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(54) Duplex filter

(57) The invention relates to a radio-frequency filter with a good temperature stability and power handling capacity. The invention can be applied in the pre-stages of portable mobile telephone apparatuses, for example. The receiver branch (2) of the filter construction according to the invention employs two filter stages (3, 4), the first of which (3) attenuates the signal connected to the second filter stage, said second filter stage being a SAW filter (4). Said first filter stage (3) can be realized with a helix or dielectric resonator, for example. In a second embodiment of the invention, said first filter stage (3) is used to compensate for changes caused by the temperature dependence of the frequency response of the SAW filter (4).

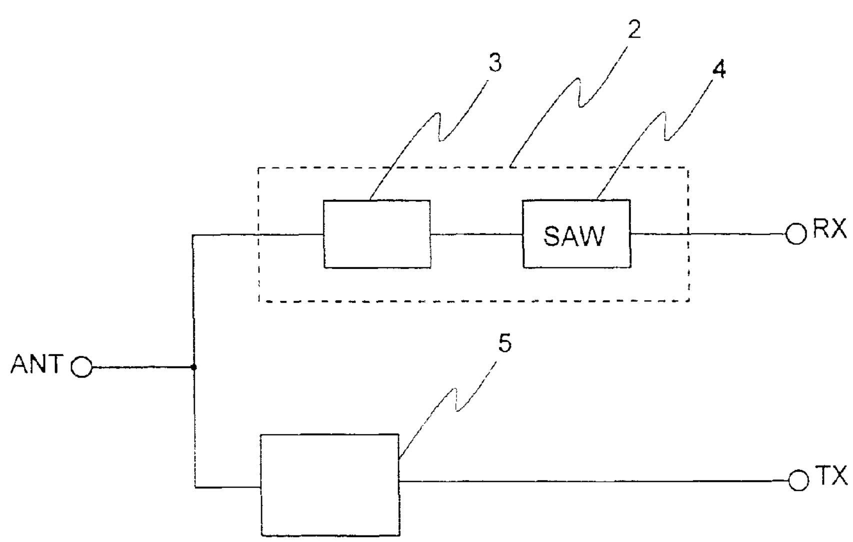

Fig. 2

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Description

The invention is concerned with the good temperature stability and power handling capacity of a radio-frequency filter. The invention can be applied in the pre-stages of portable mobile telephone apparatuses, for example.

Figure 1 shows the underlying structure of a duplex filter. A duplex filter is a two-branch filter structure comprising a transmitter branch filter 5 for connecting the transmitter stages TX and a receiver branch filter 2 for connecting the receiver stages RX. Antenna ANT of the radio apparatus is typically connected to the common connection point of the transmitter and receiver branches. The purpose of the receiver branch filter, in addition to serving as a normal receiver pre-stage filter, is to prevent as effectively as possible the transmitter signal from entering the receiver pre-stages. So the receiver branch filter operates on a certain frequency band as a notch filter attenuating power, and on another certain frequency band it allows the signal to pass. Duplex filters can be used in systems wherein the transmitting and receiving frequency bands are separate. Typically, duplex filters are implemented using helix or dielectric resonators. Their main disadvantage is their big size, which is one of the most important factors restricting the miniaturizing of modern mobile telecommunication devices.

Surface acoustic wave (SAW) filters are small in size and have good frequency characteristics. However, their power handling capacity has prevented them from being used in duplex filters in mobile telephones' receiver pre-stages where, depending on the system, the power levels are, say, 0.6 to 1.2 W (in the digital advanced mobile phone service, DAMPS) or 0.8 to 2 W (in the global system for mobile communications, GSM). Typically the SAW filters can handle 0.04 to 0.1 W.

The final characteristics of a SAW filter depend very much on the material of the substrate of the filter. Generally, the filter material is a single-crystal piezoelectric material. The material must not be expensive and its mechanical properties, coupling coefficient and temperature stability have to be good. The most widely used SAW substrates are lithium niobate ($LiNbO_3$), lithium-tantalum ($LiTaO_3$) and quartz (SiO_2). The bandwidths of mobile telephone systems are fairly broad and a small insertion loss is required of all front-end filter components. The coupling loss generates in the filter thermal power in proportion to the dissipated power and the frequency response of the filter changes as the filter warms up. Of the above-mentioned materials only lithium niobate and lithium-tantalum meet these criteria with their high enough coupling coefficients. The weak point of both these materials is their temperature stability. For example, lithium niobate cut in the Y-Z plane has a temperature coefficient of 94 ppm/°C and lithium-tantalum cut in the Y plane has a temperature coefficient of 31 ppm/°C. In addition to the low power handling capacity, also the temperature dependence of the frequency response of the SAW filter causes problems in radio equipment design.

