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The Transfer function of the distortionless SAW Duplexer for IS'95, GSM and UMTS Mobile systems

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Abstract

This paper presents the transfer function of three mobile systems (IS'95, GSM and UMTS) of the distortionless surface acoustic wave duplexer for different window lengths (0.2 μ sec and 2.0 μ sec) using the Fourier transform convolution technique. The closed form of the transfer function of the systems is expressed in terms of the sine integral function. The surface acoustic wave duplexer is considered the main part of the mobile communication devices because of its advantages (small size, high reliability, low cost, high quality factor, temperature stability, wide dynamic range, linear phase response, ruggedness, high stability, reproducibility and achieve superior performance bandwidth). The obtained results show the comparison between the performances of these three mobile systems, the Fresnel ripples in the pass bands and Gibbs ripples in the stop bands are decreased by increasing the window length (SAW transducer time length).

I. Introduction

The current mobile telephones and wireless communication system around the world operate in frequency bands from about 200 MHz to 2 GHz; the dramatic increase in consumer use of such products and systems has led to corresponding upsurge in the production of SAW-devices products for these systems [1]. This paper is concerned with three digital mobile radio systems: the global system for mobile communications (GSM), the American interim standard 95, or IS-95 which is now called CDMAONE and the Universal Mobile Telecommunications System (UMTS) which is the 3G system. The multiple access method used by GSM is time division multiple access (TDMA), and this represented a significant change from the first generation (1G) analogue systems that operated with frequency division multiple access (FDMA). IS-95 had a more complex radio interface than GSM, employing code division multiple access (CDMA). Engineers at that time often held strong and somewhat uncompromising views regarding multiple access methods. GSM was deployed before CDMAONE and is the market leader, entrenched in many parts of the world. Its success is due to numerous factors: its advanced backbone network, the introduction of subscriber identity modules (SIMs) that decoupled handsets from subscribers, its good security system and the low cost equipment due to open (i.e. public) interfaces. CDMAONE started as a radio interface. It was a bold step to use CDMA at a time when few thought CDMA could work in a cellular environment. But it did so, acquiring the necessary backbone network, and became a global standard offering tough competition to GSM. It is also worthy of note that Europe, which had designed and promoted GSM, has opted for wideband CDMA for its third generation (3G) networks [2].

II. SAW Duplexers

A duplexer allows simultaneous transmitter and receiver operation with a single antenna. The ideal duplexer perfectly isolates the receiver and transmitter from each other while providing lossless connection to the antenna for both. A duplexer is characterized by insertion loss. Excessive insertion loss degrades the noise figure of the system, which in turn inhibits signal-to-noise ratio performance [3]. Recently, mobile handsets have required numerous functions and high performance, including slim design, compact body, camera, high-resolution and large LCD, high-speed data transmission, and multiple bands. The electronic components being mounted in terminals also need to be more integrated, smaller and lighter, resistant to temperature change, vibration and shock as well as highly reliable. In responding to these demands, Kyocera [4] has developed the Duplexer SD25 series of Chip Size Package (CSP) by taking advantage of its unique simulation technology that mounts minimized SAW element directly on ceramic substrate, seals it and coats it with resin. Optimizing the combination of the SAW element and the substrate enables the Duplexer to be as small as 2.5 x 2.0 x 0.8 mm (typical value), making it one of the smallest duplexers in the industry. The product boasts excellent resistance to climate and mechanical impact thanks to its airtight structure, which seals with soldering the surrounding of the element mounted on the substrate. Fig.1. represents the basic GSM Transceiver with I-Q Modulation - Demodulation showing possible SAW components and Fig.2. Shows a duplexer circuit with SAW components.

