SAW antenna duplexer promotes miniaturization of Japan CDMA mobile terminals for market

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An antenna duplexer is used as a front-end unit linked to an antenna which is capable of simultaneous transmitter and receiver, by separating the sending and receiving signals. In recent years, wide band filters have been required in mobile terminals, both those used in Japan and those used overseas, and in general, a band-division type antenna duplexer is used which has a switching circuit (Fig. 1) for dividing the band in two. Furthermore, mobile terminals based on Japan Code Division Multiple Access (hereinafter, “CDMA”) systems have been developed which incorporate extra functions, such as GPS, etc. Such developments have led to rising demands for miniaturization of individual products, as well as performance upgrading, without increase in the external dimensions of recent mobile terminals. In the report, We represent on the full-band Surface Acoustic Wave (SAW) antenna duplexer developed by Oki, which is more suited to device miniaturization than conventional band dividing type duplexers.

Examining miniaturization

Conventional mobile terminals based on Japan CDMA system use band dividing types because of their broad bandwidth. SAW filters have usually been restricted to use in bandpass filters of transmitting particular band only, in order to ensure a bandwidth of around 25−30 MHz due to impedance matching conditions, in the 800 MHz frequency band. Japan CDMA specifications cover a total bandwidth of 38 MHz, with 14 MHz space for both transmitting and receiving signals. Therefore, the band dividing type makes effective use of these 14 MHz spaces and is designed according to the frequency bands shown in Table 1 and Fig. 2. The frequency band results in a narrow bandwidth of 14 MHz or 10 MHz, and 41 MHz separation between the transmitting and receiving bands, which means that, accounting for the dimensional accuracy of the electrode pattern width in the SAW resonator, a design without sharp attenuation characteristics can be achieved. However, in a full-band device, despite the broad 38 MHz bandwidth, the separation between transmitting and receiving bands is narrow 17 MHz and therefore a filter with sharp attenuation characteristics is required in order to reduce noise. Yet our research findings shows that some level of impedance matching can still be achieved, even with 38 MHz broad bandwidth. As devices are made smaller and smaller, band dividing types reach operational limits due to the inclusion