An object of the present invention is to provide a duplex filter structure which facilitates the production of duplex filters smaller in size than prior art duplex filters.

This object may be achieved using a SAW filter in the receiver branch of the duplex filter and connecting a filter stage between the SAW filter and the antenna to attenuate the power from the transmitter to a level that the SAW filter can handle. Temperature stability is achieved by adjusting the temperature dependence of the frequency response of said filter stage such that the temperature dependence of the frequency response of the SAW filter is substantially cancelled.

The system according to the invention, in one aspect, is characterized in that

- at least one receiver branch filter stage is a SAW filter and
- the receiver branch also includes at least one other filter stage connected between the SAW filter and the receiver branch end coupled to the transmitter branch in order to attenuate the transmitter branch signal power connected to the SAW filter, and the temperature dependence of the frequency response of said other filter stage is arranged so as to substantially cancel the changes in the frequency response of the receiver branch caused by the temperature dependence of the frequency response of the SAW filter.

The receiver branch of the filter construction according to the invention employs two filter stages and the purpose of the first filter stage is to attenuate the signal connected to the second filter stage which is a SAW filter. The magnitude of attenuation needed depends on the transmission power of the system and on the power handling capacity of the SAW filter. For example, attenuation of 10 dB, approximately, suffices to attenuate the 1-watt antenna power of a telephone to the level of 0.1 W, approximately, which can be handled by a typical SAW filter. Said first filter stage can be realized using a helix or dielectric resonator, for example.

In a second embodiment of the invention, said first filter stage is used to compensate for changes caused by the temperature dependence of the frequency response of the SAW filter. The temperature dependence of said first filter stage is adjusted such that the changes caused by the temperature in the SAW filter characteristics are substantially cancelled. The temperature dependence of the frequency response of a helix resonator can be adjusted as desired e.g. by introducing in the helix resonator a temperature-dependent capacitance affecting the resonator's frequency response. The temperature characteristics of the frequency response of a dielectric resonator can be controlled by selecting different dielectric body materials for the resonator.

An embodiment of the invention is described in more detail with reference to the preferred embodiments, presented for the sake of illustration, and to the accompanying drawings, wherein

Figure 1 shows the block diagram of a duplex filter according to the prior art,

Figure 2 shows the block diagram of the filter according to the invention,

Figure 3 shows the temperature dependence of the frequency response of a SAW filter for various temperatures,

Figure 4 shows the temperature dependence of the center frequency of a helix resonator without temperature compensation,

Figure 5 shows a simplified structure of a temperature-compensated helix resonator,

Figure 6 shows an electrical equivalent circuit of a temperature-dependent helix resonator,

Figure 7 shows the temperature dependence of the frequency response of a helix resonator when a plate capacitance has been formed at the open end of the resonator,

Figure 8 shows the frequency response of a receiver branch formed by a temperature-compensated helix resonator and a SAW filter in various temperatures, and

Figure 9 shows the frequency response of the receiver branch according to the second preferred embodiment of the invention in various temperatures.

Like elements in the drawings are denoted by like reference designators.

Figure 2 shows the block diagram of the duplex filter according to an embodiment of the invention. The duplex filter comprises two branches, a receiver branch 2 and a transmitter branch 5. In the filter according to the invention, a SAW filter 4 is used in the receiver branch 2. Between the SAW filter and the antenna interface ANT there is a front-end filter 3 that can be a helix or dielectric filter. The first task of the front-end filter 3 is to attenuate the power from the transmitter branch 5 so that the SAW filter 4 is not damaged. In the second preferred embodiment of the invention, the second task of the front-end filter 3 is to compensate for changes in the frequency response of the whole receiver branch caused by the temperature dependence of the frequency response of the SAW filter 4 in various temperatures.

Because of a high temperature coefficient the pass band of the SAW filter in the receiver branch has to be made very broad in order to achieve a small insertion loss throughout the temperature range. The stop-band attenuation of the filter is then heavily dependent on the temperature, especially at the higher frequencies of the band, which is illustrated in Figure 3 showing diagrammatically at various temperatures the frequency response of a SAW filter designed for duplex filter use. The solid line N represents a situation according to the normal temperature, dashed line C a situation where the temperature is below the normal, and dotted line W a situation where the temperature is above the normal. The figure shows that the temperature has a considerable effect on the transmitter band attenuation and that the value measured at the highest operating temperature determines the lower limit for the attenuation. Figure 3 also shows the transmitting and receiving frequency bands f_{TX} and f_{RX}.

