Baluns and band-pass filters (BPF) are important components in wireless communication systems. Many prior art designs use discrete, cascaded components to achieve both balance and filtering functions. The baluns are implemented as a distributed-line in which size is inversely proportional to the operation frequency. The smaller the operational frequency, the larger the requisite balun. Yet, consumer demand calls for smaller size which makes miniaturization difficult in lower frequency applications, such as GSM cellular.

Summary of the Invention

A need exists to miniaturize baluns for RF signal processing circuits. Accordingly, in one embodiment, the present invention is a ~~method of making a semiconductor device comprising the steps of providing a substrate, forming a first inductor over the substrate, forming a second inductor over the substrate, and forming a third inductor over the substrate adjacent to the first inductor and second inductor to induce magnetic coupling between the first, second, and third inductors. The first inductor and second inductor are substantially coplanar.~~ band-pass filter including a plurality of frequency band channels each having a first and second balanced ports and first and second unbalanced ports. Each frequency band channel includes a first inductor having a first terminal coupled to the first balanced port and a second terminal coupled to the second balanced port. A first capacitor is coupled between the first and second terminals of the first inductor. A second inductor has a first terminal coupled to the first unbalanced port and a second terminal coupled to the

second unbalanced port. The second inductor is disposed within a first distance of the first inductor to induce magnetic coupling between the first and second inductors. A second capacitor is coupled between the first and second terminals of the second inductor. A third inductor is disposed within a second distance of the first inductor and within a third distance of the second inductor to induce magnetic coupling between the first, second, and third inductors. A third capacitor is coupled between first and second terminals of the third inductor.

In another embodiment, the present invention is a ~~method of making a semiconductor device comprising the steps of providing a first inductor, providing a second inductor disposed adjacent to and non-overlapping with the first inductor, and providing a third inductor adjacent to the first inductor and second inductor to induce magnetic coupling between the first, second, and third inductors.~~ band-pass filter including a plurality of LC resonators each having a first and second balanced ports and first and second unbalanced ports. The band-pass filter comprises a first inductor having a first terminal coupled to the first balanced port and a second terminal coupled to the second balanced port. A first capacitor is coupled between the first and second terminals of the first inductor. A second inductor has a first terminal coupled to the first unbalanced port and a second terminal coupled to the second unbalanced port. A second capacitor is coupled between the first and second terminals of the second inductor. A third inductor is disposed adjacent to the first and second inductors to induce magnetic coupling between the first, second, and third inductors. A third capacitor is coupled between first and

second terminals of the third inductor.

In another embodiment, the present invention is ~~a~~

~~semiconductor device comprising a substrate and first inductor formed over the substrate. A second inductor is formed over the substrate. A third inductor is formed over the substrate adjacent to the first inductor and second inductor to induce magnetic coupling between the first, second, and third inductors. The first inductor and second inductor are substantially coplanar.~~ an LC resonator circuit comprising a first inductor having first and second terminals. A first capacitor is coupled between the first and second terminals of the first inductor. A second inductor has first and second terminals. A second capacitor is coupled between the first and second terminals of the second inductor. A third inductor is disposed adjacent to the first and second inductors to induce magnetic coupling between the first, second, and third inductors. A third capacitor is coupled between first and second terminals of the third inductor.

In another embodiment, the present invention is ~~a semiconductor device comprising a first inductor and second inductor disposed adjacent to and non-overlapping with the first inductor. A third inductor is disposed adjacent to the first inductor and second inductor to induce magnetic coupling between the first, second, and third inductors.~~ an integrated circuit package housing a plurality of LC resonators and having first, second, third, and fourth interconnect terminals. The integrated circuit including a first inductor having a first terminal coupled to the first interconnect terminal and a second terminal coupled to the second interconnect terminal. A first capacitor is coupled between the first and second terminals of the first inductor. A second inductor has a first terminal coupled to the first interconnect terminal and a second terminal

coupled to the second interconnect terminal. A second capacitor is coupled between the first and second terminals of the second inductor. A third inductor is disposed adjacent to the first and second inductors to induce magnetic coupling between the first, second, and third inductors. A third capacitor is coupled between first and second terminals of the third inductor.

Brief Description of the Drawings

FIG. 1 illustrates a PCB with different types of packages mounted to its surface;

FIGs. 2a-2c illustrate further detail of the semiconductor packages mounted to the PCB;

FIG. 3 illustrates a semiconductor package containing an integrated passive device;

FIG. 4 illustrates a multi-channel RF signal processing circuit coupled to a transceiver;

FIG. 5 illustrates a layout of the multi-channel RF signal processing circuit;

FIGs. 6a-6c are schematic diagrams of individual RF signal processing channels;

FIG. 7 illustrates a plurality of LC resonators for use in an RF signal processing channel;

Claims

What is claimed:

1. A method of making a semiconductor device, comprising:

providing a substrate;

forming a first inductor over the substrate;

forming a second inductor over the substrate; and

forming a third inductor ~~over the substrate adjacent to the first inductor and second inductor to induce magnetic coupling between the first, second, and third inductors, wherein the first inductor and second inductor are substantially coplanar~~ including a first end terminal of the third inductor oriented towards a second end terminal of the third inductor over the substrate around a perimeter of the first inductor and second inductor and non-overlapping and non-interleaving with the first inductor and second inductor to induce magnetic coupling between the first, second, and third inductors, wherein the first inductor is displaced off-center with respect to the second inductor.

