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QUARTZ CRYSTAL OSCILLATORS WITH LOW ACCELERATION SENSITIVITY

J. J. Gagnepain* and F. L. Walls**

The acceleration sensitivity of quartz crystal resonators imposes severe limitation on their use in non-laboratory environments. This work shows that by using two resonators connected in series and properly orientated with respect to one another, it is possible to substantially reduce the net acceleration sensitivity of the composite or compound crystal resonator. First qualitative experimental results on acceleration, also some experimental theories of studies related to the introduction of the two resonators comprising the compound resonator, are presented. From these studies it appears feasible to fabricate compound crystal resonators exhibiting acceleration sensitivities at least 10 times smaller than the resonators used individually.

Key words: Acceleration field; acceleration sensitivity; compound crystal resonator; crystalographic axis; non-linear elastic effect; resonance frequency.

When a quartz crystal resonator is in an acceleration field, the induced body forces and the reaction forces give a static or quasistatic deformation. Because of the non-linear elastic effects, an interaction occurs between the elastic wave and this static deformation, changing the wave velocity, and by a small amount, the crystal sizes. The result is a variation of the resonance frequency, related to the applied acceleration field direction, as shown in Fig. 1 [1].

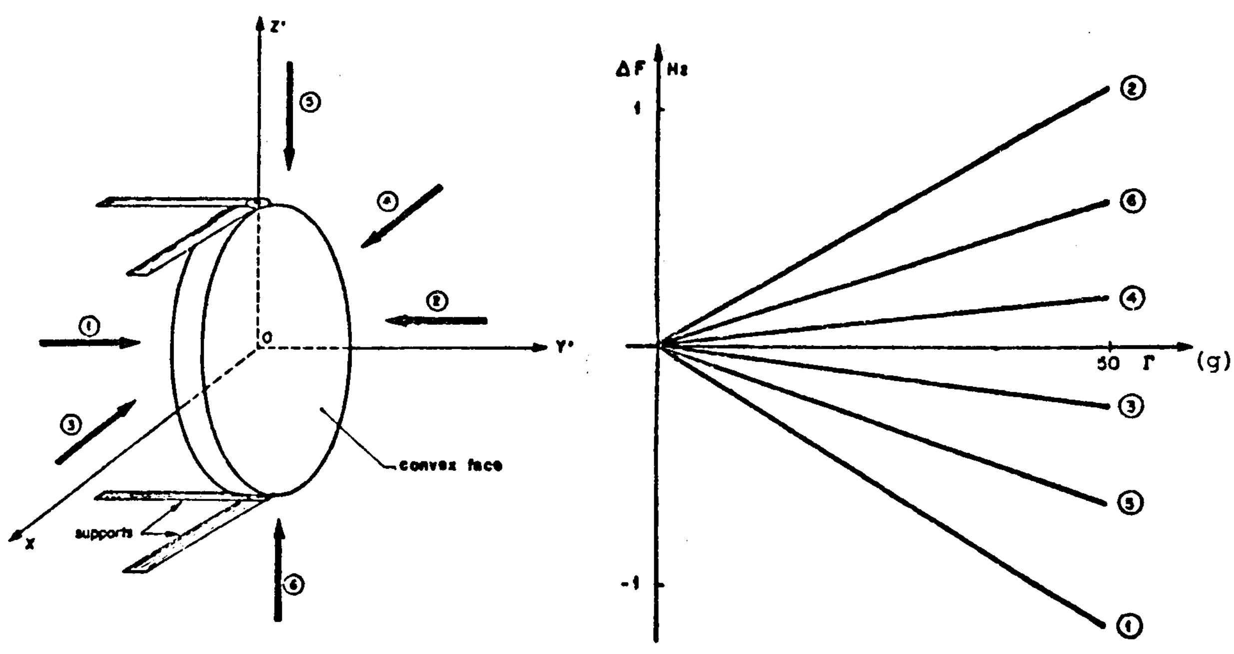

FIGURE 1 Frequency variation of a quartz resonator for several different directions of applied force.

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For a practical application, the acceleration field Γ can be represented by the two vector components: Γ_3 parallel to the y' axis (therefore perpendicular to the plane of the crystal), and Γ_1 in the crystal plane,

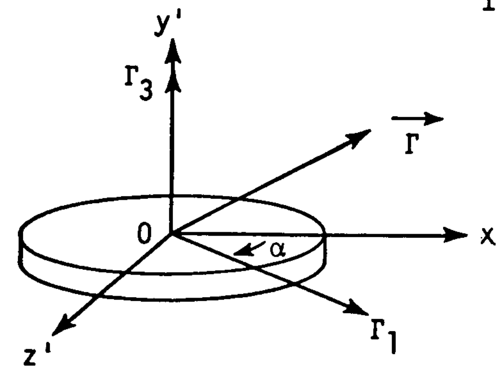

FIGURE 2 Decomposition of the generalized vector, Γ, into two components, Γ_3 and Γ_1, which are referenced to the x and y' crystalographic axis.

where α is the azimuth angle between Γ_1 and the X crystalographic axis. See Fig. 2.

Rotating the crystal plate around the y' axis, it is possible to find some particular values of α for which the sensitivity due to Γ_1 is approximately zero.

For a given crystal technology, the effect of Γ_3 cannot be reduced with only one crystal. However, using two crystal resonators oriented as mirror images with respect to the y' axis connected in series can lead to first-order cancellation of the acceleration effect.

Fig. 3 shows the equivalent circuit for two crystal resonators connected in series.

