Active Filters, NICs, NACs, and Knocks

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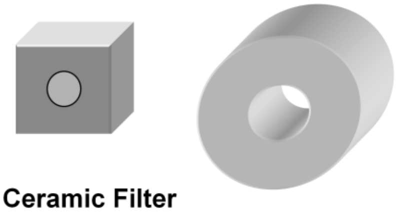
Discrete Filter Technology



Ceramic Filter

Insertion Loss…………………Low 0.3 to 5.0 dB

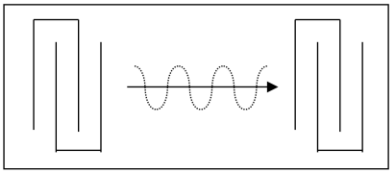
Power Handling
Capability…………………….. Medium 1 to 50 watts

Physical size……….	**12mm,**	**6mm,**	**4mm,**	**3mm diam**
Freq range (ε =90)	**<.8**	**<1.5**	**<2.4**	**<3GHz**
(ε =36)	**<1.2**	**<2.2**	**<3.6**	**<5GHz**
Q (at mid freq)	**600**	**400**	**300**	**250**

Temperature Stability……..Very Good, adjustable

Mechanical Stability…………………Very Good

Bandwidth……………1.5 to 10%



Saw, and other acoustic filters

Insertion Loss………..3.0 to 20.0 dB

Power Handling
Capability…………….Low <1 w

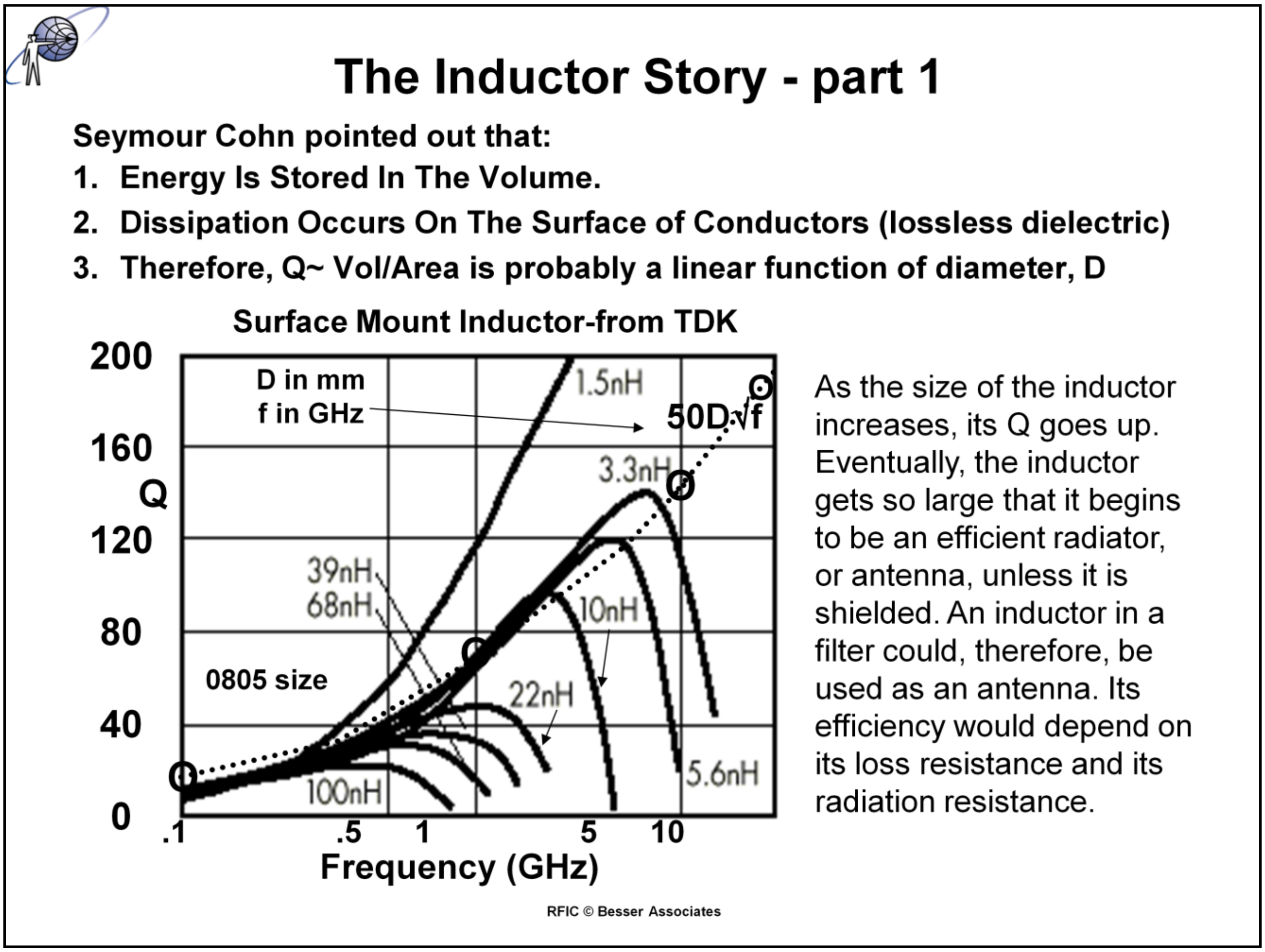
Physical Size…………Very Small

Temperature
Stability………………Good

Mechanical
Stability………………..Very Good

Very Narrow Bandwidth…..<5%

But, we are going to look at filters that can be integrated.



