IEC 62604-2

Edition 2.0 2017-11

INTERNATIONAL STANDARD

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Surface acoustic wave (SAW) and bulk acoustic wave (BAW) duplexers of assessed quality –
Part 2: Guidelines for the use

IEC 62604-2:2017-11(en)

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SURFACE ACOUSTIC WAVE (SAW) AND BULK ACOUSTIC WAVE (BAW) DUPLEXERS OF ASSESSED QUALITY –

Part 2: Guidelines for the use

FOREWORD

International Standard IEC 62604-2 has been prepared by IEC technical committee 49: Piezoelectric, dielectric and electrostatic devices and associated materials for frequency control, selection and detection.

This second edition cancels and replaces the first edition published in 2011. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- diplexers are described;
- duplexers with a balanced RX port are considered in the measurement method subclause (7.3).

NOTE In this standard, SAW and BAW duplexers are treated simultaneously because both duplexers are used in the same manner especially in mobile phone systems and have same requirements of characteristics, test method and so on.

The text of this International Standard is based on the following documents:

CDV	Report on voting
49/1217/CDV	49/1251/RVC

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62604 series, published under the general title *Surface acoustic wave (SAW) and bulk acoustic wave (BAW) duplexers of assessed quality*, can be found on the IEC website.

A bilingual version of this publication may be issued at a later date.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

SURFACE ACOUSTIC WAVE (SAW) AND BULK ACOUSTIC WAVE (BAW) DUPLEXERS OF ASSESSED QUALITY –

Part 2: Guidelines for the use

1 Scope

This part of IEC 62604 concerns duplexers which can separate receiving signals from transmitting signals and are key components for two-way radio communications, and which are generally used in mobile phone systems compliant with CDMA systems such as N-CDMA in second generation mobile telecommunication systems (2G), W-CDMA / UMTS (3G) or LTE (4G). While in 2G systems mainly dielectric duplexers have been used, the ongoing miniaturization in 3G and 4G mobile communication systems promoted the development and application of acoustic wave duplexers due to their small size, light weight and good electrical performance. While standard surface acoustic wave (SAW) duplexers have been employed for applications with moderate requirements regarding the steepness of individual filters, applications with narrow duplex gap (e.g. Bands 2, 3, 8, 25), i.e. the frequency gap between receiving and transmitting bands, require the application of temperature-compensated (TC) SAW or bulk acoustic wave (BAW) technology, because of their better temperature characteristics and resonator Q-factors.

It is neither the aim of these guidelines to explain theory, nor to attempt to cover all the eventualities which may arise in practical circumstances. These guidelines draw attention to some of the more fundamental questions, which should be considered by the user before he places an order for SAW and BAW duplexers for a new application. Such a procedure will be the user’s insurance against unsatisfactory performance. Because SAW and BAW duplexers have very similar performance for the usage, it is useful and convenient for users that both duplexers are described in one standard.

Standard specifications, such as those of IEC, of which these guidelines form a part, and national specifications or detail specifications issued by manufacturers will define the available combinations of centre frequency, pass bandwidth and insertion attenuation for each sort of transmitting and receiving filters and the isolation level between transmitter and receiver ports, etc. These specifications are compiled to include a wide range of SAW and BAW duplexers with standardized performances. It cannot be over-emphasized that the user should, wherever possible, select his duplexers from these specifications, when available, even if it may lead to making small modifications to his circuit to enable the use of standard duplexers. This applies particularly to the selection of the nominal frequency band.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60862-1:2015, *Surface acoustic wave (SAW) filters of assessed quality – Part 1: Generic specification*

IEC 62575-1:2015, *Radio frequency (RF) bulk acoustic wave (BAW) filters of assessed quality – Part 1: Generic specification*

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

4 Technical considerations

It is of prime interest to a user that the duplexer characteristics should satisfy particular specifications. The selection of the front-end circuits in user equipments and SAW and BAW duplexers to meet such specifications should be a matter of agreement between the user and the manufacturer.

Duplexer characteristics are usually expressed in terms of centre frequency, pass bandwidth and insertion attenuation for each of transmitting and receiving filter parts in the duplexer and isolation level between the transmitter and receiver ports. Since the SAW and BAW duplexer is used in RF front-end of the user equipments, lower insertion attenuation, higher isolation/rejection level, stronger power durability and smaller/thinner package dimensions are strictly required.

5 Fundamentals of SAW and BAW duplexers

5.1 Basic function

5.1.1 General

Duplexers are necessary for frequency division duplex (FDD) equipments to receive and transmit signals simultaneously. Duplexers are 3-port devices which consist of an antenna port, a transmitter port (TX port) and a receiver port (RX port), as shown in Figure 1. The duplexer has three basic functions;

– to transfer the transmitting signal from the TX port to the antenna port;
– to transfer the receiving signal from the antenna port to the RX port;
– to prevent transfer of the transmitting signal and noise from the TX port to the RX port.

The transmitting and the receiving frequencies are determined corresponding to each mobile communication system. For example, Table 1 shows typical allocated frequency bands for UMTS.

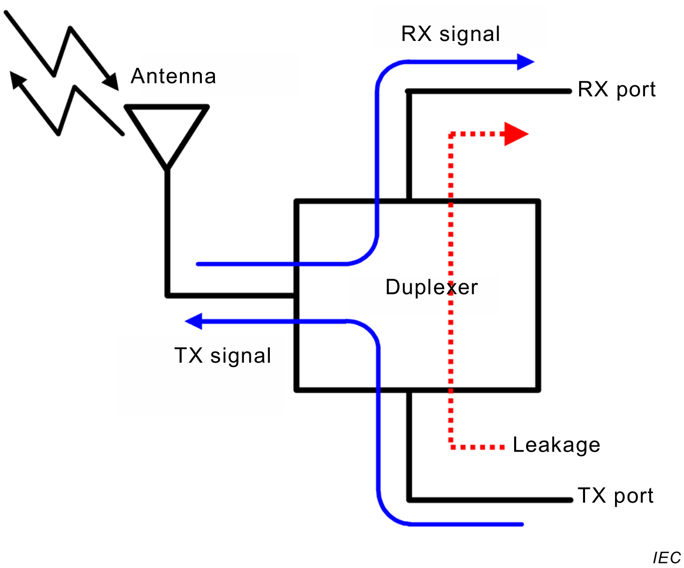

Figure 1 – Basic duplexer configuration

Table 1 – Frequency allocation for typical LTE frequency division duplex (FDD) bands

Band	**Uplink frequency** (MHz)	**Downlink frequency** (MHz)	**Band**	**Uplink frequency** (MHz)	**Downlink frequency** (MHz)
1	1 920 – 1 980	2 110 – 2 170	16	2 010 – 2 025	2 585 – 2 600
2	1 850 – 1 910	1 930 – 1 990	17	704 – 716	734 – 746
3	1 710 – 1 785	1 805 – 1 880	18	815 – 830	860 – 875
4	1 710 – 1 755	2 110 – 2 155	19	830 – 845	875 – 890
5	824 – 849	869 – 894	20	832 – 862	791 – 821
6	830 – 840	875 – 885	21	1 447,9 – 1 462,9	1 495,5 – 1 510,9
7	2 500 – 2 570	2 620 – 2 690	22	3 410 – 3 490	3 510 – 3 590
8	880 – 915	925 – 960	23	2 000 – 2 020	2 180 – 2 200
9	1 749,9 – 1 784,9	1 844,9 – 1 879,9	24	1 626,5 – 1 660,5	1 525 – 1 559
10	1 710 – 1 770	2 110 – 2 170	25	1 850 – 1 915	1 930 – 1 995
11	1 427,9 – 1 447,9	1 475,9 – 1 495,9	26	814 – 849	859 – 894
12	699 – 716	729 – 746	27	807 – 824	852 – 869
13	777 – 787	746 – 756	28	703 – 748	758 – 803
14	788 – 798	758 – 768	30	2 305 – 2 315	2 350 – 2 360
15	1 900 – 1 920	2 600 – 2 620	31	452,5 – 457,5	462,5 – 467,5

NOTE For a user equipment, uplink frequency means transmitting frequency and downlink frequency means receiving frequency respectively.