As the temperature rises, thermal expansion makes the helix resonator longer and the frequency response tends to go down. As the temperature drops, the frequency response moves toward higher frequencies as the helix resonator becomes shorter than normal. Figure 4 is a diagrammatic representation of the temperature dependence of a helix resonator in the frequency domain. The solid line N depicts the frequency response at the normal temperature, dashed line C the frequency response in a situation colder than normal,and dotted line W the frequency response in a situation warmer than normal. So, a change of temperature produces a shift in the frequency response of a helix resonator in the same direction as in the frequency response of a SAW filter.

In the construction according to an embodiment of the invention, it is particularly advantageous to use as a front-end filter 3 a helix resonator equipped with an element providing temperature compensation. Figure 5 shows a simplified structure of a temperature-compensated helix resonator. There is at the open end of the helix 12 a temperature-dependent capacitance which is formed by means of the plate-like support structure of the helix and electrically conductive coatings formed on both sides of the support structure. The electrically conductive coating 14 on a first side of the support structure is in electric contact with the helix 12. The electrically conductive coating 15 on a second side of the support structure is grounded. The leg 16 of the helix 12 is grounded. Said support structure 13 and its conductive coatings 14, 15 can advantageously be formed of ordinary two-sided printed circuit board material using ordinary printed circuit board manufacturing methods. In Figure 4, connection to the helix is arranged with a tapping strip 17, but the connection can be arranged using any known technique.

Figure 6 shows an electrical equivalent circuit of a temperature-compensated helix resonator. In the equivalent circuit the helix 12 and its leg 16 are depicted as inductances, the tapping strip 17 as a resistor and the electrically conductive coatings 14, 15 of the support structure of the helix as a temperature-dependent capacitance 18.

The conductive coatings 14, 15 on the sides of the support structure 13 constitute a capacitive element. A rise in the temperature makes the support structure 13 expand, thereby increasing the distance between the coatings 14, 15 and decreasing the capacitance of said capacitive element which means that the resonating frequency of the helix resonator tends to rise. With suitable realization of the coatings 14, 15 and suitable material and thickness of the support structure 13 the temperature dependence of the frequency response of the whole helix resonator can be compensated for. With a high enough capacitance 18 it is even possible to turn around the temperature dependence of the frequency response of the helix resonator as illustrated in Figure 7. The solid line N depicts the frequency response at the normal temperature, dashed line C the frequency response in a situation colder than normal, and dotted line W the frequency response in a situation warmer than normal.

Figure 8 shows the frequency response of the receiver branch in an embodiment of the invention at various temperatures. In this embodiment, the receiver branch front-end filter 3 is a temperature-compensated helix resonator the frequency response of which is made, by means of a capacitance 18, substantially independent of the temperature. The solid line N depicts the frequency response at the normal temperature, dashed line C the frequency response in a situation colder than normal, and dotted line W the frequency response in a situation warmer than normal. Figure 8 shows that the temperature dependence of the SAW filter 4 still has a significant effect on the attenuation of the transmitter band f_{TX}.

Figure 9 shows the frequency response, at various temperatures, of the receiver branch in another embodiment of the invention, more advantageous than the one above. In this embodiment, the receiver branch front-end filter 3 is implemented with a helix resonator having a capacitance 18, wherein the temperature dependence of the frequency response is inverse to the temperature dependence of the frequency response of the SAW filter 4. The solid line N depicts the frequency response at the normal temperature, dashed line C the frequency response in a situation colder than normal, and dotted line W the frequency response in a situation warmer than normal. Figure 9 shows that in this embodiment the transmitter band attenuation is higher than in the embodiment above where changes in temperature do not significantly change the frequency response of filter 3. In the example depicted, the increase in attenuation is close to 10 dB.

In the illustrative embodiments described above, a helix resonator is used as the receiver branch front-end filter 3. In the construction according to the invention it is also possible to use a dielectric filter as the receiver branch front-end filter 3. The temperature dependence of the frequency response of a dielectric filter can be controlled with the choice of the dielectric body material of the filter. With a suitable material it is possible to realize a dielectric filter the resonating frequency of which increases as the temperature rises. So it is also possible to compensate for the temperature dependence of the frequency response of a SAW filter by means of dielectric resonator properties.

In the construction according to the described embodiment of the invention, the transmitter branch filters can be realized using any filter constructions according to the prior art, such as helix or dielectric resonators, for example.

