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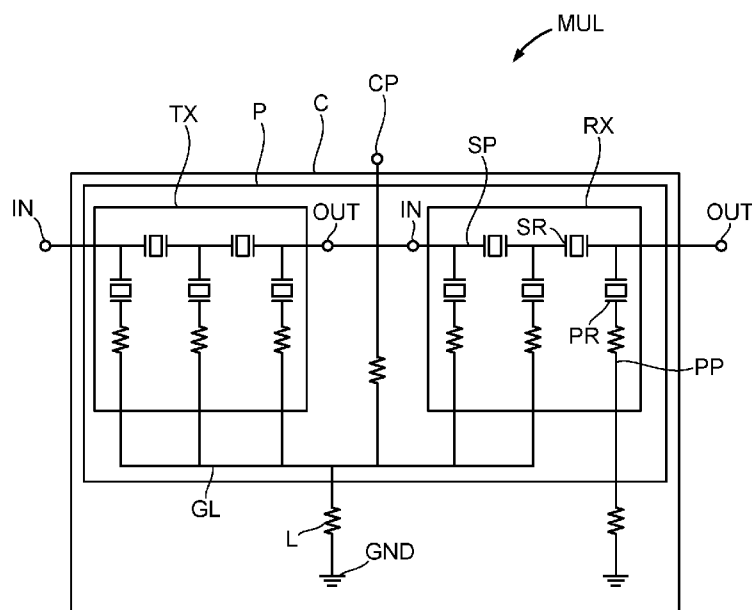


FIG. 1

(57) Abstract: A multiplexer with an improved isolation between TX and RX is provided. To that end, at least one of the TX and RX filters has two ground connections separate from each other.



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MULTIPLEXER WITH IMPROVED ISOLATION, MODULE COMPRISING A
MULTIPLEXER AND A METHOD FOR DESIGNING A MULTIPLEXER TOPOLOGY

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority to German Patent Application No. 102016122000.0, filed November 16, 2016, which is expressly incorporated herein by reference in its entirety.

Description

The present invention refers to multiplexers with improved isolation characteristics. Further, the invention refers to modules in which corresponding multiplexer topologies are realized and to methods for designing a multiplexer topology.

Multiplexer topologies and modules realizing such multiplexers should provide more and more frequency bands while their physical dimensions have to be decreased due to the current trend towards miniaturization. Further, the data transfer rate should be increased, e.g. by CA (carrier aggregation). Carrier aggregation should not only be possible in a receive mode but also in a transmit mode (TX-CA). Further, carrier aggregation should be possible with TDD (Time Division Duplexing) and FDD (Frequency Division Duplexing) modes. What is problematic in such multiplexers is the isolation between a transmission signal path and a reception signal path. If the isolation is too bad, then telephone calls in mobile handsets may be dropped due to poor signal quality. Further, the data rates are reduced, too.

Thus, what is needed is a multiplexer that is compatible with the increasing demands towards data rates and frequency bands, carrier aggregation, TDD and FDD modes and that has a sufficiently high isolation between transmission signal paths and reception signal paths. Further, the physical realization of such multiplexers should be possible with conventional materials, e.g. the use of conventional PCB boards. Further, as multiplexers handle two or more frequency bands, non-linear mixing products should be avoided.

To that end, a multiplexer according to independent claim 1 is provided. Dependent claims provide preferred embodiments.

A multiplexer with improved isolation comprises a transmission filter and a reception filter. The transmission filter has an input port, an output port, a signal path between the input port and the output port, two series resonators in the signal path and three shunt resonators in corresponding shunt paths. The reception filter has an input port, an output port, a signal path between the input port and the output port, two series resonators in the signal path and three shunt resonators in shunt paths. Further, the multiplexer has a common port between the transmission filter and the reception filter. One of the filters has two ground connections separate from each other.

Such a multiplexer may be a duplexer, a triplexer, a quadplexer or a multiplexer of a still higher order. A multiplexer of the fourth order may have two transmission filters and two reception filters. A multiplexer of the order N may have m transmission filters and n reception filters for the FDD case, and k transmission and reception filters for the TDD case, with $N = m+n+k$, and $m, n, k \geq 0$.

The input port of each transmission filter is provided to receive input signals in the form of RF signals. The output port of a transmission filter is provided to conduct RF signals to the common port. The input port of a reception filter is provided to receive RF signals from the common port. The output port of a reception filter is provided for conducting RF signals from the common port to an external circuit environment.

It is possible that the common port may be directly connected to or coupled to an antenna port.

It was recognized that the grounding strategy in designing multiplexers is crucial for obtaining a high isolation between transmission filters and reception filters. The transmission

filters and the reception filters may comprise ladder-type filter structures or ladder-type-like filter structures where a series resonator and a parallel resonator in a shunt path establish a basic circuit element. Shunt paths may comprise shunt resonators and electrically connect the signal path to ground or couple the signal path to ground. The resonators may be established as electroacoustic resonators utilizing a piezoelectric material. Accordingly, it is possible that a module comprises a chip having a piezoelectric material in which or on which the resonators are created. The chip with the piezoelectric material may be part of a filter package that can be arranged on a carrier. It was recognized that the grounding strategy is crucial because in physical realizations of multiplexers, the ground potential of a component may be different from a perfect ground assumed when designing multiplexer topologies. A ground potential may be imperfect due to so-called "ground-loop" effects, i.e. due to finite values of the resistivity of metallization structures in grounding conductors different sections of the grounding conductors may have a potential that slightly differs from the perfect ground potential. As a consequence thereof, electrical connections being connected to such grounding conductors are electrically coupled. This problem becomes prominent when the complexity of a multiplexer is increased due to increased demands concerning the number of frequency bands and carrier aggregation and the corresponding complexity of a mobile handset.

Thus, it was recognized that ground loop voltages and ground loop currents between two points that are supposed to be at the same potential but are actually at different potentials should be reduced as much as possible and possibly eliminated. However, the complexity of modern multiplexer topologies, especially when their electrical components should be combined in a small volume makes ground loop effects nearly unavoidable.

In contrast to known multiplexer topologies where due to the trend towards miniaturization the number of ground connections

is reduced to a minimum, a separation of ground connections for a single filter is suggested. In conventional multiplexer topologies, all shunt paths of a single filter share the same ground connection to keep the components small, to keep the number of external contacts small and to avoid the need for conductor crossings.

It is possible that the transmission filter and/or the reception filter comprises a combination of a ladder type structure with two series resonators and three parallel resonators together with a DMS (DMS = Dual Mode SAW) filter.

However, by providing a multiplexer where at least one filter has two ground connections separate from each other, ground loop effects could significantly be reduced and the isolation of the multiplexer improved.

It is possible that the two separated ground connections are from a filter chip to a package ground or to a carrier ground. The filter chip can carry the filters' structures and be arranged on a carrier, e.g. a substrate.

It is possible that both filters have separate ground connections.

Thus, it is possible that each of both filters has two separate ground connections separate from each other. The number of ground connections of a multiplexer with two filters, one transmission and one reception filter, can be three: the transmission filter has two separate ground connections and the reception filter has one ground connection. It is also possible that the transmission filter has one ground connection and the reception filter has two separate ground connections. However, with the number of separate ground connections being three, the transmission filter can have separate ground connections while the reception filter has separate ground connections, too. The transmission filter has one separate ground connection. The reception has one separate ground connection. The remaining

shunt paths of the transmission and the remaining shunt paths of the reception filter share the same ground connection separate from the respective other two ground connections.

It is possible that one separate ground connection connects an input port side or an output port side shunt path to ground.

An input port side shunt path is a shunt path that is electrically closest to the input port of the corresponding filter. An output port side shunt path is the electrically nearest shunt path to the output port of the corresponding filter.

It was recognized that these terminal-sided shunt paths have a special impact on the isolation of the multiplexer.

In the context of the present multiplexers, it is possible that a separate ground connection electrically connects only a single shunt path to a ground potential that is not provided on the piezoelectric chip but on a carrier on which the piezoelectric chip is arranged. This is in contrast to common ground connections where one ground potential is provided on the piezoelectric chip for different shunt paths of the multiplexer topology.

Correspondingly, it was surprisingly found that strongly improved isolation characteristics can be obtained although the number of separate ground connections does not exceed the number of ground connections of conventional duplexers. Even more surprisingly it was found that an improved isolation can be obtained if shunt paths of the transmission filter and shunt paths of the reception filter share a common separate ground connection while known duplexers avoid a common use of a separate ground connection for shunt paths of the transmission filter and the reception filter. However, such a counter-intuitive common use of a separate ground connection of TX and RX shunt paths improves the isolation of a port-side shunt path of the transmission filter and a port-side shunt path of the

reception filter have their own separate ground connections. An explanation for this surprising result can be found when inspecting voltages and currents in each leg of the individual GND paths.

The commonly used separate ground connection can also be used as a ground connection for a phase shifter between the transmission filter and the reception filter. Such a phase shifter can comprise capacitive and/or inductive circuit elements.

It is possible that a first separate ground connection connects an input port side shunt path of the transmission filter to ground. A second separate ground connection connects the output port side shunt path of the reception filter to ground. A first common ground connection connects the remaining shunt paths of the transmission filter and the remaining shunt paths of the reception filter to ground.

Then, as described above, shunt paths of the transmission filter and shunt paths of the reception filter are coupled due to ground loop effects. However, the separation of the port side ground connections leads to an overall improvement of isolation.

It is possible that a first separate ground connection connects an input port side shunt path of the transmission filter to ground. A second separate ground connection connects the output port side shunt path of the reception filter to ground. A first common ground connection connects the remaining shunt paths of the transmission filter to ground. A second common ground connection connects the remaining shunt paths of the reception filter to ground.

Although the number of separate ground connections is increased to four, such a topology may be beneficial because the possibility of unwanted ground loop effects due to coupled shunt paths of the transmission filter and the reception filter is further decreased as the transmission filter and the reception

filter have only shunt paths without a galvanic connection on the piezoelectric chip.

Compared to conventional duplexers, the separation of ground connections within the transmission filter and within the reception filter enhances the isolation.

It is possible that the above-mentioned second common ground connection also couples the common port to ground.

It is alternatively possible that the first common ground connection also couples the common port to ground.

i.e. the common port may be coupled to ground either via a separate ground connection of the shunt paths of the transmission filter or of the shunt paths of the reception filter.

It is possible that the multiplexer has a first separate ground connection that connects an output port side shunt path of the transmission filter to ground. A second separate ground connection connects the input port side shunt path of the reception filter to ground. A third separate ground connection couples the common port to ground. A first common ground connection connects the remaining shunt paths of the transmission filter to ground. A second common ground connection connects the remaining shunt paths of the reception filter to ground.

Thus, five separate ground connections are needed to connect the elements of the multiplexer of the piezoelectric chip to ground. However, the isolation of such a configuration is very good and such a configuration provides a tradeoff emphasizing isolation aspects.

It is possible that the multiplexer has three separate ground connections. A first separate ground connection connects an output port side shunt path of the transmission filter to ground. A first common ground connection connects the remaining shunt paths of the transmission filter to ground. The first

separate ground connection also connects an input port side shunt path of the reception filter to ground. A second common ground connection connects the remaining shunt paths of the reception filter to ground.

In addition thereto, it is further possible that the first separate ground connection also couples the common port to ground.

Besides the mentioned transmission and the mentioned reception filter, the multiplexer can comprise one or more further transmission filters and one or more further reception filters. The above-mentioned grounding strategies can also be applied to the further transmission filters and to the further reception filters.

A multiplexer module can comprise a carrier, a package, and has integrated one of the above-mentioned multiplexers. The filters are arranged in the package. The package is arranged on the carrier. The separate ground connections are established on the carrier.

The package may include the piezoelectric material, i.e. a piezoelectric chip, that is needed when the resonators in the series paths and in the shunt paths work with acoustic waves.

Resonators could be SAW resonators (SAW = Surface Acoustic Wave), BAW resonators (BAW = Bulk Acoustic Wave) (e.g. FBAR (thin Film Bulk Acoustic Resonators), GBAW resonators (GBAW = Guided Bulk Acoustic Wave) or any other resonator based on micro-acoustic wave propagation.

The package and the carrier may comprise a multi-layer stack with dielectric layers, e.g. made from a dielectric material such as a ceramic material, and metallization layers in which signal conductors and circuit elements such as capacitive or inductive elements are structured.

It is possible that such a module is a PAiD module (Power

Amplifier with integrated Duplexers), a FEMiD module (Front-End Module with integrated Duplexer), or a FEM (Front-End Module) using duplexers or multiplexers. The carrier may be PCB (Printed Circuit Board).

A method for designing a multiplexer topology comprises the step of monitoring and minimizing the voltage across a ground loop inductor.

A ground loop inductor is an electrically conducting structure that electrically connects two or more shunt paths to an ideal ground potential.

It was found that the strength of an electrical signal, i.e. a voltage or a current, across such a ground loop inductor is a measure for the quality of the isolation between the TX branch and the RX branch of a duplexer or a multiplexer. Thus, in order to estimate the isolation based on complex simulations and elaborate multiplexer demonstrators monitoring this calculated/simulated quantity allows to simplify the designing process considerably.

