

Notes On The Design Of Matching Systems For Piezo Elements

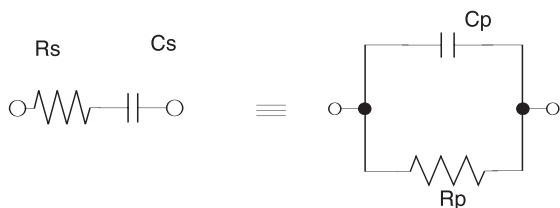
These notes describe a simplified approach to match a piezo device to a source of power. The optimum matching circuit will result in maximum transmitted energy which will result in stronger echoes.

Delivering power to a piezo device, such as a transducer for a ranging instrument, is relatively simple in a normal situation. If the fundamentals are understood, then special circumstances can also be

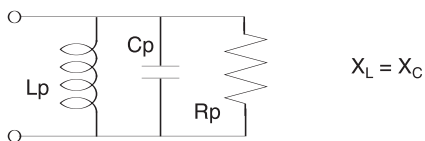
accommodated in a straightforward manner.

Like most reactive loads, a piezo device can be represented by a series resistor and capacitor. The values of both these elements vary with frequency.

By means of the classic transformation, the series values may be transformed to an exactly equivalent parallel resistor and capacitor combination. Unfortunately, the value of these components also vary with frequency (See Transducer Impedance).



The solution to these variations with frequency of operation is to use the values at the desired frequency. In the case of a depth sounder, it is the "Best Echo Frequency". At exactly this frequency, the resistance and capacitance values of the piezo device are obtained either by measurement or from the manufacturer of the device.

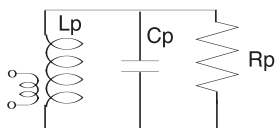


The simplest matching method is to use an inductor to tune out the reactance of the parallel capacitance, yielding a purely resistive load very nearly equal to the parallel resistance. If the resulting load

resistance is too high to directly match the driving source, the inductor may also be used as a tuned transformer to provide a lower, more convenient driving point.

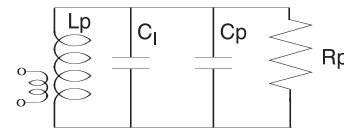
The procedure now follows classic RF matching methods. First, the Q (figure of merit) of the inductor load must be reasonable (5-7 is acceptable).

$$Q = \frac{R_p}{X_L} = \frac{X_L}{R_s}$$

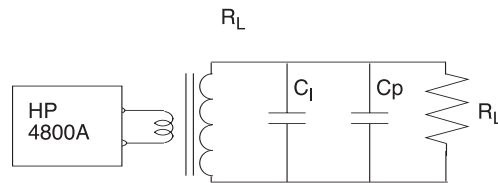
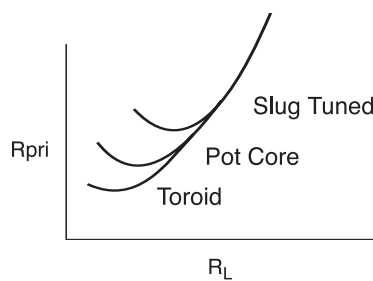


If the Q is too low, place a capacitor across the load and reduce "L" until the load is again resistive.

$$X_L = \frac{X_{C1}(X_{CP})}{X_{C1} + X_{CP}}$$

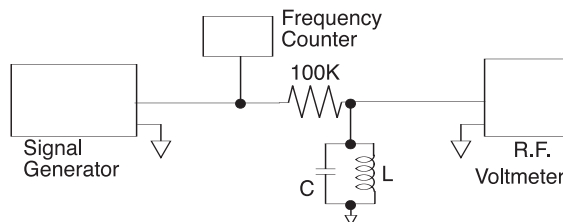


A low impedance winding may now be added to provide a match to the driving source. The turns ratio is the square root of the impedance ratio. However, there is a limit to how high the turns ratio can be. For the usual universal wound inductor with a ferrite adjustment slug and ferrite shell, a ratio of 22 to 1 is about the maximum that can be achieved. Higher ratios may be achieved if toroidal forms are used for the inductor. This is because tighter coupling is achieved with toroids than is available with other types of inductors. Pot cores are between toroids and slug-tuned coils in coupling.