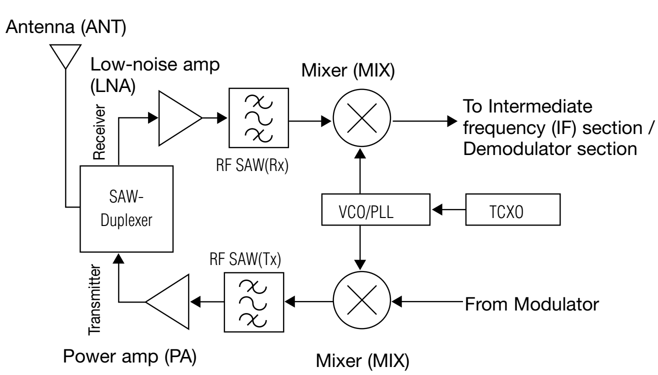

Fig. 1 Block diagram of radio frequency section in mobile phones

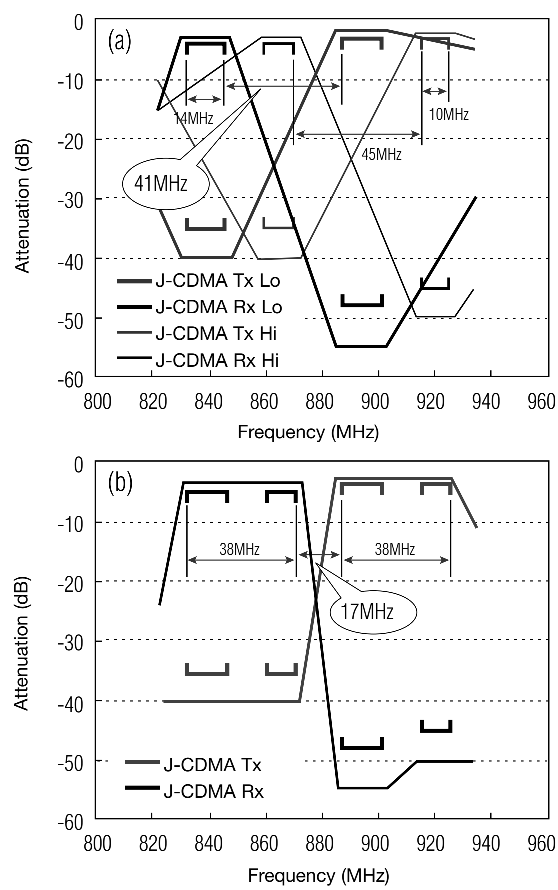

Fig. 2 Comparison of attenuation band in Japan CDMA band dividing type (a), and full-band type (b)

Table 1 Comparison of band dividing type and full-band type in Japan CDMA

		band division type		full-band type
		Low-Side	High-Side	
Transmitting side	Center frequency	894MHz	920MHz	906MHz
	Bandwidth	14MHz	10MHz	38MHz
	Pass band	887 - 901MHz	915 - 920MHz	887 - 925MHz
	Attenuation band	832 - 846MHz	860 - 870MHz	832 - 870MHz
Receiving side	Center frequency	839MHz	865MHz	851MHz
	Bandwidth	14MHz	10MHz	38MHz
	Pass band	832 - 846MHz	860 - 870MHz	832 - 870MHz
	Attenuation band	887 - 901MHz	915 - 925MHz	887 - 925MHz
Separation between transmitting and receiving bands		41MHz	45MHz	17MHz

of switching elements and this also gives rise to degraded performance. In response to this, we developed a full-band analysis of the duplexer.

Composition of transmitting and receiving filter circuits

In our research, for both the transmitting (Tx) filter and receiving (Rx) filter, we used a circuit composition with attenuation poles based on a conventional circuit, provided with attenuation poles in the desired frequency band.1) Fig. 3 shows the attenuation characteristics of a transmitting filter based on a conventional circuit composition with attenuation poles. By adopting an inductor, a transmitting filter circuit with sharp attenuation on the low frequency side of the pass band is obtained, as shown in Fig. 4. The attenuation characteristics of this circuit are illustrated in Fig. 5. Comparing these characteristicts, it can be seen that the frequency difference of the 3 dB loss and 38 dB

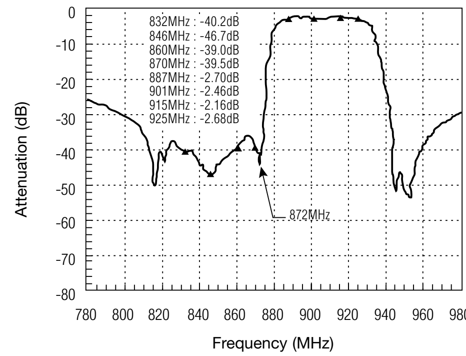

Fig. 5 Attenuation characteristics of a transmitting filter based on a new circuit composition with attenuation poles

attenuation between the transmitting band and the receiving band (870 – 887 MHz) is reduced to 12.8 MHz from the previous figure of 14.4 MHz. Moreover, in the attenuation characteristics in Fig. 3 and Fig. 5, although the attenuation on the low frequency side of the pass band is shifted from 868 MHz to 872 MHz towards the pass band, the low frequency side loss is improved from –2.74 dB to –2.70 dB, and hence sharp attenuation characteristics of circuits with attenuation poles are achieved.

Next, the attenuation characteristics of the receiving filter based on a conventional circuit structure are illustrated in Fig. 6. Furthermore, Fig. 7 shows the composition of a receiving filter which has high attenuation in the transmitting band by adopting a circuit composition with attenuation poles, and Fig. 8 shows the attenuation characteristics of this circuit. Comparing these characteristics, we can see that the attenuation is increased to –50.8 dB from –45.3 dB in the transmitting band (887–925 MHz), so the circuit behaviour with attenuation poles can be obtained on the receiving side also.