The Inductor Story - part 1

Seymour Cohn pointed out that:

1. **Energy Is Stored In The Volume.**
2. **Dissipation Occurs On The Surface of Conductors (lossless dielectric)**
3. **Therefore, Q~ Vol/Area is probably a linear function of diameter, D**

Surface Mount Inductor-from TDK

As the size of the inductor increases, its Q goes up. Eventually, the inductor gets so large that it begins to be an efficient radiator, or antenna, unless it is shielded. An inductor in a filter could, therefore, be used as an antenna. Its efficiency would depend on its loss resistance and its radiation resistance.

The **50D√f** line does a good job of predicting inductor Q for a family of inductors with wildly different winding parameters, but the same core diameter. The wire was close spaced in some cases, overlapped in others, and very widely spaced, larger diameter for the smallest values. Eventually, the parasitic capacitance of the inductor causes its effective Q to roll off at high frequencies. Smaller coil forms simply scale down Q with size.

The Inductor Story-part 2

Seymour Cohn pointed out that:

1. **Magnetic energy is stored in the volume.**
2. **Dissipation occurs on the surface of conductors (lossless dielectric)**
3. **Therefore, Q~ Vol/Area is a linear function of diameter, D… NOT L**

4P. The Q dependence on inductor value is due to the measurement frequency and distributed capacitance, but what about the figure below? **Xh(4.5GHz) is calculated from X(.5GHz), and Q~√f**

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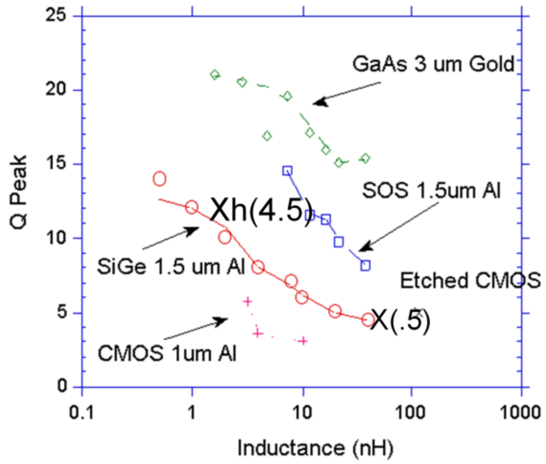


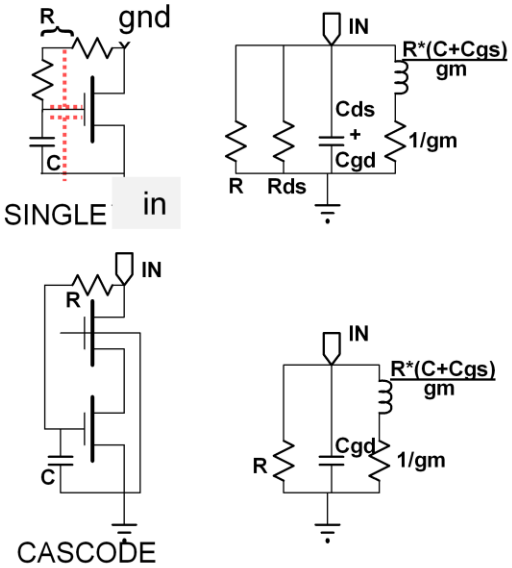
It is very likely that the Q dependence on inductance seen in published data simply is caused by the fact that larger value inductors were measured at lower frequency. A Q of 4 inductor measured at .5 GHz (X on the graph—50 nH) would be equivalent to a Q of 12 inductor (Xh on the graph—2 nH) measured at 4.5 GHz.

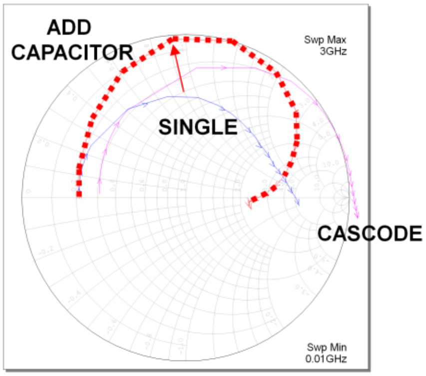
If Only Filters Were Not So Difficult!

Simple Laws Of Physics Determine Filter Performance:

1. Energy Is Stored In The Volume.
2. Dissipation Occurs On The Conductors And In The Dielectric.
3. High Q, High Permeability Material Would Be Nice.
4. The Best Active Filters Begin Life As Passive Filters, because:
5. TO A TRANSISTOR, GENERATING J1ma IS THE SAME AS GENERATING 1ma. A Transistor Does Not Store Energy, It Dissipates It.
6. An approach to the design of active filters for noise or power capability will follow.

Active Inductor Equivalent Circuits





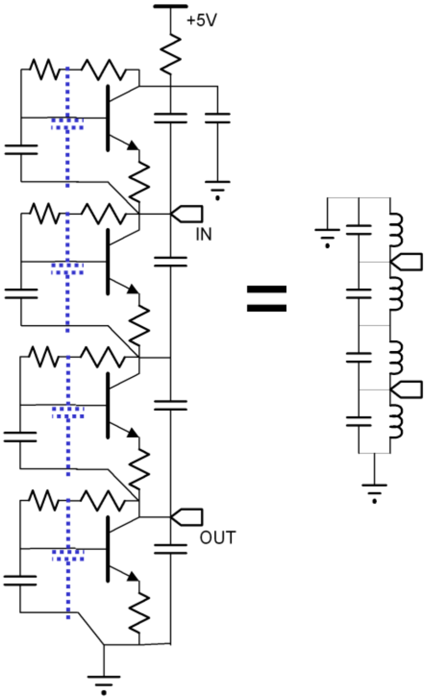
These are the simplest, traditional circuit realizations for active inductors. More complex circuits, suitable for ICs, are discussed later. Delay in the feedback loop rotates the C towards a negative resistance, and makes everything move more quickly with frequency.