Further, it was found that some multiplexer topologies are very sensitive to the value of the inductivity of a ground connection. Especially when such a multiplexer is embedded in a complex external circuit environment and has a complex intrinsic structure, too, such values are difficult to determine. However, as was found in the context of the present invention, the increased effort in determining these values are beneficial because precisely adapted values have a strong positive influence on the multiplexer's isolation.

The basic concept of the present multiplexer, specific details of the equivalent circuit diagram and preferred embodiments are shown in the schematic accompanying figures.

In the figures:

FIG. 1 shows possible basic circuit elements of an

equivalent circuit diagram of a duplexer.

FIG. 2 shows the theoretically preferred but practically unachievable solution.

FIG. 3 shows a practically easy obtainable multiplexer with bad isolation properties.

FIG. 4 shows basic elements of an equivalent circuit diagram of a general concept of the present multiplexer.

FIG. 5 shows basic circuit elements of a preferred embodiment.

FIG. 6 shows a duplexer with an exemplary phase shifter.

FIG. 7 shows basic elements of an equivalent circuit diagram of a possible topology.

FIG. 8 shows basic elements of an equivalent circuit diagram of a possible topology.

FIG. 9 shows basic circuit elements of a topology with a large number of separate ground connections.

FIG. 10 shows basic circuit elements of an alternative embodiment.

FIG. 11 shows basic circuit elements of a quadplexer.

FIG. 12 shows the isolation characteristics of the reference duplexer (thick curve) and of a simple duplexer (thin curve) with the ground loop shown in fig. 3.

FIG. 13 shows the voltage across a ground loop inductor of a simple duplexer topology.

FIG. 14 shows the isolation of a reference duplexer (thick) and conventional duplexer (thin).

FIG. 15 shows isolation characteristics for a reference duplexer (thick), a conventional duplexer (thin) and simple duplexer (thin, with Isolation less than 60dB).

FIG. 16 shows voltages across different ground loop inductors of a conventional duplexer.

FIG. 17 shows the improved isolation of a duplexer according to one embodiment (thin) of the provided duplexers and of a reference duplexer (thick).

FIG. 18 shows voltages across ground loop inductors of the duplexer according to FIG. 17.

FIG. 19 shows the isolation of a duplexer according to an alternative embodiment (thin) and of a reference duplexer (thick).

FIG. 20 shows voltages across ground loop inductors according to an embodiment of a duplexer.

FIG. 21 shows isolation characteristics according to one embodiment of a duplexer (thin) and of a reference duplexer (thick).

FIG. 22 shows voltages across ground loop inductors of the embodiment corresponding to FIG. 21.

FIG. 23 shows isolation characteristics of a duplexer according to one embodiment.

FIG. 24 shows corresponding voltages across ground loop inductors.

FIG. 25 shows isolation characteristics of a duplexer according to one embodiment depending on the inductivity of a ground loop inductor.

FIG. 26 shows isolation characteristics of a duplexer according to one embodiment.

FIG. 27 shows corresponding voltages across ground loop inductors.

FIG. 28 shows isolation characteristics of a quadplexer having conventional grounding connections.

FIG. 29 shows isolation characteristics of a quadplexer with improved grounding connections.

FIG. 1 shows details of an equivalent circuit diagram of one possible realization of a multiplexer MUL with an improved isolation. The multiplexer MUL - here being a duplexer - has a transmission filter TX and a reception filter RX. The transmission filter TX has an input port IN and an output port OUT. The reception filter RX has an input port IN and output port OUT. Further, the multiplexer MUL has a common port CP being connected to or coupled to the output port OUT of the transmission filter TX and the input port IN of the reception filter RX. The common port CP may be provided for an electrical connection to an antenna port. The transmission filter TX and the reception filter RX both have a ladder-type-like construction with series resonators SR in a signal path SP and with parallel resonators PR in parallel shunt paths PP. Ladder-type-like filter structures are characterized in that the shunt paths PP are connected to ground GND.

The ground potential GND should be as good as possible. However, due to finite conductivity of signal lines and due to electrical interaction between adjacent signal lines and due to interconnects from the filter chip to package or module carriers, ground potentials in physical devices are non-perfect and ground loop effects take place.

The RX filter can also contain one or more DMS alike structures either stand-alone or in addition to the ladder-type structure. In fact, the DMS is a more complex resonator but showing similar effects to wrong groundings as the simple two-port resonators.

Resonators of the transmission filter TX and the reception filter RX may be established on a chip. If electroacoustic resonators are used, the chip may comprise a piezoelectric

material. Such a piezoelectric chip P may be arranged on a carrier C. The carrier C may provide a better ground potential. However, a small number of electrical connections between the piezoelectric chip P and the carrier C is preferred and as many parallel shunt paths PP should be electrically connected at the corresponding ground site on the piezoelectric chip P. Thus, a connecting ground loop connector GL is created. Inductors L within parallel paths PP and ground connections refer to the finite inductivity of signal conductors, such as bump connections between the piezo chip P and the carrier C.

As an example, the topology shown in FIG. 1 has a reception filter RX with two separate ground connections. One separate ground connection connects the output side parallel shunt paths PP of the reception filter RX to a ground potential provided by the carrier C, e.g. at a board site and outside the piezoelectric package.

The remaining shunt paths of the reception filter are electrically connected to ground via an additional connection separate from the connection of the output side shunt path. Thus, the reception filter RX has two ground connections separate from each other.

FIG. 2 illustrates an ideal grounding condition where each of the shunt paths of the transmission filter TX and of the reception filter RX and of an antenna coil is connected to a perfect ground. However, such a grounding system is incompatible with moderate production costs and especially with the current trend towards miniaturization. But the configuration shown in FIG. 2 can be modelled and acts as a reference configuration to which more practical approaches can be compared.

The bottom curve in FIG. 12 (thick line with higher isolation) shows the TX to RX isolation of such a reference duplexer grounding configuration. All other isolation curves will refer to this particular configuration.

FIG. 3 shows a grounding configuration where all shunt paths of all filters are combined on the piezo chip for minimizing grounding efforts. The upper curve of FIG. 12 shows the corresponding isolation of this configuration being orders of magnitude away from ideal grounding configuration possibilities.

FIG. 4 shows basic circuit elements of an equivalent circuit diagram of an embodiment of a duplexer. The output port side shunt path of the transmission filter TX is separate from the grounding connections of the other shunt paths of the transmission filter.

The remaining shunt paths of the transmission filter TX are connected on the piezo chip P and connected to a single commonly used ground CG on the carrier C.

FIG. 5 shows a preferred embodiment of a duplexer with improved isolation because the number of separate ground connections is three and does not exceed the number of ground connections of conventional duplexers without improved isolation. The input side shunt path of the transmission filter TX and the output side shunt path of the reception filter have their own separate grounds SG on the carrier C. Counter-intuitively, the remaining shunt paths of the transmission filter TX and the remaining shunt paths of the reception filter RX are combined on the piezo chip P and connected to a common ground connection CG on the carrier C. Further, an antenna coil connected to the common port is also combined to the common ground CG.

Despite the direct on-chip connection of shunt paths of the transmission filter and of the reception filter and without an increase of the number of separate ground connections on the carrier C, the configuration shown in FIG. 5 provides an improved isolation.

FIG. 6 shows a configuration where additional capacitive elements in the signal paths are provided. The capacitance

elements, the shunt coil of the antenna and the output side resonator of the transmission filter and the input port side resonator of the reception filter establish a phase shifter PS to improve the frequency dependent impedance of transmit signals and receive signals at the common port. Thus, the isolation is improved and no energy of a receive signal obtained from the common port is dissipated in the transmission filter. The number of series resonators in the transmission filter is three. The number of shunt paths with parallel resonators in the transmission filter is four. The reception filter has four series resonators and three parallel resonators in three shunt paths in this example.

FIG. 7 shows a configuration where the input side shunt path has its own first separate ground connection. The output side shunt path of the reception filter has a second separate ground connection. The remaining shunt paths of the transmission filter have a first common ground connection separate from the other ground connections and the remaining parallel paths of the reception filter and the antenna coil have a second common ground connection separate from the other ground connections. This grounding configuration provides a good isolation. However, an additional grounding connection is needed.

FIG. 8 shows a configuration similar to the configuration of the duplexer shown in FIG. 7. However, the antenna coil shares the ground connection together with the remaining shunt paths of the transmission filter.

FIG. 9 shows a configuration where the output side shunt path of the transmission filter has a separate ground connection. The input side of the reception filter has a separate ground connection. The antenna coil at the common port has its separate ground connection. The remaining shunt paths of the transmission filter have their common ground connection and the remaining two shunt paths of the reception filter have their common ground connection.

The transmission filter has three series resonators and four shunt paths. The reception filter has four series resonators and three shunt paths.

FIG. 10 shows a configuration where the output side shunt path of the transmission filter is separate from the remaining shunt paths of the transmission filter. Further, the input side shunt path of the reception filter is separate from the remaining shunt paths of the reception filter. The separate output port side of the transmission filter and the separate input port side shunt path of the reception filter are combined with the antenna coil and connected to ground with a ground connection separate from the ground connection of the remaining shunt paths of the transmission filter and the remaining shunt paths of the reception filter.

FIG. 11 shows a quadplexer comprising a first duplexer with a first transmission filter TX and a first reception filter RX and a second duplexer with a second transmission filter TX2 and a second reception filter RX2. The two duplexers are combined at the common port via two usually different phase shifters PS. The two individual duplexers of the quadplexer comprise the grounding configuration of the duplexer of FIG. 10.

FIG. 12 shows the comparison between the isolation of the reference design of FIG. 2 (bottom isolation curve) and of the simple approach according to FIG. 3 (upper curve, thick line). As can be seen, the isolation of the simple approach is almost ruined as there is a huge gap of approximately 25 db. Thus, the grounding strategy fails. If the voltage across the ground loop inductor having a 0 dBm source at 50 Ω , applied at the input port of the transmission filter is regarded there is substantial voltage in both transmission and reception frequencies visible. This voltage is responsible for the massive degradation in isolation that should be reduced with more sophisticated grounding approaches.

FIG 13 shows the voltage across a ground loop inductor of the simple approach according to FIG. 3.

FIG. 14 shows the isolation of a conventional configuration where there is only one ground connection per filter compared to the ideal isolation of the reference design of FIG. 2. Especially the isolation in transmission and in reception frequency bands suffer.

FIG. 15 shows the comparison between the isolation of conventional topologies and the simple approach according to FIG. 3. The conventional isolation is improved but leaves room for further improvement.

FIG. 16 shows the voltages across the three ground loop inductors (TX for the transmission filter, RX for the reception filter, ANT for the phase shifter at an antenna port). As can be seen, the ground loop voltage of the transmission ground loop inductor is almost identical to the voltage (a) of the duplexer of FIG. 3.

FIG. 17 shows the isolation of a topology according to an embodiment as shown in FIG. 5 compared to the reference isolation. Compared to the isolation of conventional duplexers, a significant improvement is visible.

FIG. 18 shows the voltages across the three ground loop inductors for the configuration according to FIG. 5. Especially the reception ground loop voltage is extremely small. It was recognized that this situation is equivalent to a TX power received at the RX output being very small. Thus, monitoring ground loop voltages is a useful measure to obtain reliable information concerning the isolation.

FIG. 19 shows the frequency dependent isolation of an embodiment according to FIG. 7. Four individual ground loop inductors for separate ground connections are required. However, isolation values are so good that they may justify the additional effort.

FIG. 20 shows the four voltages across the four ground loop inductors of the configuration of FIG. 7.

FIG. 21 shows the comparison between a frequency depending isolation of a configuration according to FIG. 8 and the reference configuration. Four ground loops need to be considered. However, there is almost no coupling from the TX signals towards the RX output.

FIG. 22 shows the voltages across the ground loop inductors of the configuration of FIG. 8.

FIG. 23 shows the frequency dependent isolation of a duplexer configuration of a topology as shown in FIG. 9. Five separate ground connections are needed. However, the isolation between transmission filter and reception filter is good.

FIG. 24 shows the corresponding five voltages across the ground loop inductors.

The grounding configuration of FIG. 9 is very sensitive to the value of the ground loop inductor. Correspondingly, FIG. 25 shows obtained frequency dependent isolations for a topology according to FIG. 9 if the value of the ground loop inductor is changed from 0.05 nH to 0.1 nH. All of the ground inductances are assumed to have the same value, i.e. they all changed from 0.05 to 0.1nH

So it is important that for suitable and proper grounding strategy, the sensitivity against changes in the ground loop value need to be monitored. The topology of FIG. 9 can obtain a strongly improved isolation in optimum cases. However, not carefully chosen values may result in a strongly reduced isolation. As a consequence, care must be taken when considering effects of integrating the multiplexer in a complex circuit environment and the voltage across the ground loop inductors should be monitored.

FIG. 26 shows the frequency dependent isolation of a topology according to FIG. 10.

FIG. 27 shows the corresponding three voltages across the ground loop inductors.

FIG. 28 shows isolation curves for a quadplexer with conventional topologies.

In contrast, FIG. 29 shows the isolations of a quadplexer with topologies according to the embodiment shown in FIG. 10.