5.1.2 TX filter response (filter response from TX port to antenna port)

Figure 2 shows an example of frequency characteristics of the TX filter. The required frequency characteristics are low insertion attenuation in the transmitting frequency band (f_T), high insertion attenuation in the receiving frequency band (f_R) and good impedance matching.

5.1.3 RX filter response (filter response from antenna port to RX port)

Figure 3 shows an example of frequency characteristics of the RX filter. The required frequency characteristics are low insertion attenuation in the receiving band (f_R) and high insertion attenuation in the transmitting frequency band (f_T).

5.1.4 Isolation (isolation from TX port to RX port)

Figure 4 shows an example of isolation characteristics. One of the important functions for the duplexers is isolation characteristics, which show the frequency dependence of the leakage power from the TX port to the RX port.

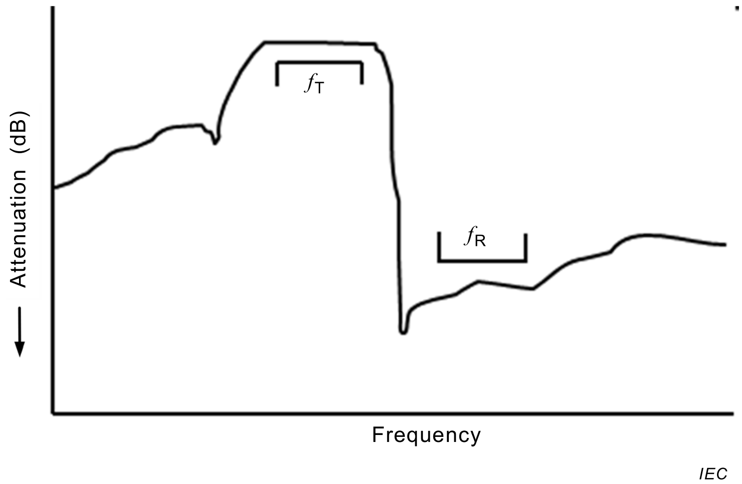

Figure 2 – Basic TX filter response example of SAW and BAW duplexers

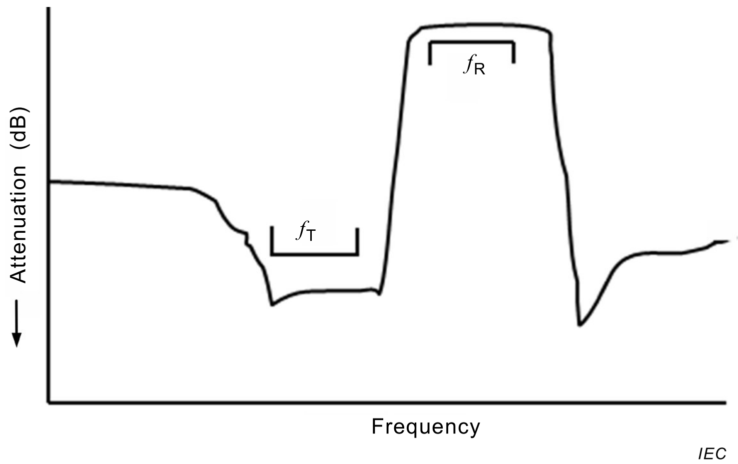

Figure 3 – Basic RX filter response example of SAW and BAW duplexers

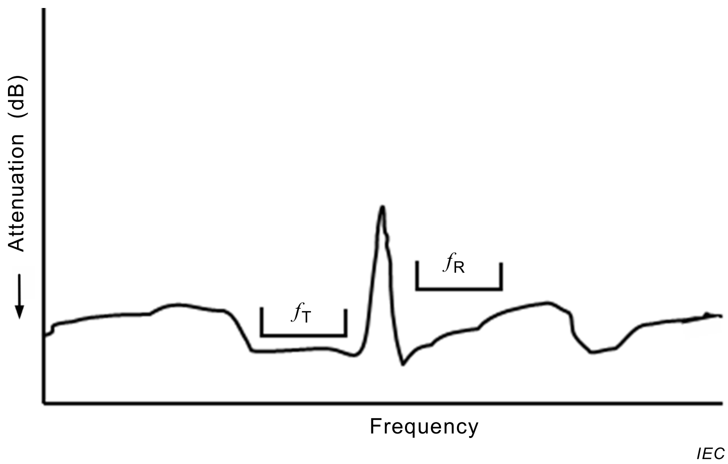

Figure 4 – Basic isolation characteristics example of SAW and BAW duplexers

5.2 Basic structure

Duplexers are 3-port devices/modules, which enable to transmit and receive signals simultaneously through a common antenna. A basic structure of duplexers is shown in Figure 5. SAW and BAW duplexers consist of a transmitter (TX) part and a receiver (RX) part. These two parts, which may add a phase shifter, are connected to an antenna port. The phase shifter is utilized to prevent the interaction between the filters. In Figure 5, Z_t and Z_r correspond to the impedance of the TX and RX part at the antenna port side, whereas Z_o is the impedance of the antenna port. The following conditions shall be fulfilled to achieve the duplexer functions.

$Z_o \cong Z_t$ and $|Z_o| << |Z_r|$ in the TX pass band

$Z_o \cong Z_r$ and $|Z_o| << |Z_t|$ in the RX pass band

DMS (double mode SAW) type filters which are also known as LCRF (longitudinally coupled resonator filters)[1], ladder type SAW[2] and BAW filters and other type of SAW filters such as interdigitated interdigital transducer (IIDT) resonator filters[3] can be adopted as TX and RX filters. High power durability is required in the TX filters.

5.3 Principle of operation

In the TX pass band, the impedance of the TX part in the antenna port side (Z_t) is almost the same as that of antenna(Z_o), while that of the RX part (Z_r) is much higher, which means that at the antenna port, the RX part has large reflection coefficient in this band.

$Z_o \cong Z_t$ and $|Z_o| << |Z_r|$ in the TX pass band

On the other hand, in the RX pass band, the impedance of the RX part at the antenna port side (Z_r) is almost the same as that of antenna (Z_o), while that of the TX part (Z_t) is much higher. This also means the TX part has large reflection coefficient in this band.

$Z_o \cong Z_r$ and $|Z_o| << |Z_t|$ in the RX pass band

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1) See IEC 60862-2:2012, 5.3.

2) See IEC 60862-2:2012, 5.2.

3) See IEC 60862-2:2012, 5.4.