The construction according to the described embodiment of the invention makes possible to use SAW filters in the pre-stages of radio equipment. The use of SAW filters has the advantage that a duplex filter realized in this manner is considerably smaller in size than a duplex filter constructed according to the prior art. Two filter stages provide a good signal attenuation in the receiver branch. Two filter stages also provide a filter which has very stable frequency characteristics with respect to temperature changes.

Claims

1. A filter construction comprising:

   - a receiver branch (2), which comprises at least two filter stages, and
   - a transmitter branch (5), which comprises at least one filter stage,

   wherein first ends of said transmitter and receiver branches are connected to each other, characterized in that

   - at least one receiver branch filter stage is a SAW filter (4), and
   - the receiver branch further comprises at least one other filter stage (3), which is connected between the SAW filter and the receiver branch end connected to the transmitter branch in order to attenuate the transmitter branch signal power connected to the SAW filter, and the temperature dependence of the frequency response of said other filter stage (3) is arranged so as to substantially cancel the changes in the frequency response of the receiver branch (2) caused by the temperature dependence of the frequency response of the SAW filter (4).

2. The filter construction of claim 1, characterized in that said other filter stage (3) is a helix resonator (3).

3. The filter construction of claim 1, characterized in that said other filter stage (3) is a dielectric resonator (3).

4. The filter construction of claim 4, characterized in that said other filter stage (3) is a helix resonator (3) having a capacitive element (14, 15, 18) the capacitance value of which depends on the temperature.

5. The filter construction of claim 5, characterized in that said capacitive element (18) is formed by means of electrically conductive patterns (14, 15) on the support structure (13) of the helix.

6. The filter construction of claim 4, characterized in that said other filter stage (3) is a dielectric resonator (3) wherein the temperature dependence of the frequency response is determined through the choice of a suitable dielectric body material.

