Resonant Transducer

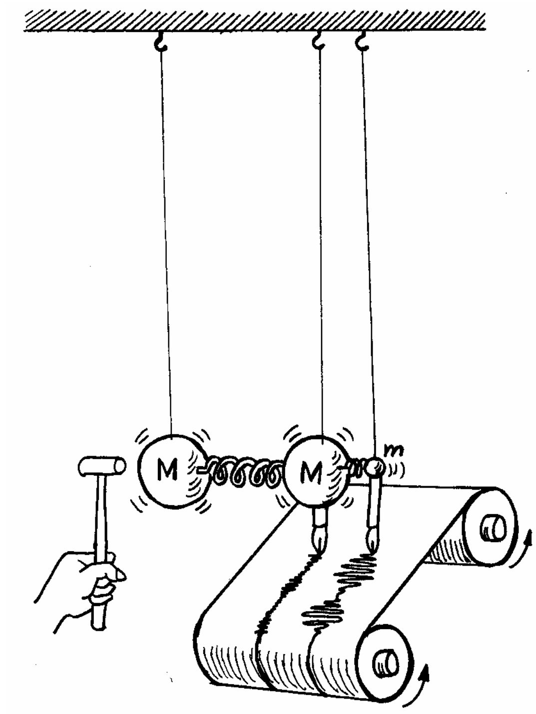

Figure 1. Principle of a resonant transducer. The antenna excitation drives the resonant mass. The energy is transferred back and forth between the two masses by a beat.

Figure 1 illustrates the principle of a resonant transducer [Paik, 1972]. The antenna with mass *M* receives a tiny "hammer blow" from the GW. If the resonance frequency of the small mass *m* is tuned to that of the antenna, the antenna begins to drive the resonator, transferring its entire energy to the small mass. The displacement of the transducer then becomes $(M/m)^{1/2}$ times larger than the initial displacement of the antenna. The energy flows back and forth between the two masses with a beat period of $(2\pi/\omega_a)\,(M/m)^{1/2}$.

Since the energy coupling constant of the transducer, β_S, is inversely proportional to the mass that it is coupled to, the resonant transducer improves β_S by the ratio of M/m. However, since it takes half the beat period for the signal to appear fully at the output of the transduer, the detection bandwidth is restricted to

$$\Delta\omega_S \approx \omega_a (m/M)^{1/2}. \tag{1}$$

To obtain the largest $\Delta\omega_S$, one must choose an optimum value of the transducer mass, m_{opt}, which satisfies the two conditions simultaneously:

$$(\Delta\omega_S/\omega_S)_{\max} \approx \beta_S(m_{opt}) \approx (m_{opt}/M)^{1/2}. \tag{2}$$

For the superconducting inductive transducer [Paik, 1976] of Figure 2,

$$\beta_S = \frac{2\eta}{1+\gamma}\frac{B^2 S}{\mu_0 m \omega_a^2 d}, \tag{3}$$

where $\gamma \equiv L_3(L_1^{-1} + L_2^{-1})$, η is the fraction of the electrical energy coupled to the SQUID, *S* is the area of each (pancake) sensing coil, *d* is the gap between each sening coil and the transducer mass, B is the dc magnetic field stored in the gap, and μ_0 is the permeability of vacuum. For the single-mode Maryland transducer presently mounted on ALLEGRO, m = 0.62 kg, $S = 3.5 \times 10^{-3}$ m^2, $d = 2.5 \times 10^{-5}$ m, B = 0.12 T (H_{c1} of niobium at 4.5 K), $\omega_a/2\pi$ = 915 Hz, $\eta \approx 0.4$, and $\gamma \approx 1$, which yields $\beta_S \approx 0.03$. With the antenna mass M = 1150 kg, we find $(m/M)^{1/2} = 0.023$. Thus the transducer mass is close to optimum and allows $\Delta\omega_S/\omega_S \approx 0.03$.

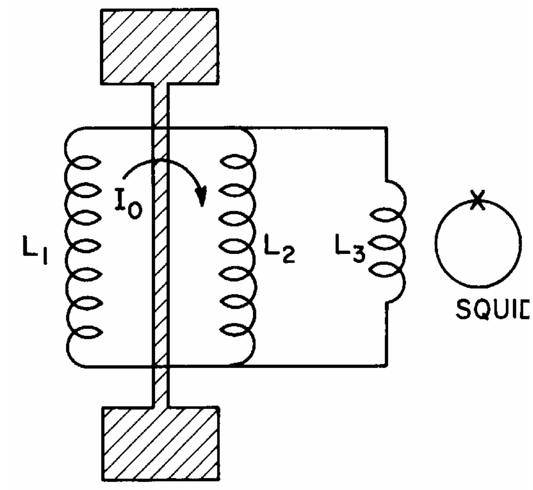

Figure 2. A superconducting inductive transducer. The magnetic field produced by the persistent current I_0 provides the coupling.

The resonant transducer concept can be extended further by using a cascade of n resonators with geometrically decreasing masses [Richard, 1979]. Since the beat frequency is determined by the ratio of neighboring masses, Eq. (2) is modified to

$$(\Delta\omega_S/\omega_S)_{\max} \approx \beta_S(m_{opt}) \approx (m_{opt}/M)^{1/(2n-2)}. \tag{4}$$

In principle, $\Delta\omega_S/\omega_S$ arbitrarily close to unity can be obtained by increasing n. The resulting increase in $\Delta\omega_S$, however, is slow beyond n = 3, while the hardware becomes very complex with increasing n. The practical limit for n appears to be 3 for most cases of interest.

The parameters chosen for the two-mode Maryland transducer under construction are m = 0.050 kg, $S = 1.8 \times 10^{-3}$ m^2, and $d = 5.0 \times 10^{-5}$ m, with the others unchanged. This leads to $\beta_S \approx 0.10$ and $(m/M)^{1/4} = 0.081$. Again, the transducer mass is close to optimum and allows $\Delta\omega_S/\omega_S \approx 0.10$ (close to a 100-Hz bandwidth).

Paik, H. J. (1972), in *Proc. International School of Physics "Enrico Fermi" Experimental Gravitation* (Academic Press, New York, 1974), ed. B. Bertotti, p. 515-524.

Paik, H. J. (1976), *J. Appl. Phys.* **47**, 1168-1178.

Richard, J.-P. (1979), in *Proc. 2nd Marcel Grossmann Meeting on General Relativity* (North-Holland, New York, 1982), ed. R. Ruffini, pp. 1239-1244.