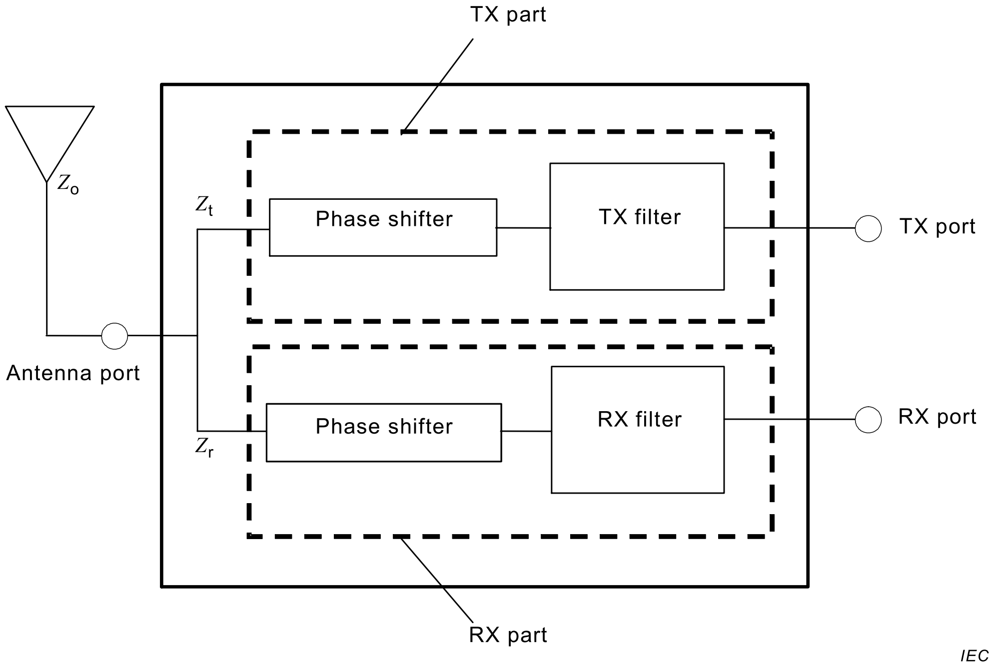


Figure 5 – The block diagram of a duplexer

The transmitting signal applied to the TX port passes through the TX filter and then flows to the antenna port, not the RX filter. The received signal from the antenna port does not flow to the TX filter, but to the RX filter. As a result, the TX part and the RX part can share the common antenna port. In the following explanation, the impedance of the antenna (Z_o) is assumed to be 50 Ω. The S_{11} curve of the TX part at the antenna port side shall satisfy the demanded condition indicated in Figure 6. The impedance of its pass band shall be around 50 Ω. In the rejection band, the impedance shall be sufficiently larger than 50 Ω. In the actual duplexer, the S_{11} trace in the Smith chart of the TX filter is rotated to its optimum state by a phase shifter, as shown in Figure 7. On the other hand, the frequency characteristics of the amplitude of S_{21} remains the same as that without phase shifter. Figure 8 shows the S_{21} frequency characteristics and S_{11} demanded condition of the RX part.