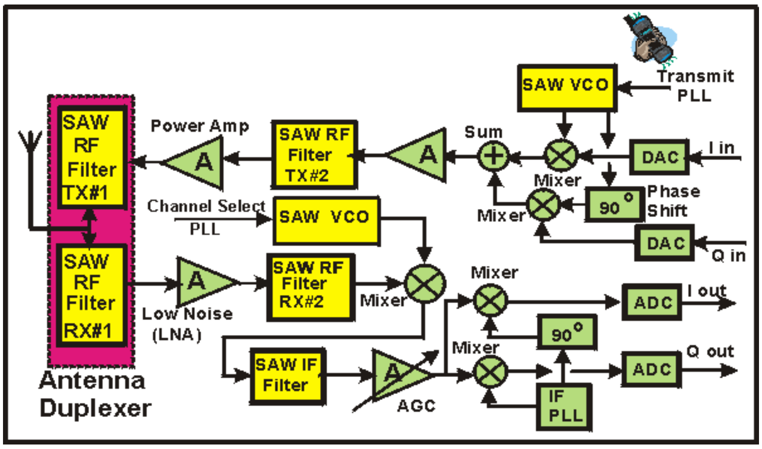

Fig.1. Basic GSM Transceiver With I-Q Modulation/Demodulation, Showing Possible SAW Components [5].

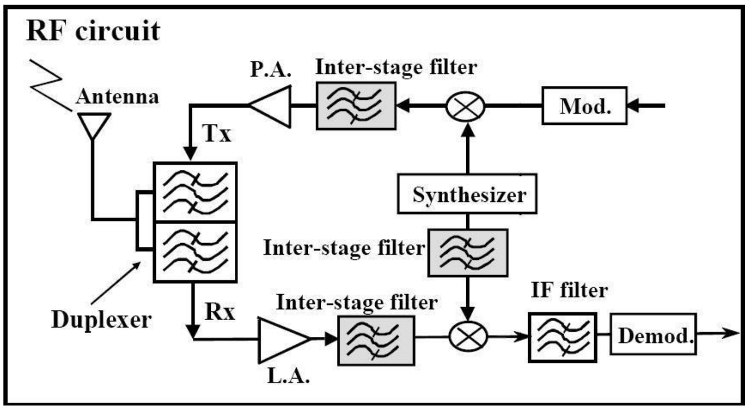

Fig.2. Duplexer Circuit with SAW components [6].

III. Mobile Systems

1- The global system for mobile communications (GSM)

a- GSM is a cellular network, which means that mobile phones connect to it by searching for cells in the immediate vicinity. GSM networks operate in four different frequency ranges. Most GSM networks operate in the 900 MHz or 1800 MHz bands. Some countries in the Americas (including Canada and the United States) use the 850 MHz and 1900 MHz bands because the 900 and 1800 MHz frequency bands were already allocated. The rarer 400 and 450 MHz frequency bands are assigned in some countries, notably Scandinavia, where these frequencies were previously used for first-generation systems. Time division multiplexing is used to allow eight full-rate or sixteen half-rate speech channels per radio frequency channel. There are eight radio timeslots (giving eight burst periods) grouped into what is called a TDMA frame. Half rate channels use alternate frames in the same timeslot. The channel data rate is 270.833 Kbit/s, and the frame duration is 4.615 msec. There are four different cell sizes in a GSM network macro, micro, pico and umbrella cells. The coverage area of each cell varies according to the implementation environment. Macro cells can be regarded as cells where the base station antenna is installed on a mast or a building above average roof top level. Micro cells are cells whose antenna height is under average roof top level; they are typically used in urban areas. Pico cells are small cells whose coverage diameter is a few dozen meters; they are mainly used indoors. Umbrella cells are used to cover shadowed regions of smaller cells and fill in gaps in coverage between those cells. The main features of GSM are: 1) Frequency bands (Uplink (TX) From 890 MHz to 915 MHz and Downlink (RX) From 935 MHz to 960 MHz), 2) The Modulation used in GSM systems is Gaussian MSK, 3) 200 KHz is the Carrier channel spacing, 4) 124 are the Number of Channels, 5) 8 users per channel, and 6) Access scheme TDMA/FDM.

2- The American interim standard 95, or IS-95

IS-95 was the first CDMA mobile phone system to gain widespread use and it is found widely in North America. Its brand name is CDMAONE and the initial specification for the system was IS95A, but its performance was later upgraded under IS-95B. It is this later specification that is synonymous with CDMAONE. Apart from voice the mobile phone system is also able to carry data at rates up to 14.4 kbps for IS-95A and 115 kbps for IS-95B. The IS-95 system was introduced by Qualcomm. They had been investigating the use of direct sequence spread spectrum techniques for military use when it was realized that it could be used as a multiple access technology for mobile communications [7]. The main features of IS-95 are: 1) Frequency bands (Uplink (TX) from 824 MHz to 849 MHz and Downlink (RX) From 869 MHz to 894 MHz), 2) The Modulation used in CDMAONE systems is QPSK/OQPSK, 3) 1250 KHz is the Carrier channel spacing, 4) 20 are the Number of Channels, 5) 798 users per channel, and 6) Access scheme CDMA/FDM.

