Fermilab

$\bar{p}$ Note #351

Linearization of Bunch Rotation in the Debuncher by Addition of Second Harmonic RF

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The addition of some ~~to~~ second or third harmonic to the RF in the debuncher to reduce distortion of the bunch during rotation was considered for the lattice with $\eta = -.0037$; no significant reduction was found. The present lattice has $\eta = -.0047$; thus the distortion resulting from the nonlinear dependence of orbit length on momentum is much less.[2] The other source of the distortion is the nonlinearity of the RF ~~for~~ focussing force. The effects of the RF nonlinearity is aggravated by the necessity of carrying out the last quarter of the rotation in a rapidly shrinking bucket as the voltage is driven down to provide a matched bucket for the rotated bunch. It would be eliminated by a linear sawtooth or ramp waveform having its minimum and maximum at $-\pi$ and π respectively. Although such a waveform requires an infinite bandwidth system, ~~one may~~ perhaps a useful improvement can be obtained with one or a few low harmonics of the accelerating ~~freq~~ RF. Specifically, it may be possible to obtain approximate linearity over some usefully large fraction of the period ~~wha~~ and have major deviations only near the ends of the bucket where no ~~particles~~ antiprotons will be affected.

Consider the Fourier expansion of a triangular sawtooth with period 2π, amplitude 1, and extrema at $\varphi = \pm q\pi$. The value of q can be chosen to make a given harmonic amplitude (or indeed a family of amplitudes) vanish. Of particular interest in the present context are the values $q = 1/2$ and $q = 2/3$ for which the second and third harmonics are zero respectively. The first few amplitudes and phases are given in the Table. The sum of the first two terms of each series are plotted in Fig ~~1~~ & Fig 2. The figures show that the two term function for $q = 2/3$ provides a rather good fit to a line segment over a range of $\sim \pm .63\pi$ and the $q = 1/2$ function is useful over $\sim \pm .48\pi$. ~~The~~ An interesting point is that the the $q = 2/3$ fit is nearly as good as the $q = 1/2$ ~~fit in even~~ almost everywhere inside the latter's lesser range. The table of amplitudes suggests that higher amplitudes, though appreciable in magnitude are phased to cancel substantially in the central portion of the $q = 2/3$ sawtooth.

Therefore, by addition of second harmonic only it should be possible to handle efficiently a momentum spread up to that which rotates to span $\pm .63\pi$ in the bucket instead of the $\pm \pi/2$ which has been assumed for pure sinewave R.F. In fact the useful span in the ~~conventional~~ single frequency bucket has been shown by simulation to be $\sim .4\pi$ for the TeV I design report parameters.

Fig 3 shows the ratio of final energy spread as a function of the initial energy spread for the design parameters. The point for $\Delta p/p = 3\%$ is just at the begining of a rapid rise in the curve and the rotated bunch for this case fills spans ±.4% of the bucket. For the same initial momentum spread one needs ~3.8 MV of fundamental plus 700 kV of second harmonic to get the same final momentum spread. One could go to considerably lower voltage and still have rather linear rotation, but the final momentum spread would be larger because the smaller bucket has left less for the adiabatic debunching phase to do.

The proposition becomes distinctly more interesting in the context of what voltage is required to exploit the full 4% momentum acceptance of the Debuncher. For this momentum spread the 5 MV single frequency RF distorts the bunch unacceptably whereas 3.15 MV plus second harmonic is still acceptably linear, giving the "+" point added to Fig 3. The level at which sinewave RF would give the same final momentum spread for 4% initial spread has not been determined directly by simmulation, but from Fig 3 one can argue that about 7 MV would be required.

The most immediate question is whether there is any reason to change our design of the Debuncher RF system to incorporate second harmonic

cavities. Sticking strictly with the September 1983 Design Report criteria of $\Delta p/p = 3\%$ and 53 MHz voltage of 5 MV one ~~gains~~ makes about 10% reduction in final momentum spread by adding 900 kV of second harmonic. Additionally one has the ability to run with reasonable efficiency at lower voltage should it become operationally useful to keep running with some cavities not working. There does not seem to be any great cost saving in making, ~~to~~ say, two fewer 53 MHz cavities and adding ~~2~~ two 106 MHz cavities, thereby getting the same performance from a somewhat more complicated system. ~~The question to man~~ Because second harmonic RF makes a rather modest improvement with respect to the immediate design goals I would personally recommend that ~~they~~ it be included in an early upgrade ~~of~~ with aim of improving performance slightly for $\Delta p/p = 3\%$, contributing to greater operating reliability by permitting useful operation at reduced voltage, and most importantly permitting attempts to use a greater momentum bite.