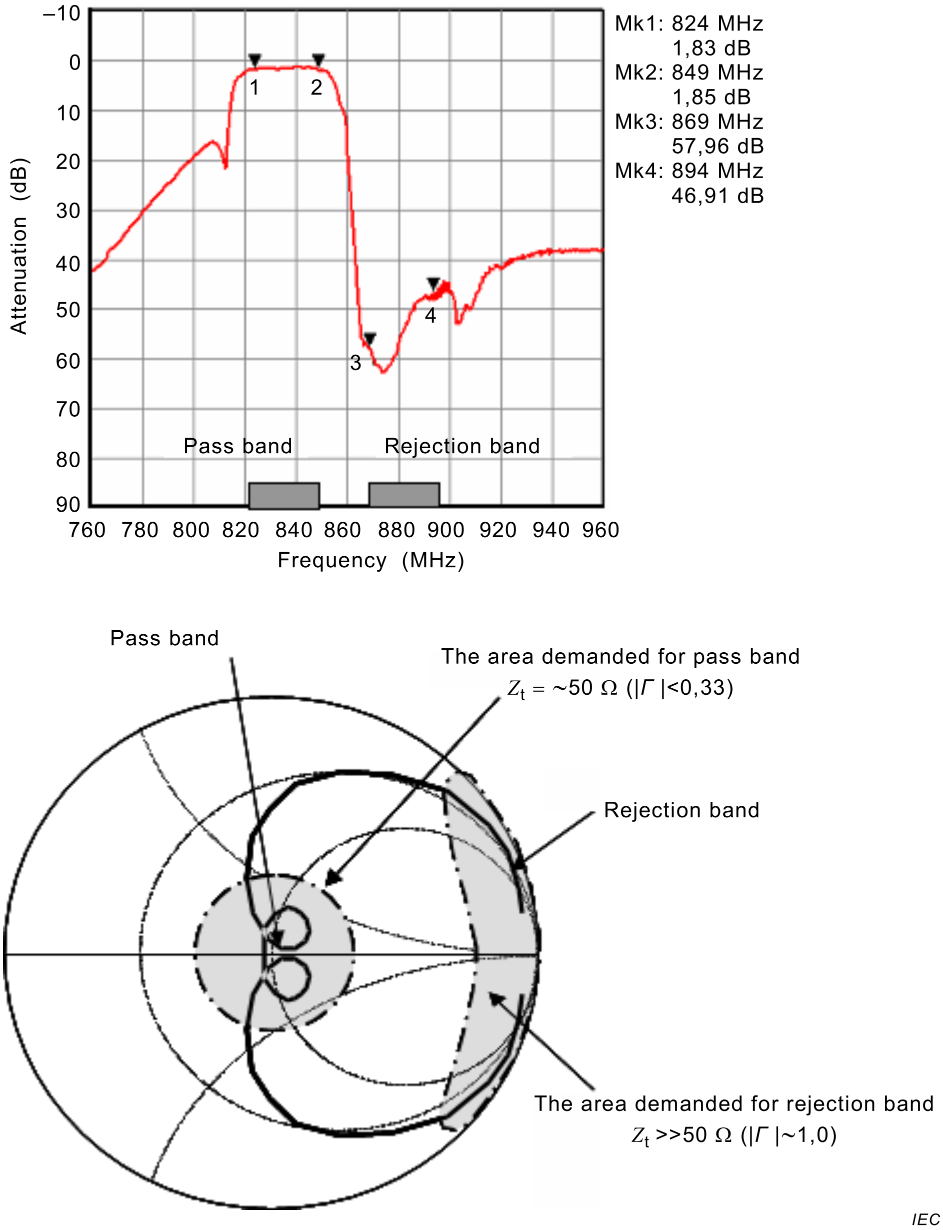


Figure 6 – Demanded condition of TX part for duplexers

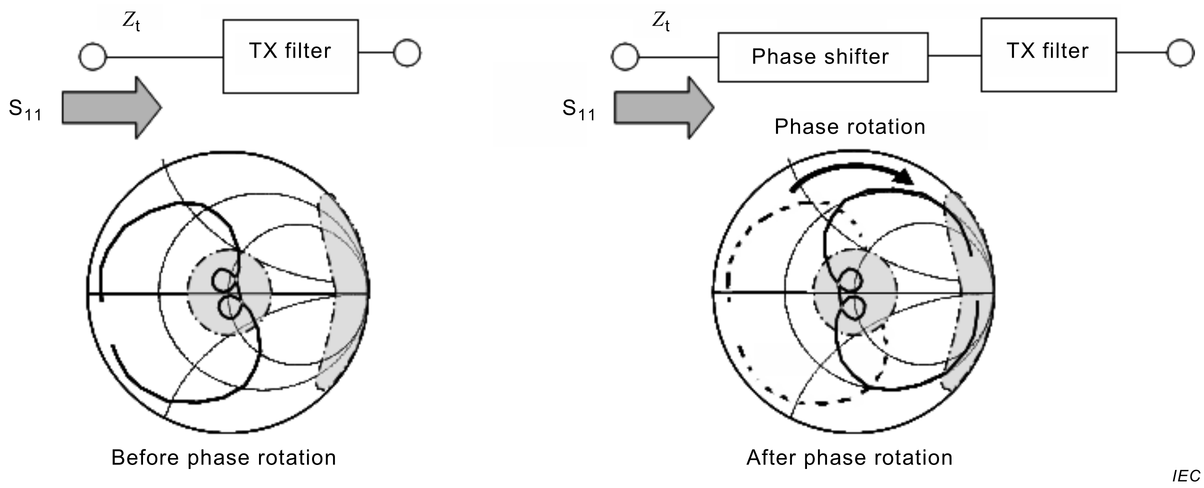
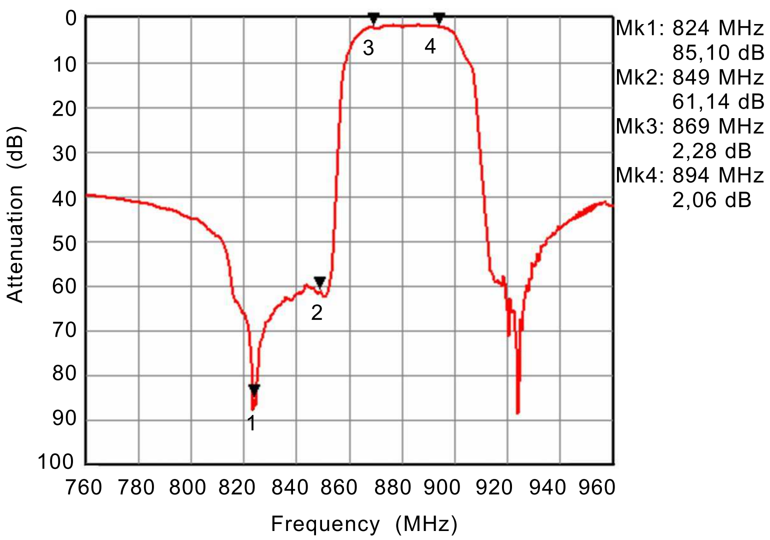


Figure 7 – Phase rotation in TX part



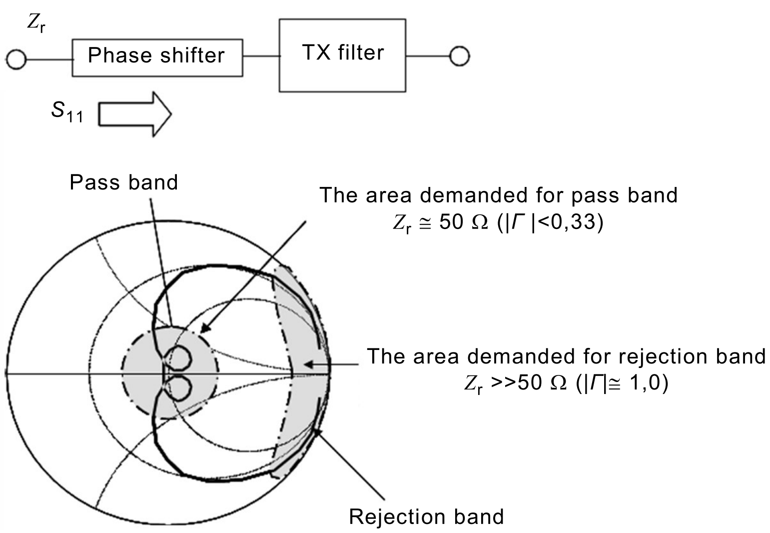


Figure 8 – Demanded condition of RX part for duplexers

5.4 Diplexer

Diplexers combine different frequency domains as shown in Figure 9. They have a structure and an operation principle very similar to those of duplexers.

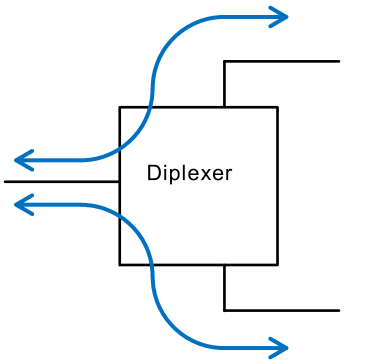


Figure 9 – Basic diplexer configuration

6 SAW and BAW duplexer characteristics

6.1 General conditions for SAW and BAW duplexers

The TX filter, RX filter and phase shifter, which compose SAW and BAW duplexers, as shown in 5.2, are described in Clause 6. The duplexer assembly configuration is also explained here.

– TX filter

The TX filter of the duplexers needs high power durability against the transmitting signal. To ensure the durability against high power, e.g. 1 W, a ladder filter or lattice filter is used for the TX filter because of their higher power durability among several types of SAW and BAW filters. SAW ladder and lattice filters are described in 5.2 of IEC 60862-2:2012 and BAW ladder filter is described in 4.4 of IEC 62575-2:2012.

Besides low insertion attenuation in the TX band (f_T) and high insertion attenuation in the RX band (f_R) described in 5.1, the high attenuation in the second harmonic ($2f_T$) and the third harmonic ($3f_T$) is also important. The attenuation in spurious frequency (f_{SP}) suppresses the inter-modulation signal at $f_R = 2f_T - f_{SP}$. The typical frequency response is shown in Figure 10.

– RX filter

Transmitting power passes through the TX filter and attacks the antenna port side of the RX filter. Filter types used for the TX filter can be adopted for the RX filter, but DMS (double mode SAW) type filters which are also known as LCRF (longitudinally coupled resonator filters) have the possibility of adoption with trap elements to block the transmitting power.

Besides low insertion attenuation in the RX band(f_R) and high insertion attenuation in the TX band(f_T) described in 5.1, a heterodyne receiver with the intermediate frequency (f_{IF}) demands high attenuation in the local oscillation frequency(f_{LO}) and the image frequency ($f_{IM} = f_{LO} + f_{IF}$ for upper local system). The inter-modulation signal in f_R can be reduced by high attenuation in the duplex image frequency ($f_{DIM} = 2f_T - f_R$). The typical frequency response is shown in Figure 11.

– Phase shifter

There are various types of phase shifters according to duplexer configurations and the out-of-band complex impedance of TX and RX filters. To construct the phase shifter of a delay line with the desired electrical length, a stripline is located between the inside layers of a package, or a microstrip line is located on the surface of a package as shown in Figure 12. Figure 13 shows a lumped element phase shifter. A suitable number of lumped elements is not fixed at three. In some cases no phase shifter is necessary.

– Duplexer configuration

Figure 14 shows two types of the duplexer configuration. They have merits and demerits with regard to characteristics, size, cost and other items.

Figure 14(a) shows a module type, which mounts SAW and BAW filters and other components on a substrate, such as a printed board. Figure 14(b) shows a device type, which seals the package after mounting SAW and BAW filter bare chips on a package, such as multi-layered ceramics. In those two types, the TX and RX filters/chips are separated from each other, and there is the possibility of a single filter/chip solution.