The multiplexer can comprise further filters and resonators and further series and parallel paths and further ground connections. The module can comprise further components such as chips with integrated amplifiers and the method for designing topologies can comprise further steps of determining characteristic values.

List of reference signs

C:	carrier
CG:	common ground connection
CP:	common port
GL:	ground loop connection
GND:	ground
IN:	input port
L:	inductor
MUL:	multiplexer
OUT:	output port
P:	(piezo-)chip
PP:	(parallel)shunt path
PR:	parallel resonator
PS:	phase shifter
RX:	reception filter
RX2:	second reception filter
SG:	separate ground connection
SP:	signal path
SR:	series resonator
TX:	transmission filter
TX2:	second transmission filter

Claims

1. A multiplexer (MUL) with improved isolation, comprising
a transmission filter (TX) with an input port (IN), an output port (OUT), a signal path (SP) between the input port (IN) and the output port (OUT), two or more series resonators (SR) in the signal path (SP) and three or more shunt resonators (SR) in shunt paths (PP),
a reception filter (RX) with an input port (IN), an output port (OUT), a signal path (SP) between the input port (IN) and the output port (OUT), two or more series resonators (SR) in the signal path (SP) and three or more shunt resonators (PR) in shunt paths (PP),
a common port (CP) between the transmission filter (TX) and the reception filter (RX),
wherein
one of the filters (TX, RX) has two ground (GND) connections separated from each other.
2. The multiplexer of the previous claim, wherein the two separated ground connections are from a filter chip (P) to a package ground (GND) or to a carrier ground (GND).
3. The multiplexer of the previous claim, wherein each of both filters (TX, RX) has two separate ground (GND) connections separated from each other.
4. The multiplexer of one of the previous claims, wherein one separate ground (GND) connection connects an input port (IN) side or an output port (OUT) side shunt path (PP) to ground (GND).
5. The multiplexer of one of claims 1 to 4, wherein
a first separate ground (GND) connection connects an input port (IN) side shunt path (PP) of the transmission filter (TX) to ground (GND),
a second separate ground (GND) connection connects the

output port (OUT) side shunt path (PP) of the reception filter (RX) to ground (GND),

a first common ground (GND) connection connects the remaining shunt paths (PP) of the transmission filter (TX) and the remaining shunt paths (PP) of the reception filter (RX) to ground.

6. The multiplexer of one of claims 1 to 4, wherein

a first separate ground (GND) connection connects an input port (IN) side shunt path (PP) of the transmission filter (TX) to ground (GND),

a second separate ground (GND) connection connects the output port (OUT) side shunt path (PP) of the reception filter (RX) to ground (GND),

a first common ground (GND) connection connects the remaining shunt paths (PP) of the transmission filter (TX) to ground,

a second common ground (GND) connection connects the remaining shunt paths (PP) of the reception filter (RX) to ground (GND).

7. The multiplexer of claim 6, wherein

the second common ground (GND) connection also couples the common port (CP) to ground (GND).

8. The multiplexer of claim 6, wherein

the first common ground (GND) connection also couples the common port (CP) to ground (GND).

9. The multiplexer of one of claims 1 to 4, wherein

a first separate ground (GND) connection connects an output port (OUT) side shunt path (PP) of the transmission filter (TX) to ground (GND),

a second separate ground (GND) connection connects the input port (IN) side shunt path (PP) of the reception filter (RX) to ground (GND),

a third separate ground (GND) connection couples the common port (CP) to ground (GND),

a first common ground (GND) connection connects the remaining shunt paths (PP) of the transmission filter (TX) to ground (GND),

a second common ground (GND) connection connects the remaining shunt paths (PP) of the reception filter (RX) to ground (GND).

10. The multiplexer of one of claims 1 to 4, wherein

a first separate ground (GND) connection connects an output port (OUT) side shunt path (PP) of the transmission filter (TX) to ground (GND),

a first common ground (GND) connection connects the remaining shunt paths (PP) of the transmission filter (TX) to ground (GND),

the first separate ground (GND) connection also connects an input port (IN) side shunt path (PP) of the reception filter (RX) to ground (GND),

a second common ground (GND) connection connects the remaining shunt paths (PP) of the reception filter (RX) to ground (GND).

11. The multiplexer of claim 10, wherein the first separate ground (GND) connection also couples the common port (CP) to ground (GND).

12. The multiplexer of one of the previous claims, comprising a further transmission filter (TX) and a further reception filter (RX).

13. A module, comprising a carrier, a package and a multiplexer (MUL) of one of the previous claims, wherein

the filters (TX, RX) are arranged in the package,

the package is arranged on the carrier,

the separate ground (GND) connections are established on

the carrier.

14. A method for designing a multiplexer (MUL) topology comprising the step of monitoring and minimizing the voltage across a ground loop (GL) inductor (L).

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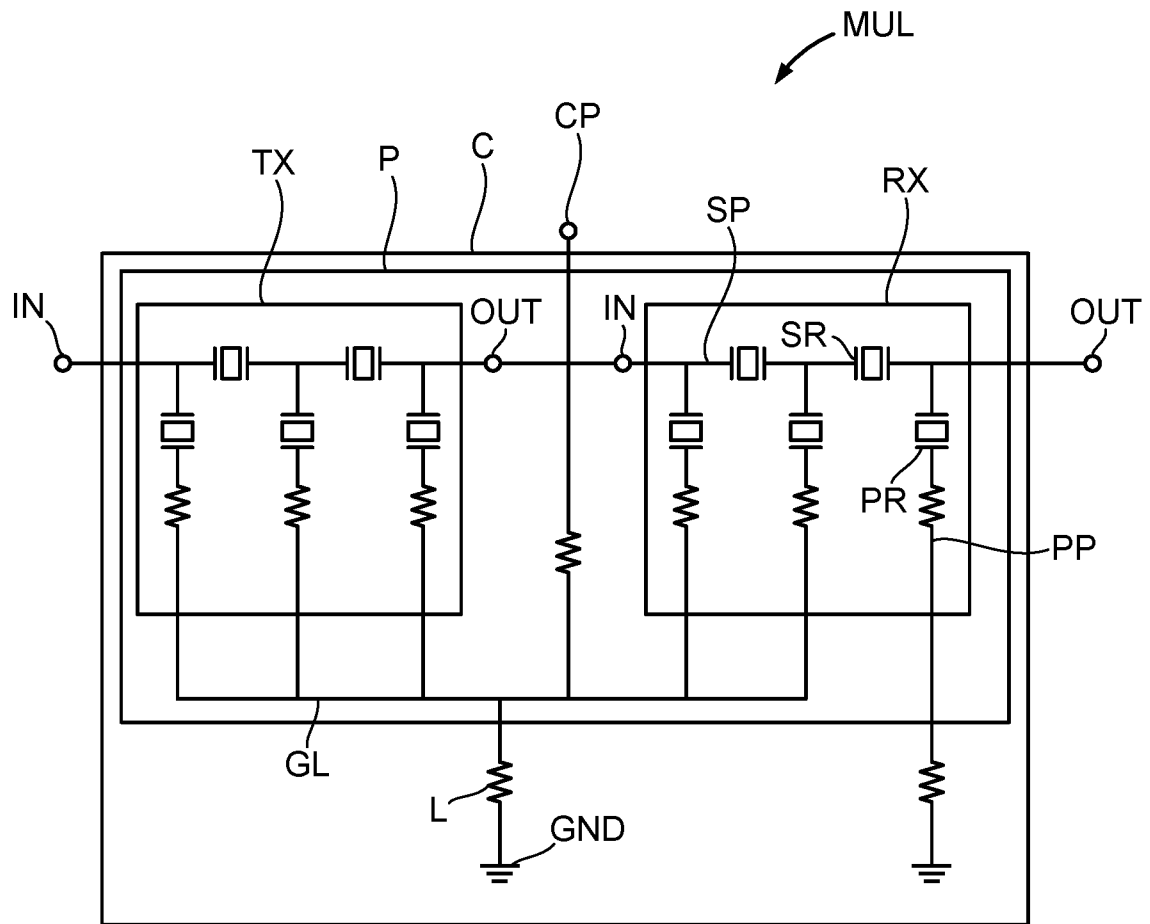


FIG. 1

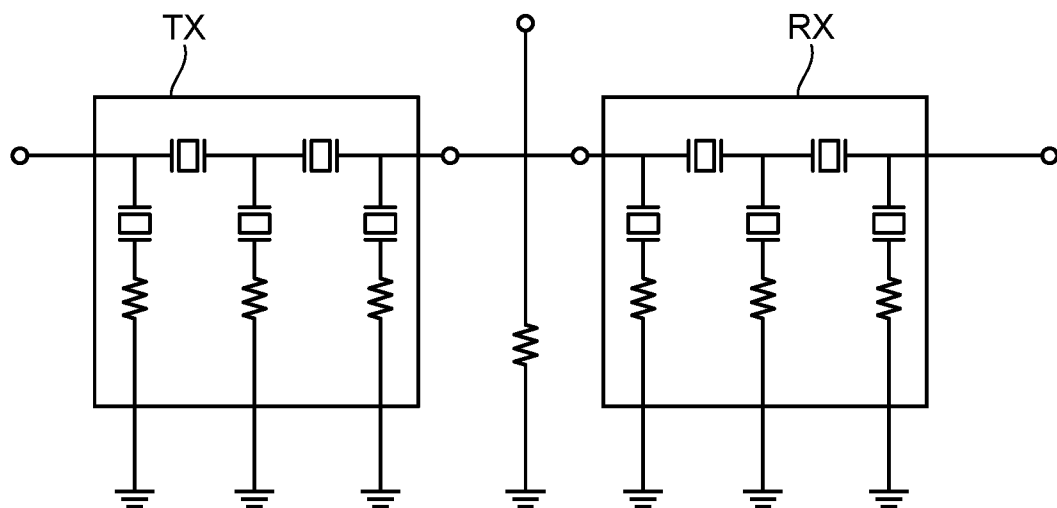


FIG. 2

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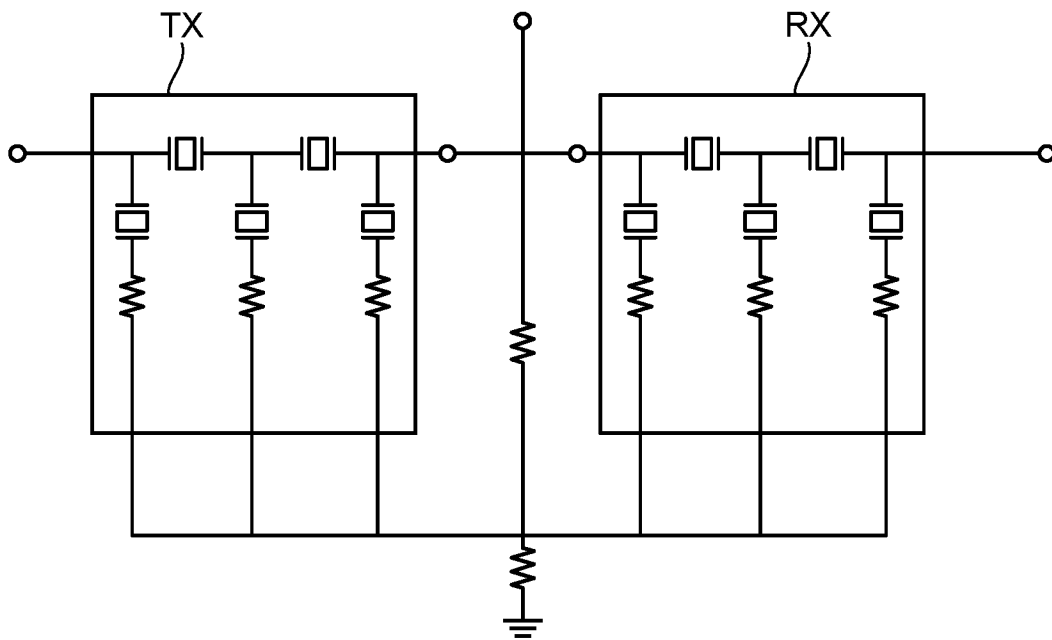