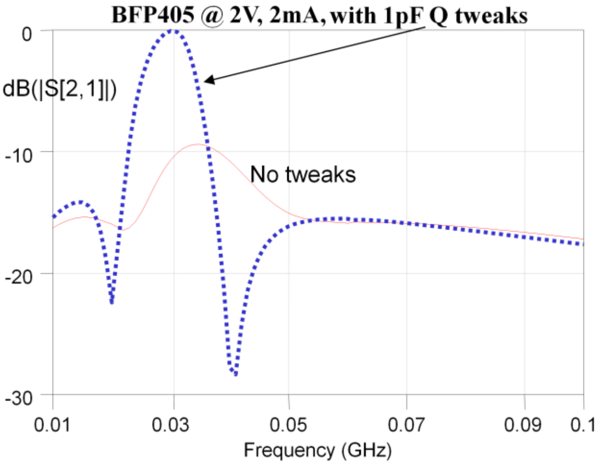
More On Active Inductors

- An opamp is not necessary. Every device in the loop adds delay, reduces the useable bandwidth
- Fix the problems that the active devices have
- Multiple devices are cheap
- Darlington and cascode raise impedance, gain
- Use negative feedback to reduce sensitivity
- Delay adds negative resistance, narrows bandwidth

- The “inductor” current is provided by an active device
- Any Q greater than 1 will mean that large “reactive” current will flow through the active device.
- Even a low Q passive inductor is better than an active one

SIMPLE CAUER ACTIVE FILTER





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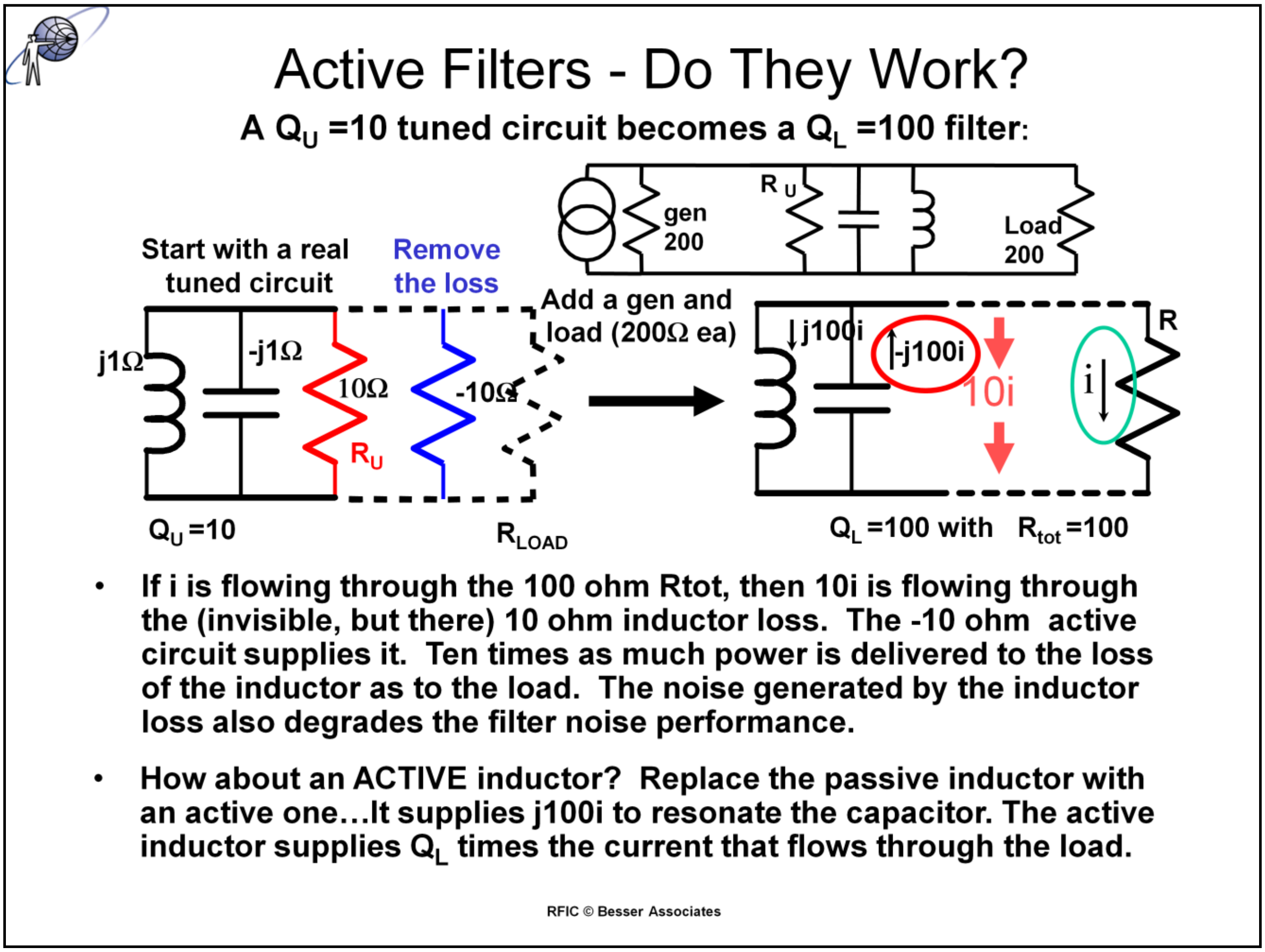

Active Filters - Do They Work?

