MAGNETIC-COUPLING: SELECTIVITY & SENSITIVITY

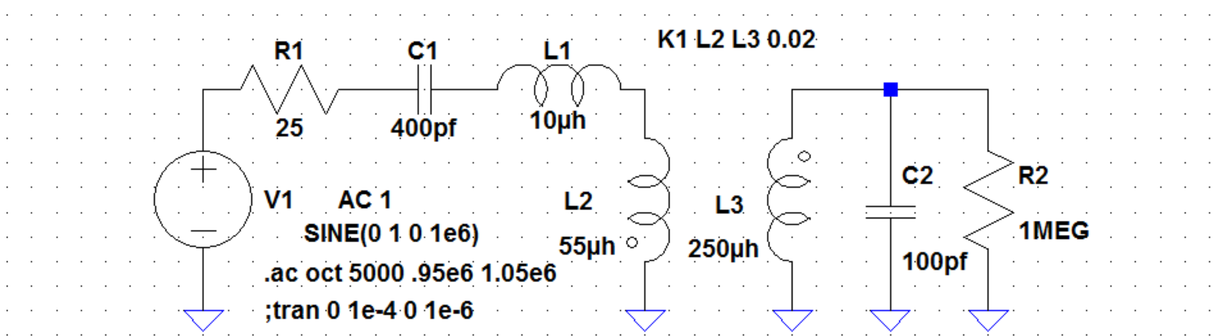
Phil Anderson, WØXI.

Figure 1 shows a simulated antenna circuit with loading inductor coupled to a tank circuit – the basics of a crystal set if you will. The antenna parameters are R1, C1, and L1 at 1 MHz, with values of 50 ohms, 400 pf, and 10 uh respectively. A loading coil, L2, is picked (or tapped) to resonate the antenna at 1 MHz, thereby enabling a maximum of RF current through itself. L2 is then positioned in line with the tank coil, L3, to couple received signals to the tank. The distance between L2 and L3 is varied to adjust the amount of loading/sensitivity developed atop the tank.

R2 was added to the simulation circuit to set the unloaded "Q" of the tank. A tank circuit Q of 666 was assumed, yielding a value for R2 as follows:

(1.1) $$R_P = XQ = (2\pi fL)Q = 6.28*1*250*650 = 1{,}021K.$$

Figure 1: Simulated Antenna & Loading Coil Coupled to an LC Tank.



A number of frequency sweeps of the circuit were then simulated with LTspice, a computer circuit program, each time varying the amount of coupling. I started with a coupling factor of 0.02, as noted in the spice statement K1 L2 L3 0.02 of Figure 1. Given the variation in coils one could use and the varied environments of test benches, one would need to run experiments/measurements to see how this coupling compares to actual distances used. The circuit should predict the general behavior of magnetically coupled crystal sets.

The first simulation, displayed in Figure 2 with k=0.02, resulted in a loaded Q of the tank (by the antenna circuit) of about 180. Cursors within the spice program, as noted in spectrum sweep display of Figure 2, allow for measurement of the 3 dB bandwidth. At first, a reduction in Q to 180 seems dramatic; but, given the Q of the antenna circuit, perhaps not. The Q of the antenna series tuned circuit can be calculated as follows:

(1.2) $Q \approx \frac{X}{r} = \frac{2\pi fL}{r}$, where r is the total resistance, f frequency, and L total inductance.

The total antenna and ground resistance of an L type antenna is typically 15 to 50 ohms for the broadcast band (AM). I arbitrarily assigned an achievable value of 25 ohms to the simulation circuit of Figure 1. Hence, the antenna circuit Q is about:

(1.3) $Q \approx \frac{6.28*1*65}{25} = 16.$

A number of simulation runs are noted in Table 1.

Figure 2: Frequency Response (Tank Output) with coupling = 2%

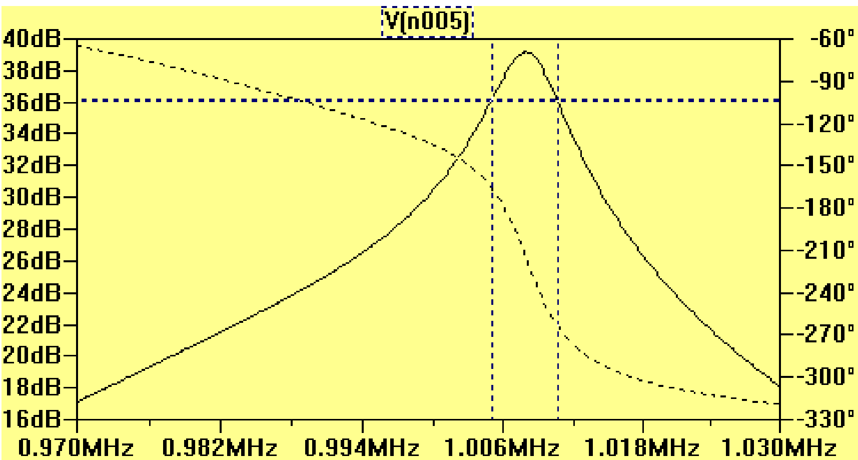


Table 1: BW, Q and Peak Tank Response Versus Amount of Coupling at 1 MHz.

Coupling factor k	Resulting Tank Q	Tank Bandwidth kHz	Tank peak response
0.02	169	5.9	39 dB
0.01	370	2.7	39 dB
0.005	500	2.0	37 dB
0.001	625	1.6	24 dB
0.0005	625	1.6	18 dB

Clearly, this gedanke (think) experiment, with the help of spice simulation, demonstrates the reduction in tank Q with increased loading from the antenna. As the tank is broadened, adjacent stations become noticeable. Counter to this, as coupling is decreased, tank Q increases, approaching its unloaded value as coupling diminishes toward zero. And, as Q increases – due to reduced coupling – signal levels fall. Thus the simple circuit of Figure 1 has been used to demonstrate the fundamental tradeoff of selectivity versus sensitivity.