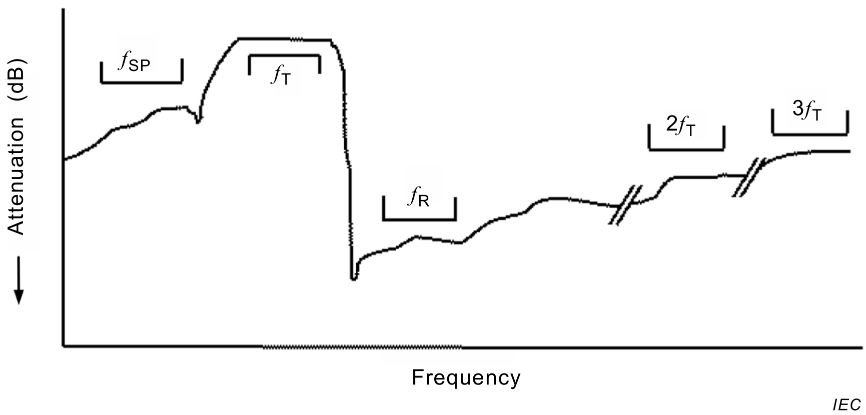


Figure 10 – Typical wide range frequency response of TX filter

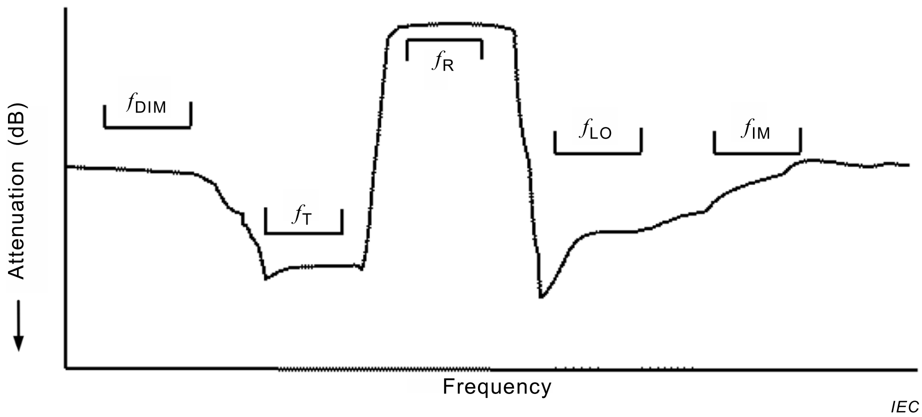


Figure 11 – Typical wide range frequency response of RX filter for upper local system

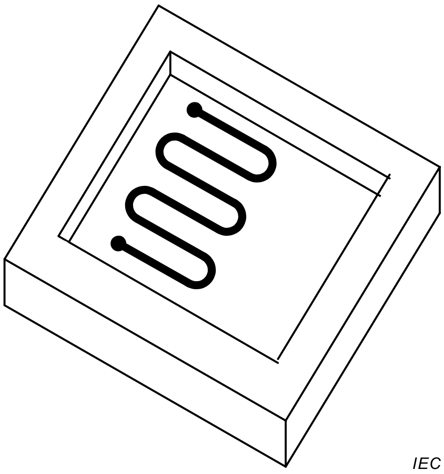


Figure 12 – Phase shifter by microstrip line on the surface of a ceramic package

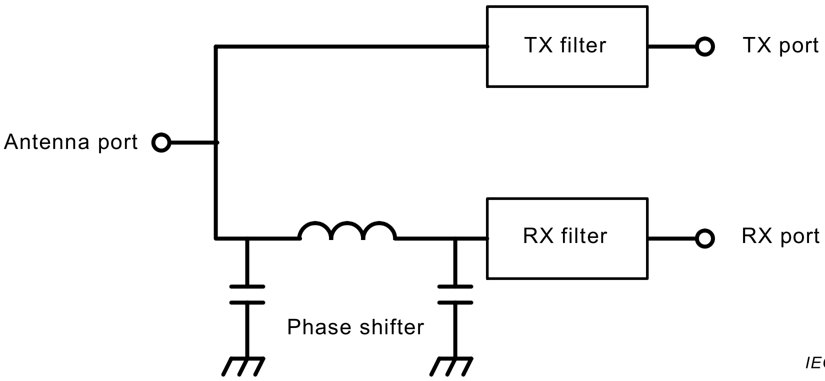


Figure 13 – Lumped element phase shifter

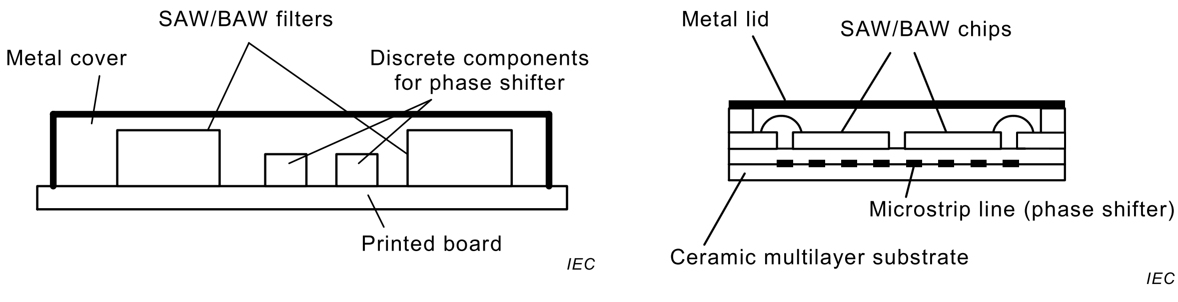


Figure 14 – Duplexer configuration

6.2 Typical characteristics of SAW and BAW duplexers

6.2.1 UMTS duplexer

As an example of a duplexer for a UMTS system, a SAW duplexer for UMTS Band 1 is shown in 6.2. The frequency regulation of Band 1 is provided by a third generation partnership project (3GPP). The transmitter and receiver pass bands in the handset are 1 920 MHz to 1 980 MHz and 2 110 MHz to 2 170 MHz, respectively. Both frequency bands are indicated by f_T and f_R in Figure 15. The size of this duplexer is typically 4,9 mm × 4,9 mm × 1,7 mm. A 41° rotated Y cut X propagated $LiNbO_3$ crystal is used as substrate. The structure of the filter is a ladder (see 5.2 of IEC 60862-2:2012), and the electrodes material is made by Al-Ti alloy for high power durability.

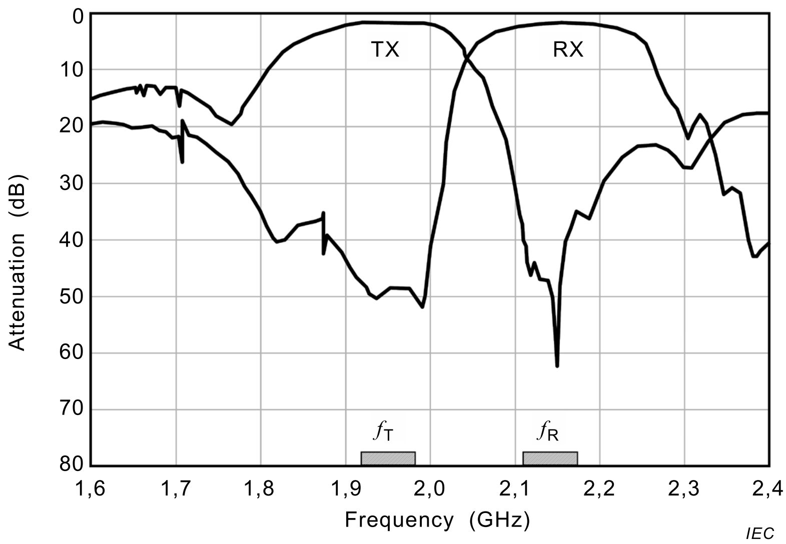
Frequency characteristics of this SAW duplexer for UMTS Band 1 are shown in Figure 15. The typical insertion attenuation from the TX port to the antenna port and that from the antenna port to the RX port are 1,4 dB and 2,3 dB, respectively. The isolation values between transmitter and receiver ports are typically 48 dB for the TX band and 40 dB for the RX band.