A Q_U =10 tuned circuit becomes a Q_L =100 filter:

- **If i is flowing through the 100 ohm Rtot, then 10i is flowing through the (invisible, but there) 10 ohm inductor loss. The -10 ohm active circuit supplies it. Ten times as much power is delivered to the loss of the inductor as to the load. The noise generated by the inductor loss also degrades the filter noise performance.**
- **How about an ACTIVE inductor? Replace the passive inductor with an active one…It supplies j100i to resonate the capacitor. The active inductor supplies Q_L times the current that flows through the load.**

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The same voltage(V) is across the tuned circuit and the load. $Pdiss=V^2/R_U$, and $Pout=V^2/R_L$:
$Pout/Pdiss = R_U/R_L$ (1)

The unloaded Q of the tuned circuit is: $Qu = Ru/Xc$ (2)

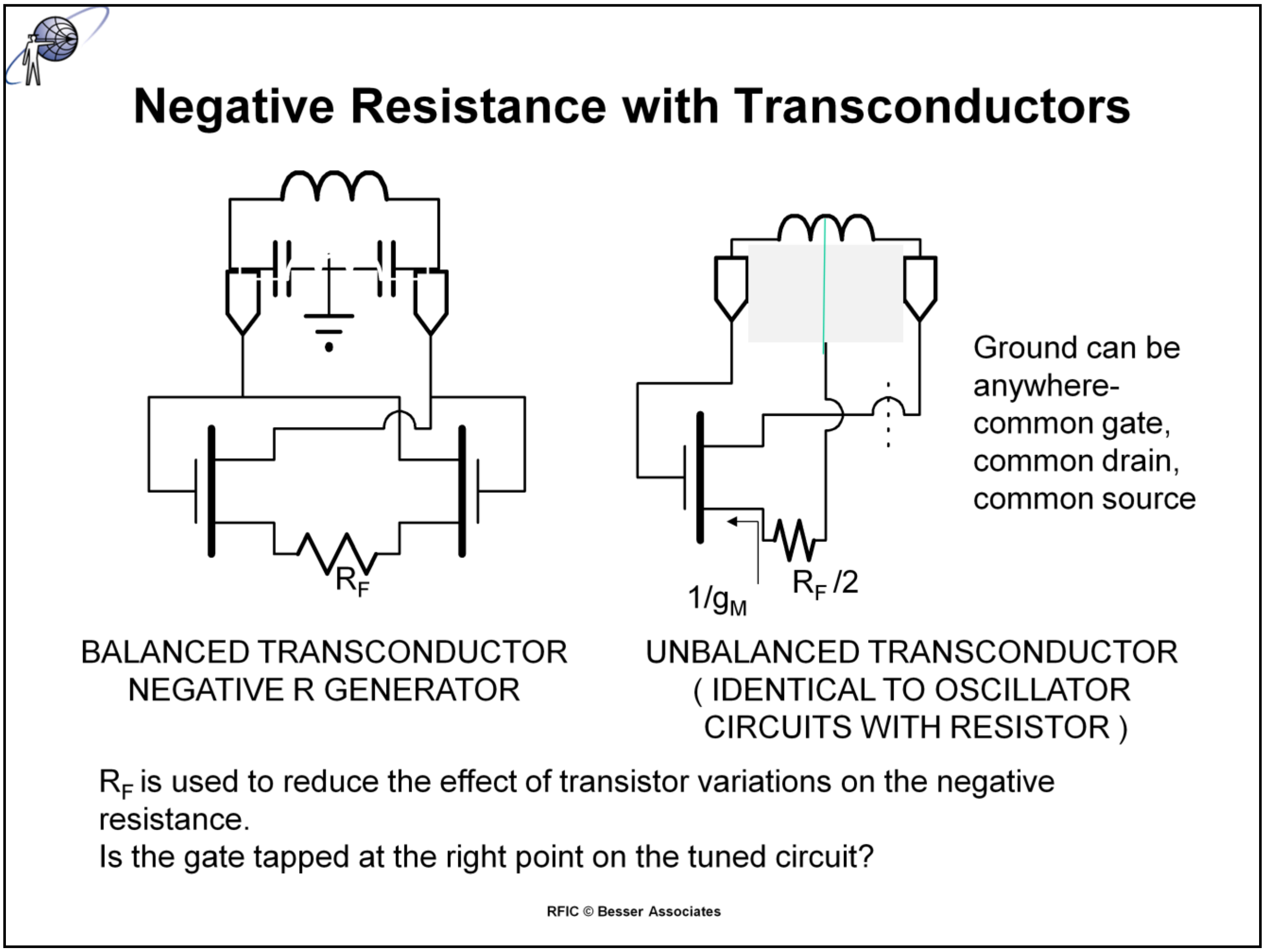
After canceling the circuit loss (Ru), the source(R_L)and the load(R_L) equally load the tuned circuit: $Q_L = R_L/2X_C$ (3)

Therefore, substituting (2) and (3) into (1) : $Pout/Pdiss = Q_U/2Q_L$,

or in dB, $Pdiss = Pout + 10*LOG_{10}(2QL/QU) = Pout + 10*LOG_{10}(QL/QU) + 3dB$ (4)

For both noise figure and power handling, EQN. (4) gives the degradation of performance due to the tuned circuit not being truly lossless, but actively loss cancelled.

NFdB = NF(active device, in circuit) + $10*LOG_{10}(QL/QU) + 3dB$ (5)



Negative Resistance with Transconductors

Ground can be anywhere- common gate, common drain, common source

BALANCED TRANSCONDUCTOR
NEGATIVE R GENERATOR

UNBALANCED TRANSCONDUCTOR
(IDENTICAL TO OSCILLATOR
CIRCUITS WITH RESISTOR)

R_F is used to reduce the effect of transistor variations on the negative resistance.
Is the gate tapped at the right point on the tuned circuit?