FIG. 3

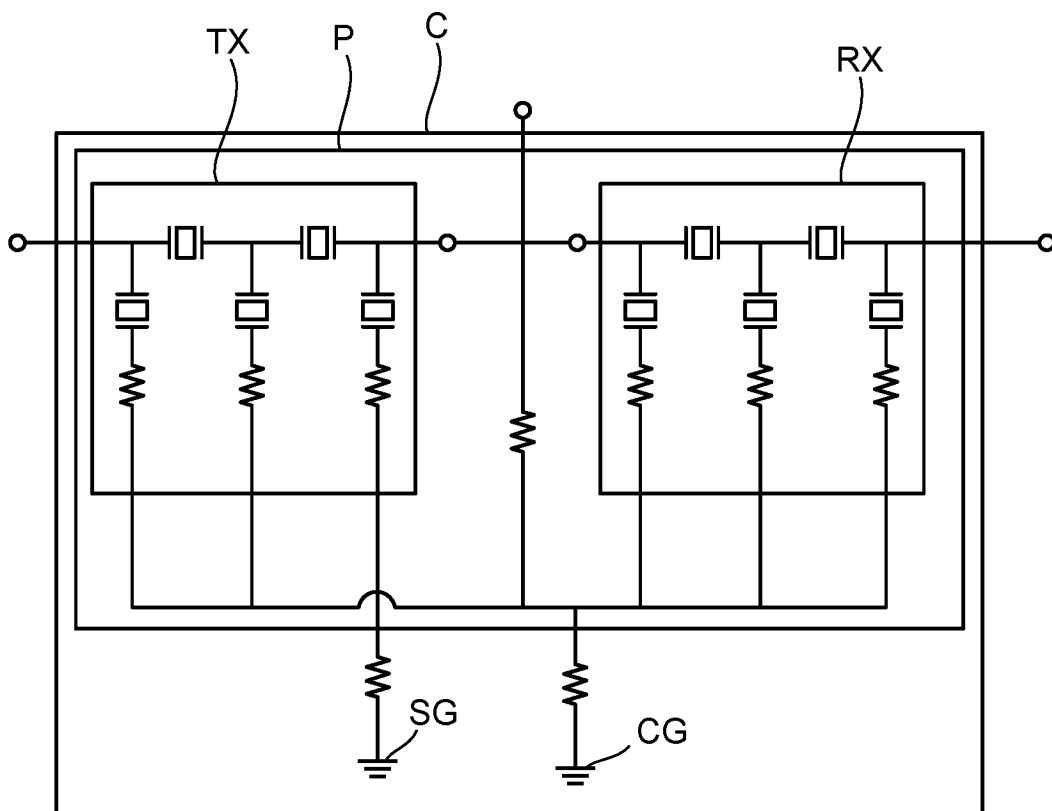


FIG. 4

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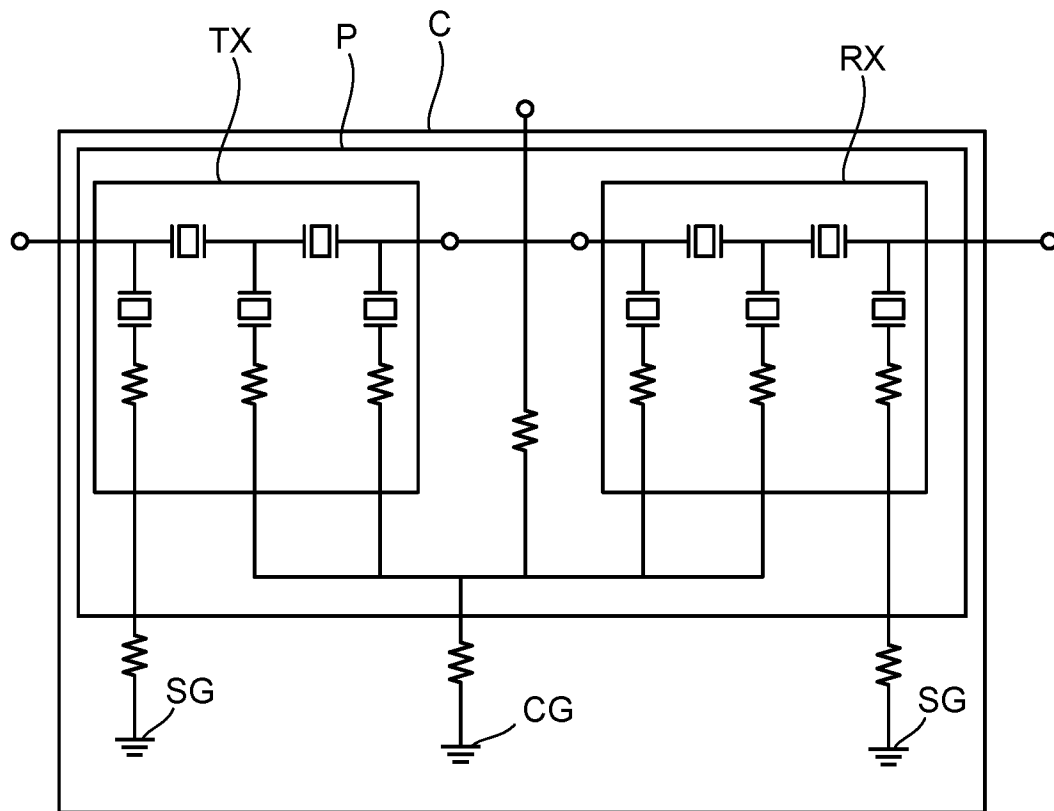


FIG. 5

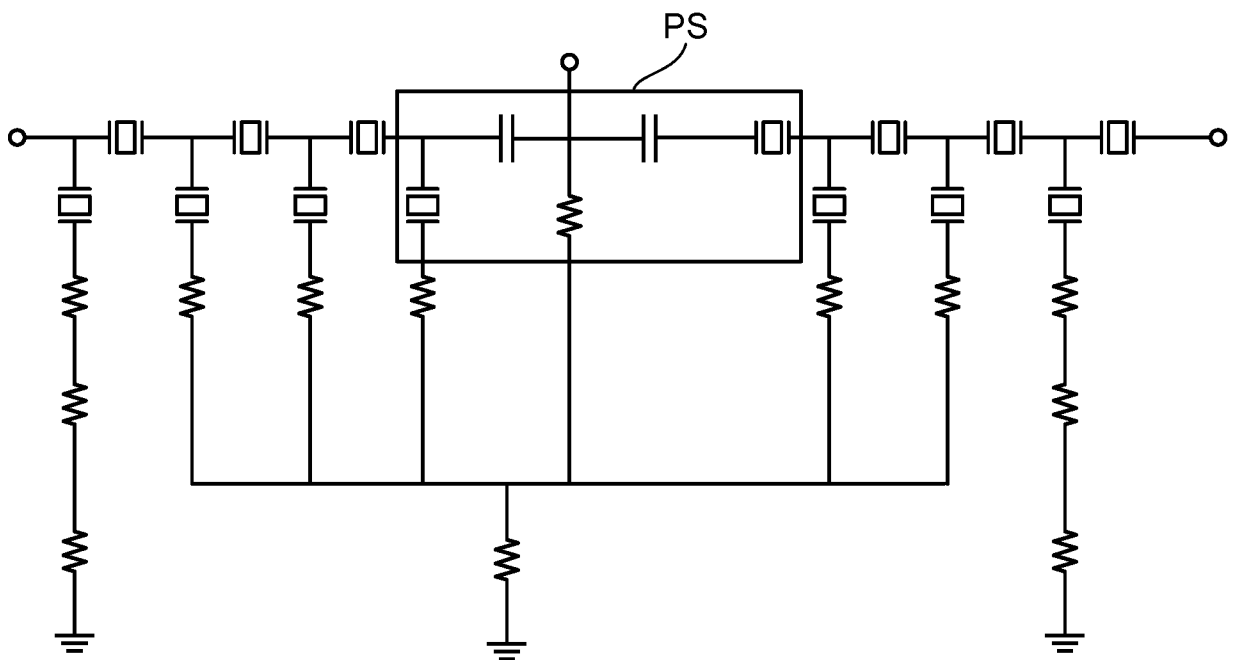


FIG. 6

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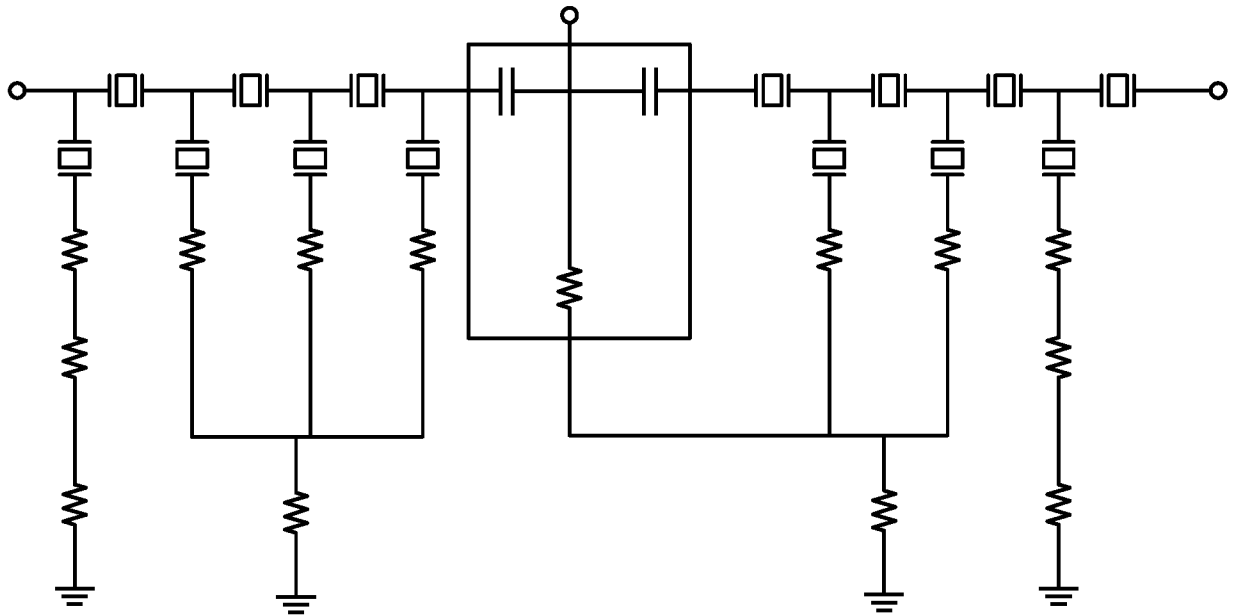


