losses of 7dB have been obtained in 2-8.5 GHz frequency range. The width of the beam can be fluently varied in 100mcm – 1 mm range. The dynamics of the acoustic wave excitation have been investigated which reveals the features of impulse excitation in planar structure. Optimal condition for efficient AW excitation, when one half of common losses of the mode is transformed to acoustic wave energy, have been achieved in any YIG film (6-12 mcm thick) at any surface conditions.

Session: 5D

SAW RF FILTERS
Chair: C. Ruppel
EPCOS AG

5D-1  8:30 a.m.

THE APPROACH TO REALIZE THE CHARACTERISTICS OF SAW RESONATOR WITH THE TEMPERATURE COMPENSATION AND STEEPNESS FOR PCS DUPLEXER

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In order to transmit and receive signals simultaneously, the antenna duplexer is necessary device for the cellular phone. Because the antenna duplexers require high quality characteristics and high power durability, dielectric antenna duplexers have been used conventionally. However, recently, the quality and the power durability of SAW filters have been improved dramatically and SAW antenna duplexers have been developed and put to practical use in several cellular phone systems. However, in the PCS in US, which is one of the system using CDMA, SAW antenna duplexer has not been in practical use, yet. The frequency allocation of US-PCS consists of both 1850-1910 MHz Tx band and 1930-1990 MHz Rx band. Therefore the cross-band width is 20 MHz, which is only about 1% fractional band width. Moreover, when we design the filter for PCS duplexer, the actual cross-band is narrower because of the temperature coefficient of frequency (TCF) of a substrate. These make realization of PCS SAW duplexer using conventional LT substrate and design technology difficult. Against these backgrounds, we have proposed the band-switching antenna duplexer that consists of two duplexers, as the one of the method using conventional substrate and design technology. In this time we examined the feasibility of full-band SAW PCS duplexer. As I mentioned above, it is necessary to improve the temperature coefficient and steepness of the resonators which the filters consist of. To improve temperature coefficient of LT, we have adopted the method using SiO2 film. When the resonator is covered with SiO2, TCF is improved and steepness becomes sharp due to capacitance ratio increasing. However, in case of the resonator with SiO2 of which TCF is approximately 0 ppm/C, it is difficult to
design the filter using such resonator because capacitance ratio and Q-value is too small. In this paper, we will show that it is possible to achieve the resonator characteristics that are suitable to design the filter for PCS SAW duplexer by optimizing the temperature characteristics and frequency characteristics of Saw resonator covered with SiO2.

5D-2 8:45 a.m.

1.9 GHZ RANGE ULTRA-LOW-LOSS AND STEEP CUT-OFF DOUBLE MODE SAW FILTER FOR THE RX BAND IN THE PCS ANTENNA DUPLEXER

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This paper describes the DMS (Double Mode SAW) filter design techniques to achieve the ultra-low-loss and steep cut-off characteristics required for the Rx filter in the PCS duplexer. It is the first attempt to employ the DMS filters for SAW duplexers.

In spite of the 1.9GHz range, PCS system has only 20MHz guard band. This means that it is necessary to reduce the transition band of the Tx and Rx filters to as narrow as 10 MHz for the PCS duplexer, since the temperature drift of the frequency and the productivity have to be taken into account. The Rx filter in the PCS duplexer needs to have the ultra-steep cut-off characteristics at the lower frequency side of the pass band. The DMS filters are superior, in terms of the skirts steepness at the lower frequency side, to the ladder-type SAW filters, which are commonly used for SAW duplexers, however, further improvements are needed in order to realize the PCS Rx filter.

One major breakthrough was that we utilized the parasitic reactance for the purpose of improving the skirts steepness. From the simulation, we found that the coupling capacitance between the input and the output terminals and the ground inductance of the DMS filters dramatically improved not only the skirts steepness but also the attenuation level at the Tx band. In the experiments, we controlled and optimized the values of these parasitic reactances by modifying the filter layouts and the package structures. Moreover, larger insertion loss and poorer power durability of the DMS filters were overcome by the multiple connections in parallel. As a result, ultra-low-loss and steep cut-off DMS filters were realized which had less than 10 MHz transition band. By using above mentioned DMS technologies for the Rx filter and the advanced ladder-type design for the Tx filter, we have developed PCS SAW duplexers in the size of 5 x 5 x 1.5 mm³.
INVESTIGATION OF MERGED RX-DIFFERENTIAL OUTPUT FOR MULTI-BAND SAW FRONT-END MODULE

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Multi-band operation in GSM-based cellular phones has been accelerated by adoption of new technologies, such as a direct-conversion demodulation, an offset-phase-lock-loop modulation, etc. Recently, a quad-band FEM, i.e. 900-MHz EGSM, 1.8-GHz DCS for Europe, and 800-MHz GSM850, 1.9-GHz PCS for the USA, has been already required. However, general RF-ICs can deal with up to triple bands, i.e. EGSM, DCS, and PCS. We have proposed a new structure of a quad-band FEM with merged-type Rx output, which reduces number of Rx output ports of the FEM and can be used with common RF-ICs. First, we investigated new types of merging methods for EGSM and GSM850. We will show several examples of merging methods and will compare their features in the paper. Moreover, in addition to the multiple bands, system expansions in GSM have been continued, that is GPRS (General Packet Radio Service) has already serviced, and EDGE (Enhanced Data GSM Environment) will be serviced in Europe and the USA in near future. Especially in EGDE, it uses $3\pi/8$-rotated 8-PSK (Phase Shift Keying) modulation, which requires very accurate balanced characteristics for differential Rx-outputs for FEMs. A certain simulation results showed that amplitude- and phase-imbalances of less than ±0.8dB and ±3deg. were necessary, which were much smaller than those required for FEMs used in GSM system with GMSK (Guassian Filtered Minimum Shift Keying) modulation [1]. We also investigated a new method to achieve very accurate balanced characteristics for common Rx-differential output of EGSM/GSM850-merged FEM used in EGDE system. The design procedures and the experimental results for a new FEM structure which has a merged Rx-differential output and good balanced characteristics will be also presented in the paper.