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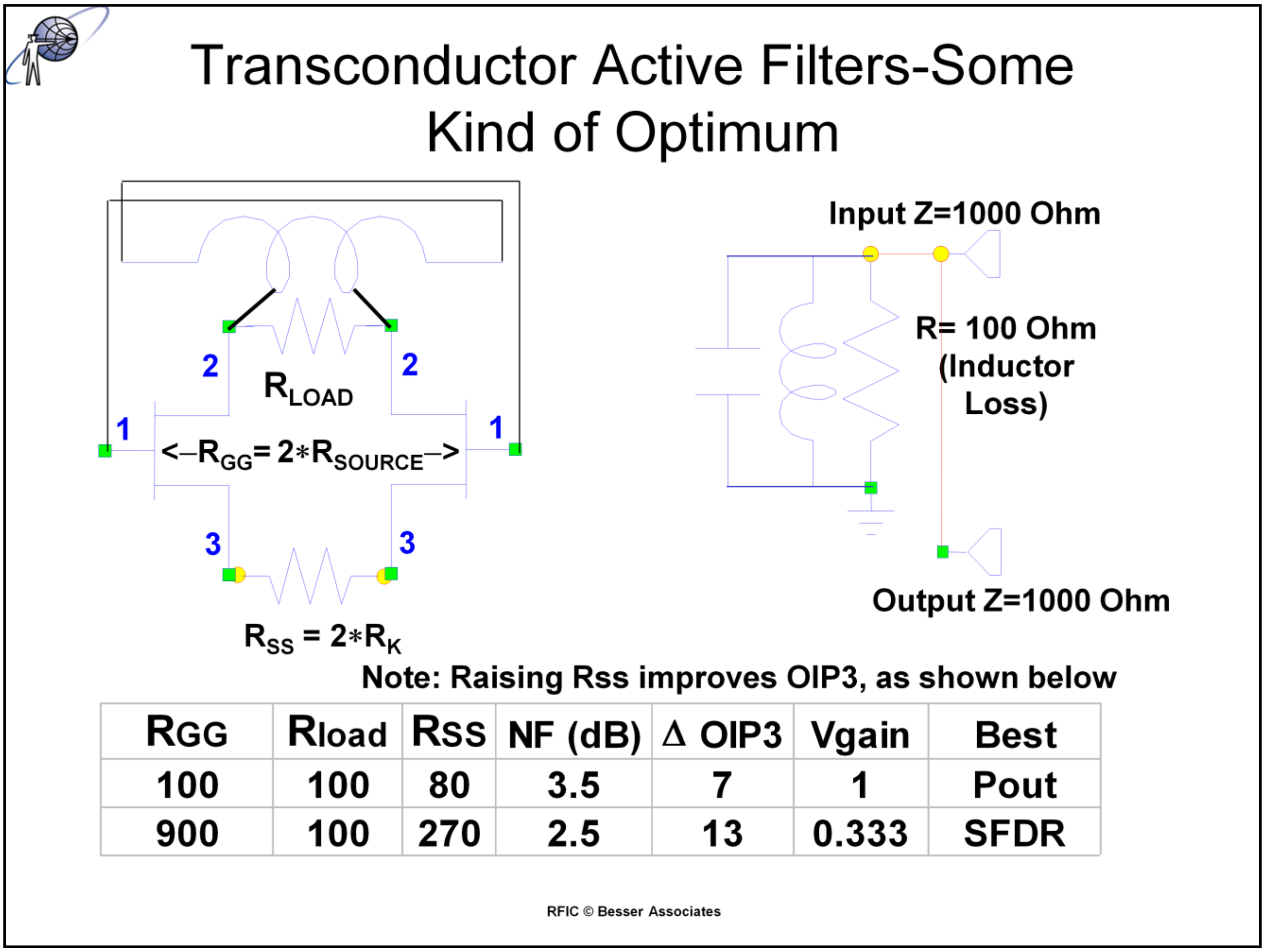
Bisecting the circuit makes it clear by inspection that the gate tap does not have to be equal to the drain tap point. The optimum source impedance for noise figure is not likely to be the optimum load impedance for power output. In general, the gate-source will want to be tapped up, that is, at a higher impedance point than the drain-source. Not only does this improve the noise figure, it also raises the available gain, allowing more negative feedback. This improves the intermodulation distortion.



Transconductor Active Filters-Some Kind of Optimum

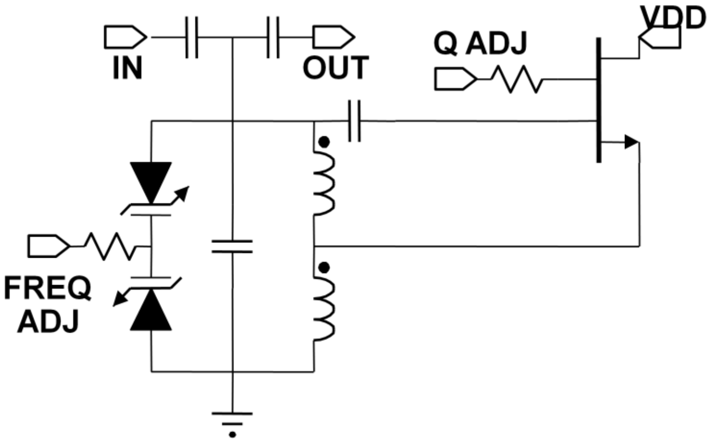
Note: Raising Rss improves OIP3, as shown below

RGG	Rload	RSS	NF (dB)	Δ OIP3	Vgain	Best
100	100	80	3.5	7	1	Pout
900	100	270	2.5	13	0.333	SFDR

