The Incidental Double Tuned Circuit
A TransceiverT/R Design Subtlety.

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A common topology for low power communications transceivers uses a Transmit-Receive (T/R) switch with a single series tuned circuit. Imbedded diode or transistor switches become a "short circuit" during transmit, preventing energy from reaching the receiver. There is, however, an interaction that often occurs when this single tuned circuit is attached to the one normally found in the receiver front-end. The result is an unwanted overall response that could lead to IMD and other overload problems. We illustrate this problem (and a solution) with a design example, a simple transceiver using a NE-602 Gilbert Cell mixer receiver front end.

We begin with a single tuncd circuit at 7 MHz to drive a NE602 or NE612 receiver front end IC. This part has an input resistance of 3K Ohms. (See the comment at the end of this report.) Assume a bandwidth of 200 kHz at 7 MHz center frequency. Filter Q is then 7/0.2=35.

But our inductor has an unloaded Q of 250, so the external filter Q will be Qe=42. This results from the relationship

$$\frac{1}{Q_f} = \frac{1}{Q_u} + \frac{1}{Q_e}$$

We wish to load the tuned circuit equally by the connection on each side, so the external Q will be 84 on each side. The 3K ohm input resistance of the IC should create this Q of 84 for the inductor in the tuned circuit. But Q relates to parallel load resistance through

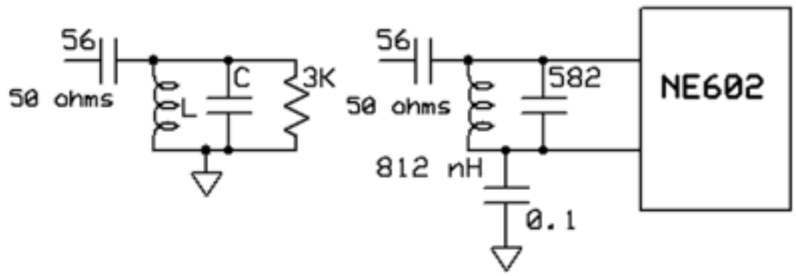
$$R_p = Q\omega L$$

Solving this for L at 7 MHz yields L=812 nH. The total C required for resonance at 7 MHz is calculated from the usual to produce C=637 pF.

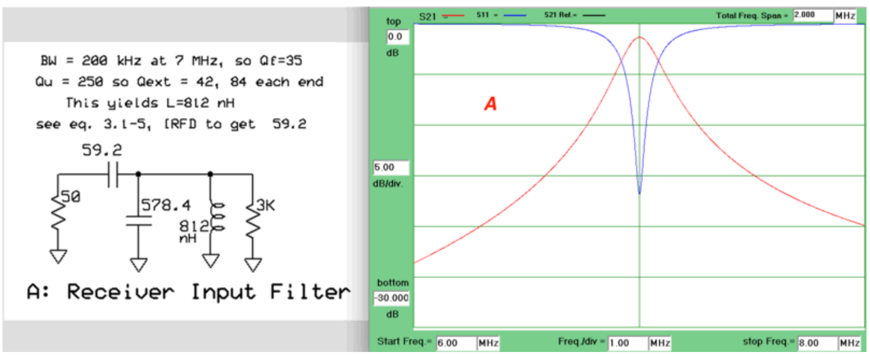
The 50 Ohm antenna connection at the other end loads the tuned circuit with a series capacitor with reactance given by