6.2.2 US CDMA duplexer

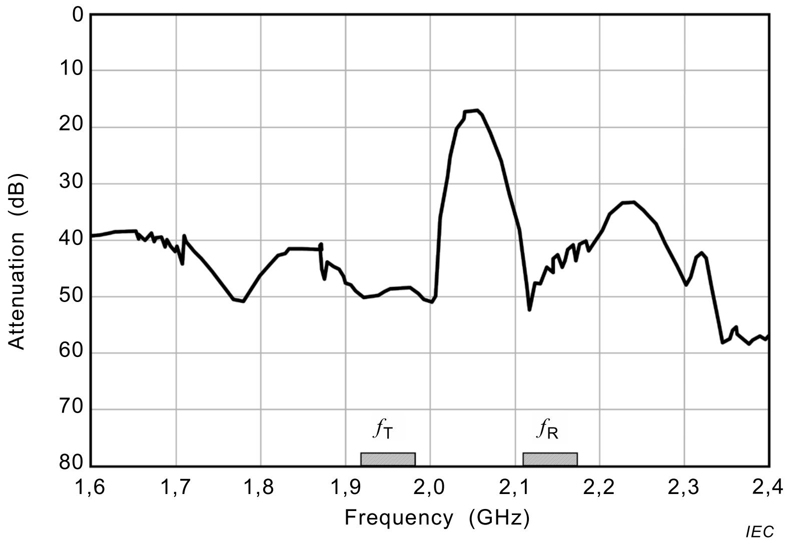
The frequency characteristics example of US CDMA duplexer is shown in Figure 16. This type of duplexer is also applicable to UMTS Band 5. The TX passband frequency is 824 MHz to 849 MHz, while RX passband frequency is 869 MHz to 894 MHz. Both frequency bands are indicated by f_T and f_R in the figure. The dimension of this duplexer is typically 3,8 mm × 3,8 mm × 1,6 mm. Y cut X propagated $LiTaO_3$ with a rotation angle optimized around 36° is used as a substrate. The ladder type SAW filters are used for both TX and RX parts. Typical insertion attenuation is 1,8 dB from TX port to antenna port. And 2,5 dB typical insertion attenuation is from antenna port to RX port. The isolation between TX port and RX port is typically 60 dB for the TX band and 47 dB for the RX band.

6.2.3 PCS CDMA duplexer

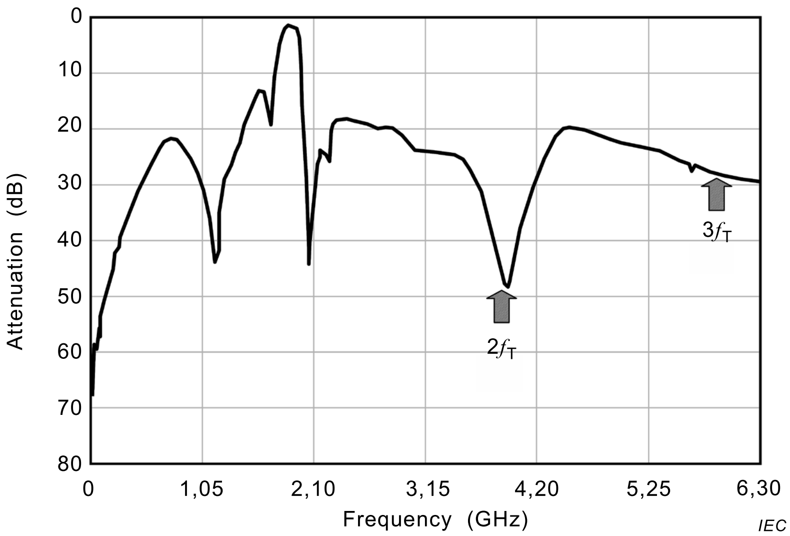
According to Table 1, the guard band or a gap distance between the transmitting and receiving frequencies for UMTS band 2 or PCS band is relatively narrow, and high Q characteristics or a sharp filter response in the transition band is required. From this requirement, BAW duplexers which are composed of film bulk acoustic resonators (FBAR) or solidly mounted resonators (SMR) are mainly used for PCS CDMA duplexers. The frequency characteristics example of a PCS CDMA duplexer using FBAR is shown in Figure 17. The TX passband frequency is 1 850 MHz to 1 910 MHz, while the RX passband frequency is 1 930 MHz to 1 990 MHz. This duplexer can comply with the specified maximum insertion attenuation of 3,5 dB for the TX band and 4,0 dB for the RX band, with excellent transition band responses between the TX and RX bands. Also, the specified minimum isolation values between the transmitter and receiver ports are 54 dB for the TX band and 43 dB for the RX band.



a) Amplitude responses of the duplexer from TX port to antenna port and from antenna port to RX port (near pass band)

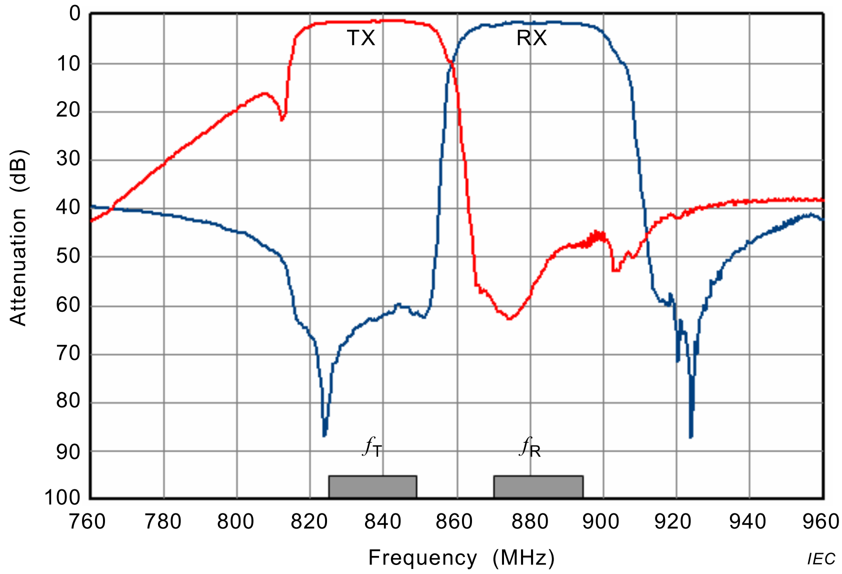


b) Isolation characteristics of the duplexer between RX port and TX port

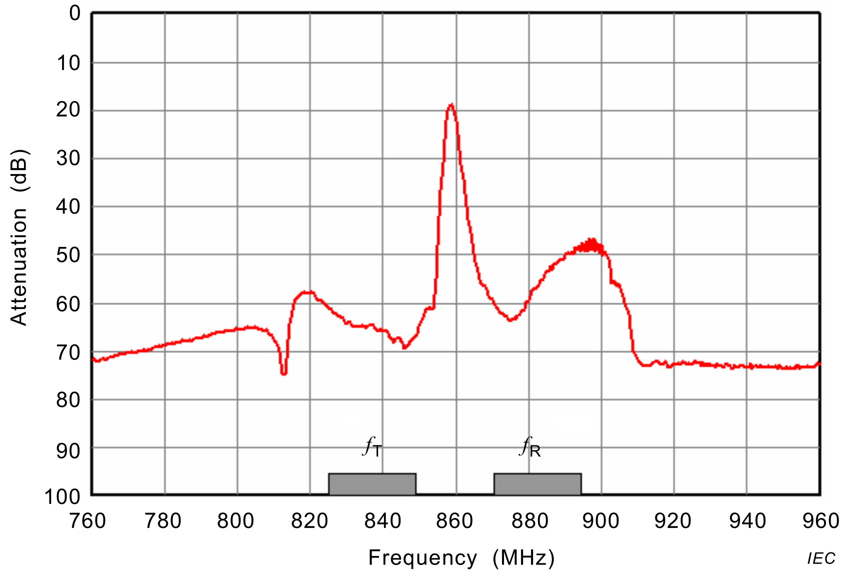


c) Amplitude response of the duplexer from TX port to antenna port (DC to 6 GHz)