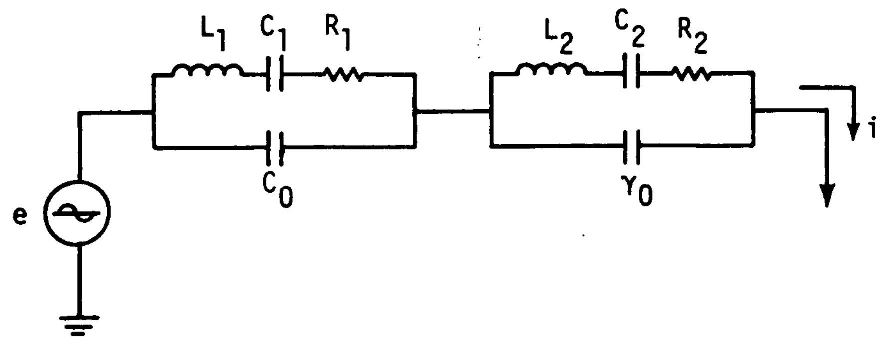

FIGURE 3 The equivalent circuit for two crystal resonators connected in series.

Solving the equation for $\left|\frac{i}{e}\right|^2$ yields:

$$\left|\frac{i}{e}\right|^2 = \frac{[uv - R_1R_2C_0\gamma_0\omega_1\omega_2] + [R_1C_0\omega_1 v + R_2\gamma_0\omega_2 u]}{[R_1V+R_2u-2L_1\omega_1R_2\gamma_0\omega_2 -2L_2\omega_2R_1C_0\omega_1 y]^2 + [R_1R_2(C_0\omega_1+\gamma_0\omega_2)+2L_1\omega_1 x v+2L_2\omega_2 y\omega]}$$

with $u = 1 - 2L_1C_0\omega_1^2$

$v = 1 - 2L_2\gamma_0\omega_2^2\, y$

$x = \frac{\Delta f}{F_1}$ $\quad y = \frac{\Delta f - \varepsilon}{F_2}$ $\quad \Delta f = F - F_1$ $\qquad 4\pi^2 F_1^2 = \frac{1}{L_1C_1}$

F is the driving frequency,
F_1 is the series resonance frequency of the 1st resonator, F_2 is the series resonance frequency of the 2nd resonator and
ε is the difference between the frequencies F_1 and F_2.

Calculated variations of $\left|\frac{i}{e}\right|$ as a function of the driving frequency and various parameters are represented in Fig. 4,5,6, and 7:

Fig. 4) Parameter: parallel capacitor C_0; F_1 = 10 MHz,

Fig. 5) Parameter: λ_0; F_1 = 10 MHz,

Fig. 6) Parameter: L_2 F_1 = 10 MHz,

Fig. 7) Parameter: ε; F_1 = 10 MHz.

Figure 8 shows the experimental results obtained with a pair of 3rd overtone AT cut 10 MHz crystals whose resonance frequencies are widely separated. Figure 9 shows the experimental results with a pair of 3rd overtone AT cut 10 MHz crystals. Figure 10 shows the results for a pair of 5th overtone AT cut 5 MHz crystals manufactured at the Ecole Nationale Superieure de Chronometrie et Micromecanique (ENSCM).

The experimental curves verify that the series connected resonators essentially produce a single resonance curve even when the individual resonance frequencies differ by more than the linewidth. This means that resonators need only be reasonably close in frequency which is easily satisfied by current manufacturing tolerances. In fact the separation of curves A and B in Fig. 8 (350 Hz is more than 5 times larger than standard tolerance for these types of crystals .

Using crystal blanks from Manufacturer A, two resonators have been mounted using glass tubes as supports, their individual resonance frequencies were:

Quartz A) F_o = 10 000 155 Hz,

Quartz B) F_o = 9 998 805 Hz.

These resonators were connected in series and used in the circuit shown in Fig. 11. The frequency response has two peaks: a very small one at F = 10 000 800 Hz and a large one at f = 9.999 049 Hz which was used for the measurements.

This circuit was mounted on a loudspeaker and subjected to vibrations at a frequency of 500 Hz.

a) For constant amplitude sinusoidal acceleration in the Γ_3 or y' direction the phase variation amplitudes which is proportional to the frequency difference between the compound crystal resonator and the driving frequency, was:

Quartz A alone:	amplitude	0.07 V per arbitrary unit of acceleration
Quartz B alone:	amplitude	0.15 V
Quartz A + B:	amplitude	0.05 V

b) By proper rotations of the crystals about the y' axis the acceleration sensitivity could be reduced to the noise level, or less than .01 div. The noise was primarily due to thermal transient effects caused by the lack of enclosures around the resonators.

Although the two individual resonators do not have the same acceleration sensitivities, the compound crystal nevertheless, exhibits a substantial reduction in acceleration sensitivity. Also the acceleration sensitivities of production crystals should be inherently much more closely matched than these two prototype crystals. It therefore appears that a factor of 10 reduction in acceleration sensitivity can be achieved without elaborate matching techniques.

These first experiments show qualitatively that it is possible to decrease the total acceleration sensitivity of a quartz crystal oscillator using two resonators in series. Further work in this area needs to be done to quantitavely demonstrate the amount of acceleration desensitization that can be achieved .

To obtain quantitative results, improved mounting including good enclosures and an improved measurement system are necessary.

Reference [1] Influence of environment conditions on a quartz resonator. M. Valdois, J.J. Gagnepain, J. Besson. Proc. 28th Annual Freq. Contr. Symp., Fort Monmouth, NJ, 1974.

Acknowledgment

We would like to thank S. Jarvis for writing the computer program used in calculating the effect of various parameters on the resonate behavior of the resonators.