$$X_C = \sqrt{R_p R_0 - R_0^2}$$

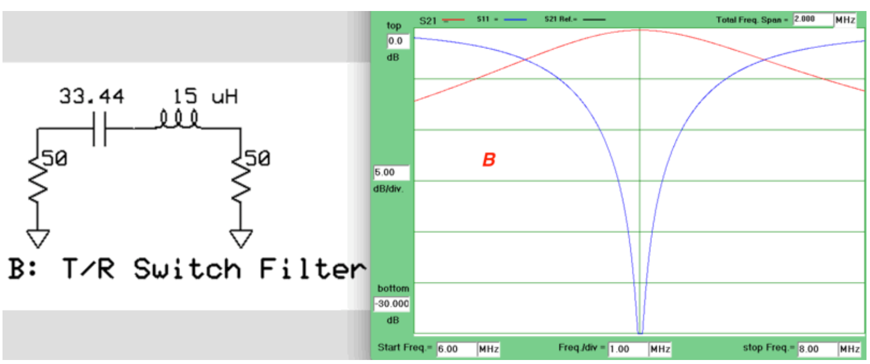
where R_0 is 50 and R_P is 3K. The resulting series capacitor is 59 pF. We will use a standard value of 56 pF for further analysis. The resulting circuit is



The response (S21) of this single tuned circuit is shown in Fig. A below in red. The blue trace represents the input impedance match, indicated by the magnitude of S11 looking into the receiver. The value shown, S11=-17 dB, is a good input match looking into the receiver.

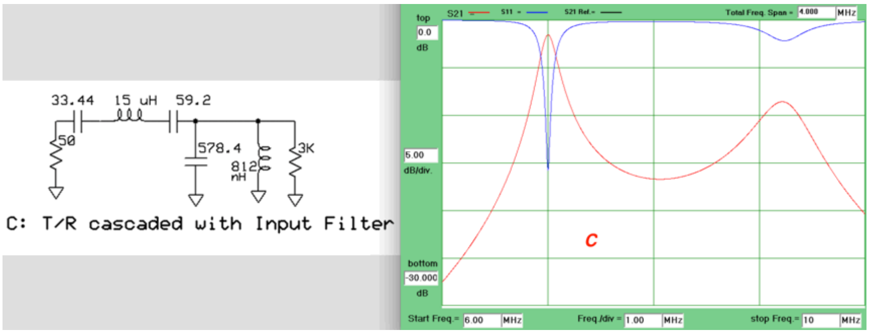


The T/R switch tuned circuit is shown below. A 50 Ohm termination is assumed at each end, resulting in Fig. B.

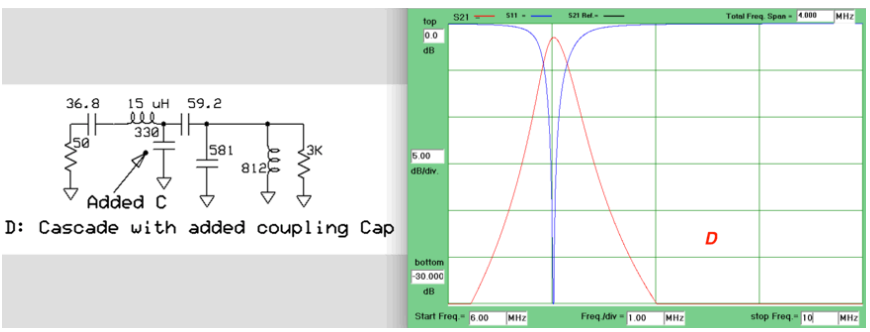


Both gain and impedance match are excellent. The 15 uH inductor is assumed here to have the same unloaded Q=250 as was used with the original receiver resonator. The usual T/R design includes a pair of back to back diodes from the junction of the L and C connected to ground. The diodes are transparent, appearing as open circuits during receive, but turn on during transmit intervals, creating the needed short circuit to ground that protects the receiver. See details in the paper "**Electronic Antenna Switching**," QEX, 1995, including performance data.

We now connect the two circuits together, only to discover an undesired interaction, shown below in Fig. C. This is our smoking gun! The response is severely compromised with significant energy appearing at the output at both the 7 MHz design frequency and around 9.2 MHz. The interaction is normal for an over-coupled double tuned circuit. (See **"The Double-Tuned Circuit: An Experimenter's Tutorial,"** QST, December, 1991.)