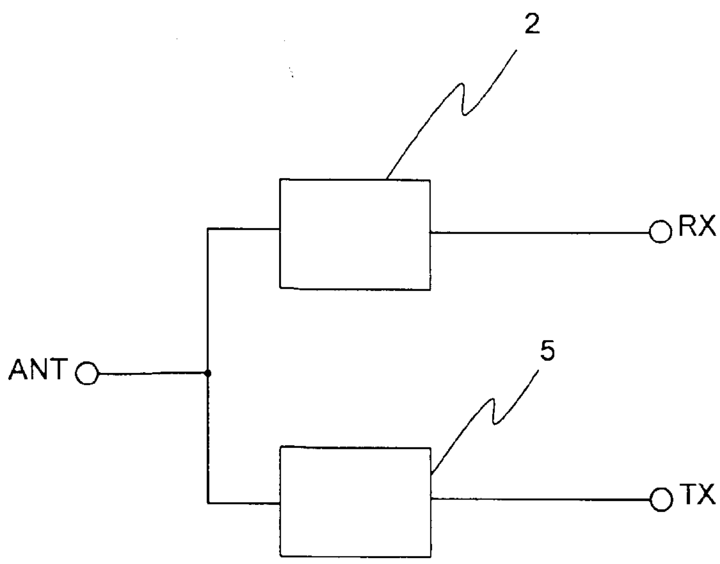

Fig. 1

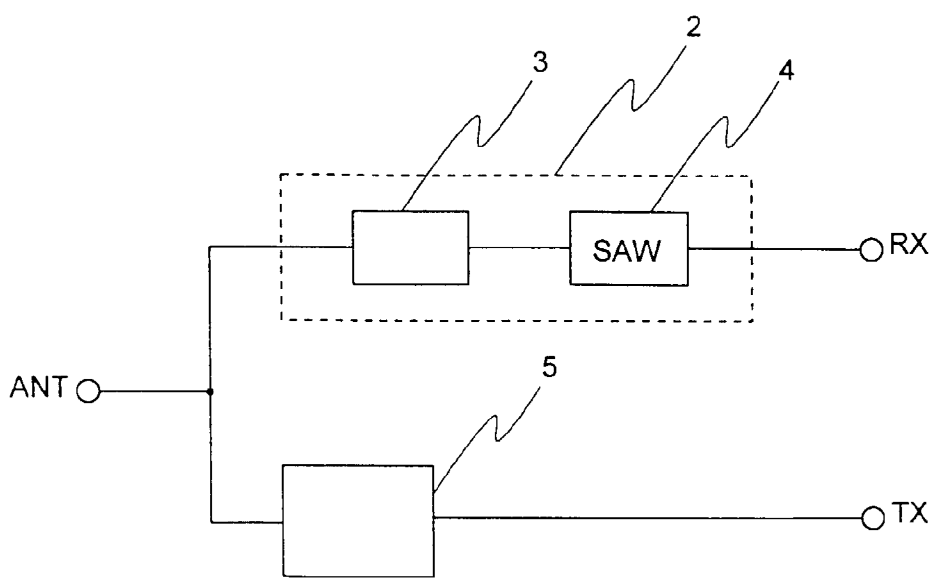

Fig. 2

