

RADIO FREQUENCY FILTER HAVING A
TEMPERATURE COMPENSATED CERAMIC RESONATOR

Background of the Invention

The present invention relates generally to radio frequency (RF) filters and more particularly to an RF filter having a temperature compensated ceramic resonator adaptable for use in antenna combiners coupling a plurality of RF transmitters to a single antenna.

In order to combine a number of RF transmitters, the RF signals from each transmitter must be isolated from one another to prevent intermodulation and possible damage to the transmitters. RF filters of the air-filled cavity type may be utilized to provide isolation between the RF transmitters. Each such cavity filter is tuned to pass only the RF signal from the transmitter to which it is connected, each RF transmitter producing a different frequency RF signal. A conventional mechanism utilized to temperature compensate such cavity filters is described in U.S. Patent No. 4,024,481. However, such air-filled cavity filters are both expensive and relatively large in size such that these cavity filters consume an inordinate amount of precious space at remote antenna sites located on top of buildings and mountains.

The size of such RF filters can be reduced by utilizing a ceramic resonator. One such filter utilizing a ceramic resonator is described in U.S. Patent

No. 4,241,322. Although providing a more compact filter, the ceramic resonator in such a filter is not temperature compensated for temperature changes in the ceramic due to RF power dissipation in the ceramic and therefore can
5 experience large shifts in resonant frequency due to RF power dissipation and the fact that the ceramic cannot be made with exactly zero temperature coefficient. Another filter described in U.S. Patent No. 4,019,161 utilizes conventional mechanisms to temperature compensate a
10 ceramic resonator mounted on a micro-integrated circuit substrate, but does not provide for dissipation of heat in the ceramic resonator.

Objects and Summary of the Invention

Accordingly, it is an object of the present invention to provide a compact and inexpensive RF filter having a uniquely temperature compensated ceramic resonator.
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It is another object of the present invention to provide an improved RF filter having a temperature compensated ceramic resonator and a ceramic tuning slug for linearly changing the resonant frequency of the
20 ceramic resonator.

It is yet a further object of the present invention to provide an improved RF filter having a temperature compensated ceramic resonator that is thermally coupled to the filter housing for minimizing temperature rise due
25 to power dissipation in the ceramic resonator.

Briefly described, the present invention encompasses an RF filter comprising a dielectric resonator sandwiched between first and second dielectric compensating discs. The resonator and first compensating disc may have
30 concentrically aligned holes therein into which a ceramic tuning slug is inserted for adjusting the resonant frequency of the ceramic resonator. The resonator, first and second compensating discs, and tuning slug are



enclosed and maintained in spatial relationship with one another by a metal housing. Input and output signals may be coupled to the RF filter by means of respective input and output probes which may be located at any suitable location on the copper housing.

Brief Description of the Drawings

Figure 1 is a perspective cutaway view of the preferred embodiment of the RF filter of the present invention.

Figure 2 is a block diagram of combining apparatus advantageously utilizing RF filters embodying the present invention for coupling RF signals from respective RF transmitters to a combiner for application to a common antenna.

Detailed Description of the Preferred Embodiment

In Figure 1, there is illustrated a perspective view of an RF filter 100 embodying the present invention. A portion of filter 100 has been cut away to more clearly illustrate the internal structure thereof.

Filter 100 in Figure 1 is particularly well adapted for use in the antenna combiner in Figure 2 which combines two or more RF transmitters operating in the frequency range from 870-890 MHz. The nominal unloaded Q of filter 100 is approximately 14,000. The frequency shift of filter 100 over the ambient temperature range of -30°C to +60°C is a maximum of 55kHz with respect to the nominal frequency at room temperature. The nominal dimensions of filter 100 are 5.5" in diameter and 3" in length, as compared to 6" in diameter and 13" in length for a conventional air-filled cavity filter. In addition, filter 100 results in a materials cost saving of 60% over an equivalent air-filled cavity filter.