FIG. 7

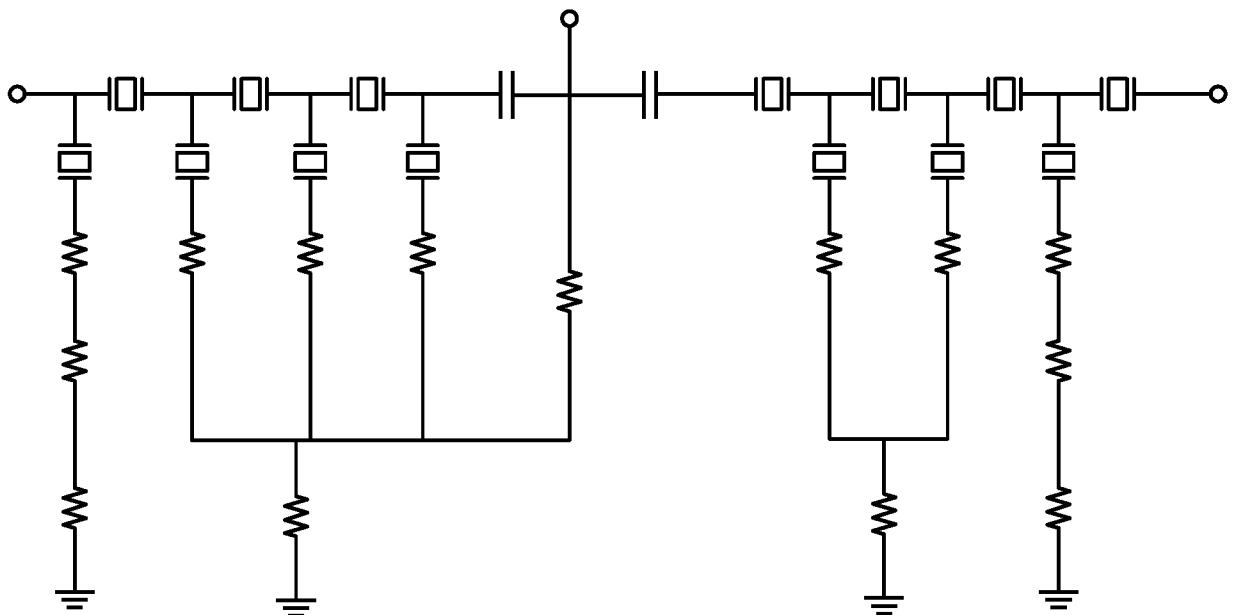
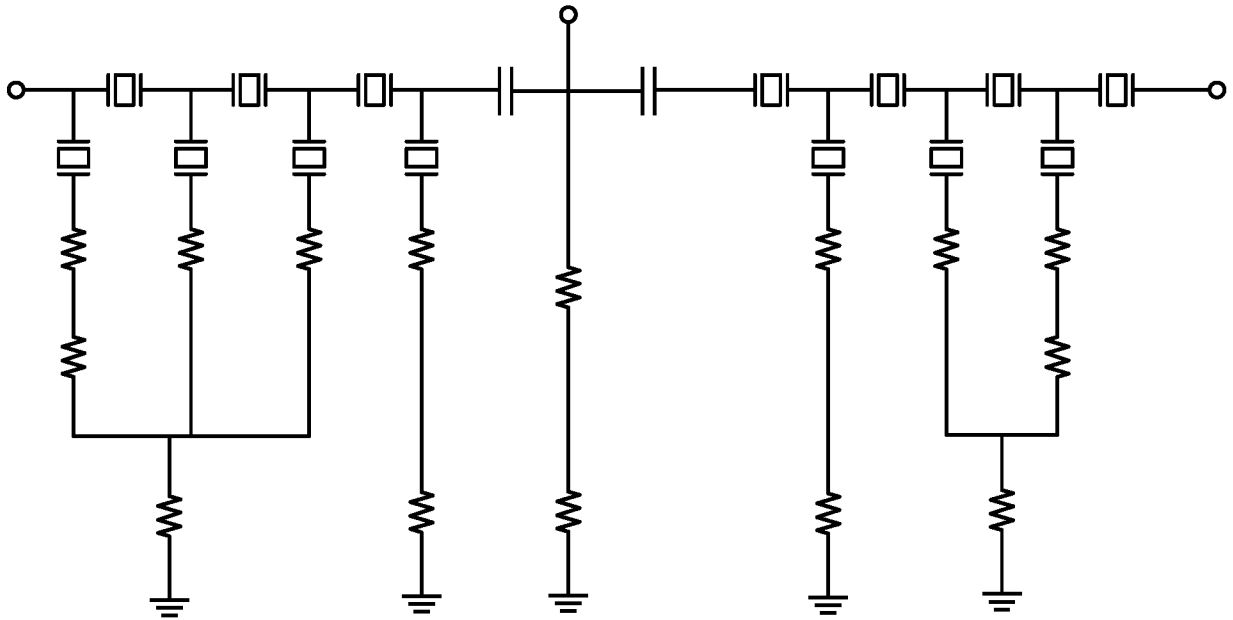
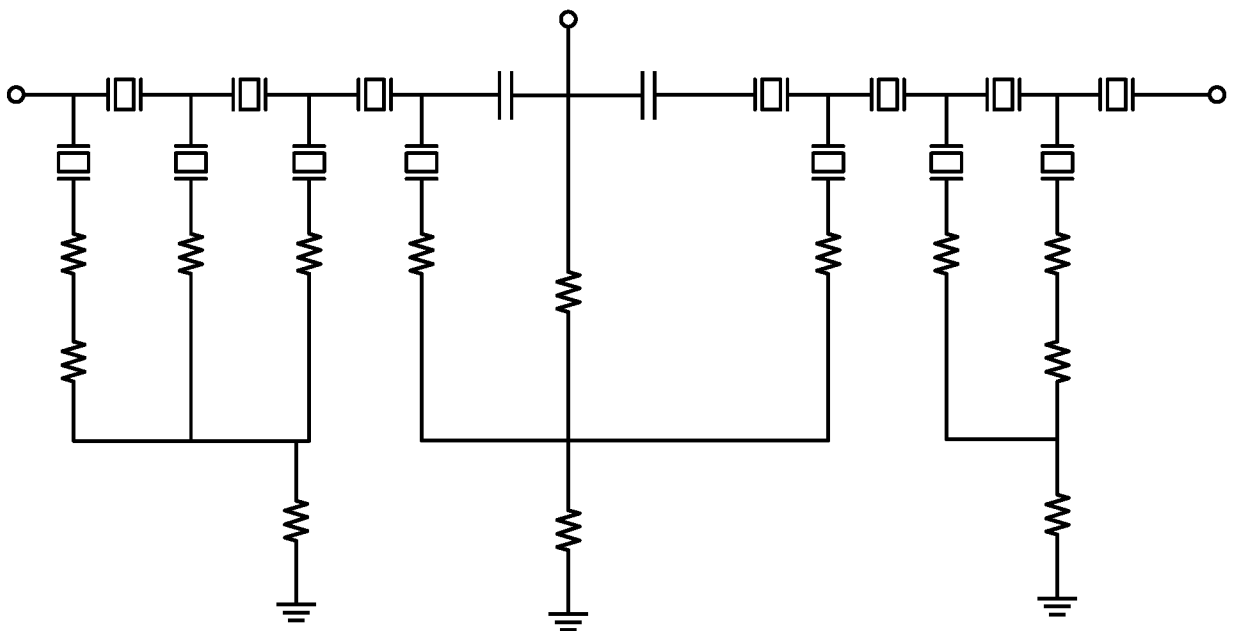


FIG. 8

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**FIG. 9****FIG. 10**

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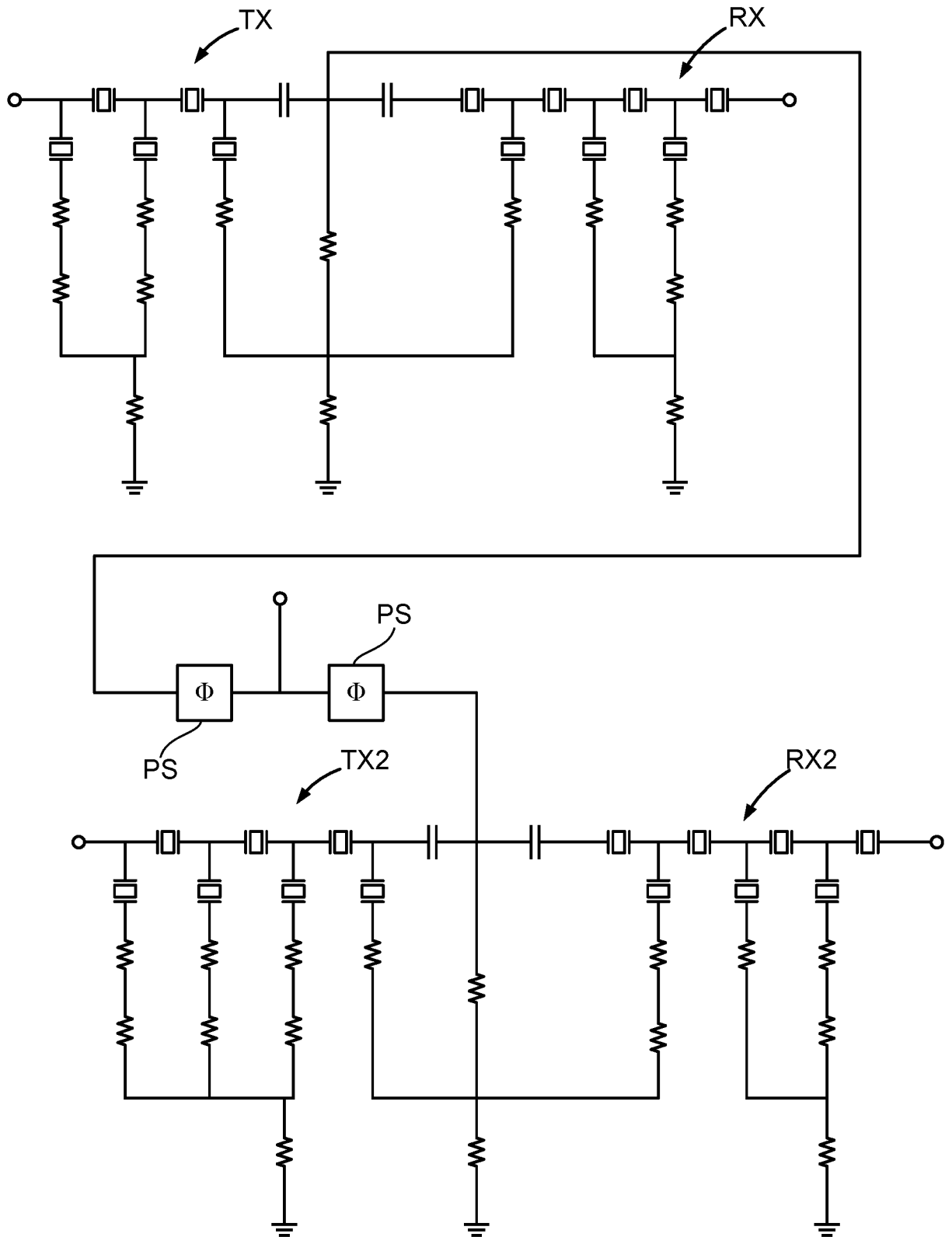
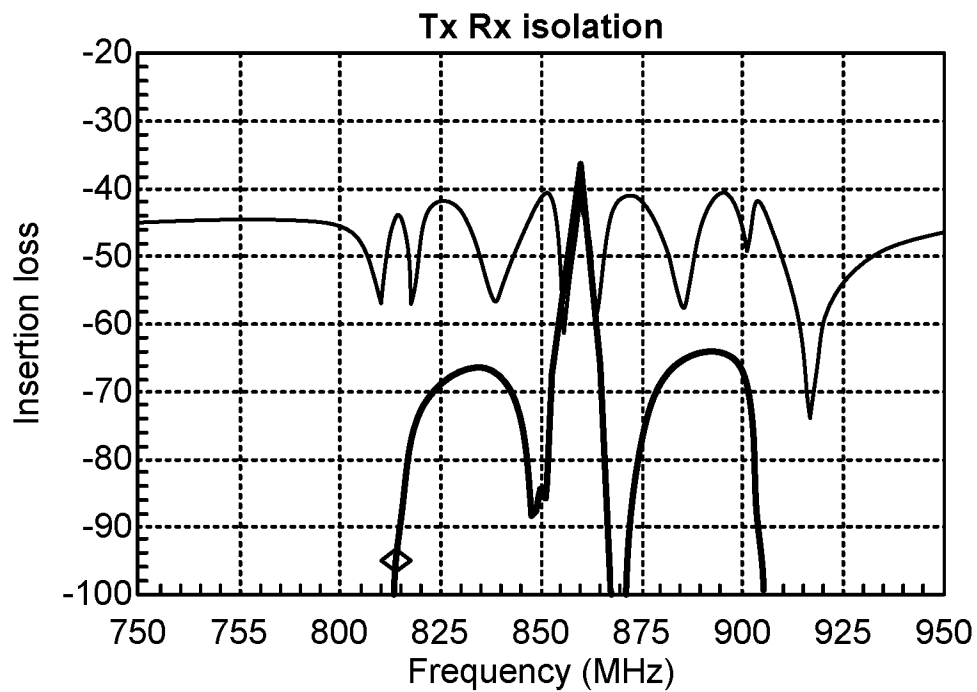
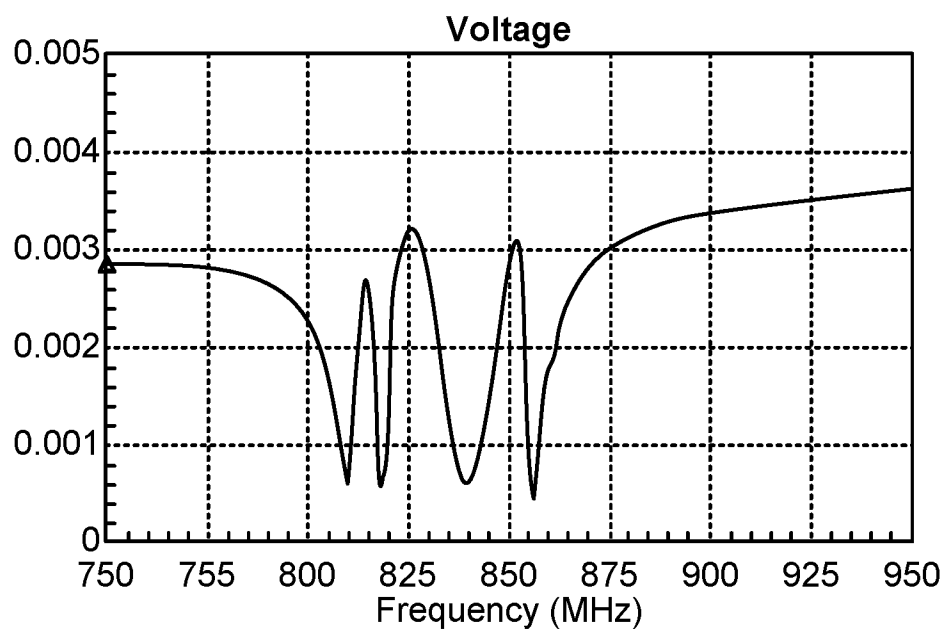
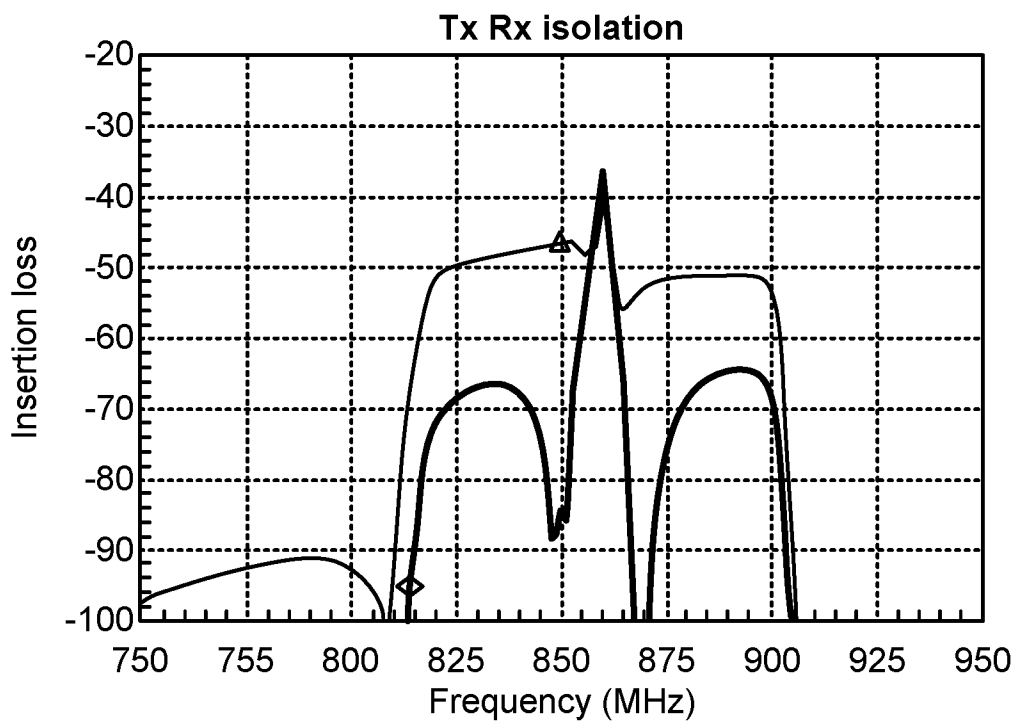
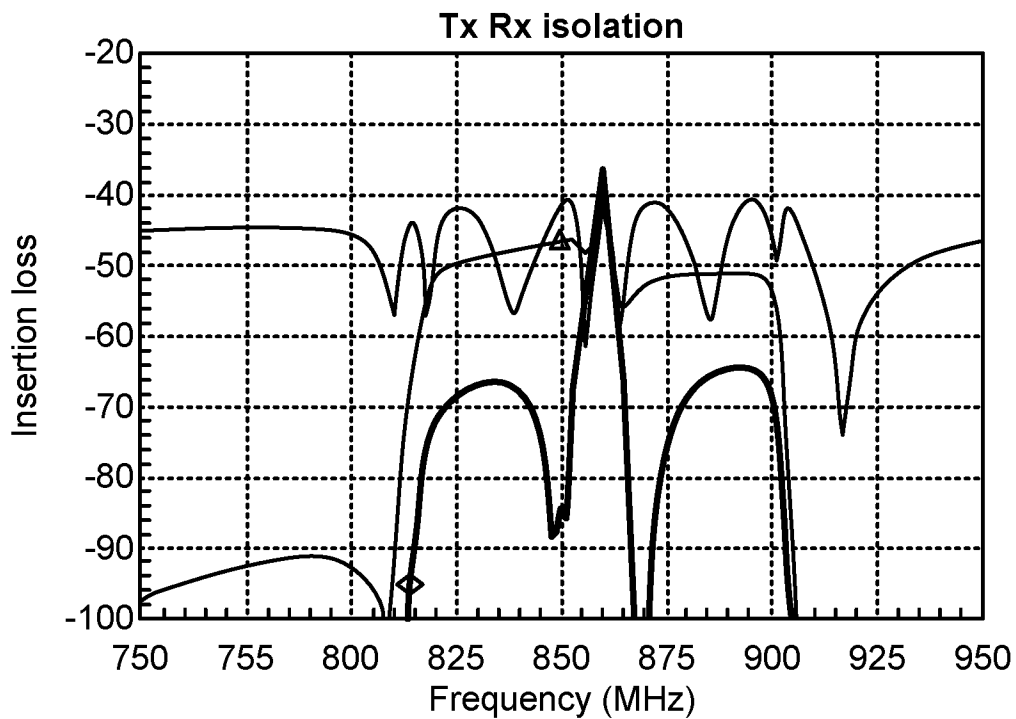