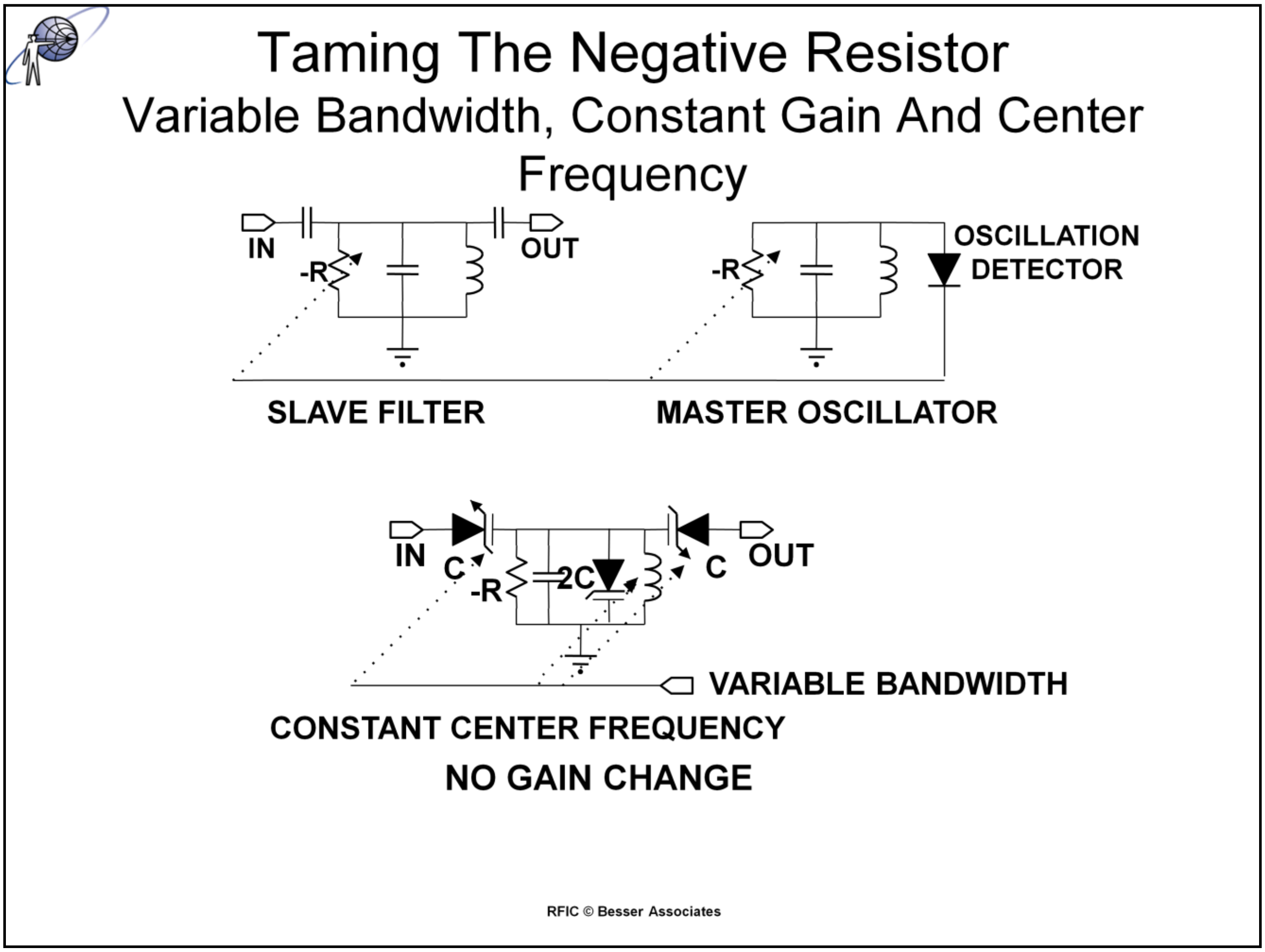
This illustrates the point that the gate-to-gate source impedance can be advantageously raised to improve both noise figure and intercept.

Narrow Band MMIC Filters

No Degeneration, Gain Set By Second Gate



Setting the transconductance, and hence the negative resistance by starving the lower FET as in this example will not result in a process tolerant, or high dynamic range filter. Adjustable negative feedback would be better. (FET as a variable resistor, or use a varactor)