Notes

1) October 1982 Design Report Tevatron I Project

2) See for example A. Ando & K. Takayama "Synchrotron Oscillations with Very Small η", IEEE Trans. on Nucl. Sci., #4, August, 198[illegible], p2604.

$Q = \frac{1}{2}$

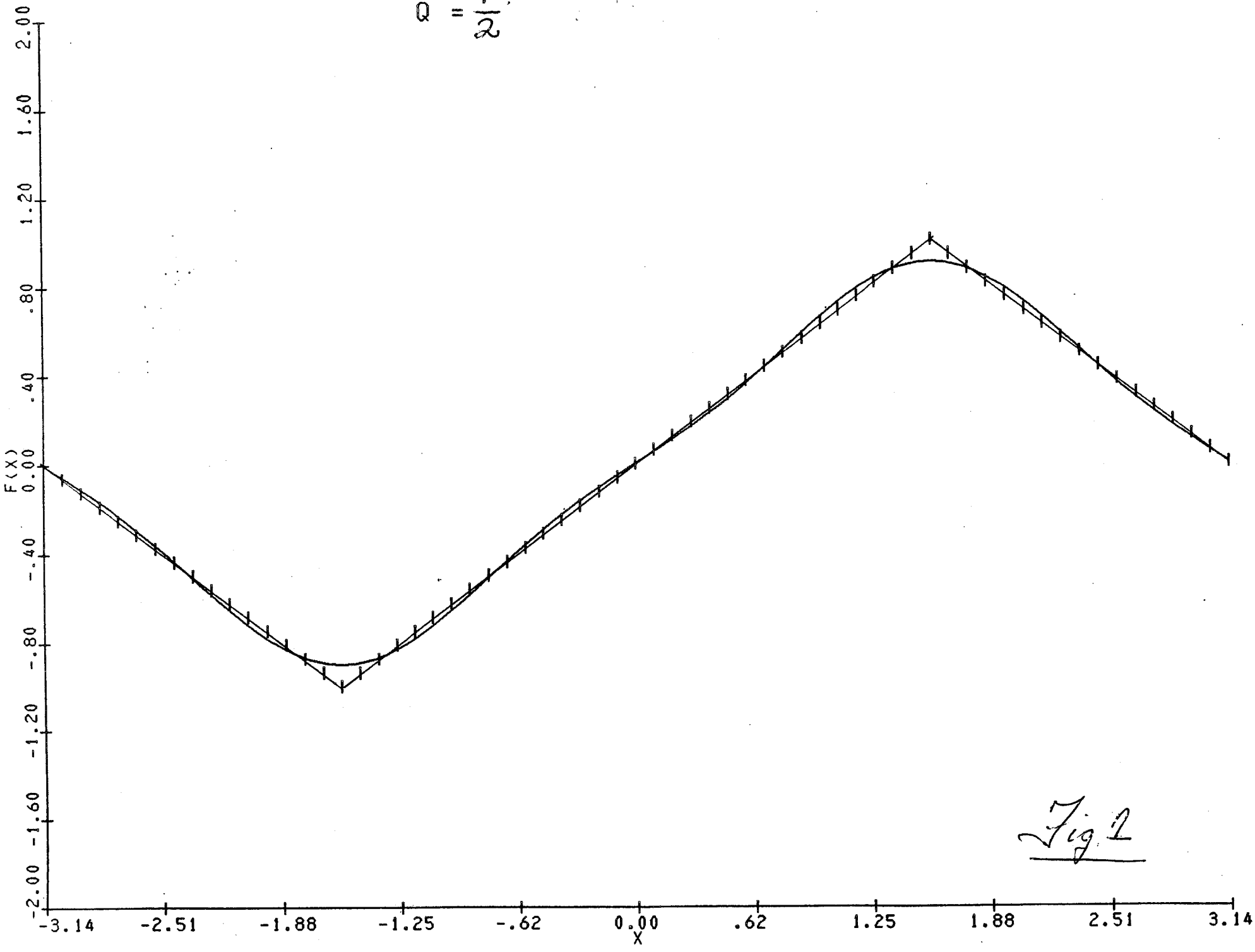

Fig 1

$Q = \frac{2}{3}$

