

"Wide bandwidth microwave filter network"

The present invention relates to microwave equipment and more specifically to using capacitive T-networks implemented with thin film methods.

Networks of capacitors and inductors can be used in various microwave applications to make bandpass filters. Figure 1A shows a typical capacitor pi-network (so-called because its configuration resembles the Greek letter π) in narrow bandwidth filters. A convenient measure of bandwidth is the percentage bandwidth (%BW), which is:

$$\%BW = \frac{f_2 - f_1}{f_0}$$

where f_0 is the centre frequency, f_1 is the lower cutoff frequency, and f_2 is the upper cutoff frequency.

A typical implementation of such a pi-network 10 is shown in Figures 1B and 1C. The Pi-network 10 comprises three metal plates 12, 14, and 16 separated by a polyamide layer 18 on an alumina substrate 20 having a groundplane 22. Capacitor C1 is formed between metal plate 12 and groundplane 22. Capacitor C3 is formed between metal plate 14 and groundplane 22. Capacitor C2 is actually two capacitors formed by metal plates 12 and 16, for one of the series capacitors, and metal plates 16 and 14, for the other. Such a network is described in US-A-4,881,050, issued Nov. 14, 1989 to Swanson, Jr. The network consists of a filter fabricated from a planar dielectric substrate having a ground plane on one side and two thin-film metal layers and an insulation layer on the other side. The metal and insulation layers are configured to form one or

more capacitive pi-networks and spiral inductors, which are electrically interconnected to form the filter.

In order to increase the %BW, capacitors C1 and C3 must be made smaller and capacitor C2 must be made bigger. The sizes of the plate areas, dielectric thickness, and dielectric materials used can all be adjusted to manipulate the values of the capacitors, but practical limits are reached at even modest %BW figures. The problem, traditionally, with microwave filters has been the very limited dynamic range of element values. (Which is not a problem at lower frequencies because discrete capacitors and inductors can be used). The prior art solutions have usually centred on coming up with clever topologies to get around these restrictions.

It is therefore an object of the present invention to produce a microwave filter that has a wide percentage bandwidth.

In one aspect, the present invention provides a substrate including a groundplane on a first side and a plurality of first metal plates on a second side that is opposite to said first side; a dielectric layer covering said first metal plates on said second side of the substrate; a plurality of T-networks of capacitors each formed by a second and a third metal plate that are each deposited on the dielectric layer and each disposed entirely within an area defined by projecting the boundaries of a respective one of said first metal plates normal to the groundplane so that said first metal plate intervenes between each of said second and third metal plates and said groundplane; and a plurality of inductors formed primarily on the dielectric layer and each connected to and between respective ones of the T-networks of capacitors in cascade.

In another aspect, the present invention provides a method of fabricating a thin-film microwave filter, comprising the steps of: depositing a groundplane on a

first side of a substrate; depositing a first metal layer on a second side of said substrate that is opposite to said first side and forming a plurality of first metal plates; depositing a dielectric layer over said plurality of first metal plates; forming each of a plurality of T-networks of capacitors by depositing a second metal layer over said dielectric layer and forming second and third metal plates that are each entirely within an area defined by projecting the boundaries of a respective first metal plate normal to the groundplane; and forming inductors in said second metal layer that are each respectively electrically connected to ones of said T-networks of capacitors.

In one embodiment of the present invention a filter network comprises a T-network of capacitors implemented with thin-film techniques by applying a groundplane to one side of an alumina substrate and a first plate to the other side. A silicon nitride dielectric layer having a high density of capacitance is deposited over the first plate, and then a second and third capacitor plate are deposited on the dielectric over the first plate.

An advantage of the present invention is that bandwidth percentages greater than thirty percent can be practically implemented using thin-film techniques.

Another advantage of the present invention is that parasitic capacitances are reduced.

In order that the invention may be more readily understood, embodiments thereof will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1A is a schematic circuit of a prior art capacitor pi-network.

