Miniaturization Technology of RF Devices for Mobile Communication Systems

Toru Yamada, Toshio Ishizaki and Makoto Sakakura
Device Engineering Development Center, Matsushita Electric Industrial Co., Ltd.
1006 Kadoma Osaka 571-8501, JAPAN

**ABSTRACT** Miniaturization of RF devices is a very important factor for success in the portable telephone business. The down-sizing technologies have been studied. The situation is still the same for the development of the next generation portable telephone terminals. There are two major approaches for miniaturizing the terminals. One is simplifying the RF circuit structure. For this purpose, the direct conversion technologies are reviewed. The other approach is the miniaturization of the RF devices. The miniaturization histories of RF filters are reviewed. Especially, the miniaturization technique of dielectric filter is described in detail by way of example. Their difficulties and new ideas are illustrated with their basic concept.

**INTRODUCTION**
Recently, the number of portable telephones is rapidly increasing. The main factor of this tremendous increment is greatly dependent on the miniaturization technique. Although the system has changed from the first generation analog system to the second generation digital system and further is changing to the third generation IMT-2000 system, the demand for miniaturization is still important technology for portable telephones. The miniaturization of the base band circuit and some part of RF circuit could be achieved with semiconductor IC technologies. However, in a super heterodyne system, which has been mainly used portable telephones, many RF components are difficult to be constructed in a semiconductor. This fact causes difficulty of miniaturization because of increment of external RF components. To overcome this problem, a direct conversion system has been attracted a great deal of attention. This system requires fewer external components than the super heterodyne system. However it still remain technical difficulties such as weak interference-resistance. Furthermore, very small RF devices, which cannot be constructed in the semiconductors, are still strongly expected to

![Figure 1 Miniaturization trend of portable telephones and RF devices.](image-url)
make super compact next generation portable telephones.

In this paper, the authors review a newly proposed offset direct conversion system as compared with super heterodyne and direct conversion systems. The authors also illustrate the miniaturization technologies of RF devices. First, their histories are reviewed. The difficulty is explained for the case of dielectric filters. Then the new technologies and the new ideas are described.

PROGRESS OF RF CIRCUIT CONFIGURATION

Figure 1 shows the miniaturization trend of portable telephones and the RF devices. In recent fifteen years, the handsets have become one-tenth in volume. And the RF devices have become one-hundredth in volume. Therefore it is confirmed that the miniaturization of the RF devices greatly contributes to the miniaturization of portable telephones.

Figure 2 shows the block diagram of the super heterodyne system. This system uses one or two IF frequencies with plural of voltage controlled oscillators (VCOs) and high selectivity IF filters, such as SAW filter and piezoelectric ceramic filters. It achieves excellent interference-resistant characteristics. However many external RF components are required. It is difficult to miniaturize the RF circuit block.

Figure 3 shows the block diagram of the direct conversion system. This system has a clear advantage for miniaturization of RF circuits, due to the fact that it needs only one VCO and no needs of IF filters. However the RX signal is demodulated directly at the same radio frequency in a RF semiconductor IC. It is difficult to achieve important receiving characteristics, such as low noise, high interference-resistance and low power consumption. Furthermore, the VCO oscillates the same frequency as the radio frequency. High isolation characteristics in the RF circuit are required.

Figure 4 Block diagram of offset direct conversion system.
Table 1 Comparison of RF conversion systems

<table>
<thead>
<tr>
<th>Required number of devices</th>
<th>Super heterodyne</th>
<th>Direct conversion</th>
<th>Offset direct conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>VCO</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>TX-RF filter</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>RX-IF filter</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Characteristics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TX spurious</td>
<td>Fair</td>
<td>Excellent</td>
<td>Good</td>
</tr>
<tr>
<td>TX interference-resistance</td>
<td>Excellent</td>
<td>Bad</td>
<td>Excellent</td>
</tr>
<tr>
<td>RX interference-resistance</td>
<td>Excellent</td>
<td>Bad</td>
<td>Good</td>
</tr>
<tr>
<td>Circuit size &amp; cost</td>
<td>Bad</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
</tbody>
</table>

Figure 4 shows the block diagram of “offset direct conversion system”, which has been proposed recently[1]. Here the relation of RF signal and local frequencies are shown like following equations;

\[
f_{l_{o1}} = \frac{n}{n \pm 1} \cdot f_{RF}
\]

\[
f_{l_{o2}} = f_{IF} = \frac{1}{n} \cdot f_{l{o1}} = \frac{1}{n \pm 1} \cdot f_{RF}
\]

where \( f_{RF} \) is RF signal frequency, \( f_{l{o1}} \) is 1st local frequency and \( f_{l{o2}} \) is 2nd local frequency. The 2nd local frequency is \( 1/n \) of 1st local frequency. Then, only one VCO is required.

In this system, a receiving signal is converted to an intermediate frequency of \( 1/n \cdot f_{RF} \) at the 1st mixer. By use of IF frequency, an image frequency only has possibility to become the interference to the desired signal. In this case, the image interference frequency can be suppressed easily by simple RF filters. It doesn’t require an image rejection mixer. As for the transmitting circuit, modulating characteristics does not degrade due to the difference frequency of VCO and transmission signal. And IF modulation frequency is \( 1/n \cdot f_{RF} \), TX spurious is only occurred in integral multiples of the IF frequency. This means there is no spurious response adjacent to the transmission signal. High selectivity filters for spurious suppressing does not required.

Table 1 summarizes comparison of each system. As explained above, by sifting the local frequency from the RF signal frequency, the offset direct conversion system can achieve low spurious characteristics and simple RF circuit structure as the direct conversion system, and high RX interference-resistance characteristics equally as the heterodyne system.