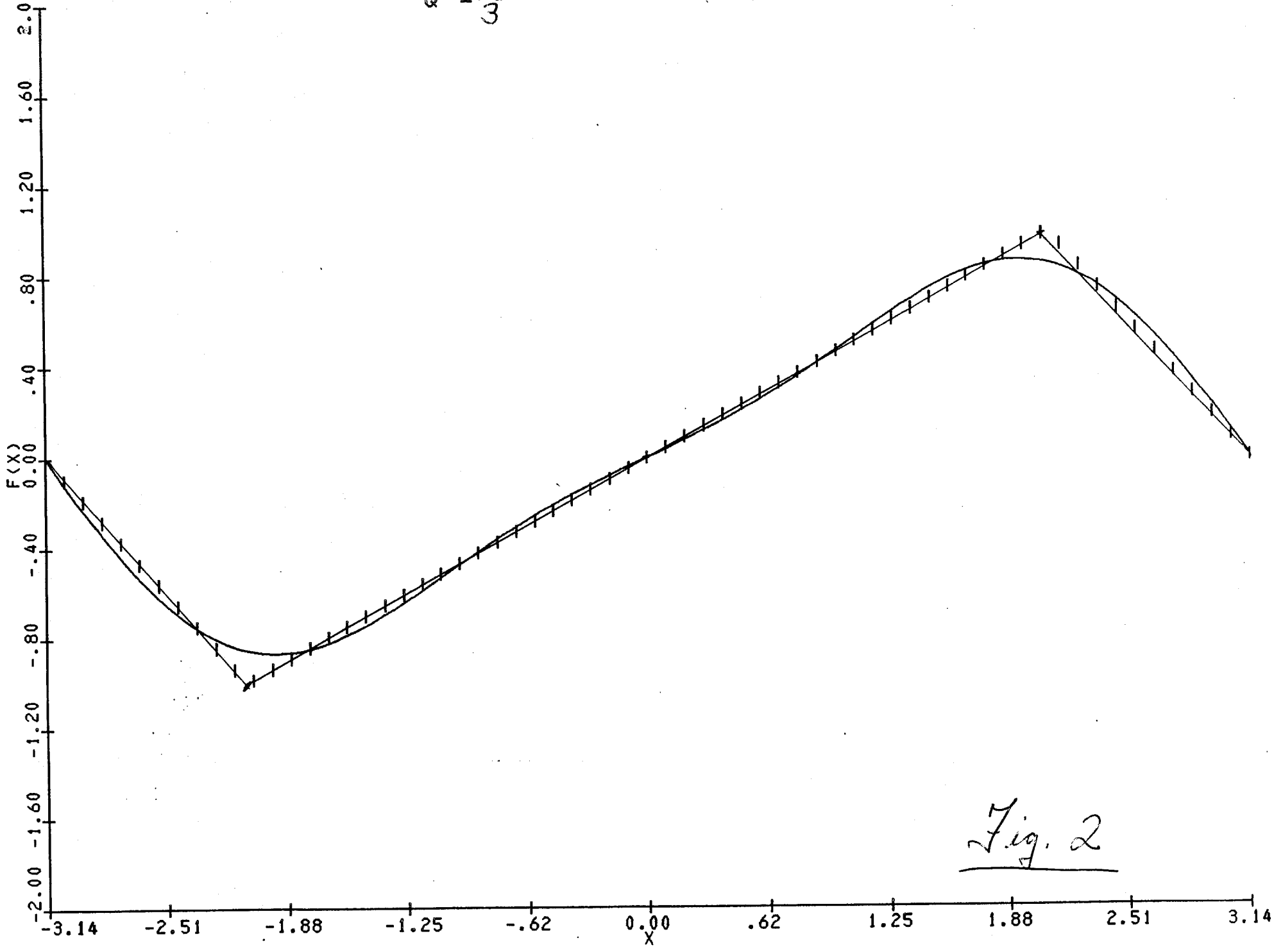

Fig. 2

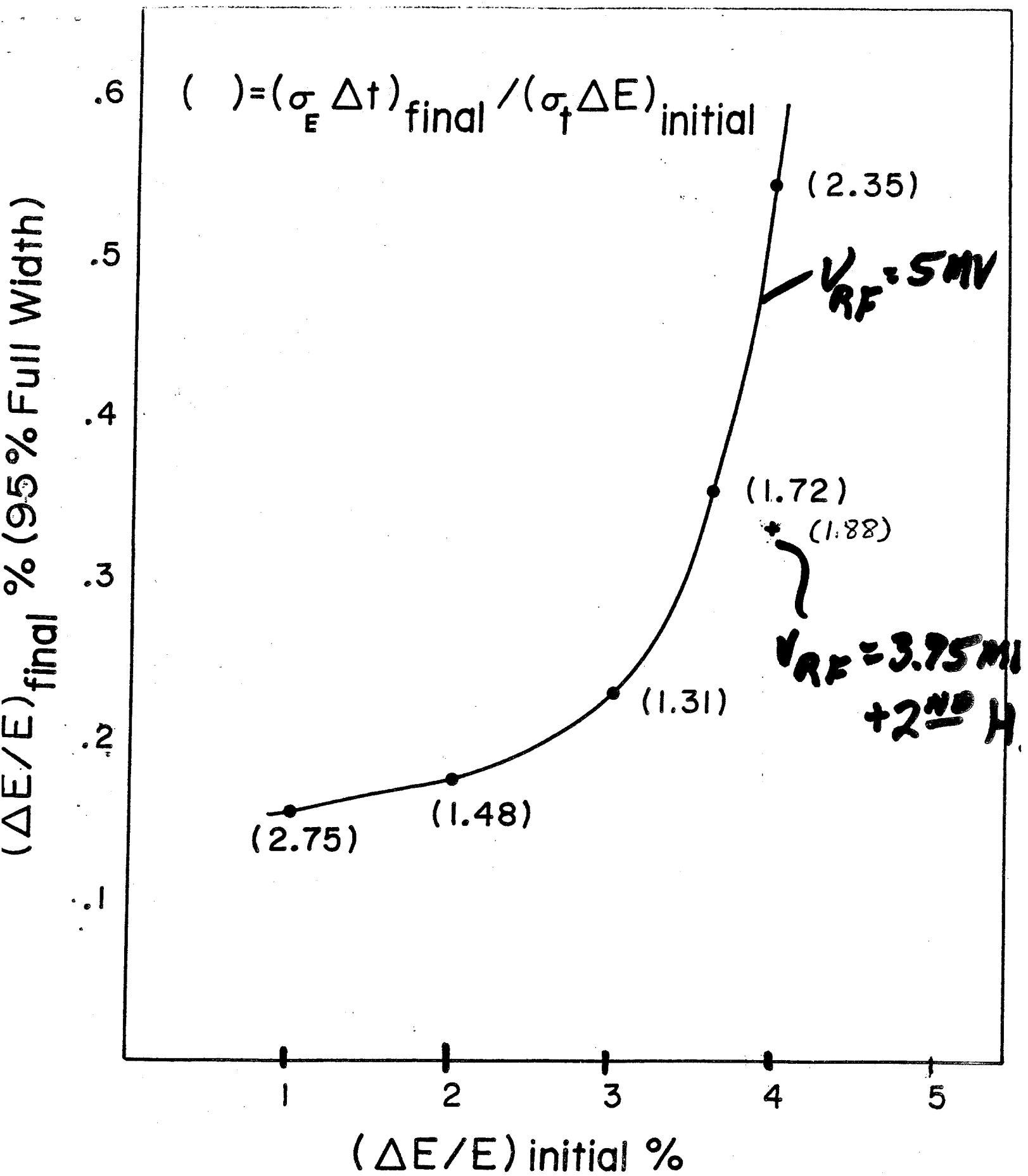
( ) = (σ_E Δt)_final / (σ_t ΔE)_initial
.6
.5
.4
.3
.2
.1
(ΔE/E)_final % (95% Full Width)
(2.35)
V_RF = 5 MV
(1.72)
(1.88)
V_RF = 3.75 MV
+2nd H
(1.31)
(1.48)
(2.75)
1
2
3
4
5
(ΔE/E) initial %

Figure 3

Table: Fourier Amplitudes & Phases for Triangular Sawtooth Waveforms of Amplitude 1

	Extrema at $\pm\pi/2$		Extrema at $\pm 2\pi/3$	
n	ampl	phase	ampl.	phase
1	.81122	0.	.78951	0.
2	0.	—	.19721	π
3	.09072	π	0.	—
4	0.	—	.04917	0.
5	.03308	0.	.03135	π
6	0.	—	0.	—
7	.017201	$-\pi$	.01594	0.
8	0.	—	.01207	$-\pi$
9	.01068	0.	0.	—
10	0.	—	.00773	0.