The foregoing discussions of matching assumes that the coil is lossless, at least compared to the Rp of the desired transducer load. Often this is not the case.

To evaluate whether there is a problem, a sample coil of the calculated inductance must be obtained. If the HP4800 is available, the Rp of the coil may be measured by placing the calculated total capacity across the coil and adjusting the frequency for zero phase angle. The instrument will indicate the Rp directly. If the HP4800 is not available, the same results can be obtained by another technique.



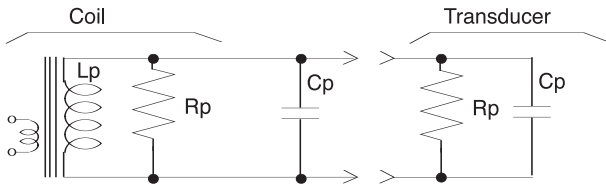
Find the frequencies at which the response of the tuned circuit is down 3dB from peak response.

$$Q = \frac{(F_H + F_L)}{F_H - F_L}$$

$F_L = \text{lower -3dB frequency}$
 $F_H = \text{higher -3dB frequency}$

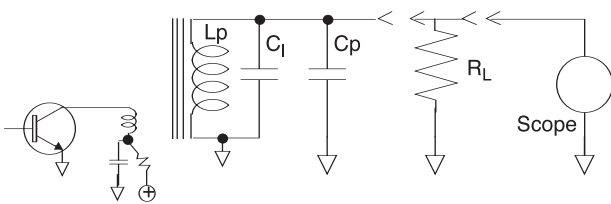
$$R_p = QX_C$$

The R_p of the coil should now be considered to be in parallel with R_p of the transducer.



The coil inductance and resonating capacity must now be recalculated based on the lower load resistance presented by the parallel combination of the R_p of both the coil and transducer.

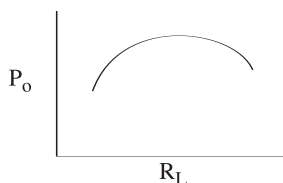
Also, the division of the available output power must be considered. If the two R_p 's are equal, only one half the power developed is available to the transducer to put into the water. So it is desirable that the R_p of the coil be as high as possible compared to the R_p of the transducer.



$$P_o = \frac{(V_{P-P})^2}{R_L}$$

Once the coil is designed and in place, the effectiveness may be checked by placing the equivalent parallel capacitance of the piezo device across the inductor.

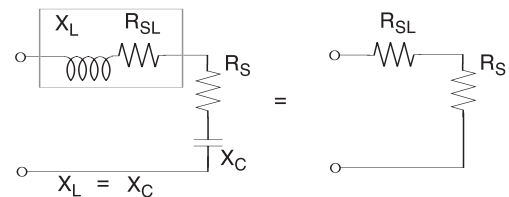
Then various resistors are placed across the inductor and the power dissipated is then calculated. A broad peak should be achieved at the value of the parallel resistance of the piezo device. If the power peak does not occur at the value of parallel resistance which the piezo device has at the frequency of interest, small adjustments in the turns ratio and/or the Q should be made.



The advantages of this method of matching are:

- Minimum components —minimum cost
- Highest impedance in the connecting cable, hence the lowest I^2R losses
- If the cable must be extended, a simple removal of fixed capacity is all that is required

Another method which might be considered is using the series equivalent values of the piezo device. To do this, an inductor is placed in series with the piezo device whose reactance is equal to the reactance of the equivalent series capacitance. This method presents the value of series resistance to the driving source. The disadvantage is that a second inductor is required because in the usual case, the series resistance is still higher than the required load impedance of semiconductor power sources. Also, the current through the load must pass through the effective series resistance of this (series) inductor, which increases the I^2R losses, resulting in a net loss of power delivered to the load in the usual case.