MINIATURIZATION HISTORIES OF RF DEVICES

So far, the portable telephone system has been changed from first generation analog system to second generation digital system. Further, in foreseeable future, third generation system will start. The required specifications for respective RF devices are greatly different. For examples, low distortions, wide signal bandwidth, high speed switching, 2GHz...
operations and so on are demanded for IMT-2000 system. Thus, new RF devices have to be developed at the transition of the generations[2].

Figure 5 shows the miniaturization histories of dielectric bandpass filters and antenna duplexers. In 1985, the configuration of bandpass filters was pin-type co-axial one. In 1990, they became SMD-type. In 1993, the laminated planar filter was introduced[3],[4]. It is very small comparing to the conventional co-axial filters. The volume is only one-twentieth. As for antenna duplexers, in 1985, the configuration of duplexer was connector-type co-axial one. In 1990, they also became SMD-type. In 1993, according to the advent of the digital system, the antenna switch duplexer was introduced[5]. In 1998, it became laminated antenna switch duplexer.

Figure 6 shows the miniaturization history of RF and IF SAW filters. In a beginning of 1990’s the
Its difficulty is explained for the case of the dielectric filters in the following section.

**DIFFICULTY OF MINIATURIZATION FOR DIELECTRIC FILTERS**

Figure 7 shows the relation between the diameter and the unloaded Q of a quarter wavelength co-axial dielectric resonator. Usually, the filter performance is evaluated by the insertion loss in the pass band and the attenuation in the stop band. A smaller insertion loss and a larger attenuation are preferable. These values of a filter are dependent on the unloaded Q of the resonator.

The unloaded Q of a resonator is related to radiation loss, material tanδ and conductor ohmic loss. For the typical co-axial resonators, the conductor ohmic loss is a main factor determining the unloaded Q.

The Q values can be read from Fig.7, as about 700 for a 10mm-diameter resonator and about 150 for a 2mm-diameter resonator. As mentioned, the resonator size becomes smaller, then the filter performance is degraded. The reason of the performance degradation is caused by the concentration of the current. Therefore the breakthrough of this trade-off is the main object to develop the very small dielectric filters.

One approach to miniaturize the dielectric filters is using stripline resonators with ceramic lamination technique. Conventional co-axial resonators have a difficulty to make a small-diameter resonator due to the limitation of precision manufacturing process of ceramics. On the other hands, ceramic lamination technique has advantage to make precision stripline resonators with thin ceramic green sheets and screen printing process. However, for compact stripline filters, the gap between stripline...
resonators becomes very narrow. It means the electro-
magnetic coupling between resonators becomes too 
large. Thus it is very difficult to make a narrow 
bandwidth bandpass filter.

To overcome this difficulty, “laminated planar 
filter”[3] and “stepped impedance comb-line 
filter”(SICF)[4] have been proposed. The laminated 
planar filter utilizes anti-resonance of the coupling 
circuit that consists of electro-magnetic coupling 
between striplines and capacitive coupling through 
a coupling capacitor. The equivalent circuit of the 
SICF is shown in Fig. 8. The resonators are stepped 
impedance type. The stripline section of the short-
end is coupled magnetically. The stripline section of 
the open-end is coupled electrically. Thus by 
controlling the each coupling independently, the 
coupling between the resonators at the center pass 
band frequency becomes either electric coupling or 
magnetic coupling. Afterward, filter performance 
with attenuation pole under the pass band or filter 
performance with attenuation pole above the pass 
band can be obtained.

By combining the techniques of the laminated 
planar filter and the SICF, the authors have developed 
small-sized and low-profile dielectric filter. The high 
selectivity has been achieved with very small size.

NEW IDEAS FOR SMALL-SIZED 
DIELECTRIC FILTERS

LAMINATED BAND ELIMINATION FILTERS

So far, all laminated filters were band pass 
type. The authors have developed laminated band 
elimination filter (BEF)[9]. Figure 9 shows the 
exploded view of 2 stage BEF. The feature of this 
filter is making use of electromagnetic coupling 
between resonators. The low insertion loss is easily 
obtained by BEF.
**FREQUENCY SHIFTABLE DUPLEXER**

For FDD systems that have narrow frequency separations between the transmitting band and the receiving band, the technique of the frequency shiftable duplexer is very effective\[10\]. The configuration and the concept are illustrated by Figs.10(a), (b). The each band is divided into lower and upper bands. Then the band is selected by control signal applied to the control terminal. Thus the substantial frequency separation becomes broad. As the results, the number of resonator can be decreased and the insertion loss becomes very small. Figure 11 shows the photograph. At this moment, the frequency shiftable duplexer consists of co-axial resonators. In the next step, the duplexer will be modified with the ceramic lamination technique to reduce the size.
LAMINATED DUPLEXER

For IMT-2000 system, the authors have developed very small laminated duplexer[11]. The volume is only one-tenth of conventional co-axial type duplexers. Figure 12 shows the photograph of the laminated duplexer for IMT-2000 system. Figure 13 shows frequency responses of TX and RX filter. This duplexer has been developed by using many miniaturizing and loss-reducing technologies mentioned in this paper. This is one of the ultimate state of the art RF devices.

CONCLUSION

The miniaturization histories of RF devices are reviewed. The new concept of offset direct conversion system is described. The miniaturization technique and new ideas for developing dielectric filters of next generation portable telephones are explained. The RF devices will be changed by using ceramic lamination technique.

REFERENCES

[5] USP5,442,812
[10] USP6,085,071