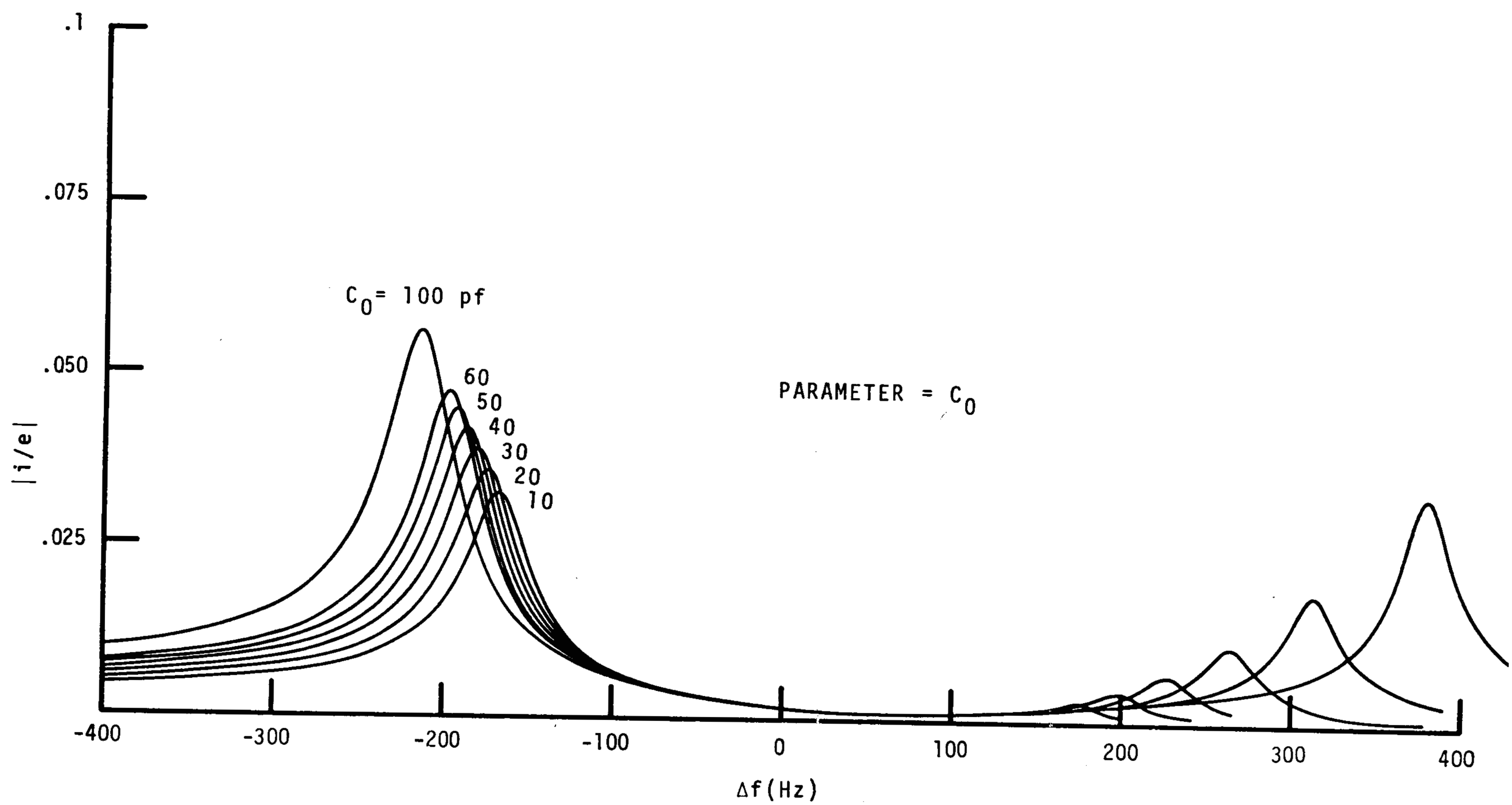

FIGURE 4 Calculated variation of $|i/e|$ as a function of Δf, the difference between the driving frequency and the resonator frequency of the first resonator and C_o, the parallel capacitance across the first resonator. Other parameters were: ϵ = -300 Hz, γ_o = 50 pf, L_1 = 0.1 H, L_2 = 0.07 H, R_1 = 15Ω, R_2 = 17Ω, F_1 = 10 MHz.