Example:

Assume that a transducer is to be matched whose "Best Echo Frequency" is 196.0 kHz and the series R and X have been measured at that frequency as 151 – j239 (C = 3400pf).

$$R_p = R_S + \frac{X_S^2}{R_S} = 151 + \frac{(239)^2}{151} = 529.3 \text{ ohms}$$

$$X_p = \frac{R_S R_p}{X_S} = \frac{151(529.3)}{239} = 334.4 \text{ ohms}$$

$$(C_p) = 2483 \text{ pf}$$

Since at resonance $X_C = X_L$, the inductor will have a reactance of 334.4 ohms

Calculate Q of this situation

$$Q = \frac{R_p}{X_L} = \frac{529.3}{334.4} = 1.58$$

This is too low so capacitance must be added. Let us calculate on the basis of a loaded Q of 6

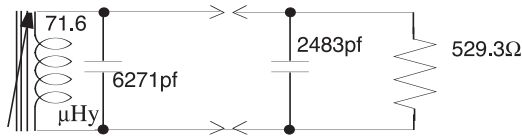
$$X_L = \frac{R_P}{Q} = \frac{529.3}{6} = 88.22 \text{ ohms}$$

$$L = \frac{X_L}{2\pi f} = \frac{88.22}{6.28(196 \times 10^3)} = 71.6 \mu\text{Hy}$$

Total C is now

$$C = \frac{1}{2\pi f X_L} = \frac{1}{6.28(196 \times 10^3)(88.22)} = 9204 \text{ pf}$$

Added capacity must then be $9204 - 2483 = 6721 \text{ pf}$



The required primary impedance is calculated as 3.6 ohms to match the driving transistor

$$N_R = \sqrt{\frac{529.3}{3.6}} = \sqrt{147} = 12.1$$

This is low enough so a slug tuned coil may be used. If a coil of 71.6mHy required 55 turns, then the primary would use 4.5 turns;

$$T_{PRI} = \frac{T_{SEC}}{N_R} = \frac{55}{12.1} = 4.55$$

The primary should be wound as tightly over the secondary as possible to obtain the best coupling. Use the start of the secondary coil as the high impedance end.

Power into a piezo device:

If the parallel resistance is known, power calculation is straightforward:

$$P = \frac{E^2}{R} \quad \begin{array}{l} E \text{ is RMS volts} \\ R \text{ is the parallel resistance of the piezo device} \end{array}$$

Of course the voltage across the load will probably be measured with an oscilloscope and read as peak to peak voltage. Therefore, it must be divided by 2.83 to change to RMS voltage.

If parallel resistance is not used in the calculation, series resistance may be used. But the calculation is a bit more involved:

1. Impedance $Z = \sqrt{R_S^2 + X_S^2}$
2. $I_L = \frac{E}{Z}$ E is RMS voltage across the load as previously shown
3. $P = I^2 R_S$

4. The above equations are combined into a single equation

$$P = \frac{R_S E^2}{R_S + X_S^2}$$

Considerations for matching systems during receive mode:

Once the matching has been accomplished for transmit, what are the considerations for receiving? If the input impedance of the receiving section is higher by a large margin, then it may be tied directly across the tuned circuit used to match in transmit.

If the receive input impedance margin is not large or is even small, then other methods must be used to achieve the maximum performance of which the piezo device is capable. Also, provisions must be made to prevent the transmit voltage from destroying the input device(s) of the receiver.

If the coupling of the transformer is high, a lower "Q" may operate satisfactorily. Reduce the capacity added in steps, increasing the inductance of the secondary in steps to maintain resonance. Keep the primary inductance constant. In the extreme it may be possible to resonate just the capacity of the transducer without adding any external capacitance. This will yield higher turns ratios and if the coupling is tight enough, will also yield more output voltage (power).

Note, however, that at Q values of 7 or less, the equation no longer holds. Until such time as an application note describing techniques of calculating such low Q matching systems is developed, proceed carefully, step by step, in developing these matching systems by empirical methods.



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