

Q ENHANCEMENT CIRCUIT AND METHOD

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BACKGROUND OF THE INVENTION

Field of the Invention:

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The present invention relates to electrical and electronic circuits and systems. More specifically, the present invention relates to systems and methods for Q enhancement for passive inductive capacitive resonators in electrical and electronic circuits and systems.

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Description of the Related Art:

In reference to a resonant mechanical or electrical circuit or a capacitor, Q is a “quality factor.” In the case of a resonant system, Q is a measure of the sharpness of the resonant peak in the frequency response of the system and is inversely proportional to the damping in the system: $Q = \text{center frequency} / \text{Hz bandwidth}$. Equalizers that contain resonant circuits are rated by their Q-value: the higher the Q, the higher and more well defined the peak in the response. In filters, the ratio of a bandpass or band-reject filter’s center frequency to its bandwidth defines Q. Thus, assuming a constant center frequency, Q is inversely proportional to bandwidth, i.e., a higher Q indicates a narrower bandwidth. (See <http://www.dilettantesdictionary.com/pdf/q.pdf>.)

Hence, for a variety of applications such as analog to digital conversion, wireless communication circuits, narrowband amplifiers, microwave circuits and the like, it is useful to provide a system or method for Q enhancement.

In analog signal processing and communication systems, Q enhancement circuits typically use negative resistor circuits to cancel out parasitic serial resistance associated with the inductors (L) in the passive inductor-capacitor (LC) resonators. When implemented in fully differential mode, these circuits are usually connected in parallel with the capacitors of the resonator and typically the capacitor is connected between two inductors. Generally, the negative resistor circuits fail to adequately cancel the parasitic resistance of the inductors. This non-ideal cancellation causes other second order effects and can cause the circuit to resonate at other frequencies.

In addition, the use of negative resistors requires voltage-to-current converters to generate negative currents for the cancellation. This makes the negative resistor circuit more susceptible to non-linear distortion and circuit delay and degrades the performance of the LC resonator.

Hence, a need remains in the art for a system or method for enhancing the Q of a circuit. Particularly, a need remains in the art for a system or method for enhancing the Q of LC resonators used in analog signal processing and communication systems to improve the linearity and resolution thereof.

SUMMARY OF THE INVENTION

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The need in the art is addressed by the Q enhancement circuit and method of the present invention. In a most general embodiment, the inventive circuit is adapted for use with a component having a parasitic resistance R_{L1} and a first resistance R_1 disposed in series with the component and an arrangement for making the resistance a negative resistance.

In the illustrative embodiment, first and second inductors constitute the components for which Q enhancement is effected. A resistance R_1 is disposed in series with the first inductor and is equal to the parasitic resistance R_{L1} thereof.

60 Likewise, a second resistance R_2 is disposed in series with the second inductor and is equal to the parasitic resistance R_{L2} thereof. In this embodiment, the Q enhancement circuit includes a first transistor Q_1 and a second transistor Q_2 . The transistors may be BJT (bipolar junction transistor), MOSFETs (metal-oxide semiconductor field effect transistors), or other type of transistors.

65 In a BJT implementation, each of the collector terminals is connected to a respective one of the first or the second resistors R_1 or R_2 and each of the emitters are connected to a respective one of the inductors. In this case, the Q enhancement circuit includes a first unity-gain amplifier (emitter follower/voltage follower) connected between the collector terminal of the first transistor and the base terminal of the
70 second transistor and a second unity-gain amplifier connected between the collector terminal of the second transistor and the base terminal of the first transistor.

In the alternative MOSFET implementation, each of the transistors has a source, a gate and a drain terminal. In this case, each of the drain terminals is connected to a respective one of the first or the second resistors R_1 or R_2 and the
75 source terminals are connected to a respective one of the inductors. A first unity-gain amplifier (source follower) is connected between the drain terminal of the first transistor and the gate terminal of the second transistor and a second unity-gain amplifier connected between the drain terminal of the second transistor and the gate terminal of the first transistor.

80 In the best mode, each of the unity gain amplifier is a emitter/source follower to achieve optimal circuit simplicity and maximal operating bandwidth.