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Referring to Figure 1, filter 100 includes a ceramic resonator 116 which is sandwiched between a first compensating disc 114 and second compensating disc 120. Resonator 116 is preferably comprised of a ceramic compound including barium oxide, titanium oxide and zirconium oxide and having a dielectric constant of at least twenty (20). One such ceramic compound suitable for use is that described in an article by G. H. Jonker and W. Kwestroo, entitled "The Ternary Systems $\text{BaO-TiO}_2\text{-SnO}_2$ and $\text{BaO-TiO}_2\text{-ZrO}_2$ ", published in the Journal of American Ceramic Society, Volume 41, Number 10, October 1978, at pages 390-394. Of the ceramic compounds described in this article, the compound $\text{Ba}_2\text{Ti}_9\text{O}_{20}$ in Table VI having the composition 18.5 mole percent BaO, 77.0 mole percent TiO_2 and 4.5 mole percent ZrO_2 and having a dielectric constant of 40 is suitable for use in resonator 116. Many of the other compositions of the type described in this article may likewise be utilized. Compensating discs 114 and 120 are preferably comprised of alumina (Al_2O_3) since alumina exhibits low dielectric loss, high thermal conductivity relative to ceramic resonator 116 and a positive dielectric temperature coefficient with respect to that of ceramic resonator 116.

According to an important feature of the present invention, the negative dielectric temperature coefficient of ceramic resonator 116 can be substantially compensated by the positive dielectric temperature coefficient of alumina compensating discs 114 and 120. That is, the -36 ppm/°C dielectric temperature coefficient of the ceramic resonator 116 can be substantially offset by the +113 ppm/°C dielectric temperature coefficient of the alumina compensating discs 114 and 120, or the +7 ppm/°C frequency temperature coefficient of the ceramic resonator 116 can be substantially offset by the -63 ppm/°C frequency temperature coefficient of

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the alumina compensating discs 114 and 120. As is known in the art, the frequency temperature coefficient of a dielectric material is opposite in polarity to the dielectric temperature coefficient and is proportional to both the physical size and the dielectric temperature coefficient of that dielectric material. Therefore, the desired compensation is achieved by selecting the proper thickness of alumina compensating discs 114 and 120.

Moreover, the alumina compensating discs 114 and 120 provide for ambient temperature compensation, minimize temperature rise due to RF power dissipation of ceramic resonator 116 by providing a low thermal resistance between ceramic resonator 116 and top and bottom plates 112 and 128 of the filter housing, and minimize the overall RF loss of the filter by supporting the resonator 116 away from the loss-inducing plates 112 and 128 with low-loss alumina. A compressive force exerted by plates 112 and 128 maintains good thermal contact between resonator 116 and discs 114 and 120 such that the thermal resistance between the resonator 116 and the filter housing is less than 1°C/W (i.e. 0.68°C/W predicted by design analysis). Therefore, according to another feature of the present invention, filter 100 can accommodate high power transmitters since the temperature rise due to power dissipation in the ceramic resonator 116 is minimized by the relatively low thermal resistance between the ceramic resonator and the filter housing. That is, with twelve watts of RF energy dissipated in the filter 100, the temperature of ceramic resonator 116 will rise only 8°C above ambient temperature and the frequency of filter 100 will drift only 42kHz.

Referring back to Figure 1, the copper housing for filter 100 both totally encloses the sandwiched ceramic resonator 116 and provides a compressive force for maintaining the spatial relationship between ceramic resonator 116 and alumina compensating discs 114 and 120.

The housing includes a copper top plate 112 which mates with copper can 124. Top plate 112 is soldered to can 124. Can 124 also includes an inside ring 126 which has threaded holes for accepting screws 138. Copper bottom plate 128 is attached to can 124 by means of screws 138. Ceramic resonator 116 and alumina compensating discs 114 and 120 are held together by means of a compressive force that is exerted by bottom plate 128. Ceramic resonator 116 and alumina compensating discs 114 and 120 may also be bonded with a suitable adhesive such as glass frit or bonding film.

According to another feature of the present invention, resonator 116 together with discs 114 and 120 may be individually or collectively sealed to prevent degradation of filter electrical characteristics due to humidity. The resonator 116 and discs 114 and 120 may be hermetically sealed with a low-loss glass such as Engelhard A-3702 dielectric ink which is fired at high temperature.