Taming The Negative Resistor

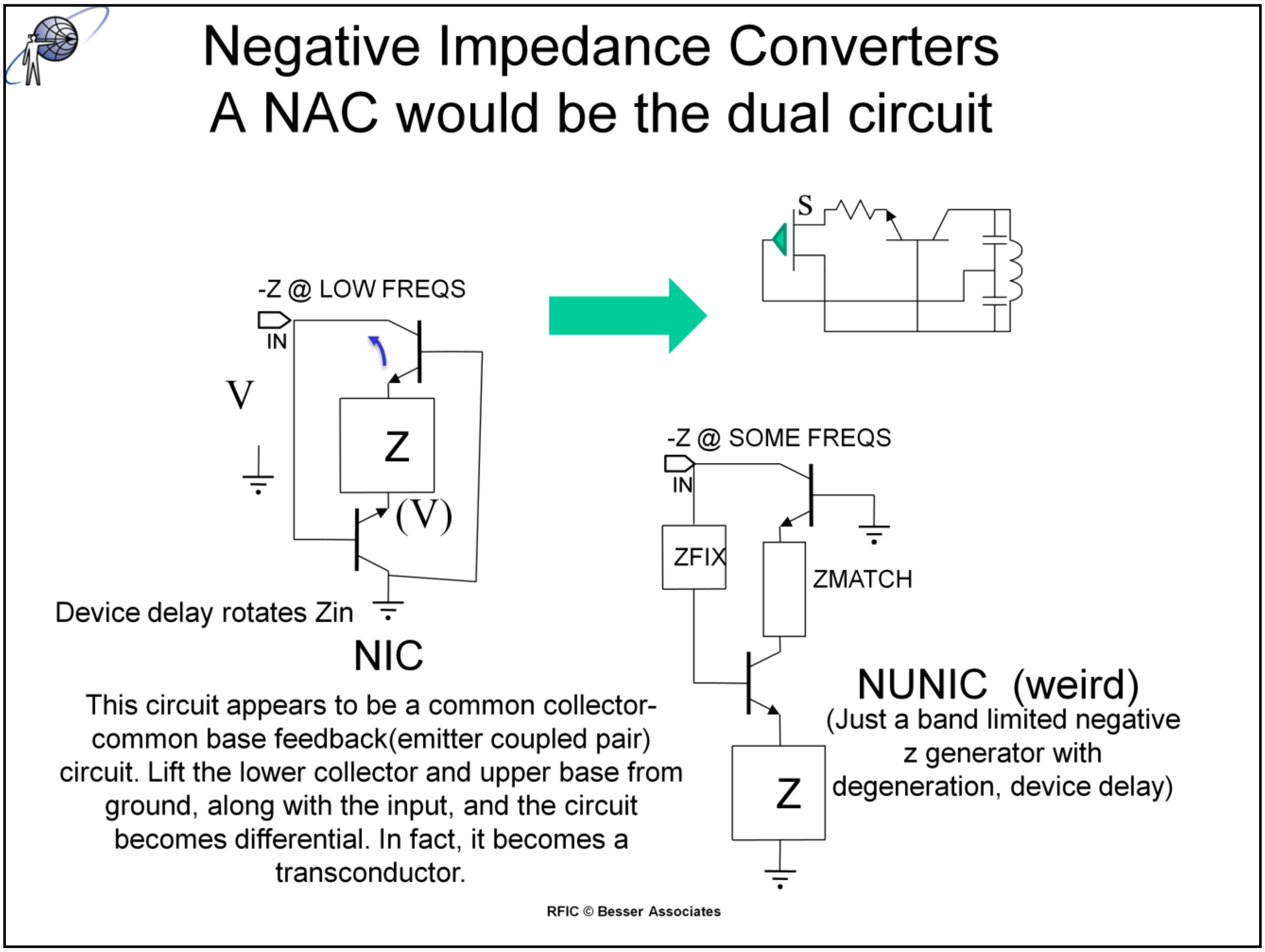
Variable Bandwidth, Constant Gain And Center Frequency

CONSTANT CENTER FREQUENCY

NO GAIN CHANGE

In the upper figure, the monolithically defined, nearly identical negative resistances track one another. The master oscillator is a tuned circuit operating outside the band of the filter, or it could be the local oscillator. Controlling the amplitude of the oscillation sets the negative resistance. The slave filter is loaded by the input and output, and thus is stable, but the negative resistance will raise the effective unloaded resonator Q to infinity.

In the lower figure, as the series coupling varactors change the bandwidth, the shunt varactors re-center the frequency of the filter.



Negative Impedance Converters
A NAC would be the dual circuit

Device delay rotates Zin

NIC

This circuit appears to be a common collector-common base feedback(emitter coupled pair) circuit. Lift the lower collector and upper base from ground, along with the input, and the circuit becomes differential. In fact, it becomes a transconductor.

NUNIC (weird)

(Just a band limited negative z generator with degeneration, device delay)

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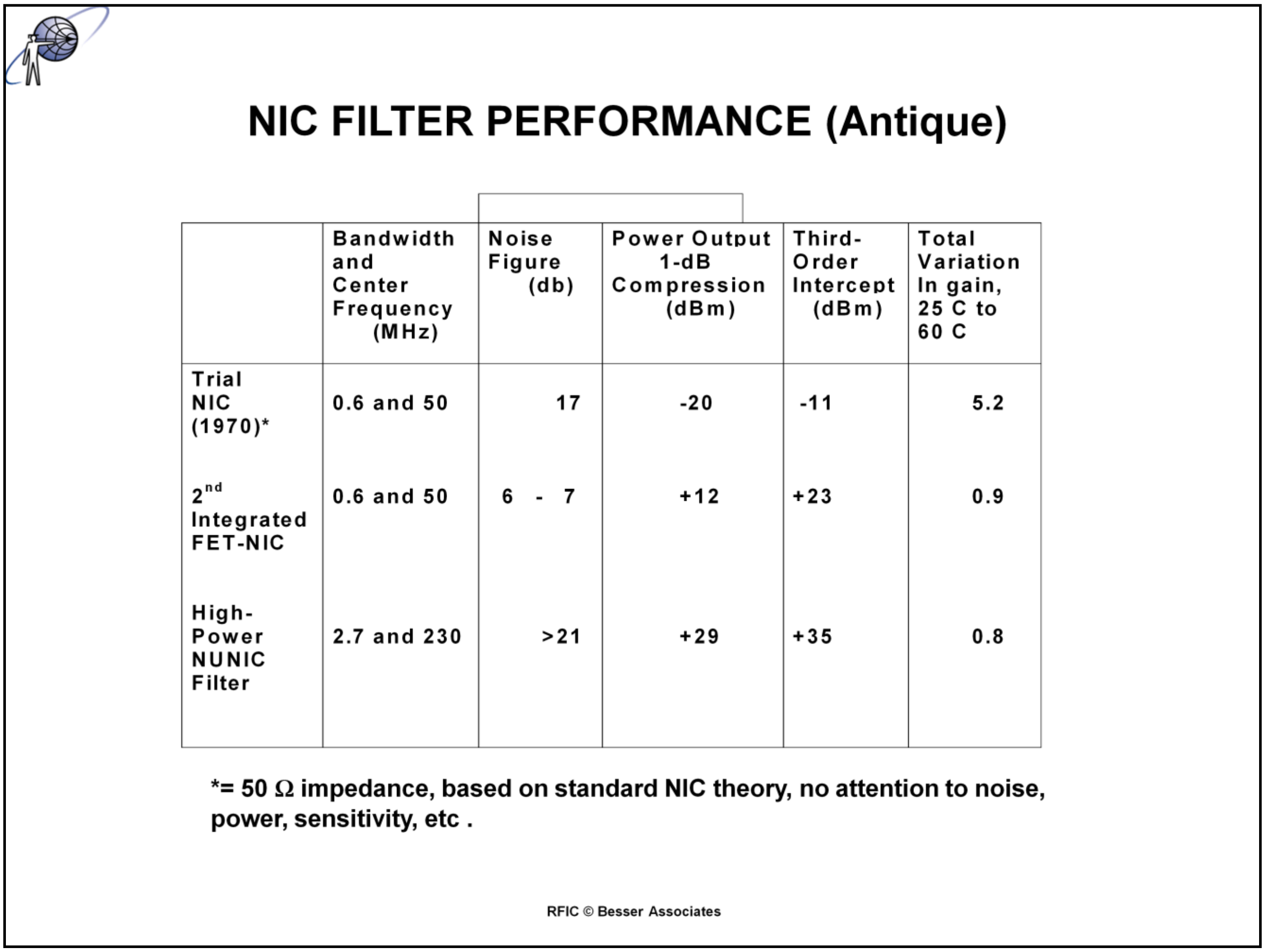
We can see that differential circuits are very closely related to their single-ended cousins. The Hartley and Colpitts oscillators are functionally equivalent, just with a change in the feedback method.