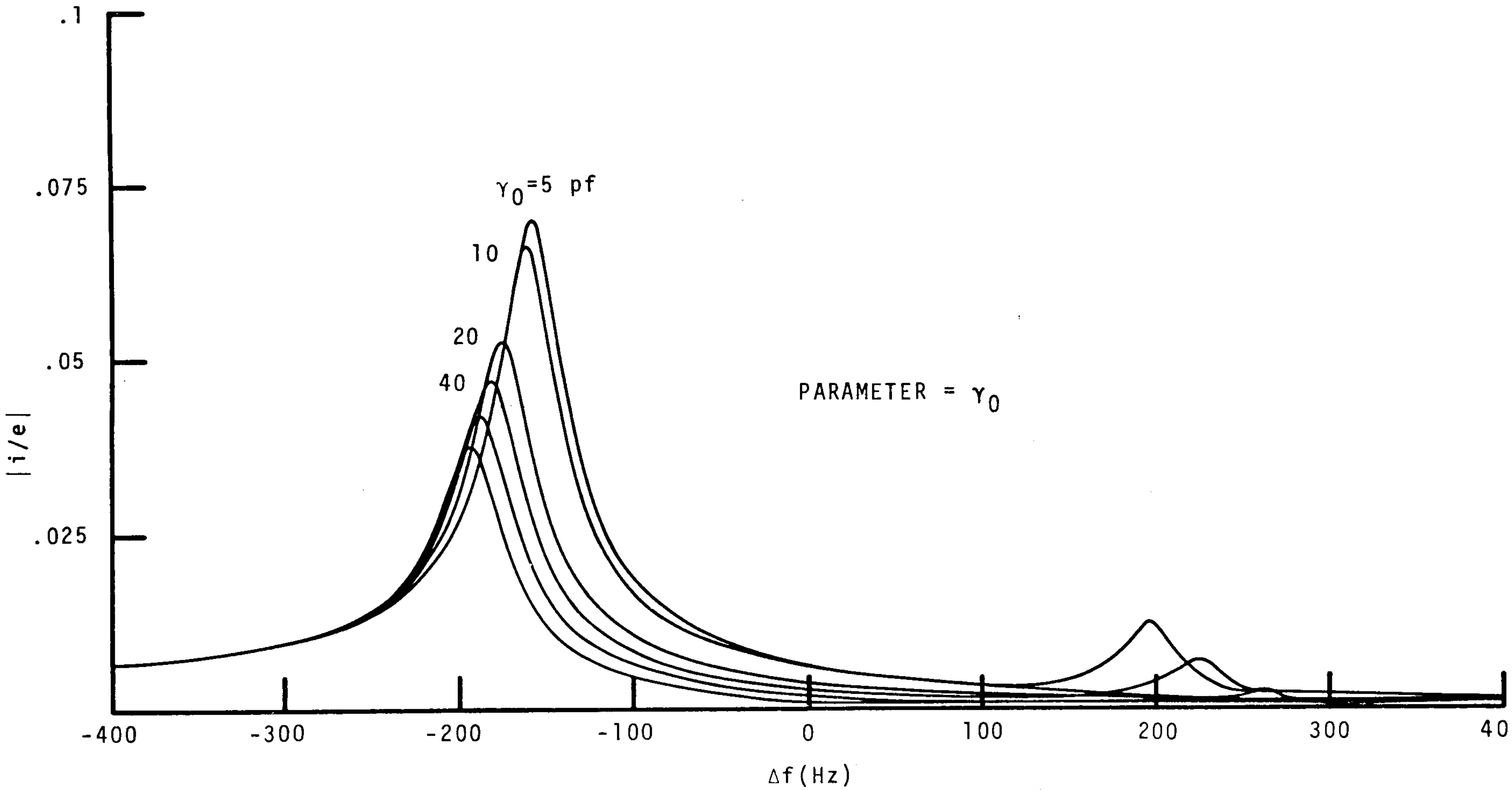

FIGURE 5 Calculated varation of $|i/e|$ as a function of Δf and γ_o, the parallel capacitance across the second resonator. Other parameters were: $\varepsilon = -300$ Hz, $C_o = 40$ pf, $L_1 = 0.1$ H, $L_2 = 0.07$ H, $R_1 = 15\Omega$, $R_2 = 17\Omega$ and $F_1 = 10$ MHz.