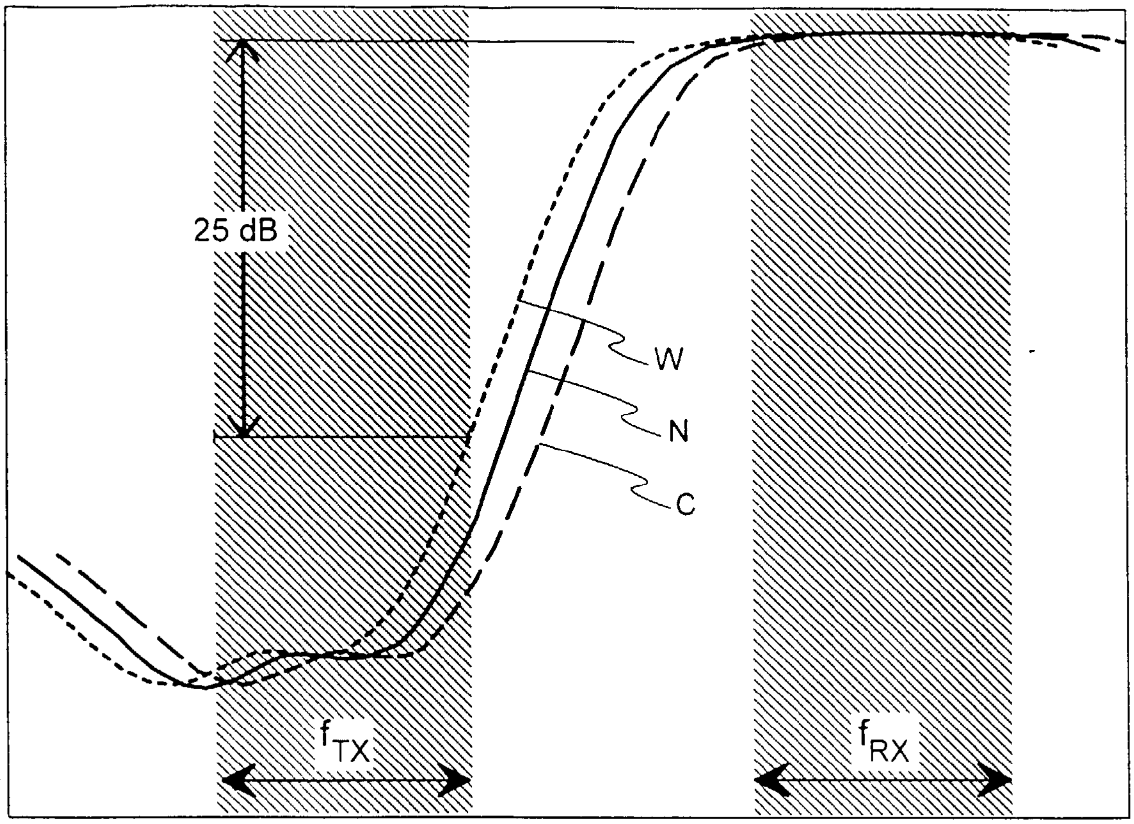

Fig. 3

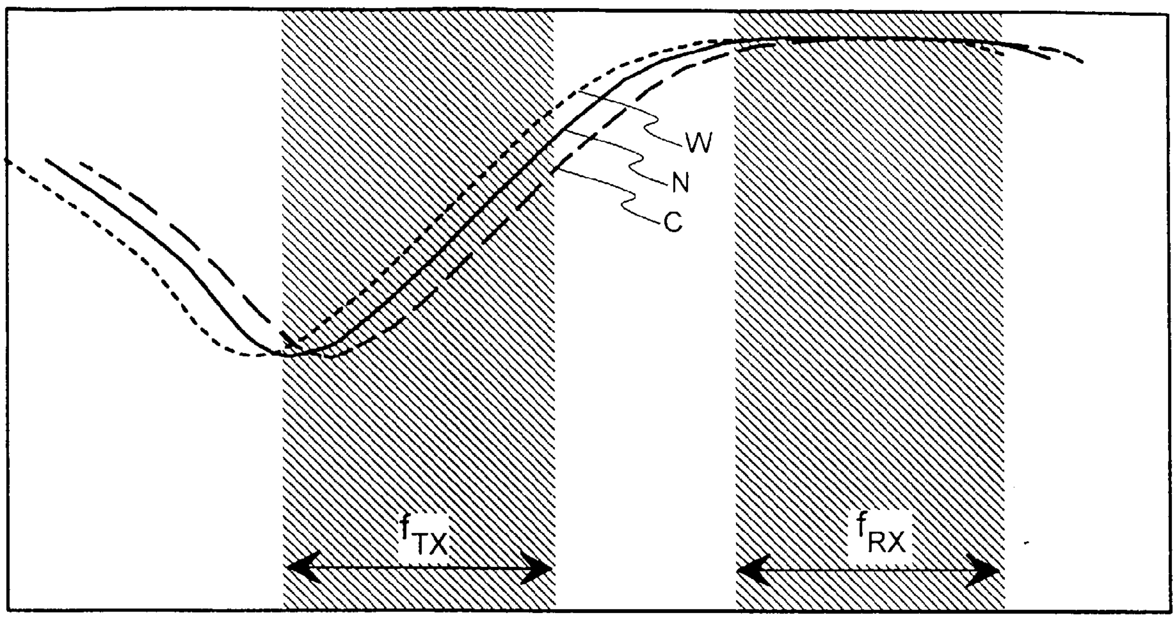

Fig. 4

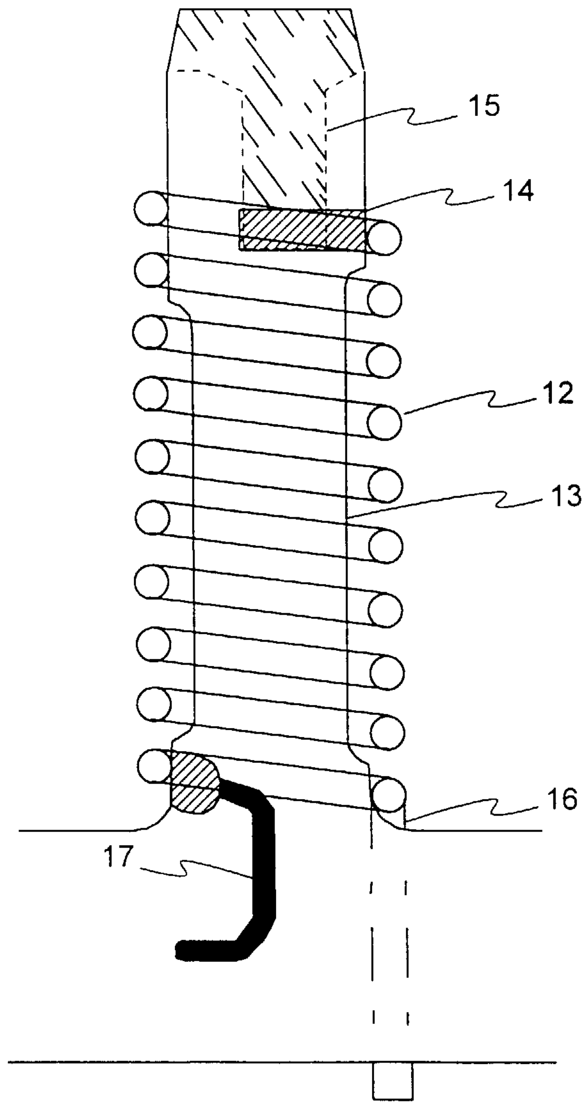