The resonant frequency of ceramic resonator 116 may be linearly adjusted by means of tuning shaft 102 and dielectric tuning slug 118 attached thereto. The resonant frequency of resonator 116 linearly decreases as tuning slug 118 is inserted into substantially concentric holes in disc 114 and resonator 116. Tuning slug 118 is preferably comprised of the same ceramic used for ceramic resonator 116. However, in other applications, tuning slug 118 may be any suitable dielectric material. The tuning slug 118 not only produces linear changes in resonant frequency, but also eliminates some spurious resonant modes (by keeping the overall copper housing dimensions constant as the frequency of resonator 116 is tuned), minimizes resonator de-Q-ing (because it employs a low-loss dielectric), and allows discs 114 and 120 to be in good thermal contact with resonator 118 over its entire top and bottom surfaces. Although resonator 116

is preferably tuned by means of tuning slug 118, other suitable conventional tuning apparatus may also be utilized.

5 Tuning shaft 102 is preferably comprised of copper-plated nickel steel, such as Invar^(RTM). Tuning shaft 102 is threaded and mates with a corresponding threaded inside top portion 108 of bushing 134. Bushing 134 has a larger threaded outside bottom portion which inserts into a corresponding threaded portion of copper pipe cover 130. 10 Pipe cover 130 is soldered to copper pipe 132 which is in turn soldered to top plate 112. The inside bottom portion of bushing 134 is not threaded so that tuning shaft 102 is fixedly held only at the inside top portion 108 of bushing 134. The top portion 108 of bushing 134 15 is also slotted and threaded on the outside so that locknut 104 may be utilized to fix the position of tuning shaft 102 and ceramic tuning slug 118. Also, a bushing locknut 106 is utilized to fix the position of the bottom portion of bushing 134 with respect to pipe cover 130.

20 According to another feature of the present invention, bushing 134, tuning shaft 102, and pipe 130, 132 may be comprised of different materials each having different coefficients of expansion for compensating for changes in the resonant frequency of resonator 116 with 25 ambient temperature. For example, tuning shaft 102 is preferably comprised of copper-plated nickel steel, bushing 134 is preferably comprised of brass, and pipe 130, 132 is preferably comprised of copper. The movement of ceramic tuning slug 118 over ambient temperatures may 30 be varied by varying the effective length of the brass bushing 134. The effective length of brass bushing 134 is adjusted by turning bushing 134 in or out of pipe 130, 132. The temperature compensation is then achieved by the difference in the coefficient of expansion between, 35 and respective sizes of, tuning shaft 102, brass bushing 134, and copper pipe 130, 132. This arrangement can

compensate for a worst case change of 0.8 ppm/°C of the frequency temperature coefficient of the entire filter.

RF signals are coupled to filter 100 by means of two probes 122 accessed by respective connectors 136. In the preferred embodiment of filter 100, two probes 122 are located substantially opposite resonator 116 on can 124 at 90° with respect to one another.

For space economy, probes 122 may be located at any suitable location on the filter housing, such as, for example, on top plate 112.

The dimensions of the various elements of an embodiment of filter 100 for operation at frequencies between 865-902 MHz are listed below in Table I. In this embodiment, the resonator 116 and tuning slug 118 are comprised of the ceramic compound Ba₂Ti₉O₂₀, discs 114 and 120 of alumina, tuning shaft 102 of copper-plated nickel steel, bushing 134 of brass and the filter housing of copper. The exact dimensions of the elements of the filter embodiment will vary depending on the desired frequency of operation and the materials chosen for each of the elements.

Table I Filter Dimensions In Inches

	<u>Element</u>	<u>Outer Diameter</u>	<u>Inner Diameter</u>	<u>Length</u>
	Resonator 116	2.680	1.260	0.772
25	Disk 114	2.800	1.260	1.139
	Disk 120	2.800	-	1.127
	Slug 118	1.225	-	1.355
	Shaft 102	0.375	-	3.500
	Can 124	5.625	5.500	3.145
30	Pipe 132	1.625	1.500	1.000
	Bushing 134	0.750	0.375	1.250

Referring next to Figure 2, there is illustrated antenna combining apparatus for coupling RF transmitters 201, 202 and 203 having different signal frequencies to a common antenna 231. Filters 211, 212, and 213 are preferably filters 100 embodying the present invention. Combiner 221 may be any suitable conventional antenna combiner such as that shown and described in the U.S.