A simple solution is shown below in Fig. D. A shunt 330 pF coupling capacitor is added between the two tuned circuits. This mutual element provides an impedance where energy can be shared between resonators, but at an intensity that actually improves the front end selectivity rather than compromising it. The double humped response of Fig C is replaced by a well defined, single peak of Fig D below.



A recent transceiver ("**The Micromountaineer Revisited**," QST, July, 2000, pp28-33) suffers from this problem. It is solved at 7 MHz by adding a capacitor across J5. Any value from 330 to 470 pF should be fine. C12 and C20 will then need retweaking.

The experimenter should not treat this difficulty as a reason to dismiss the basic T/R method, for it is still sound. Many others have used the topology with great success. (see Burdick, "**NorCal 40, A Club Project**," QRPp, Journal of the Northern California QRP Club, Vol. 1., No. 3, December 1993; Lewallen, "**An Optimized QRP Transceiver**," QST, Aug, 1980.

Any linear circuit analysis software can be used to analyze and adjust the networks prior to construction. The plots shown were generated with General Purpose Ladder Analysis, part of "LADPAC-2002," a Windows (registered to Microsoft, Inc.) based version of the software distributed with **Experimental Methods in RF Design.** (as of Feb, 2003).

Regarding the NE602 input impedance: (10Aug07)

Often we see the NE602 input modeled as ideal transistors (infinite beta) with 1.5K resistors from each input to "ground." But the '602 input is a differential pair with a total bias current of about 2 mA (1 mA per transistor.) The equivalent emitter resistance for each transistor is then re=26/Ie(mA), or 26 Ohms. If beta=100, Rin= 2.6 K. If we consider frequencies near or just above the beta cutoff, the net impedance drops down to 1.5K for each transistor. **But the basetobase input impedance of a differential pair is twice that of the single transistor**. Hence, the input impedance is around 3K paralleled with a couple of pF of capacitance. This is the value I measured with a vector network analyzer.

Additional Thoughts

Although the example was that of a simple double tuned circuit, the same problems will occur when a higher order filter is at the receiver input. One can do more elaborate analysis to better under stand the problem. The better answer is to measure the equipment. The measurements should be done with low signal levels to prevent over driving the receiver. A signal generator is attenuated to a level of around -20 or even 30 dBm and then applied to a return loss bridge. The bridge output can be detected with a spectrum analyzer, a sensitive power meter, a 50 Ohm terminated oscilloscope, or even a receiver. See EMRFD chapter 7 for measurement thoughts. Using the previous receiver example, the receiver input match is initially measured. This should be done over a suitably wide bandwidth. For the 7 MHz receiver, the measurements should probably done from 4 to 12 MHz. The T/R single series tuned circuit is also measured, without the receiver. The T/R is then attached to the receiver and the combination is measured. This is now the time to start attaching the shunt capacitor to the circuit. Various values are tried to determine a reasonable result.

Extra circuitry can be appended to the T/R to eliminate the problem, if present. One such circuit would be a bandpass/band-stop diplexer. A suitable circuit can be designed using the information on EMRFD page 3.38. One might suspect that the addition of more tuned circuits would only make things worse. This is not the case here, for the diplexer networks include resistors. These elements serve to terminate the out-of-band energy (away from 7 MHz) to prevent the detuning affects. Clearly, measurements should be done.

An amplifier can also be added, following the T/R block. A good amplifier circuit would be a common gate JFET. The signal from the T/R is applied through a blocking capacitor to the source of the FET. The drain is terminated in a medium value resistor. A wide band transformer then transforms that R down to 50 Ohms to drive coax leading to the receiver. Care should be taken to keep the gain very low. Excess gain can kill receiver dynamic range performance; the example NE602 receiver is already challenged in this regard. The low gain amplifier will still have good reverse isolation, preventing coupling between tuned circuits.