Fig. 5

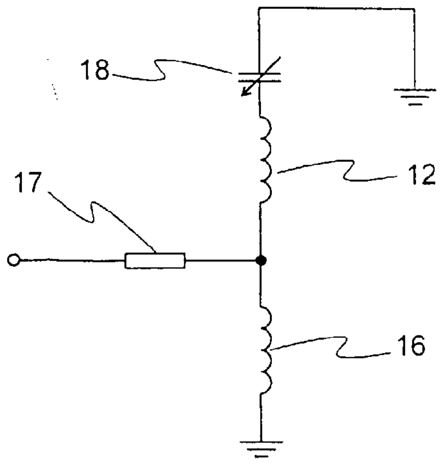

Fig. 6

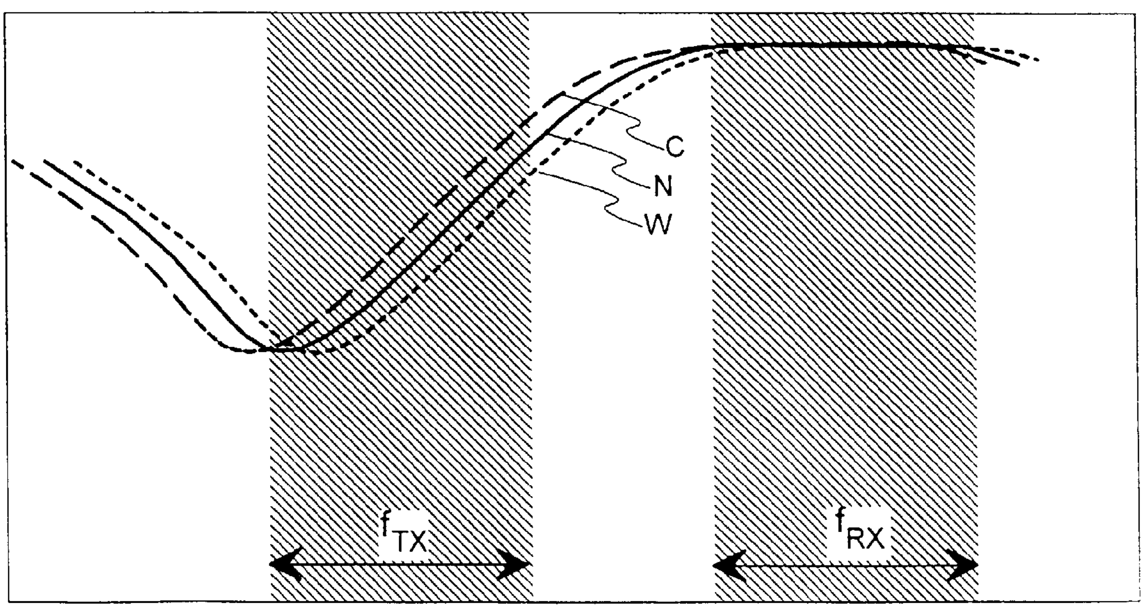