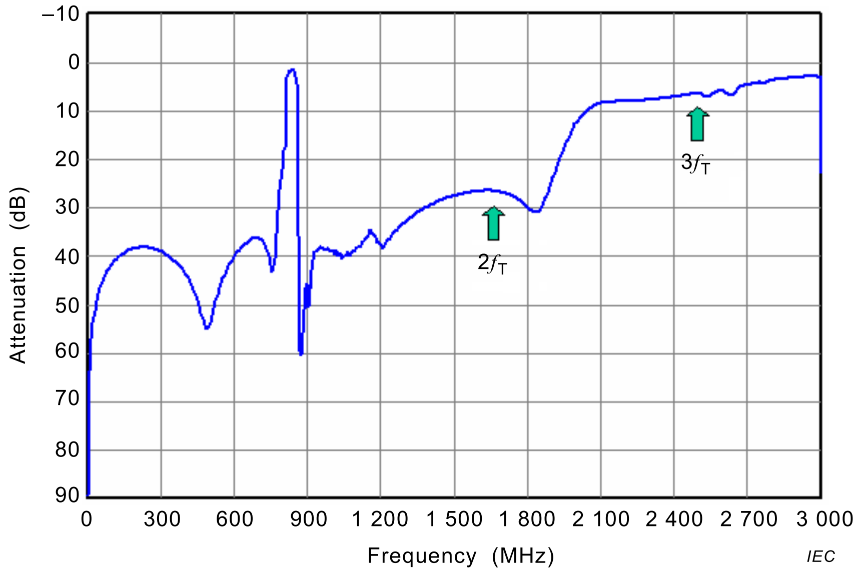
Figure 15 – Frequency characteristics of SAW duplexer for UMTS Band 1 system



a) Amplitude responses of the duplexer from TX port to antenna port and from antenna port to RX port (near pass band)

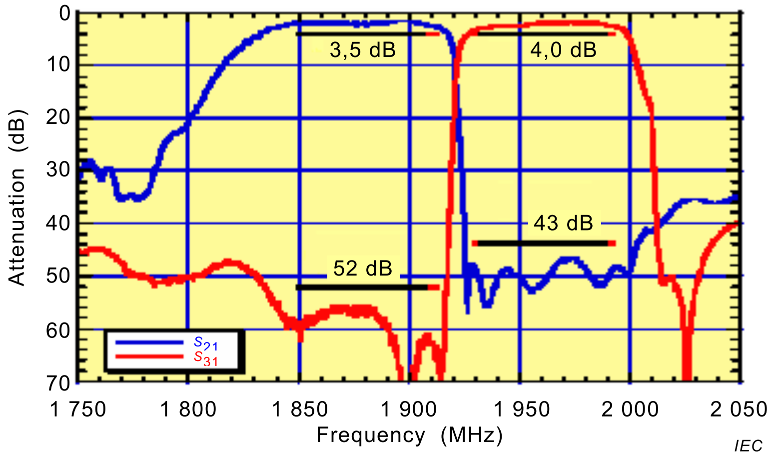


b) Isolation characteristics of the duplexer between RX port and TX port

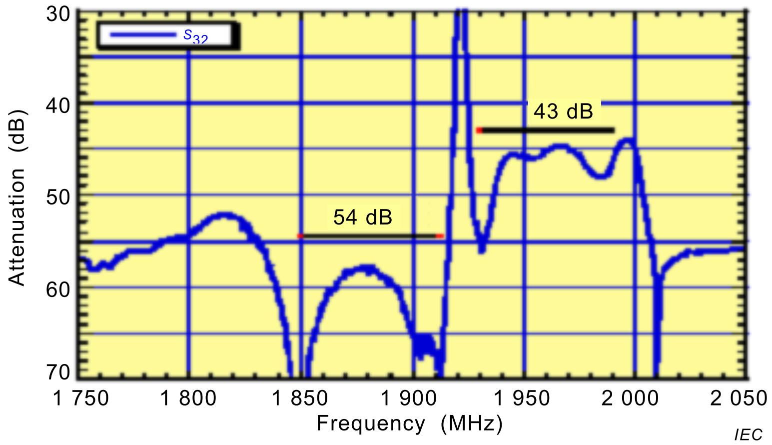


c) Amplitude response of the duplexer from TX port to antenna port (DC to 3 GHz)

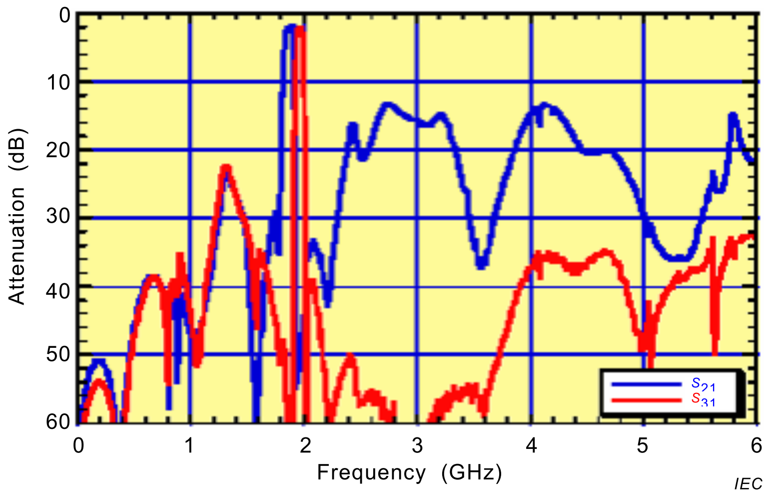
Figure 16 – Frequency characteristics of a SAW duplexer for US CDMA system



a) Amplitude responses of the duplexer from TX port to antenna port and from antenna port to RX port (near pass band)



b) Isolation characteristics of the duplexer between RX port and TX port



c) Amplitude responses of the duplexer from TX port to antenna port and from antenna port to RX port (DC to 6 GHz)

Figure 17 – Frequency characteristics of BAW duplexer for PCS CDMA system[4)]

4) P.Bradley et al.: "A 6-port Film Bulk Acoustic Resonator (FBAR) Multiplexer For U.S. CDMA Handsets Permitting use of PCS, U.S. CDMA and GPS with a single Antenna", Proc. IEEE Ultrasonics Symp., pp.325-328, 2006.

7 Application guidelines

7.1 Power durability

High power durability of about 1 W is necessary for SAW and BAW duplexers. There are two modes of damage caused by power beyond the durability and the situation is severer for a SAW duplexer than for a BAW duplexer.

The first mode is breakdown. High voltage momentarily destroys SAW electrodes. Input power should be considered to prevent their breakdown.

The second mode is stress migration. The excessive repeated mechanical stress can induce electrode deteriorations, such as voids and hillocks. They cause frequency shift and insertion attenuation degradation of the SAW duplexer.