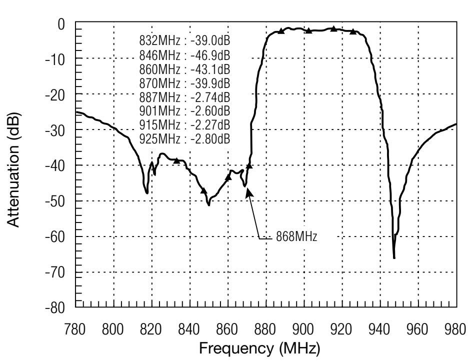

Fig. 3 Attenuation characteristics of a transmitting filter based on a conventional circuit composition with attenuation poles

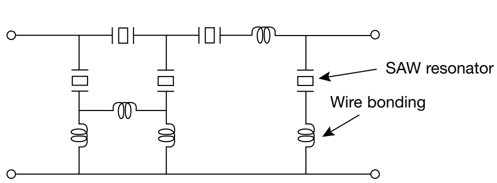

Fig. 4 New circuit composition with attenuation poles providing sharp attenuation characteristics on low frequency side of pass band

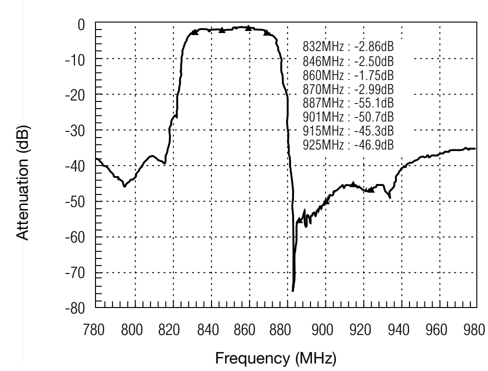

Fig. 6 Attenuation characteristics of a receiving filter based on a SAW resonator

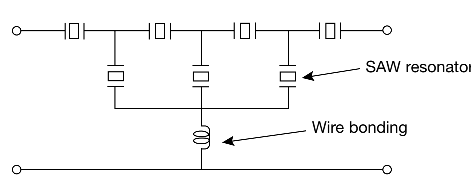

Fig. 7 Circuit composition with attenuation poles achieving high attenuation on high frequency side of pass band

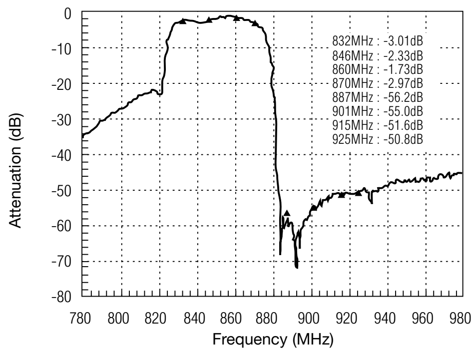

Fig. 8 Attenuation characteristics of receiving filter based on a circuit composition with attenuation poles

Design of SAW antenna duplexer

Almost antenna duplexers used in mobile telephones have to be simultaneous transmitting/ receiving filters, so they must be designed in a way which minimizes leakage of the transmitting signal into the receiving band, and of the receiving signal into the transmitting band. This means that the impedance conditions involving the impedance (Z_t) of the transmitting filter including the phase rotating line, and the impedance (Z_r) of the receiving filter including the phase rotating line, will be

$$Z_t = Z_0 << Z_r$$

in the transmitting frequency band (887 – 925 MHz), and

$$Z_r = Z_0 << Z_t$$

in the receiving frequency band (832 – 870 MHz). Incidentally, $Z_0 = 50$ [Ω].