FIG. 11

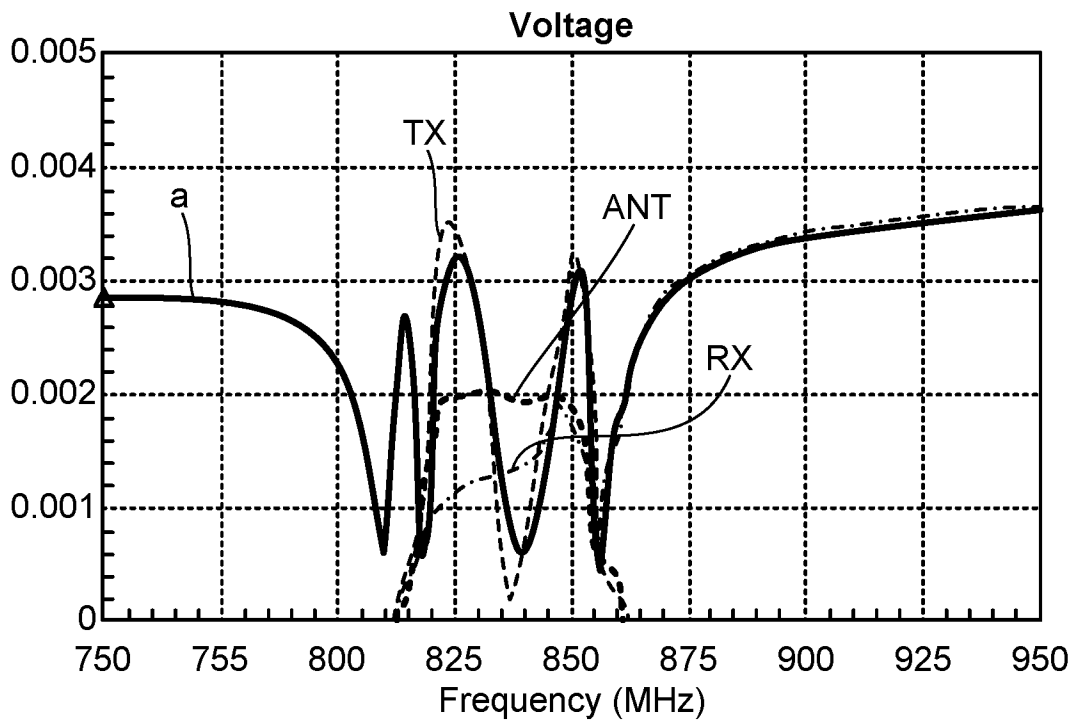
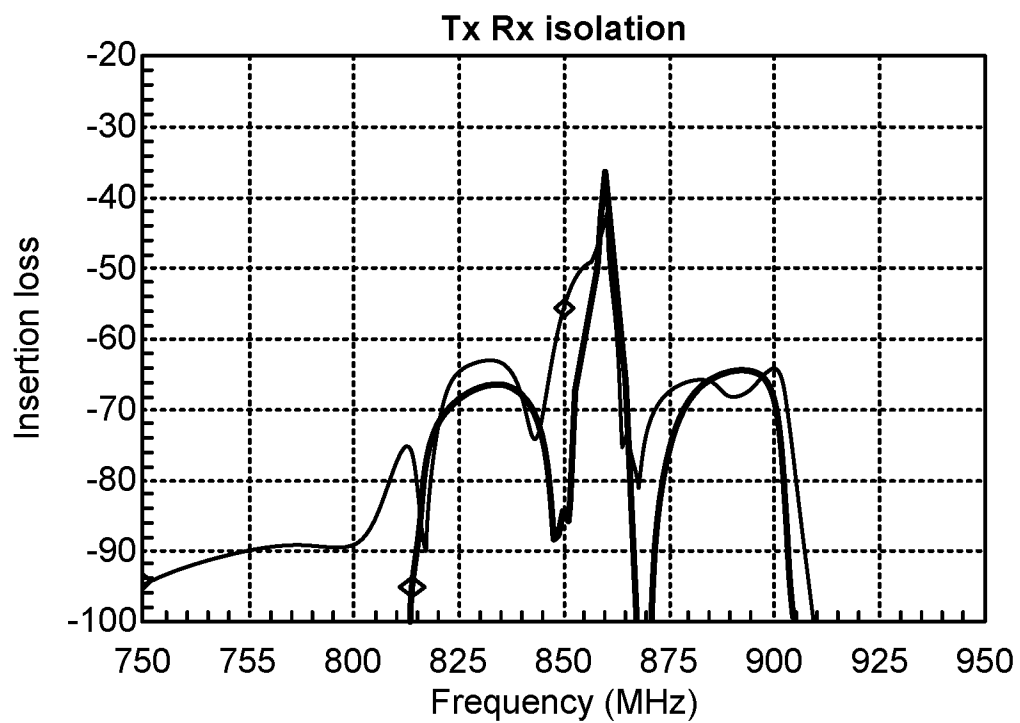
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**FIG. 12****FIG. 13**

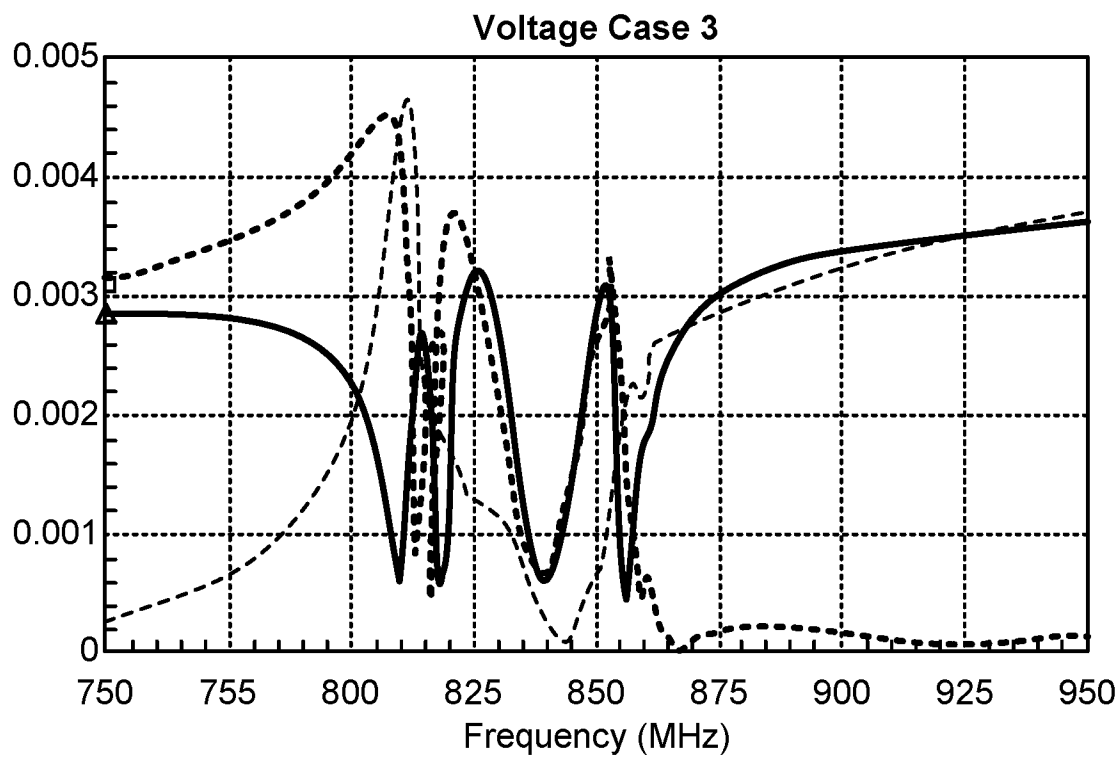
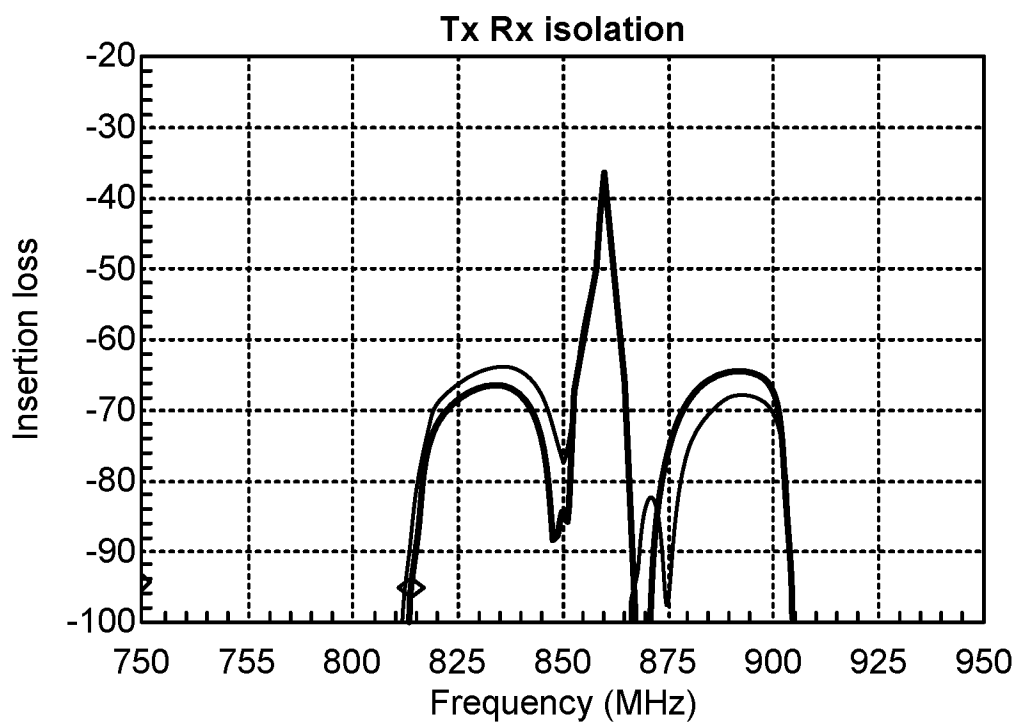
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**FIG. 14****FIG. 15**