Figure 1B is a top view of a prior art thin-film implementation of the circuit of Figure 1A;

Figure 1C is a cross-sectional view of the structure of Figure 1B taken along the lines 1C-1C;

Figure 2A is a schematic circuit of a capacitor T-network for use with an embodiment of the present invention;

Figure 2B is a top view of a thin-film implementation of the Figure 2A network;

Figure 2C is a cross-sectional view of the structure of Figure 2B taken along the lines 2C-2C;

Figure 3A is a schematic circuit of a 2-6 GHz bandpass filter representing an embodiment of the present invention;

Figure 3B is a top view of the filter of Figure 3A;

Figure 3C is a cross-sectional view of the structure of Figure 3B taken along the lines 3C-3C; and

Figure 4 is a graph of the bandpass characteristics that were calculated and measured for the filter in Figure 3A.

Figures 2A-2C illustrate a T-network of capacitors 40, comprising three capacitors which are illustrated symbolically as C4-C6 and are made from a first and a second plate 42 and 44, a third plate 46, a dielectric layer 48, an alumina substrate 50, and a groundplane 52. Substrate 50 can be made of alumina, beryllium oxide, aluminium nitride, quartz, sapphire, or any other suitable microwave substrate. All can give acceptable results. First and second plates 42 and 44, and third plate 46 can be gold deposited, such as by sputtering. Dielectric layer 48 preferably comprises silicon nitride, as opposed to the polyamide of layer 18 (Figure 1B-1C). The silicon nitride layer typically has a density of capacitance of 0.1 picofarad (pF) per square mil (15.4nF/mm^2), versus 0.005 pF per square mil (7.7pF/mm^2) for the polyamide layer, such as in US-A-4,881,050. (The density, of course, also depends on the thickness used). Chemical vapour deposition (CVD) can be used to deposit layer 48 on substrate 50. Capacitor C4 is formed between plates 42 and 46. Capacitor C6 is

formed between plate 46 and groundplane 52. Capacitor C5 is formed between plates 44 and 46. The differences in the thicknesses and dielectric materials in layer 48 and substrate 50 allow plate 46 to be made with a relatively large area than can effectively shield capacitors C4 and C5 from having stray (parasitic) capacitances to groundplane 52. Therefore, an important advantage of this structure is that parasitic capacitances are reduced, and actual filter characteristics more closely adhere to the predicted results. Preferably, the physical orientations of the metal plates are such that they take advantage of the differences in the dielectrics.

Figures 3A-3B illustrate a 2-6 GHz bandpass filter 60 according to an embodiment of the present invention. A plurality of three capacitive T-networks 61, 62 and 63 with appropriate interconnecting inductors and input/output capacitors are included. The network 61 includes a combination of three capacitors 64, 66 and 68 with the capacitor 68 extending between the groundplane and the junction of capacitor 64 and 66. An inductor 70 interconnects the networks 61 and 62. Network 62 includes a combination of three capacitors 72, 74 and 76 with the capacitor 76 extending between the groundplane and the junction of capacitors 72 and 74. An inductor 78 interconnects the networks 62 and 63. Network 63 includes a combination of three capacitors 80, 82 and 84 with the capacitor 84 extending between the groundplane and the junction of capacitors 80 and 82. Network 61 includes a combination of series capacitors 64 and 66, and are 6.5 pF, which is much larger electrically than capacitor 68 at 751

femtofarads (fF). Inductor 70 is 2.8 nanohenries (nH) and couples T-network 61 to T-network 62. Series capacitors 72 and 74 are 54pF and much larger electrically than capacitor 76 at 774 fF. Capacitor 86 is 369 femtofarads, inductor 88 is 2.25 microhenries (uH) and couples capacitor 86 to T-network 61.

Implementation of the respective T-networks 61, 62 and 63 (Figure 3B) is similar to that shown for network 40 in Figures 2B-2C. The sizes of the respective plates for each capacitor are adjusted to result in the above exemplary values. All the inductors, e.g., inductors 70 and 78, have more than one turn. But since these inductors are primarily implemented in a flat two-dimensional surface, wire bonds, or metal bridges are needed to connect the two halves of the inductor. The advantage of using via holes and connecting them with a metallization is that the whole device can be fabricated using thin-film techniques and additional assembly labour is eliminated.

In Figure 3A, capacitor 86 is implemented by a structure 94 in Figure 3B. Capacitors 64, 66 and 68 are implemented by a structure 96 in Figure 3B. Capacitors 72, 74 and 76 are implemented by a structure 98 in Figure 3B. Capacitors 80, 82 and 84 are implemented by a structure 100. Capacitor 92 is implemented by a structure 102.