To find conditions where the receiving filter does not affect the transmitting filter in the antenna duplexer, firstly, the input impedance Z_{in} (L_t) as observed from the ANT terminal in Fig. 9 to the transmitting route (transmitting filter including phase rotating line) is calculated from the following equation.

$$Z_{in} (L_t) = (\cos\theta + j\sin\theta / (Z_{in} (Tx))) / ((\cos\theta / (Z_{in} (Tx) + j\sin\theta)) \quad ... (1)$$

Here, $\theta = \beta L$, where L is the line length and $\beta = 2\pi/\lambda$, λ is wavelength of reference frequency. L_t is the phase rotating line length on the transmitting side, and Z_{in} (Tx) is the input impedance of the transmitting filter. Taking the line length in the phase rotating line as $\lambda/4$, the phase β becomes $\pi/2$ and the phase rotating line forms a gyrator. In the case of a gyrator, Equation (1) can be written as follows:

$$Z_{in} (L_t) = 1/ (Z_{in} (Tx)) \quad ... (2)$$

In other words, if Z_{in} (Tx) = 0, then Z_{in} (L_t) tends to ∞, and there is no interference in the receiving route. However, in reality, Z_{in} (Tx) does not reach zero. If Z_{in} (Tx) is small, then assuming that θ has become $\theta = \pi/2 + \Delta\theta$, equation (1) can be written as follows.

$$Z_{in} (L_t) = (-\sin \Delta\theta + j\cos \Delta\theta / (Z_{in} (Tx))) / ((\sin \Delta\theta / (Z_{in} (Tx) + j\cos \Delta\theta)) \quad ... (3)$$

In equation (3), if the input impedance of the transmitting filter Z_{in} (Tx) is small, then conditions which will ensure no effect on the receiving filter can be defined as:

$$\tan \Delta\theta = -1 / Z_{in} (Tx) \quad ... (4)$$

In other words, a design can be adopted wherein, if Z_{in} (Tx) is small, then the line length of the phase rotating line can be corrected by Δθ, to eliminate all effects on the receiving route (receiving filter including phase rotating line), just as if Z_{in} (Tx) was 0. Accordingly, in the Smith chart in Fig. 10 which shows the impedance characteristics for the transmitting filter only, the impedance is located near 0 in the receiving band of the other band. However, it was also found that by inserting a phase rotating line which turns the phase clockwise, the receiving band of the other band is shifted close to infinity, as shown in Fig. 11. We also looked at inserting a phase rotating line in the receiving route, in the same way as the transmitting route. In the Smith chart in Fig. 12, the impedance characteristics for the receiving filter only are not of the same level as the impedance characteristics of the transmitting route (transmitting filter including the phase rotating line), but the transmitting band is situated relatively near to infinity. In order to move it closer to infinity by inserting a phase rotating line, a longer line length is set than that of the phase rotating line inserted in the transmitting side. Furthermore, although the impedance setup is ideal and allows a practical design which prevents any effects on the other band transmitter, conversely, there is a risk that the loss due to the parasitic impedance caused by the phase rotating line will cause increased loss in the bandwidth of the receiving side itself. Therefore, although not ideal in terms of impedance, we adopted a design which inserts a phase rotating line in the receiving side by means of connection lines which restrict the phase rotation of the independent impedance characteristics for the receiving filter only shown in the Smith chart.