2. The method of claim 1, further including:

providing a first capacitor coupled between first and second end terminals of the first inductor; and

providing a second capacitor coupled between first and second end terminals of the second inductor.

3. The method of claim 1, further including providing a capacitor coupled between the first and second end terminals of the third inductor.

4. The method of claim 1, further including forming the first inductor adjacent to and non-overlapping with the second inductor.

5. The method of claim 1, ~~further including forming the third inductor non-overlapping with~~ wherein the first inductor and second inductor are substantially coplanar.

6. The method of claim 1, further including ~~forming the third inductor overlapping the first inductor and second inductor~~ coupling the first inductor to a first unbalanced port and a second unbalanced port.

7. The method of claim 1, further including coupling the second inductor to a first balanced port and a second balanced port.

~~7~~8. A method of making a semiconductor device, comprising:

providing a first inductor;

providing a second inductor disposed adjacent to and ~~non-overlapping with the first inductor; and~~

~~providing a third inductor adjacent to the first inductor and second inductor to induce magnetic coupling between the first, second, and third inductors~~ displaced off-center from the first inductor; and

providing a third inductor including a first end terminal facing a second end terminal around a perimeter of the first inductor and non-overlapping and non-interleaving the second inductor to induce magnetic coupling between the first, second, and third inductors.

~~8~~9. The method of claim ~~7~~8, wherein the first inductor and second inductor are substantially coplanar.

~~9~~10. The method of claim ~~7~~8, further including:

providing a first capacitor coupled between first and second end terminals of the first inductor; and

providing a second capacitor coupled between first and second end terminals of the second inductor.

~~10~~11. The method of claim ~~7~~8, further including providing a capacitor coupled between the first and second end terminals of the third inductor.

1~~1~~2. The method of claim ~~7~~8, further including forming the third inductor non-overlapping with the first inductor and second inductor.

~~12. The method of claim 7, further including forming the third inductor overlapping the first inductor and second inductor.~~

13. The method of claim ~~7~~8, further including:

providing a substrate;

forming the first inductor over the substrate;

forming the second inductor over the substrate; and

forming the third inductor over the substrate.

14. The method of claim 8, further including coupling the first inductor to a first unbalanced port and a second unbalanced port.

15. The method of claim 8, further including coupling the second inductor to a first balanced port and a second balanced port.

1~~4~~6. A semiconductor device, comprising:

a substrate;

a first inductor formed over the substrate;

a second inductor formed over the substrate~~; and~~

~~a third inductor formed over the substrate adjacent to the first inductor and second inductor to induce magnetic coupling between the first, second, and third inductors, wherein the first inductor and second inductor are substantially coplanar~~ and oriented different from the first inductor; and

a third inductor formed around and non-overlapping and non-interleaving the first inductor to induce magnetic coupling between the first, second, and third inductors..

1~~5~~7. The semiconductor device of claim 1~~4~~6, further including:

a first capacitor coupled between first and second end terminals of the first inductor; and

a second capacitor coupled between first and second end terminals of the second inductor.

168. The semiconductor device of claim 146, further including a capacitor coupled between first and second end terminals of the third inductor.

179. The semiconductor device of claim 146, wherein the first inductor is disposed adjacent to and non-overlapping with the second inductor.

~~18~~20. The semiconductor device of claim 1~~4~~6, wherein the third inductor is disposed non-overlapping with the first inductor and second inductor.

~~19~~21. The semiconductor device of claim 1~~4~~6, wherein the ~~third inductor is disposed overlapping the~~ first inductor and second inductor are substantially coplanar.

22. The semiconductor device of claim 16, further including a first unbalanced port and a second unbalanced port coupled to the first inductor.

23. The semiconductor device of claim 16, further including a first unbalanced port and a second unbalanced port coupled to the second inductor.

2~~0~~4. A semiconductor device, comprising:

a first inductor;

a second inductor disposed adjacent to and ~~non-overlapping with the first inductor; and~~

~~a third inductor disposed adjacent to the first inductor and second inductor to induce magnetic coupling between the first, second, and third inductors~~ displaced off-center with the first inductor; and

a third inductor disposed around and outside and non-overlapping and non-interleaving the first inductor and second inductor to induce magnetic coupling between the first, second, and third inductors.

215. The semiconductor device of claim 204, wherein the first inductor and second inductor are substantially coplanar.

226. The semiconductor device of claim 204, further including:

a first capacitor coupled between first and second end terminals of the first inductor;

a second capacitor coupled between first and second end terminals of the second inductor; and

a third capacitor coupled between first and second end terminals of the third inductor.

237. The semiconductor device of claim 204, wherein ~~the third inductor is disposed non-overlapping with~~ the first inductor and second inductor are formed with 8 µm conductive material.

~~24. The semiconductor device of claim 20, wherein the third inductor is disposed overlapping the first inductor and second inductor.~~

2~~5~~8. The semiconductor device of claim 2~~0~~4, further including a substrate, wherein the first inductor, second inductor, and third inductor are formed over the substrate.

29. The semiconductor device of claim 24, further including a first unbalanced port and a second unbalanced port coupled to the first inductor.

30. The semiconductor device of claim 24, further including a first unbalanced port and a second unbalanced port coupled to the second inductor.