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BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic diagram showing a differential LC resonator widely used for analog signal processing in accordance with conventional teachings.

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Figure 2 is a schematic diagram of the resonator of Figure 1 showing parasitic resistance of the inductors thereof.

Figure 3 shows an approach for Q enhancement of the resonator of Figure 2 in accordance with conventional teachings.

Figure 4 is a schematic diagram of a resonator with Q enhancement implemented in accordance with an illustrative embodiment of the teachings of the present invention.

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Figure 5 is a schematic diagram of the resonator of Figure 4 with an illustrative implementation of the negative resistors thereof.

Figure 6 is a schematic diagram of the resonator of Figure 5 with a bipolar emitter follower implementation for the voltage followers thereof.

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Figure 7 is a schematic diagram of the resonator of Figure 5 with a MOSFET source follower implementation for the voltage followers thereof.

DESCRIPTION OF THE INVENTION

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Illustrative embodiments and exemplary applications will now be described with reference to the accompanying drawings to disclose the advantageous teachings of the present invention.

While the present invention is described herein with reference to illustrative
110 embodiments for particular applications, it should be understood that the invention is not limited thereto. Those having ordinary skill in the art and access to the teachings provided herein will recognize additional modifications, applications, and embodiments within the scope thereof and additional fields in which the present invention would be of significant utility.

115 Figure 1 is a schematic diagram showing a differential LC resonator widely used for analog signal processing in accordance with conventional teachings. Figure 2 is a schematic diagram of the resonator of Figure 1 showing parasitic resistance of the inductors thereof. As shown in Figures 1 and 2, the resonator 10' includes first and second inductors L_1 and L_2 connected in parallel to a ground connection on one end
120 and a capacitor C connected across the other ends thereof. The first and second inductors L_1 and L_2 have inherent parasitic resistance shown as, respectively, as illustrated in Figure 2.

As is well known in the art, due to the parasitic serial resistors R_{L1} and R_{L2} associated with the inductors, the Q of the LC resonator is limited. One commonly
125 used technique to increase the Q is to use a negative resistor in parallel with the capacitor. This is illustrated in Figure 3.

Figure 3 shows an approach for Q enhancement of the resonator of Figure 2 in accordance with conventional teachings. In this resonator 20, a negative resistor R is connected in parallel with the capacitor C . Although this approach can increase the Q
130 of the resonator, it has not been found adequate in the cancellation of the effect of the parasitic serial resistors R_{L1} and R_{L2} on Q . In addition, the negative resistor R makes

the resonator a more complicated circuit and can cause resonance at other undesired frequencies. Hence, a need remains in the art for a system or method for enhancing the Q of a circuit.

135 Figure 4 is a schematic diagram of a resonator with Q enhancement implemented in accordance with an illustrative embodiment of the teachings of the present invention. The resonator 40 is similar to that of Figure 2 with the exception that first and second negative resistors $-R_1$ and $-R_2$ are disposed in series with the first and second inductors L_1 and L_2 , respectively.

140 Figure 5 is a schematic diagram of the resonator of Figure 4 with an illustrative implementation of the negative resistors thereof. In Figure 5, resistors R_1 and R_2 are disposed in series with the first and second inductors. The resistors R_1 and R_2 should be equal to the parasitic serial resistors R_{L1} and R_{L2} . First and second transistors Q_1 and Q_2 are connected in between the resistors R_1 and R_2 and the
145 associated component, in the illustrative application, the first and second inductors L_1 and L_2 , respectively. The collector of Q_1 is connected to R_1 at a node A and the collector of Q_2 is connected to R_2 at a node B. In accordance with the present teachings, a first voltage follower (unity-gain amplifier) 42 is connected between node A and the base of Q_2 . The second voltage follower 44 is connected between node B
150 and the base of Q_1 . The first and second voltage followers 42 and 44 can be implemented by emitter followers as shown in Figure 6 below, source followers as shown in Figure 7 or other suitable circuit arrangement as will be appreciated by those of ordinary skill in the art.