In order to protect the SAW duplexer from such deteriorations, and to keep the duplexer working for a sufficient amount of time, the drive level shall be less than 1 W. Various technologies of high power durability in SAW devices intended to extend their lifetime have been studied; these are described in 5.5 of IEC 61019-2:2005.

In the case of a BAW duplexer, it is said that its durability is stronger than that of an SAW. However, consideration of the drive level is necessary also for a BAW duplexer. More detailed studies and reports are required technically.

7.2 Harmonics and inter-modulation distortion

Nonlinearity of SAW and BAW duplexers loaded in high power can cause harmonics, which generates unwanted output signals in stop band areas, as shown by Figure 10 and Figure 11. In addition inter-modulation distortion also occurs both in stop band and pass band areas. Detailed technical information is described in 8.5.7 of IEC 60862-1:2015.

7.3 Measurement method for the duplexer

The measurement method shall basically be performed in accordance with the measurement method of IEC 60862-1:2015 and IEC 62575-1:2015. However, in the evaluation of the duplexer, the instructions given by the application notes from a vendor should be considered. Because the duplexer is a three-port device, it is recommended to use multi-port-type network analyzers. Figure 18 shows a schematic diagram of the measurement method for a duplexer with a four-port-type network analyzer, as an example.

However, a conventional two-port-type network analyzer can be also used for measuring the characteristics between any two ports chosen from three ports of the duplexer with 50 Ω termination of the unchosen port. A vector voltmeter or other filter test equipment can be also applicable in the same way instead of the network analyzer.

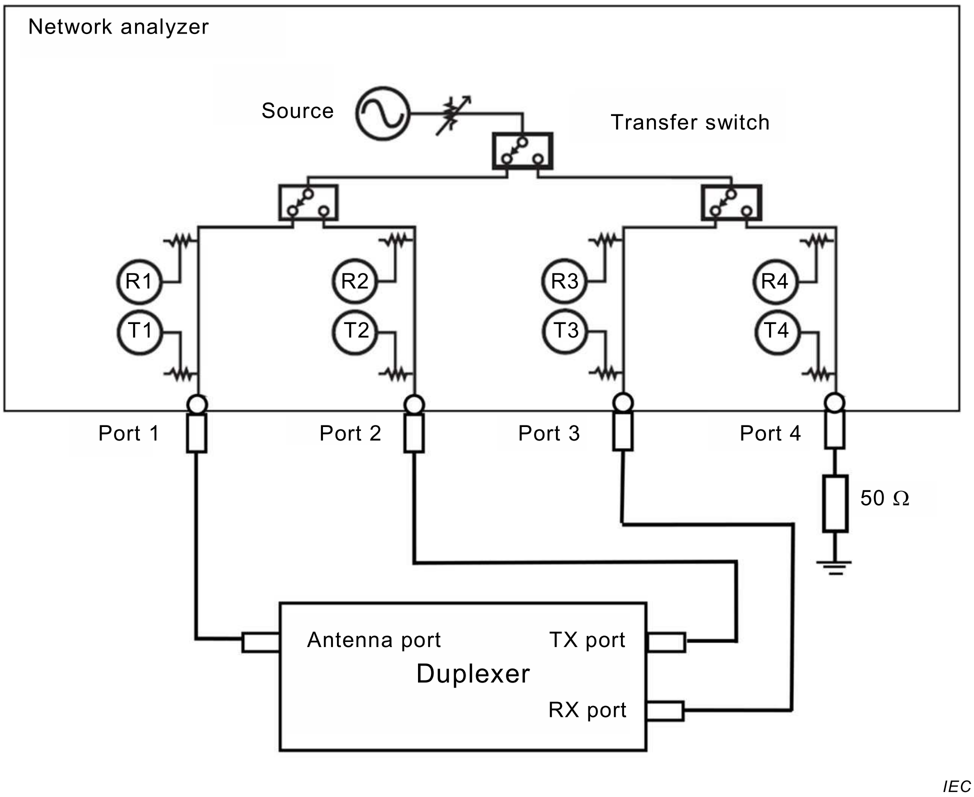


Figure 18 – Four-port-type network analyzer for duplexer measurement

Adopting a balanced connection filter[5] to the RX filter, a duplexer with a balanced RX port will be realized. It can also be evaluated using four-port-type network analyzer as shown in Figure 19.

[5] See IEC 60862-2:2012, 5.3.5.

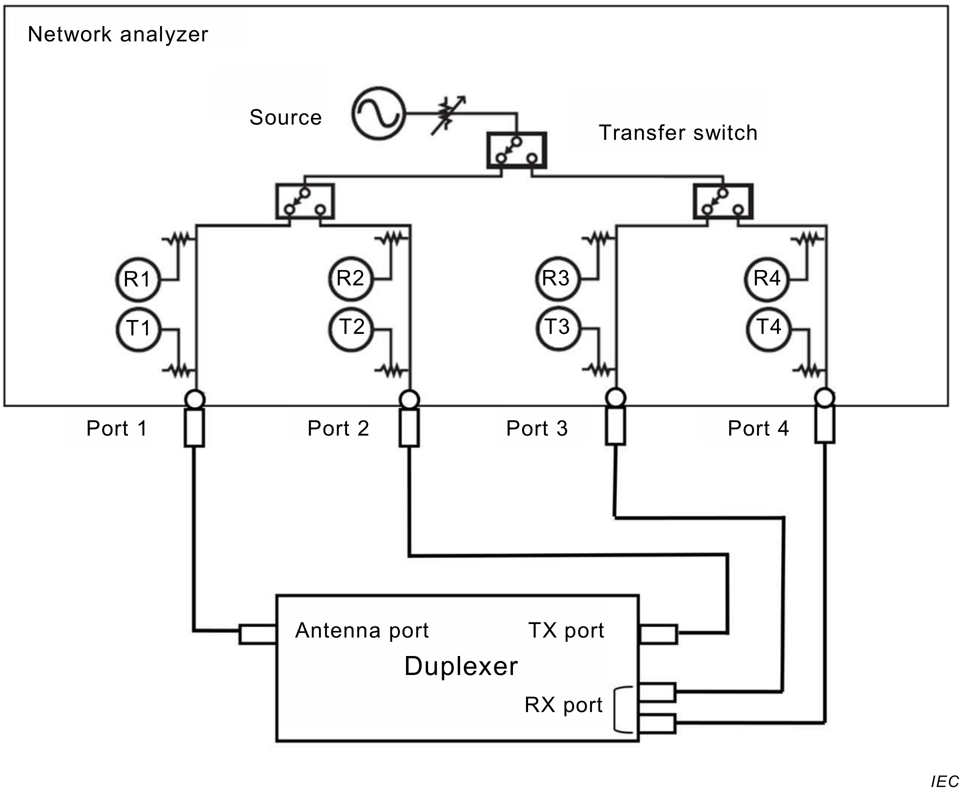


Figure 19 – Four-port-type network analyzer for measurement of a balanced RX port duplexer

7.4 Electrostatic voltage protection

Since the duplexers are used in the front-end of the user equipment, electrostatic overstress (discharge) can easily affect the device's antenna port, and a countermeasure against the static electricity is generally required, particularly for SAW duplexers. As the electrode gap of IDT in the SAW duplexer is very narrow, especially for the high frequency range, and it might be a cause of degradation or destruction to apply static electricity to a SAW duplexer, it is necessary to be careful not to apply static electricity or excessive voltage while transporting, assembling and measuring.

If the piezoelectric material of duplexers has large pyro-electricity, excessive voltage can occur during rapid temperature changes. In order to prevent such an occurrence, it is necessary to take care not to add any thermal shock. In the soldering process, adequate preheating is effective.

Bibliography

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