Patent No. 4,375,622.

By utilizing the RF filter 100 of the present invention for filters 211, 212 and 213, the overall size and space requirements of the combining apparatus in Figure 2 can be significantly reduced. Since space is at a premium in remotely located antenna sites, a substantial cost savings can be realized by utilizing the filter 100 of the present invention.

In summary, a unique high Q RF filter has been described that includes a temperature compensated ceramic resonator. The unique filter is temperature compensated, is thermally optimized so that temperature rise due to power dissipation in the ceramic resonator is minimized and has low overall RF loss. Moreover, the unique filter is substantially smaller than conventional air-filled cavity filters. The RF filter of the present invention may be advantageously utilized in any suitable application, such as, for example, combining apparatus for coupling multiple RF transmitters having different signal frequencies to a common antenna.



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Claims:

1. A radio frequency (RF) filter comprising:
resonating means having top and bottom surfaces
and being comprised of a dielectric material having a
predetermined rate of change of resonant frequency with
5 temperature;
first and second compensating means each having
top and bottom surfaces and being disposed above and
below the resonating means, respectively, and the first
and second compensating means being comprised of a
10 dielectric material having a rate of change of resonant
frequency with temperature opposite in polarity to the
predetermined rate of change; and
housing means including top, bottom and side
surfaces for substantially enclosing and compressively
15 retaining the resonating means between the first and
second compensating means, the top and bottom surfaces of
the housing means being thermally coupled to the top
surface of the first compensating means and the bottom
surface of the second compensating means, respectively,
20 for conducting heat away from said resonating means.



2. The RF filter according to claim 1, wherein said housing means further includes an input probe and an output probe disposed at a predetermined distance from one another for coupling respective input and output signals to said RF filter.

3. The RF filter according to claim 1, wherein said resonating means and first compensating means further include respective holes substantially concentrically aligned with one another, said RF filter further including tuning means comprised of a dielectric material and being insertable into the holes of the first compensating means and resonating means for changing the resonating means resonant frequency.

4. The RF filter according to claim 3, wherein said tuning means includes a tuning shaft and a tuning slug, the tuning slug being comprised of the same dielectric material as the resonating means.

5. The RF filter according to claim 4, wherein said tuning shaft is threaded and said housing means further includes threaded bushing means adapted to receive the tuning shaft.

6. The RF filter according to claim 5, wherein said tuning shaft, bushing means and housing means are comprised of different materials having different coefficients of expansion with temperature for compensating for changes in the resonating means resonant frequency with temperature.

7. The RF filter according to claim 3, wherein said housing means further includes an input probe and an output probe disposed at a predetermined distance from one another for coupling respective input and output signals to said RF filter.



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8. The RF filter according to claim 1, wherein said first and second compensating means are substantially comprised of alumina.

5 9. The RF filter according to claim 1, wherein said resonating means is substantially comprised of a dielectric material including barium oxide (BaO), titanium oxide (TiO₂) and zirconium oxide (ZrO₂).



10. A radio frequency (RF) filter comprising:
resonating means having top and bottom surfaces
and being comprised of a dielectric material having a
predetermined thermal conductivity;

5 first and second compensating means each having
top and bottom surfaces and being disposed above and
below the resonating means, respectively, and the first
and second compensating means being comprised of a
dielectric material having a thermal conductivity greater
10 than the thermal conductivity of the resonating means
dielectric material; and

housing means including top, bottom and side
surfaces for substantially enclosing and compressively
retaining the resonating means between the first and
15 second compensating means, the top and bottom surfaces of
the housing means being thermally coupled to the top
surface of the first compensating means and the bottom
surface of the second compensating means, respectively,
for conducting heat away from said resonating means.



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11. The RF filter according to claim 10, wherein said housing means further includes an input probe and an output probe disposed at a predetermined distance from one another for coupling respective input and output signals to said RF filter.