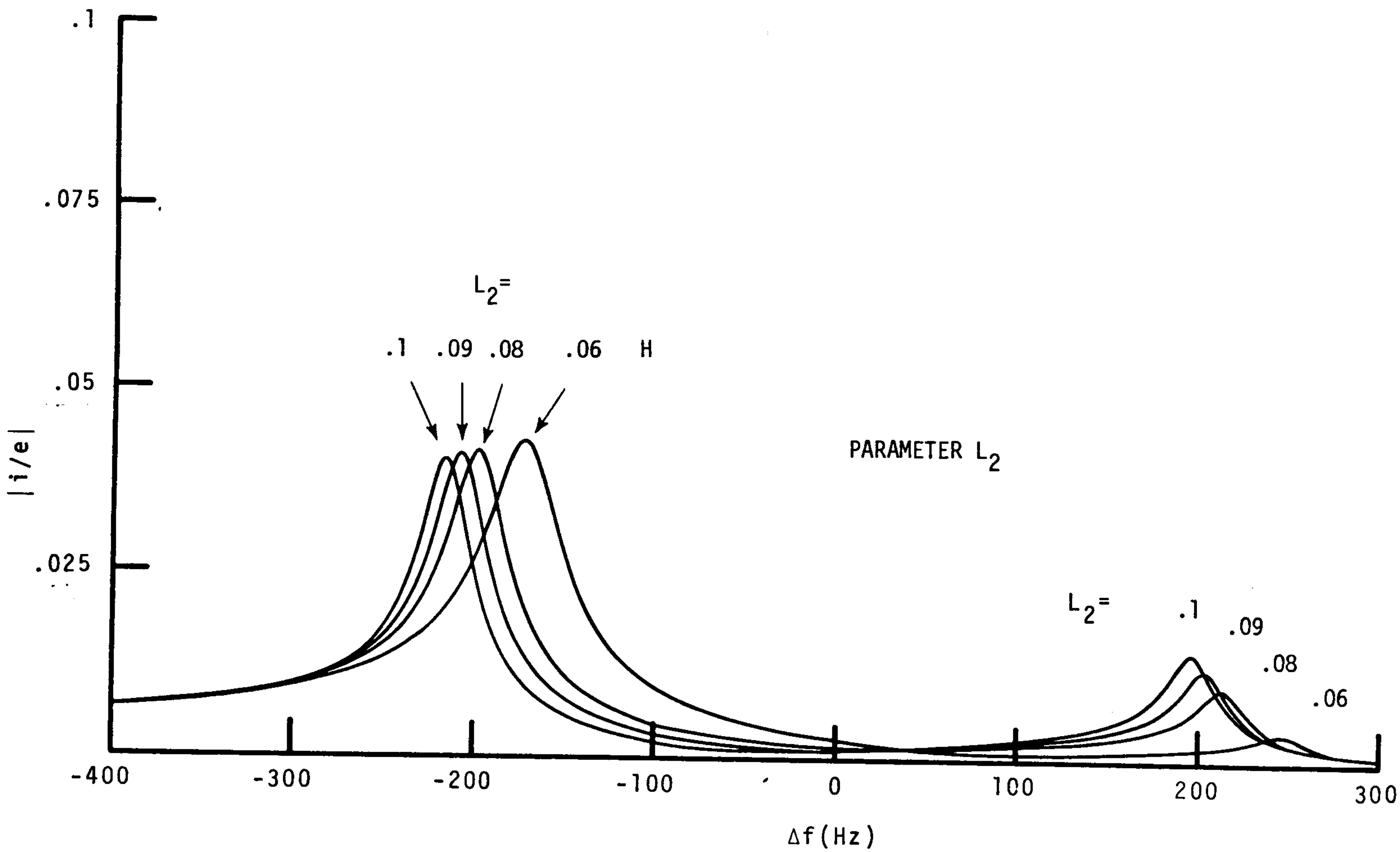

FIGURE 6 Calculated variation of $|i/e|$ as a function of Δf and ΔL_2, the change in series inductance of the second resonator in H. Other parameters were: $\varepsilon = -300$ Hz, $C_o = 40$ pf, $\gamma_o = 50$ pf, $L_1 = 0.1$ H, $R_1 = 15\Omega$, $R_2 = 17\Omega$, and $F_1 = 10$ MHz.

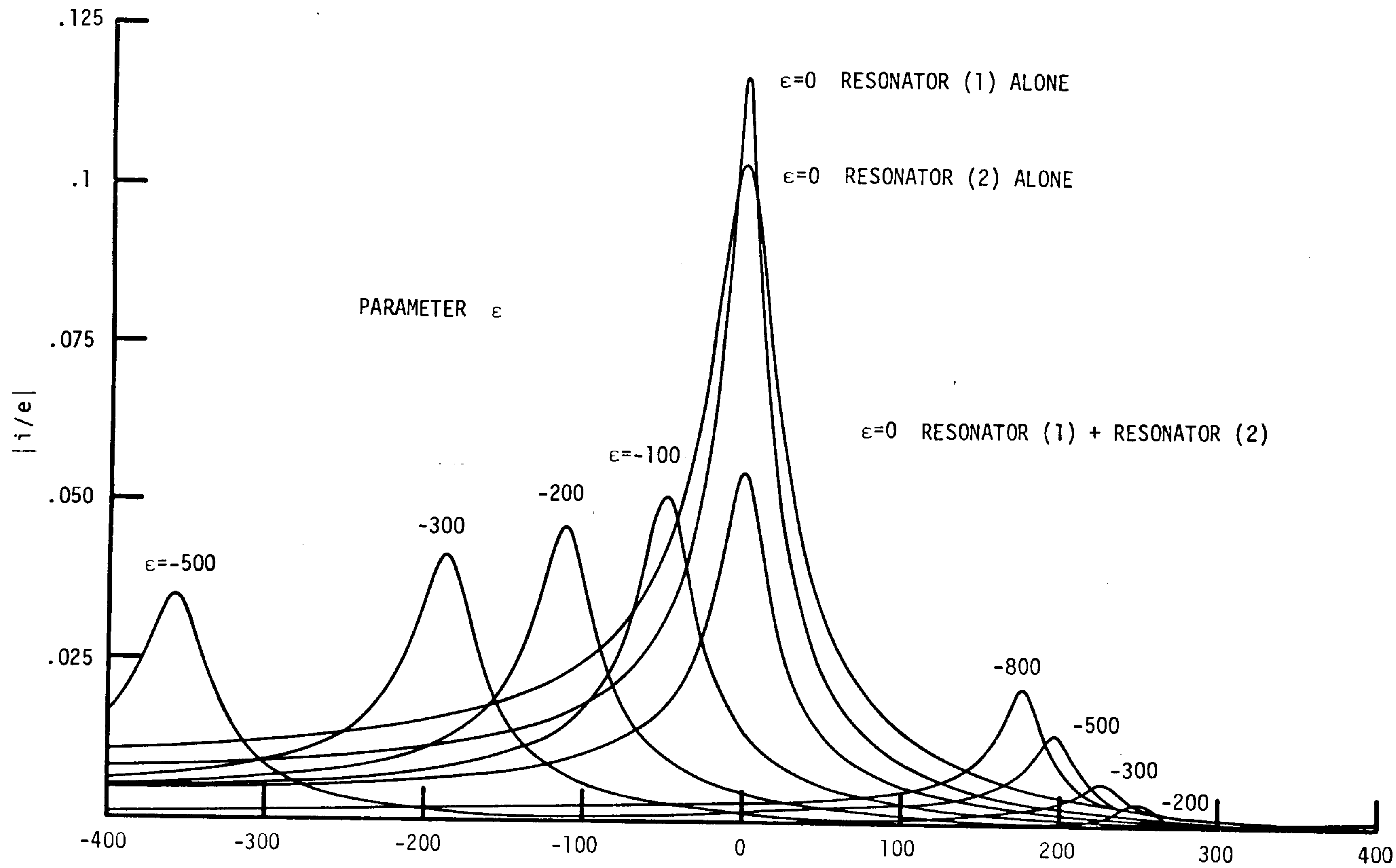

FIGURE 7 Calculated variation of $|i/e|$ as a function of Δf and ε, the frequency difference between the two resonators. Other parameters were: $C_o = 40$ pf, $\gamma_o = 50$ pf, $L_1 = 0.1$ H, $L_2 = 0.07$ H, $R_1 = 15\Omega$, $R_2 = 17\Omega$, and $F_1 = 10$ Hz.