demanded as frequency is higher and wider in mobile communication systems. Above all low insertion loss SAW filters are required, which make mobile communication terminals sensitive and low power consumption. In this paper, new structure of a low loss high pass filter with SAW resonators, a design method, and fabricated results are reported. This filter is composed of one port SAW resonators as series elements and series resonant circuits as shunt elements. We call it an m-derived ladder high pass SAW filter. An m-derived ladder high pass SAW filter has good features of low insertion loss and high attenuation in wide frequency range although the pass band frequency is apart from the rejection band frequency. We fabricate the new structure of filter to demonstrate the validity of it. The resonant circuits as shunt elements consist of chip condensers and chip inductors and the one port SAW resonators as series elements are fabricated on 128°YX-LiNbO₃ substrates. Consequently, the insertion loss of the fabricated filter is less than 0.5 dB at the frequency of 940-958 MHz, and the rejection band attenuation is more than 33 dB at the frequency of 810-828 MHz.

AN APPROACH TO ACCURATE MEASUREMENTS OF THE ELECTRICAL CHARACTERISTICS OF SAW RF FILTERS USING NEUTRAL TEST ENVIRONMENTS

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Being key components in the microwave sections of mobile terminals, surface acoustic wave (SAW) radio frequency (RF) filters have been pace makers for the development of mobile applications. In recent years form factors of SAW RF filters have decreased from 5.8x5.8 mm² to 1.4x2.0 mm², while center frequencies have shifted from 1 GHz to above 2 GHz and frequency ranges of specifications have been extended to about 6 GHz. Concurrently, there has been a constant improvement of the filter performance, such as, the matching, the close-in selectivity and the far-off selectivity as well as the isolation where applicable. Furthermore, additional functions such as impedance transformation or balun functionality have been integrated. Finally, single components such as 2-in-1 filters or duplexers combine the functions of two formerly separate filters in very compact packages.

Due to these developments the correct determination of the electrical characteristics of individual SAW RF filters has become a major issue for both design engineers of SAW filters and design engineers of mobile terminals dealing with SAW filters. So far it is well understood that the electrical properties of SAW filters largely depend on electromagnetic effects of the chip layout, the bonding structures, and the package. But with small form factors, high frequencies, and high performance requirements also the measurement setup has or can have a significant impact on the measured electrical characteristics of the filter.
The paper starts with a short discussion of typical measurement setups. The measurement setups are classified distinguishing strictly between test environments and application environments of SAW filters. By means of a couple of case studies the paper exemplifies the impact of printed circuit boards (PCBs) on the measured electrical characteristics. The effects observed are investigated using electromagnetic field simulators. Comparisons of measurements and simulations indicate excellent agreement. The paper concludes with the proposal of a neutral environment. Performing the measurement using a neutral environment allows the determination of the filter characteristics without effects caused by the PCB, which is considered an essential prerequisite for an engineering approach to a modular design of a complex system.

APPLICATION OF SAW DEVICES TO MATCHING ELEMENTS IN RF CIRCUITS
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This paper discusses the application of SAW devices to impedance matching elements in RF circuits.

Current RF ICs employ some spiral inductors for impedance matching and conversion. Although these inductors definitely improve total performances, they possess very low Q values and occupy large area. From this point of view, we have sought the possibility of replacing these inductors by inductive impedance of RF SAW devices.

First, the application of L-type configuration of two SAW resonators is discussed. It is shown that the properly designed L-type configuration enables perfect impedance matching with capacitive loads in a trade-off with achievable passband width and/or insertion loss. This is because the parallel-connected load capacitance is equivalent to an increase in the capacitance ratio of SAW resonators. Thus, when the specified passband width is rather limited and/or resonators with low capacitance ratio is obtainable, this matching function could be applied to ladder-type SAW filters of the cascaded L-type configuration.

It should be of interest to note that the required input and output impedance is conjugate, the L-type configuration can be designed without deteriorating achievable passband width and insertion loss.

Secondly, the application of double-mode SAW (DMS) filters is discussed. The DMS filters are also expected to possess the impedance matching function to some extent although they are more sensitive to capacitive loads than the L-type configuration. It is shown that for 3-IDT structure, the parallel-connected outer IDTs are less sensitive to capacitive loads than the center IDT.

Presently, chip-size packaging of SAW devices is paid much attention and seems to be applied to future System-in-Package (SiP) integration of SAW devices with RF circuitry. This suggests that the impedance matching technique discussed here may be used in SiP-integrated RF SAW devices.