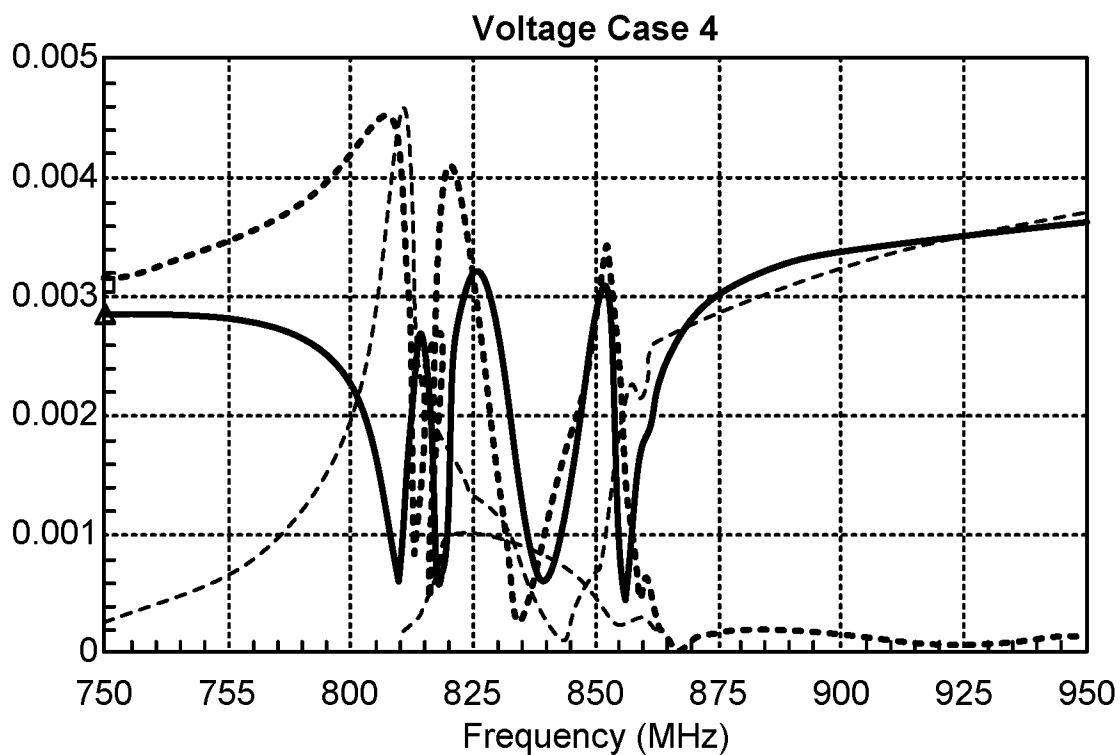
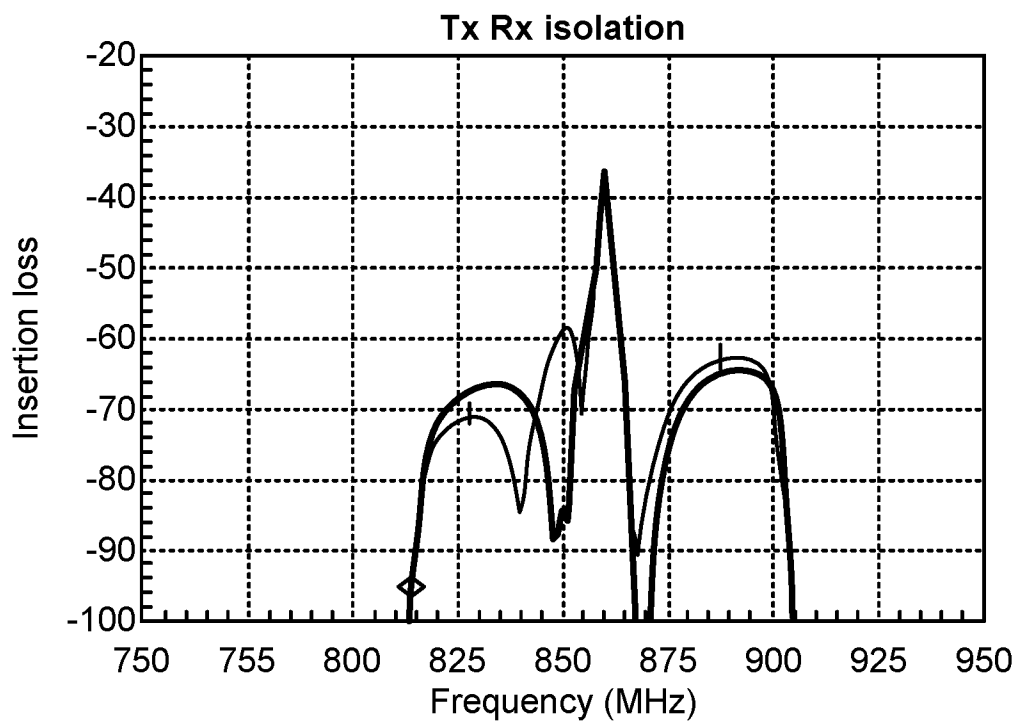
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**FIG. 16****FIG. 17**

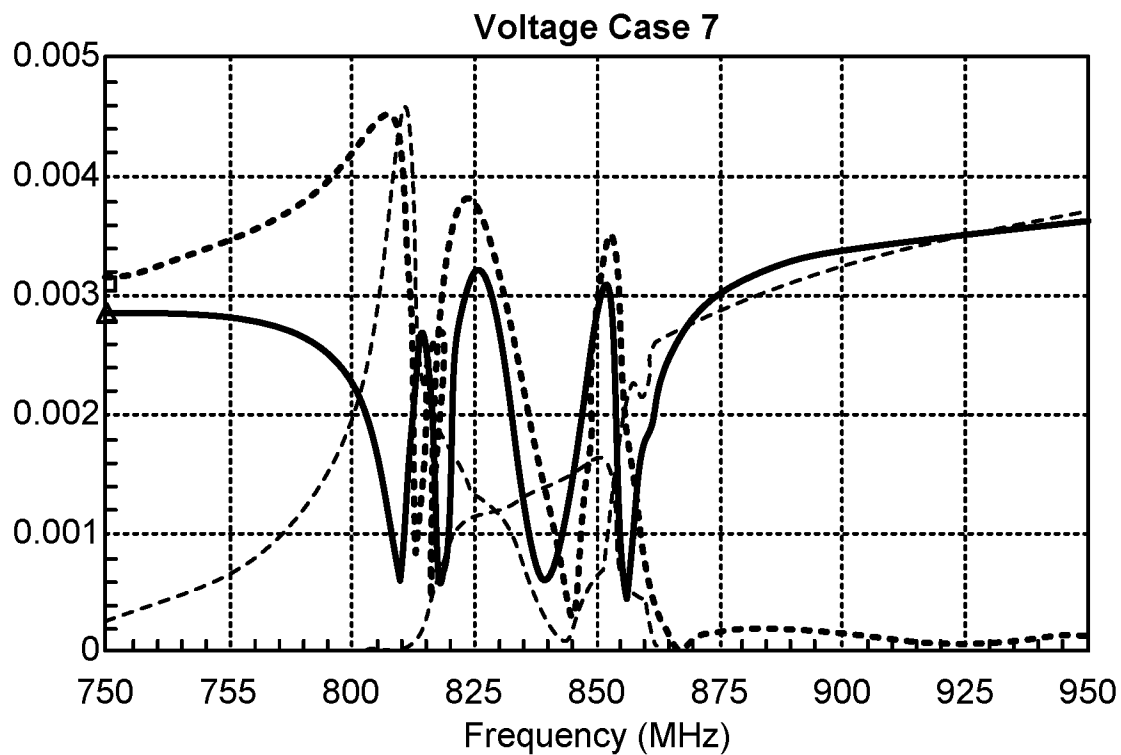
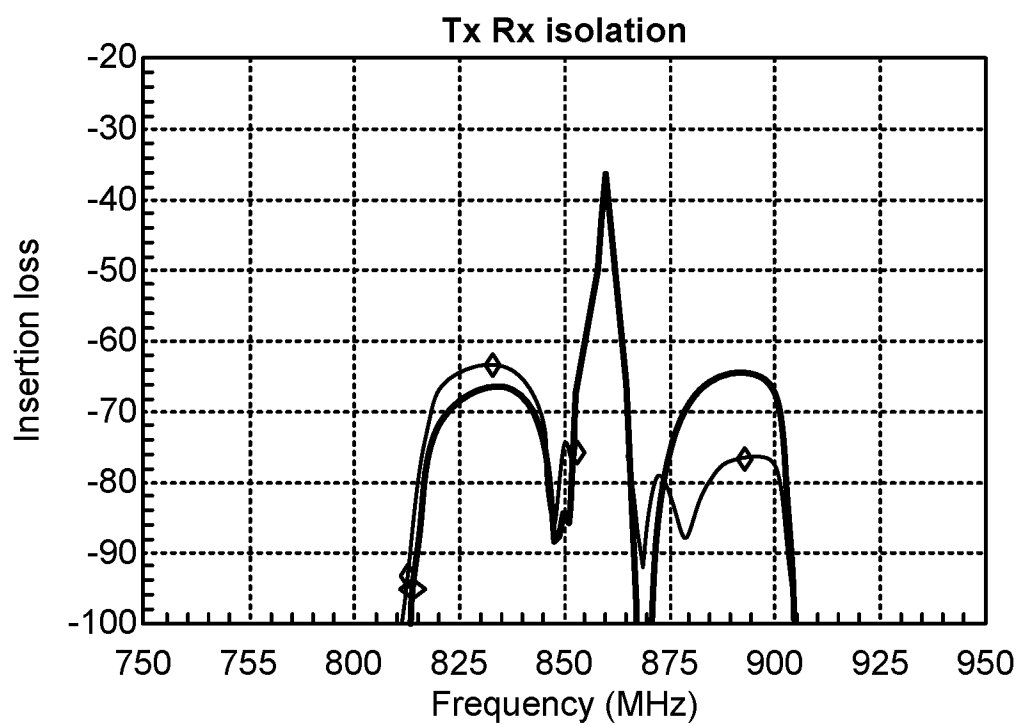
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**FIG. 18****FIG. 19**

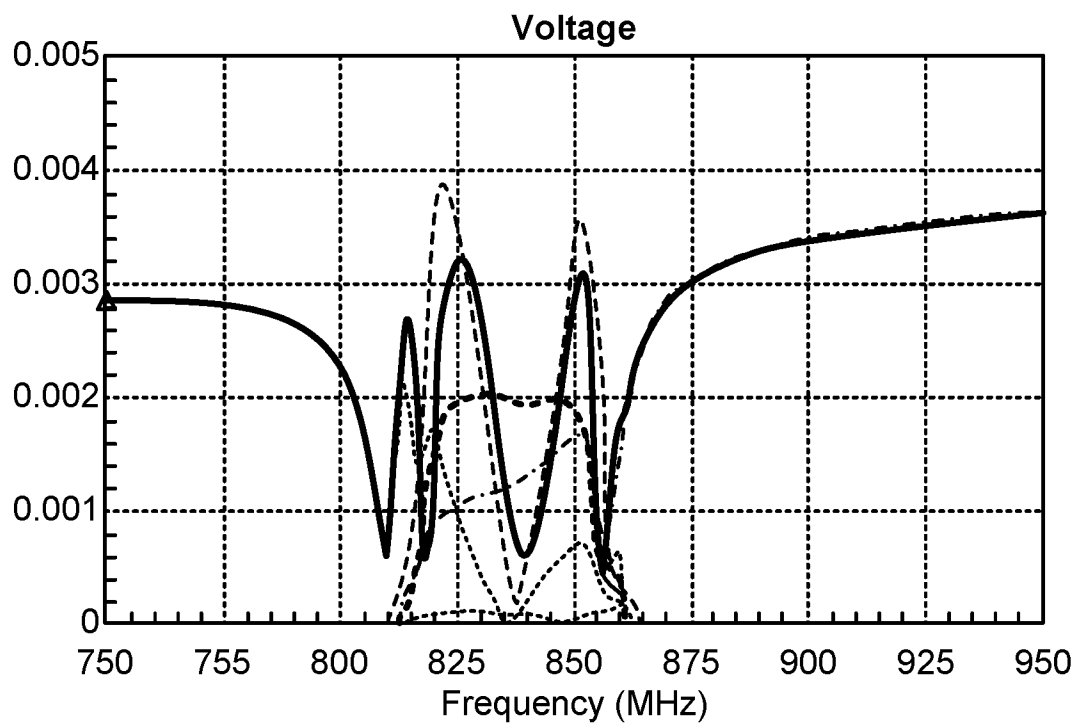
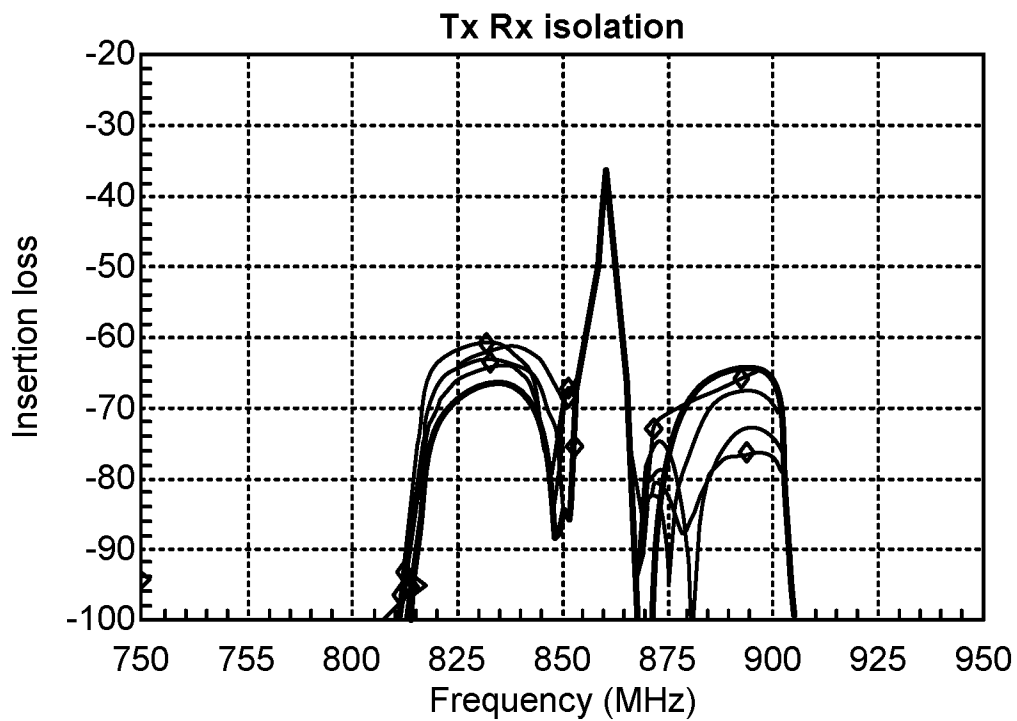
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**FIG. 20****FIG. 21**