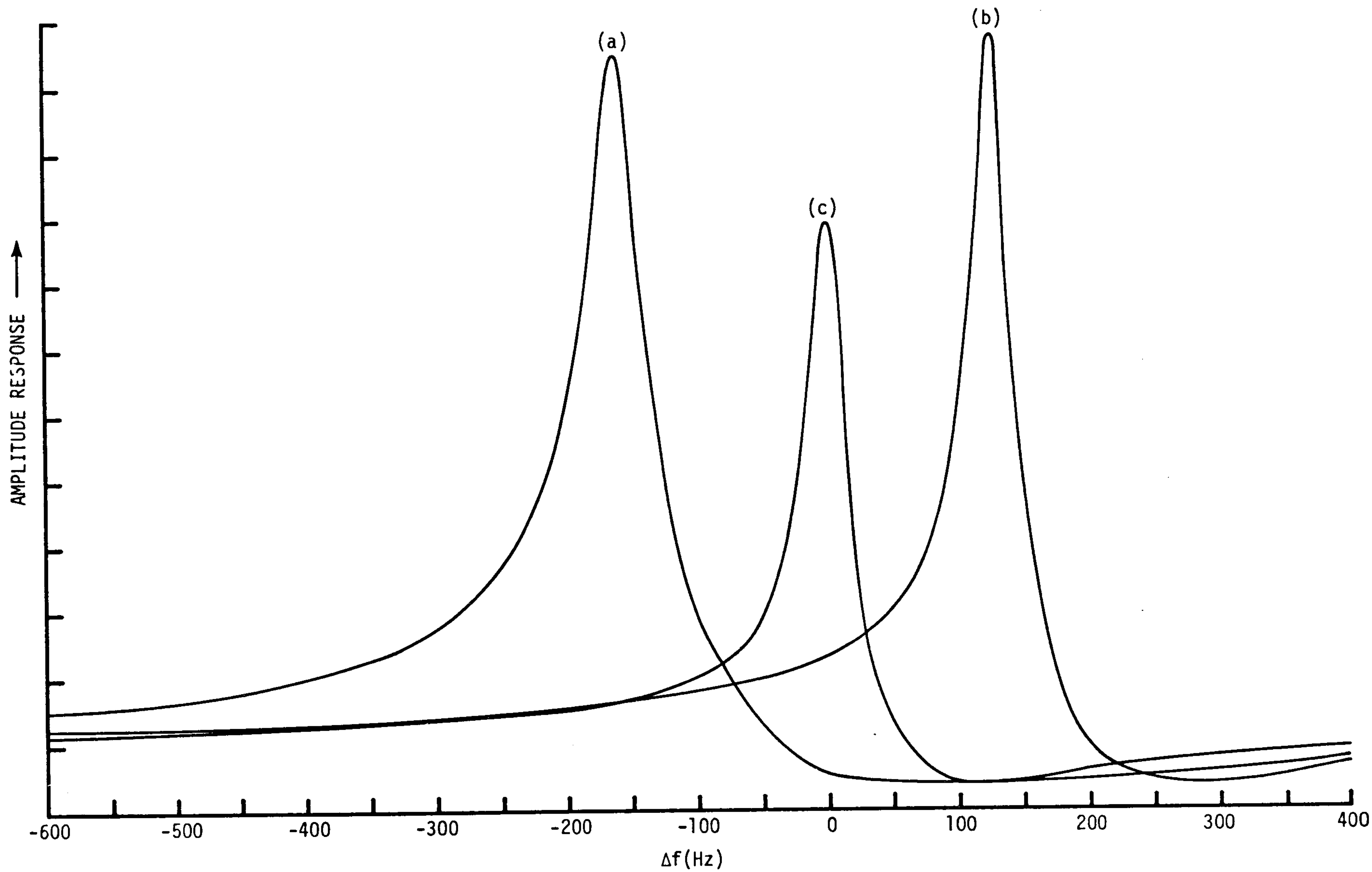

FIGURE 8 Experimental amplitude response as a function of driving frequency of: a) and b) single 3rd overtone crystals from Manufacturer A and c) the two crystals connected in series. Note the single resonance.