Also, there is no special way to generate a negative Z, any amplifier loop that results in the current flowing in the opposite direction from the element that is assumed to be connected across those terminals does the job. Over a narrow band, an inductor appears to be a negative capacitor. We are trying to make a negative capacitor that operates over a significantly wider bandwidth than a lowly inductor.

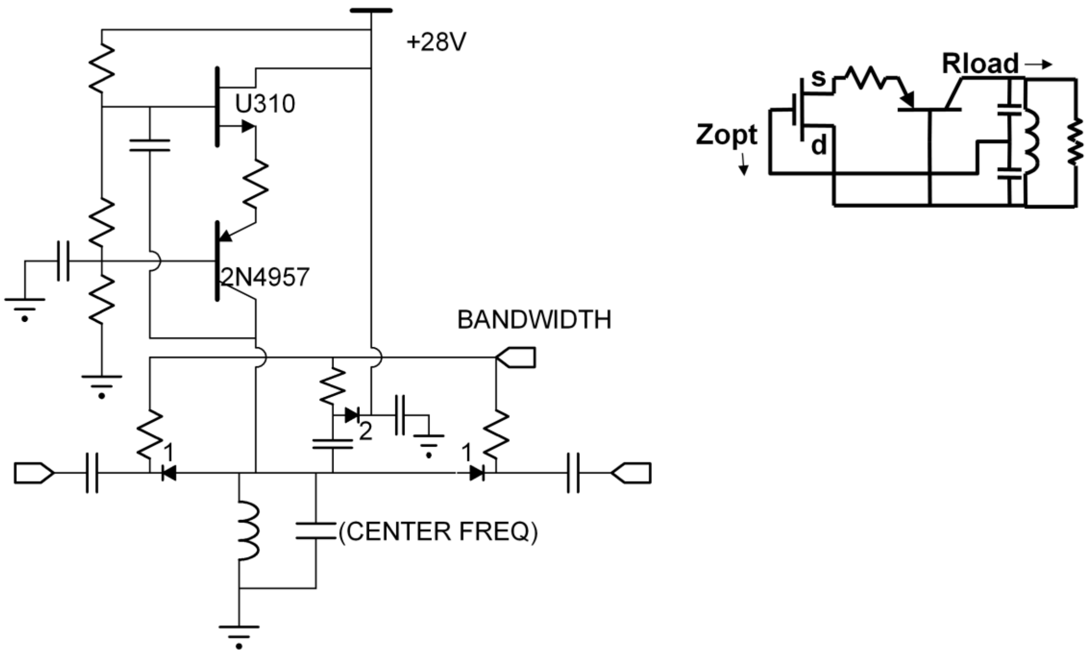


NIC FILTER PERFORMANCE (Antique)

	Bandwidth and Center Frequency (MHz)	Noise Figure (db)	Power Output 1-dB Compression (dBm)	Third-Order Intercept (dBm)	Total Variation In gain, 25 C to 60 C
Trial NIC (1970)*	0.6 and 50	17	-20	-11	5.2
2^{nd} Integrated FET-NIC	0.6 and 50	6 - 7	+12	+23	0.9
High-Power NUNIC Filter	2.7 and 230	>21	+29	+35	0.8

***= 50 Ω impedance, based on standard NIC theory, no attention to noise, power, sensitivity, etc .**

Schematic Diagram Of Fet/Bipolar NIC



Conveniently, the FET chosen had an optimum noise source impedance close to the optimum load for power output of the PNP transistor, and could share the same port, directly across the tuned circuit.

Given Their Limitations, Are Active Filters Useful?

- **Active inductors make good low power loads for broadband amplifiers.**
- **Yes, for small signal, low power, tolerant applications**
- **In notch filters, they can de-tune themselves - watch out**
- **Negative resistance can be stabilized with excess gain.**

Making Active Filters Work

For - r filters... Use the master-slave approach to tame the unstable characteristics of negative resistance filters

1. **Beware of N.F. And power handling in-band;**
   <u>Design</u> for N.F. , <u>Design</u> for power

2. **Band pass filters power handling probably ok out of band, but noise figure is poor in-band.**

3. **Approximate rules for bandpass designs:**
   $IP3 \cong IP3_{dev} - 10 * \log(2 * q_l/q_u) + 10 * \log(1+g_m * r_k)$
   $NF_{db} = 10 * \log(2 * q_l/q_u) + NF_{devfb}$ **and** NF_{devfb} **at its minimum is:** $10 * \log(f_{min})$
   Where $F_{min} \cong 1+(2/q_1)$ **and** $q_1 \cong (f_t/f) * (1/\, g_m * r_k)$