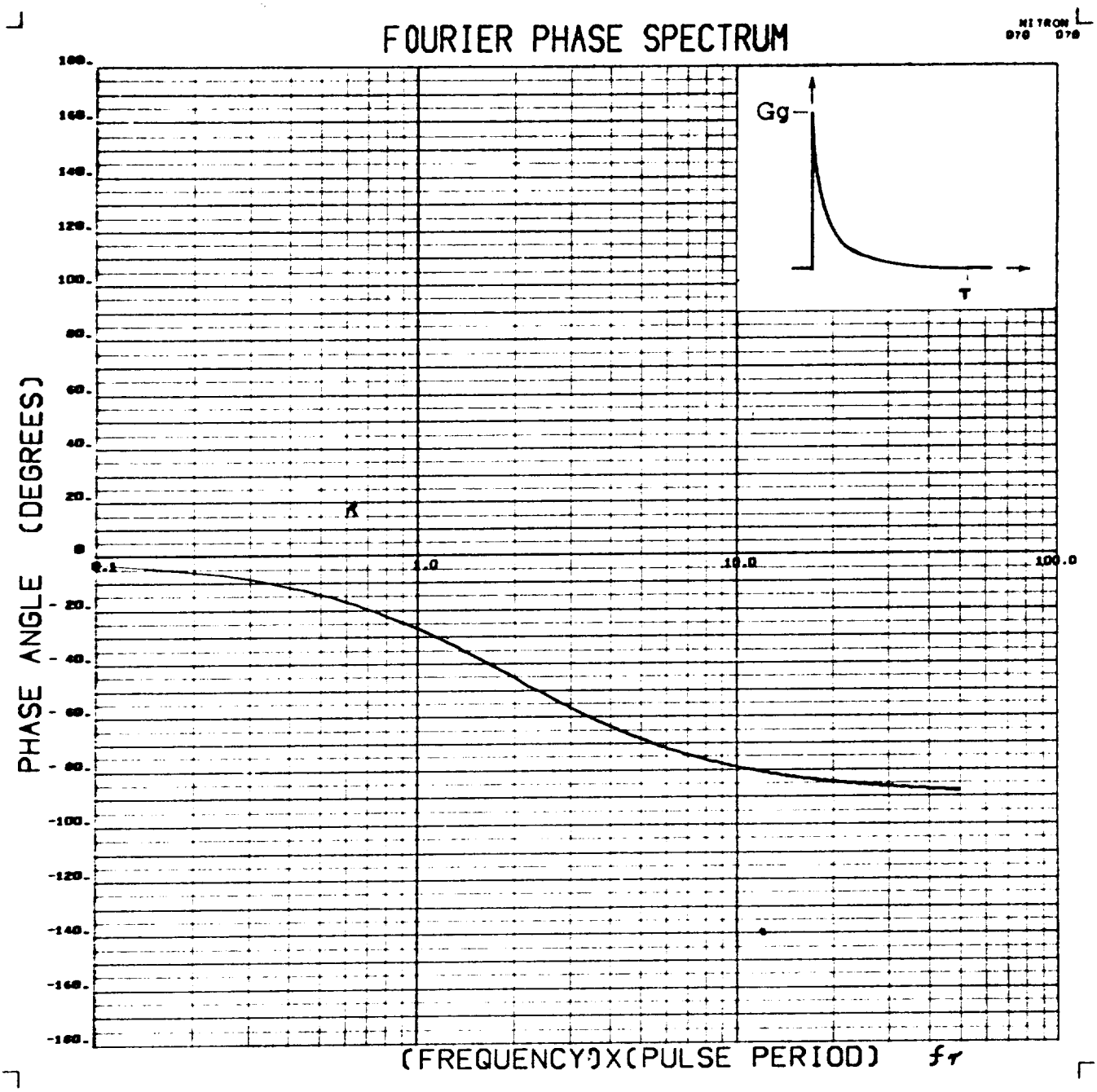



FIGURE II-120 Fourier Phase Spectrum for a Blast Acceleration Pulse with Step Rise and Decay of $e^{4\pi}$