A method of fabricating the above thin-film microwave filter comprises depositing a groundplane and first metal plate on an alumina substrate, depositing a silicon nitride dielectric layer on the metal first plate, and depositing second and third metal plates on the dielectric layer such that a T-network of capacitors is formed by the first through third metal plates. The majority of the inductor metallization is in the same layer

as plates 42 and 44. The two halves of the inductor can be connected by forming vias through the silicon nitride dielectric and an underpass using metal in the same layer as plate 46. (Here the connection technology is an underpass, in the polyamide type of prior art device the connection technology typically used is an overpass).

An advantage of the present invention is that bandwidths greater than thirty percent can be practically implemented using thin-film techniques. Figure 4 shows the bandpass characteristics that were calculated and then measured for filter 60. Low insertion loss and equiripple return loss are obtained between two and six gigahertz (100 %BW).

Although the present invention has been described in terms of the presently preferred embodiments, it is to be understood that the disclosure is not to be interpreted as limiting. Various alterations and modifications will no doubt become apparent to those skilled in the art after having read the above disclosure. Accordingly, it is intended that the appended claims be interpreted as covering all alterations and modifications as fall within the scope of the invention.

Reference is directed to our co-pending Divisional Patent Application No. 9308712.0 which has the same description as the present Application and which claims a method of fabricating a thin-film microwave filter, comprising the steps of: depositing a groundplane on a first side of an alumina substrate; depositing a first metal layer on a second side of the alumina substrate opposite to said groundplane and forming the first metal layer into a first metal plate; depositing a silicon nitride dielectric layer over the first metal plate;

depositing a second metal layer over the silicon nitride dielectric layer and forming second and third metal plates on a silicon nitride dielectric layer such that a first capacitor is formed by said first metal plate, said silicon nitride layer and said second metal plate, a second capacitor is formed by said first metal plate, said silicon nitride layer and said third metal plate, and a third capacitor is formed by said groundplane, said alumina substrate and said first metal plate, said first second and third capacitors forming a T-network of capacitors and forming inductors in the second metal layer that are electrically connected to said T-network of capacitors.

**CLAIMS**

1. A thin-film microwave filter comprising: a substrate including a groundplane on a first side and a plurality of first metal plates on a second side that is opposite to said first side; a dielectric layer covering said first metal plates on said second side of the substrate; a plurality of T-networks of capacitors each formed by a second and a third metal plate that are each deposited on the dielectric layer and each disposed entirely within an area defined by projecting the boundaries of a respective one of said first metal plates normal to the groundplane so that said first metal plate intervenes between each of said second and third metal plates and said groundplane; and a plurality of inductors formed primarily on the dielectric layer and each connected to and between respective ones of the T-networks of capacitors in cascade.
2. A filter according to Claim 1, wherein the substrate comprises a material selected from the group consisting of alumina, beryllium oxide, aluminium nitride, quartz and sapphire.
3. A filter according to Claim 1 or 2, wherein the dielectric layer comprises silicon nitride.
4. A filter according to any one of Claims 1 to 3, wherein the plurality of T-networks of capacitors is such that the filter has a percentage bandwidth that exceeds thirty percent.
5. A method of fabricating a thin-film microwave filter, comprising the steps of: depositing a groundplane on a first side of a substrate; depositing a first metal layer on a second side of said substrate that is opposite



to said first side and forming a plurality of first metal plates; depositing a dielectric layer over said plurality of first metal plates; forming each of a plurality of T-networks of capacitors by depositing a second metal layer over said dielectric layer and forming second and third metal plates that are each entirely within an area defined by projecting the boundaries of a respective first metal plate normal to the groundplane; and forming inductors in said second metal layer that are each respectively electrically connected to ones of said T-networks of capacitors.

6. A method according to Claim 5, wherein said first metal layer forms both the first metal plate and metal underpass connections that electrically complete individual turns of said inductors.

7. A method according to Claim 5 or 6, further comprising the step of forming via holes between said first and second metal layers to electrically complete said inductors such that multi-turn types of said inductors are formed entirely with thin-film techniques.

8. A method according to any one of Claims 5 to 7, wherein said substrate is an alumina substrate.

9. A method according to any one of Claims 5 to 8, wherein said dielectric layer is a silicon nitride dielectric layer.

10. A thin-film microwave filter substantially as hereinbefore described with reference to and as shown in Figures 2A, B, C, 3A, B, C and 4.