155 Figure 6 is a schematic diagram of the resonator of Figure 5 with a bipolar emitter follower implementation for the voltage followers thereof. In this embodiment, the first follower 42 is implemented with a third bipolar transistor Q_3 having its base connected to node A, its collector connected to ground and its emitter connected to a first current source 46. The second follower 44 is implemented with a fourth bipolar transistor Q_4 having its base connected to node B, its collector
160 connected to ground and its emitter connected to a second current source 48. While

an NPN implementation is shown, those skilled in the art will appreciate that a PNP implementation may be employed as well.

Figure 7 is a schematic diagram of the resonator of Figure 5 with a MOSFET source follower implementation for the voltage followers thereof. In this embodiment 30'', n-channel MOSFETs M_1 and M_2 are used in place of the first and second transistors Q_1 and Q_2 of Figure 6. In addition, the first follower 42 is implemented with a third MOSFET transistor M_3 having its gate connected to node A, its drain connected to ground and its source connected to the first current source 46. The second follower 44 is implemented with a fourth MOSFET transistor M_4 having its gate connected to node B, its drain connected to ground and its source connected to the second current source 48. While an n-channel implementation is shown, those skilled in the art will appreciate that a p-channel implementation may be employed as well.

The inventive enhancement circuit 40 should cancel the effect of the inherent parasitic resistance and improve the Q factor of the components with which it is used.

Thus, the present invention has been described herein with reference to a particular embodiment for a particular application. Those having ordinary skill in the art and access to the present teachings will recognize additional modifications applications and embodiments within the scope thereof.

It is therefore intended by the appended claims to cover any and all such applications, modifications and embodiments within the scope of the present invention.

Accordingly,

WHAT IS CLAIMED IS:

CLAIMS

1. A Q enhancement circuit (40) for a component having a parasitic resistance R_{L1} , said enhancement circuit characterized by;
a first resistance R_1 disposed in series with said component and
a first circuit (Q_1 , Q_2 , 42, and 44) for making said resistance disposed in series
5 with said component a negative resistance.
2. The invention of Claim 1 wherein said component is an inductor L_1 .
3. The invention of Claim 1 wherein said resistance R_1 disposed in series with said component is equal to said parasitic resistance R_{L1} .
4. The invention of Claim 1 wherein said first means for making said resistance a negative resistance includes a first transistor Q_1 .
5. The invention of Claim 4 further including a second component L_2 having a parasitic resistance R_{L2} .
6. The invention of Claim 5 wherein said Q enhancement circuit includes a second resistance R_2 disposed in series with said second component L_2 and second means for making said resistance R_2 a negative resistance.
7. The invention of Claim 6 wherein said second means for making said resistance a negative resistance includes a second transistor Q_2 .
8. The invention of Claim 7 wherein each of said transistors has a collector, a base and an emitter terminal.

9. The invention of Claim 8 wherein each of said collector terminals is connected to a respective one of said first or said second resistors R_1 or R_2 and said emitters are connected to a respective one of said components.

10. The invention of Claim 9 wherein said Q enhancement circuit includes a first amplifier (42) connected between the collector terminal of the first transistor and the base terminal of the second transistor and a second amplifier (44) connected between the collector terminal of said second transistor and said base terminal of said
5 first transistor.

11. The invention of Claim 10 wherein each of said amplifiers is a unity gain amplifier.

12. The invention of Claim 11 wherein each of said amplifiers is an emitter follower.

13. The invention of Claim 7 wherein each of said transistors has a source, a gate and a drain terminal.

14. The invention of Claim 13 wherein each of said drain terminals is connected to a respective one of said first or said second resistors R_1 or R_2 and said source terminals are connected to a respective one of said components.

15. The invention of Claim 14 wherein said Q enhancement circuit includes a first amplifier (42) connected between the drain terminal of the first transistor and the gate terminal of the second transistor and a second amplifier (44) connected between the drain terminal of said second transistor and said gate terminal of said first
5 transistor.

16. The invention of Claim 15 wherein each of said amplifiers is a unity gain amplifier.

17. The invention of Claim 16 wherein each of said amplifiers is a source follower.