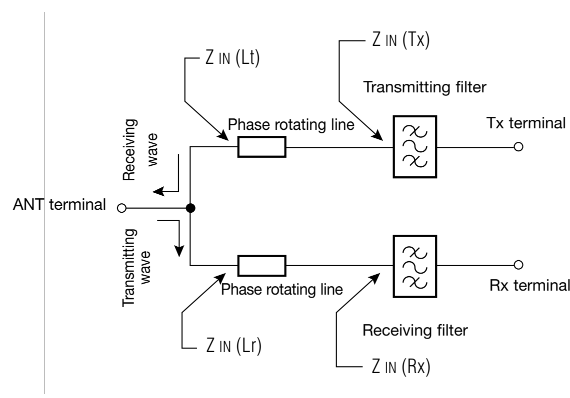

Fig. 9 Composition of SAW antenna duplexer

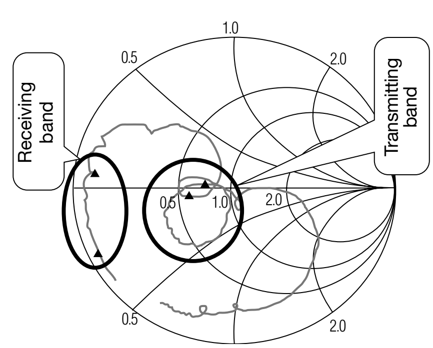

Fig. 10 Impedance characteristics of transmitting filter only

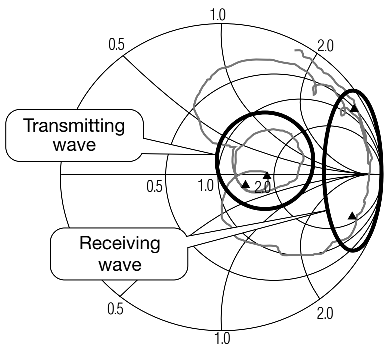

Fig. 11 Impedance characteristics of phase rotating line and transmitting filter only

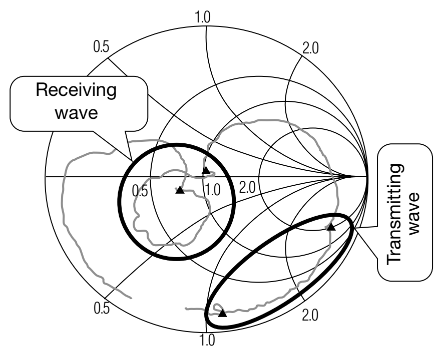

Fig. 12 Impedance characteristics of transmitting filter only

Design and trial manufacture results

A Transmitting filter using a circuit composition with attenuation poles was patterned on one chip, and a package (9.5×7.5×1.5 mm) comprising matching circuits at each terminal was mounted on the same chip. Fig. 13 shows the attenuation characteristics and simulation results for the SAW antenna duplexer for a full-band Japan CDMA system for market thus fabricated. Although there is a narrow separation between the transmitting band and the receiving band, it can be seen that satisfactory adjacent attenuation characteristics can be guaranteed. The transmitting side has 2.4 dB insertion loss, 39 dB attenuation and 58 dB isolation, whilst the receiving side has 3.0 dB insertion loss, 50 dB attenuation and 40 dB isolation.[2)]

Photograph 1 SAW antenna duplexer for Japan CDMA system

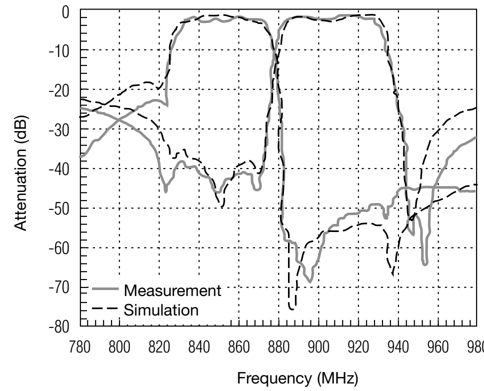

Fig. 13 Attenuation characteristics and simulation results of SAW antenna duplexer for Japan CDMA system.

Conclusion

In this paper, we have discussed the design method and trial manufacture results for an antenna duplexer based on a SAW filter. By using the advantages of circuit composition with attenuation poles to manipulate the attenuation poles, it is possible to sharpen the attenuation gradient. This helps to overcome the design barriers involved in full-band type Japan CDMA systems for market use, compared to band dividing types, and the SAW filter makes it possible to achieve a broad-band antenna duplexer with a very narrow transmitting/receiving separation.

Miniaturization and performance upgrading is expected to progress in the future, and we must now study measures for creating power resistant films, which are predicted to be the next design hurdle as devices are reduced further and further in size.

References

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