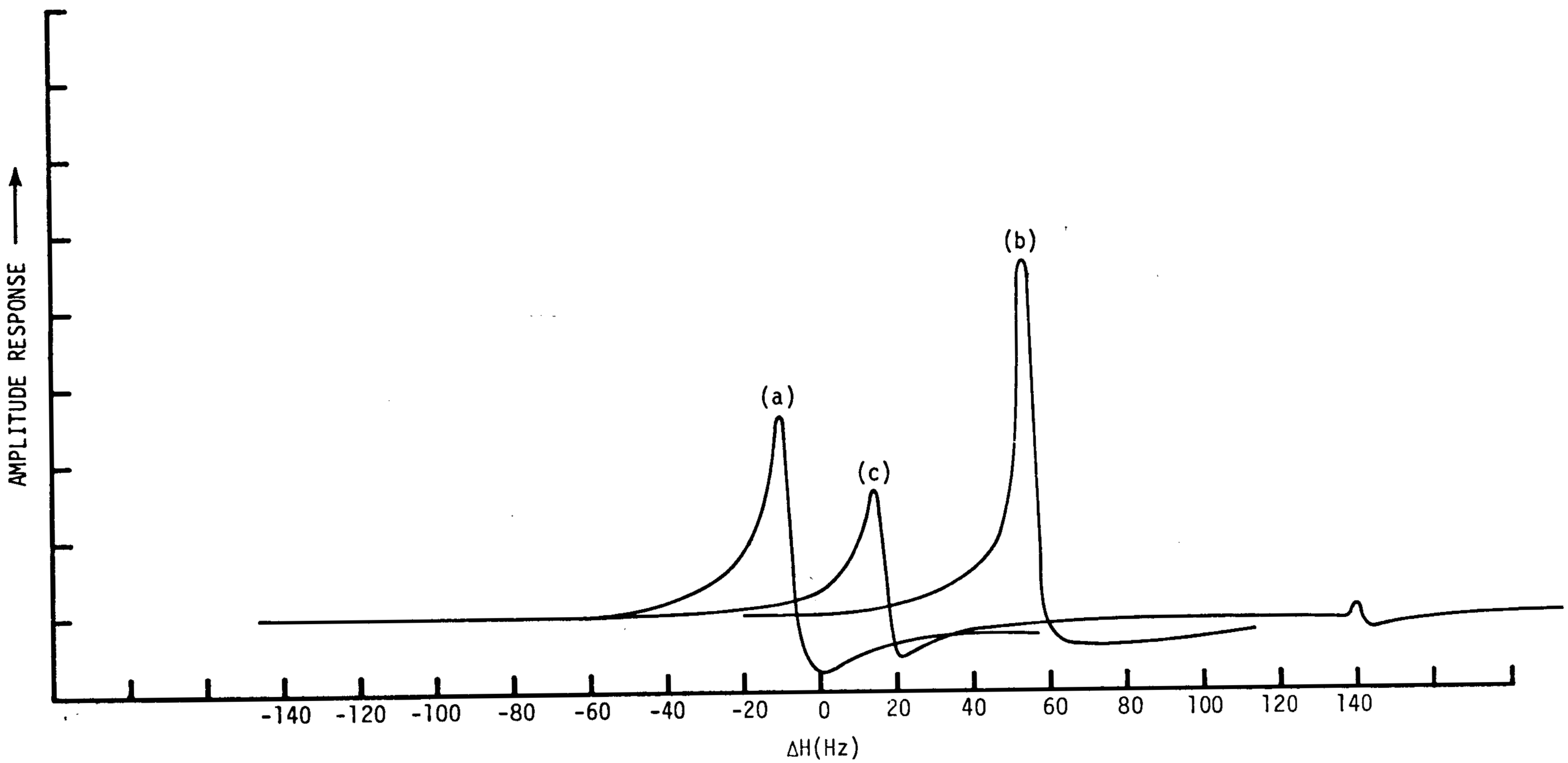

FIGURE 9 Experimental amplitude response as a function of driving frequency of a) and b) single 3rd overtone At cut 10 MHz crystals from Manufacturer B, and c) the two crystals connected in series. Note the single resonance.