12. The RF filter according to claim 10, wherein said resonating means and first compensating means further include respective holes substantially concentrically aligned with one another, said RF filter further including tuning means comprised of a dielectric material and being insertable into the holes of the first compensating means and resonating means for changing the resonating means resonant frequency.

13. The RF filter according to claim 12, wherein said tuning means includes a tuning shaft and a tuning slug, the tuning slug being comprised of the same dielectric material as the resonating means.

14. The RF filter according to claim 13, wherein said tuning shaft is threaded and said housing means further includes threaded bushing means adapted to receive the tuning shaft.

15. The RF filter according to claim 14, wherein said tuning shaft, bushing means and housing means are comprised of different materials having different coefficients of expansion with temperature for compensating for changes in the resonating means resonant frequency with temperature.

16. The RF filter according to claim 12, wherein said housing means further includes an input probe and an output probe disposed at a predetermined distance from one another for coupling respective input and output signals to said RF filter.



17. The RF filter according to claim 10, wherein said first and second compensating means are substantially comprised of alumina.

5 18. The RF filter according to claim 10, wherein said resonating means is substantially comprised of a dielectric material including barium oxide (BaO), titanium oxide (TiO₂) and zirconium oxide (ZrO₂).



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19. Combining apparatus for coupling multiple radio frequency (RF) signals to a common antenna, said combining apparatus comprising:

5 at least two transmitting means each producing respective RF signals having different signal frequencies;

at least two filter means coupled to respective transmitting means RF signals, each filter means comprising:

10 resonating means having top and bottom surfaces and being comprised of a dielectric material having a predetermined rate of change of resonant frequency with temperature;

15 first and second compensating means each having top and bottom surfaces and being disposed above and below the resonating means respectively, and the first and second compensating means being comprised of a dielectric material having a rate of change of the resonating means resonant frequency with temperature opposite in polarity to the predetermined rate of change;

20 housing means including top, bottom and side surfaces for substantially enclosing and compressively retaining the resonating means between the first and second compensating means, the top and bottom surfaces of the housing means being thermally coupled to the top surface of the first compensating means and the bottom surface of the second compensating means, respectively, for conducting heat away from said resonating means; and

30 input and output probe means coupled to the housing means, the input probe means further being coupled to the respective transmitting means RF signal, and the output probe means providing a filtered RF signal; and

35 combining means having inputs coupled to respective filtered RF signals from the filter means and having an output coupled to the common antenna.

20. Combining apparatus for coupling multiple radio frequency (RF) signals to a common antenna, said combining apparatus comprising:

at least two transmitting means each producing respective RF signals having different signal frequencies;

at least two filter means coupled to respective transmitting means RF signals, each filter means comprising:

resonating means having top and bottom surfaces and being comprised of a dielectric material having a predetermined thermal conductivity;

first and second compensating means each having top and bottom surfaces and being disposed above and below the resonating means respectively, and the first and second compensating means being comprised of a dielectric material having a thermal conductivity greater than the thermal conductivity of the resonating means dielectric material;

housing means including top, bottom and side surfaces for substantially enclosing and compressively retaining the resonating means between the first and second compensating means, the top and bottom surfaces of the housing means being thermally coupled to the top surface of the first compensating means and the bottom surface of the second compensating means, respectively, for conducting heat away from said resonating means; and

input and output probe means coupled to the housing means, the input probe means further being coupled to the respective transmitting means RF signal, and the output probe means providing a filtered RF signal; and combining means having inputs coupled to respective filtered RF signals from the filter means and having an output coupled to the common antenna.



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21. A method of temperature compensating a radio frequency (RF) filter having a ceramic resonator, first and second dielectric compensating means, and housing means having top, bottom and side surfaces for enclosing the ceramic resonator, said method comprising the steps of:

positioning the ceramic resonator between the first and second compensating means for substantially compensating for variations of the electrical characteristics of said filter due to temperature; and compressively retaining the first compensating means, ceramic resonator and second compensating means between the top and bottom surfaces of the housing means for conducting heat away from said ceramic resonator.



22. The method according to claim 21 further including the step of sealing said ceramic resonator, first compensating means and second compensating means for substantially preventing degradation of the electrical characteristics of said filter due to humidity.

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