Fig. 7

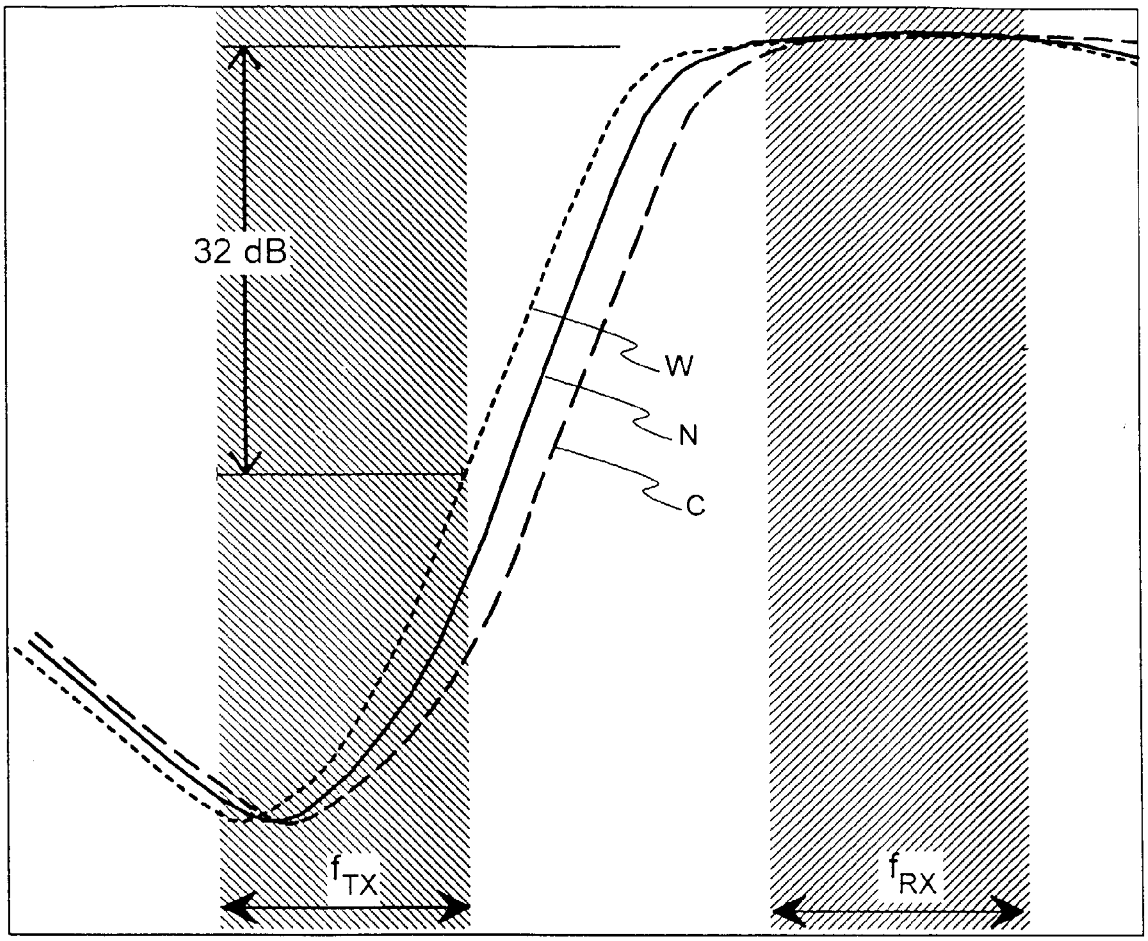

Fig. 8

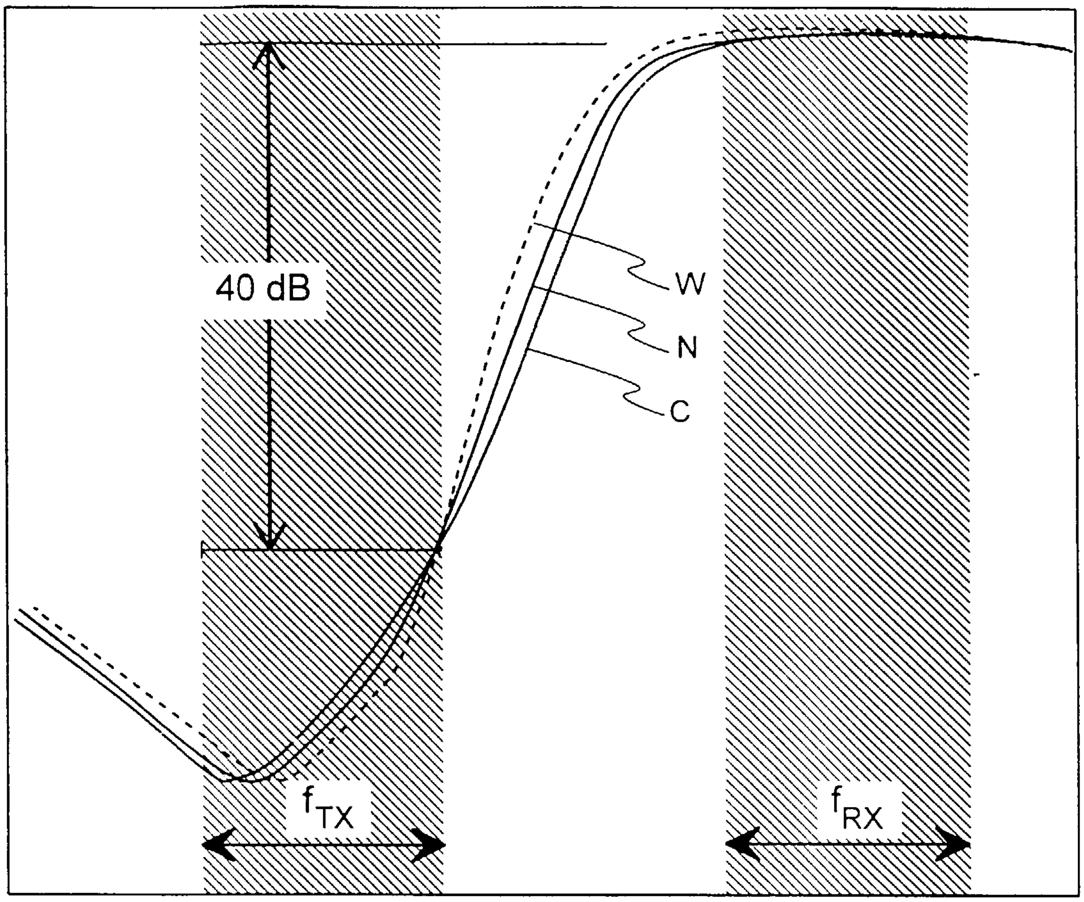

Fig. 9