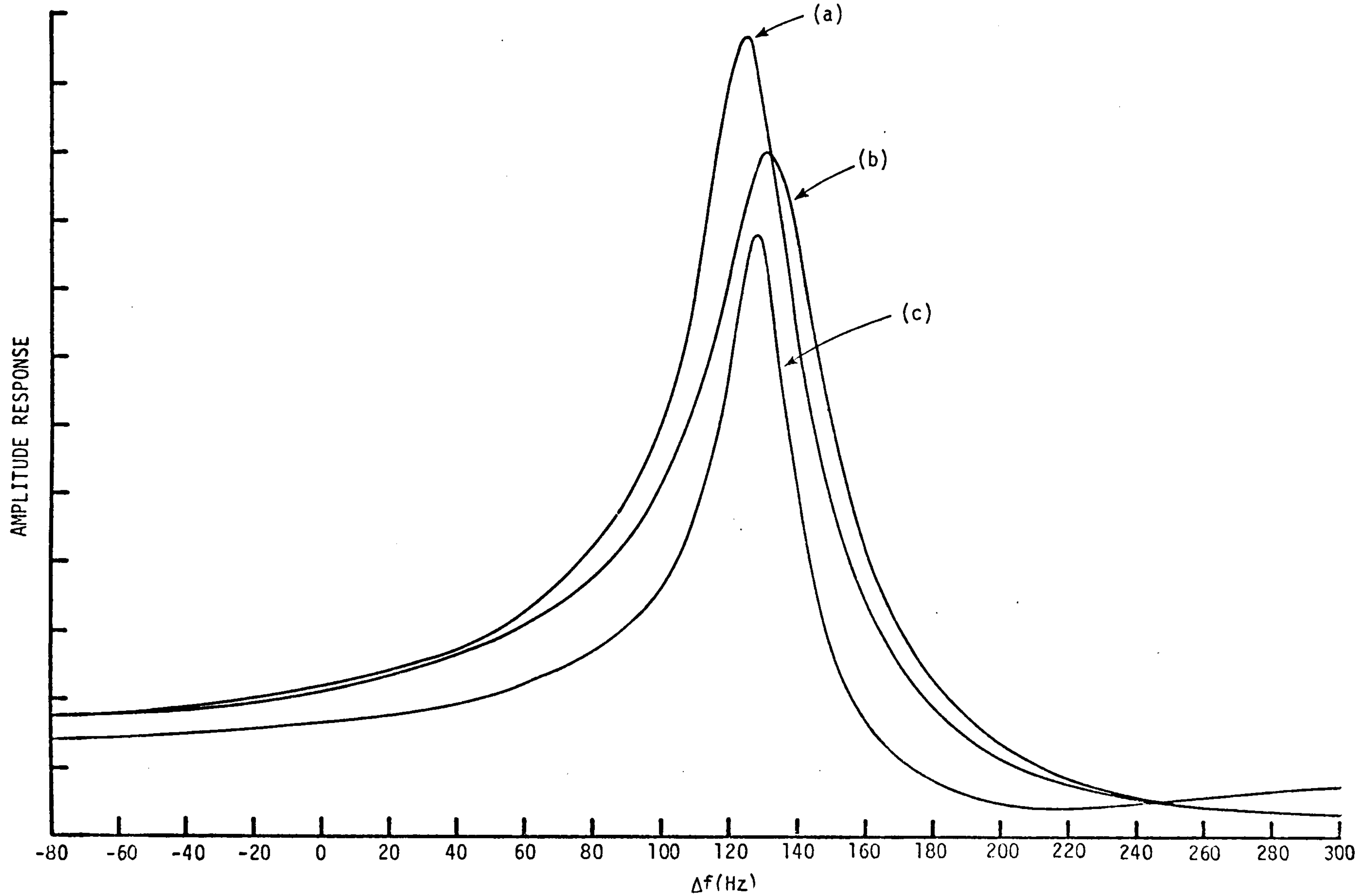

FIGURE 10 a) Amplitude response vs. driving frequency for:
(a) a 5th overtone 5 MHz crystal #EN SCM 5061
(b) a 5th overtone 5 MHz crystal #EN SCM 5071
(c) the two crystals in series. Note the single resonance.

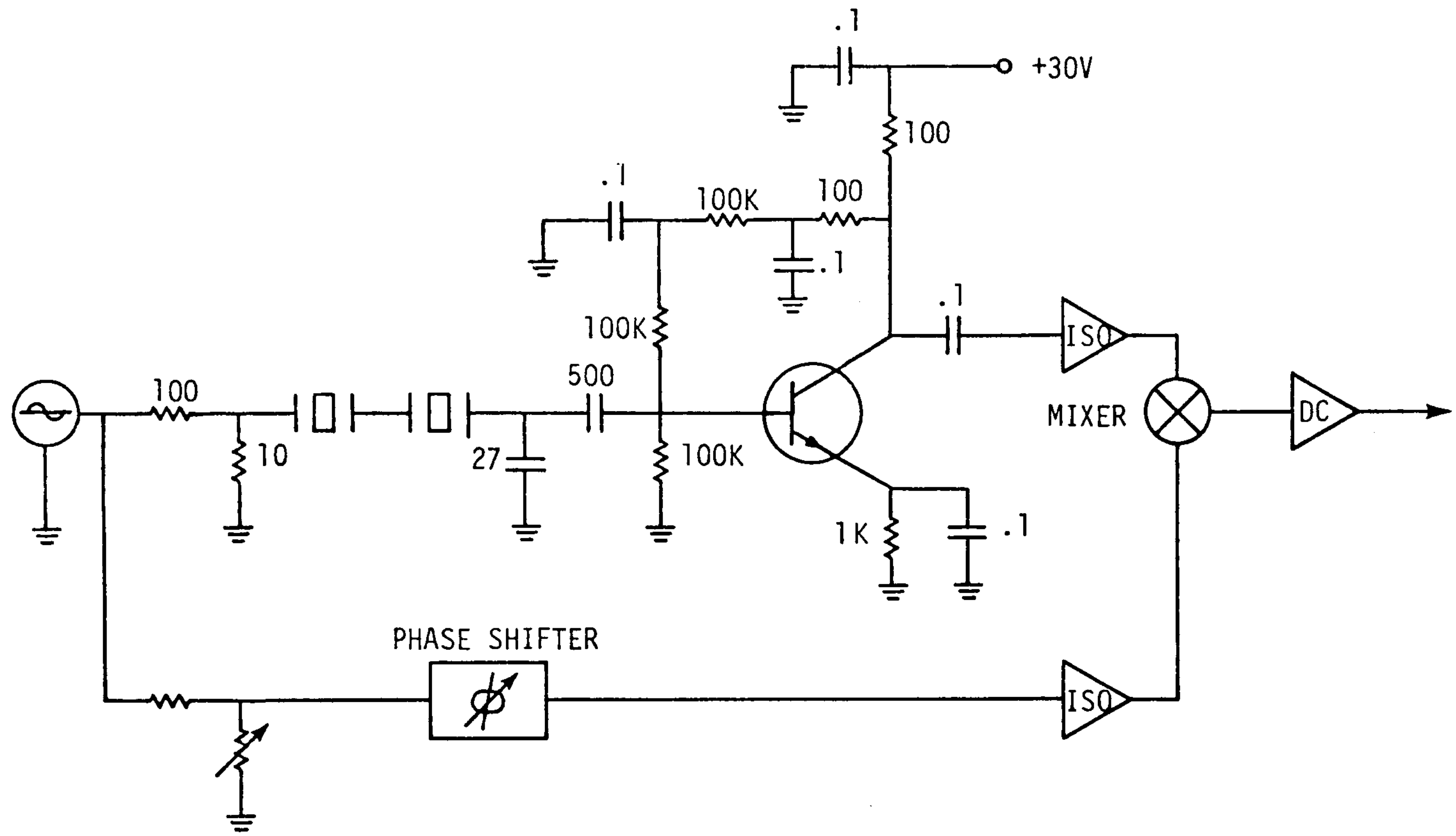

FIGURE 11 Circuit used to test acceleration sensitivity of crystals.