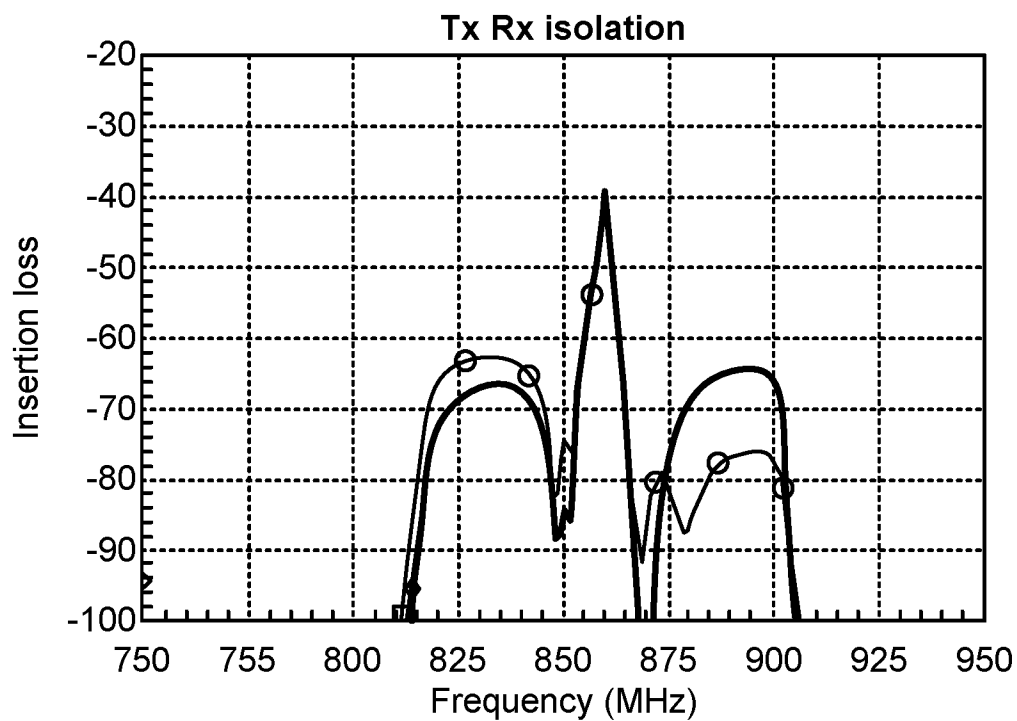
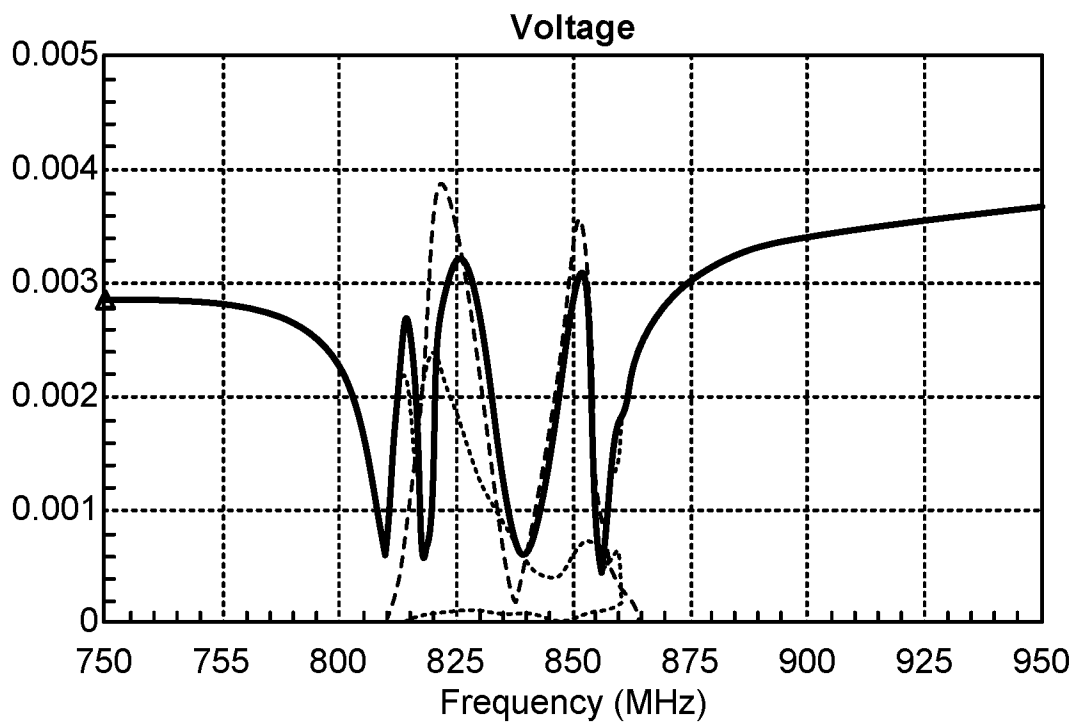
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**FIG. 22****FIG. 23**

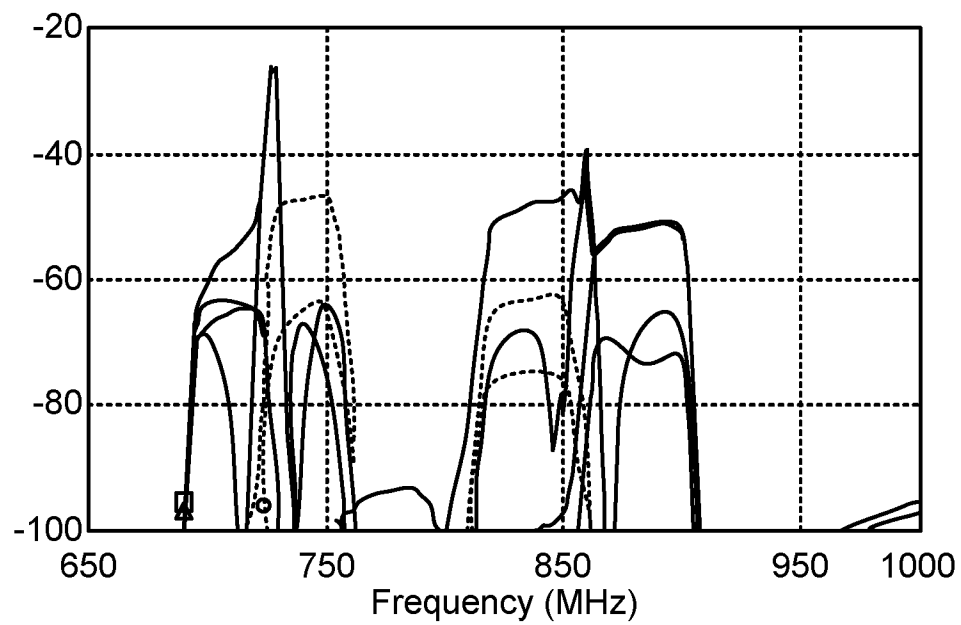
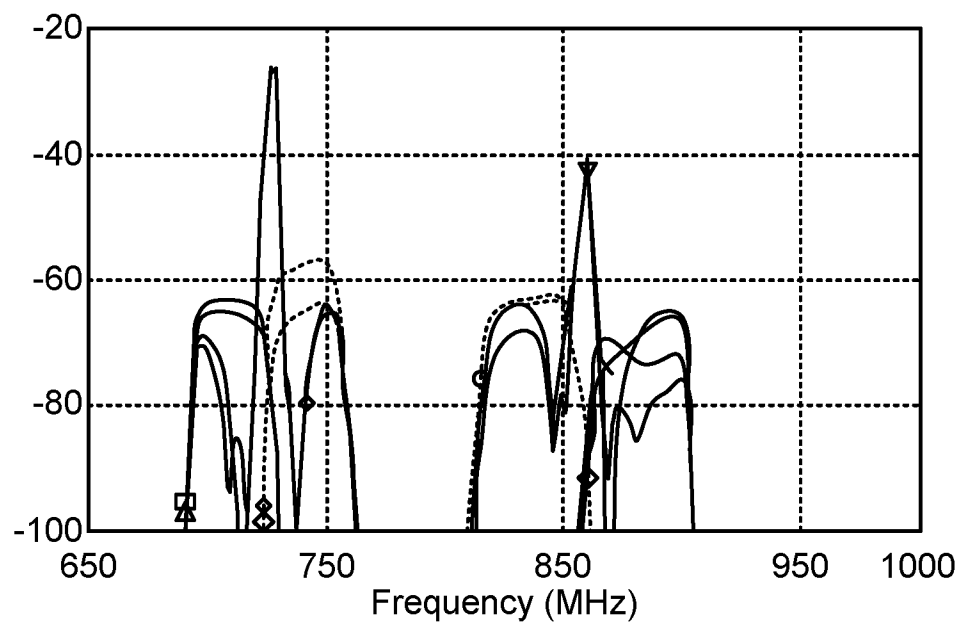
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**FIG. 24****FIG. 25**

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**FIG. 26****FIG. 27**

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**FIG. 28****FIG. 29**

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2017/056891

A. CLASSIFICATION OF SUBJECT MATTER INV. H03H7/01 H03H9/60 H03H9/64 H03H9/72 H03H9/70 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) H03H		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2016/015914 A1 (EPCOS AG [DE]) 4 February 2016 (2016-02-04) page 15, line 5 - page 16, line 10; figure 1 -----	1-4
X	US 2014/010122 A1 (KREMS TOBIAS [DE] ET AL) 9 January 2014 (2014-01-09) paragraph [0022] - paragraph [0029]; figure 2 -----	1,2,4
X	GB 2 441 036 A (AVAGO TECHNOLOGIES WIRELESS IP [SG]) 20 February 2008 (2008-02-20) figure 1 -----	1-4
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents :		
"A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family	
Date of the actual completion of the international search 15 January 2018	Date of mailing of the international search report 22/03/2018	
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer López, Gema	

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/056891

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of Item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-13

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-13

Multiplexer comprising a transmission filter and a reception filter with one of the filters having two ground connections separated from each other.

2. claim: 14

A method for designing a multiplexer topology comprising the step of monitoring and minimizing the voltage across a ground loop inductor

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2017/056891

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2016015914 A1	04-02-2016	CN 106797209 A DE 102014110905 A1 EP 3175553 A1 JP 2017522782 A US 2017201369 A1 WO 2016015914 A1	31-05-2017 04-02-2016 07-06-2017 10-08-2017 13-07-2017 04-02-2016
US 2014010122 A1	09-01-2014	DE 102010055669 A1 JP 5769817 B2 JP 2014501467 A US 2014010122 A1 WO 2012084741 A1	28-06-2012 26-08-2015 20-01-2014 09-01-2014 28-06-2012
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