3- Universal Mobile Telecommunications System (UMTS)

The target of the third generation mobile communication system is the introduction of multimedia capabilities, the bearer capability targets have been defined as 384 kbps for full coverage (internet access) and 2 Mbps for local coverage (video / picture transfer). The main features of UMTS are : 1) Frequency bands (Uplink (TX) from 1920 MHz to 1980 MHz and Downlink (RX) from 2110 MHz to 2170 MHz), 2) The Modulation used is QPSK, 3)Carrier channel spacing 5 MHz, 4) Access scheme CDMA/FDD.

IV. Distortionless SAW Duplexer

In the linear systems, with particular reference to filters and communication channels operating in the linear region, the response of the distortionless system is an exact replica of the input signal, except for a possible change of amplitude and a constant time delay. If x(t) is the input transmitted signal, the response y(t) will be

$$y(t) = k\, x(t-t_o) \qquad (1)$$

Where k is the constant which accounts for the change in amplitude and t_o is the constant time delay to accounts for the delay in transmission. Taking the FT based on the time shifting property, yields

$$Y(f) = K\, X(f)\, e^{-j2\pi f t_o} \qquad (2)$$

Where $X(f)$ and $Y(f)$ are the Fourier transformations of x(t) and y(t), respectively. The transfer function of the distortionless filter is, therefore

$$H(f) = k\, e^{-j2\pi f t_o} \qquad (3)$$

A more general expression for the transfer function of the distortionless filter is given by

$$H(f) = k\, e^{j(-2\pi f t_o \pm n\pi)} \qquad (4)$$

Where n is an integer or zero and the term $e^{\pm jn\pi}$ is equal to +1 and -1 for even and odd n, respectively. Last equation indicates that in order to achieve distortionless transmission through a filter, the transfer function must satisfy the constant amplitude response $H(f)$ equal to k and linear phase equal to $-2\pi f t_o \pm n\pi$, for all frequencies.

The spectrum of the transmitted band pass signal is limited to a band of frequencies, then equation (2) needs to be satisfied by the filter only for that band of frequencies, In practice, the conditions for distortionless filters can only be satisfied approximately. That is to say, there is always a certain amount of distortion present in the response. The filter is then said to be dispersive. Amplitude and phase distortions may be distinguished in the dispersive filter [8].

The transfer function of the theoretical distortionless filter is

$$H(f) = k\, e^{j(-2\pi f t_o)} \qquad f_c - B \le |f| \le f_c + B \qquad (5)$$
$$= 0 \qquad |f| \ge B$$

or equivalently

$$H(f) = \left\{ rect\left[\frac{f-f_c}{2B}\right] + rect\left[\frac{f+f_c}{2B}\right]\right\} e^{j(-2\pi f t_o)} \qquad (6)$$

Where for convenience k equals 1 and n equals zero. The parameter 2B defines the bandwidth of the filter and is small compared with the carrier frequency f_c. Taking the inverse Fourier Transform for equation (6) based on the time and frequency shifting properties, the impulse response yields

$$h(t) = 4B \text{ Sinc } [2B\,(t-t_o)] \cos(2\pi f_c t) \qquad (7)$$

This impulse response is a cos $(2\pi f_c t)$ wave, modulated by a Sinc function centered at the time delay t_o. The system is non-causal because it violates the Paley-Wiener criterion [9]. Which means that the impulse response $h(t)$ has infinite time. The SAW devices must be of finite length due to the finite length of the available surface wave substrates. The finite impulse response is achieved by multiplying $h(t)$ by the rectangular window function centered at $t = t_o$, so equation (7) yields

$$h_W(t) = 4B\, Sinc\,[2B\,(t - t_o)] \cos(2\pi f_c t)\ rect\left[\frac{t-t_o}{\tau}\right] \qquad (8)$$

Where τ is the SAW transducer time length. Taking the Fourier Transform for equation (8), based on the time and frequency shifting properties, the transfer function will be

$$H_W(f) = \left\{\left\{rect\left[\frac{f-f_c}{2B}\right] \otimes \tau\, Sinc\,(\tau f)\right\} + \left\{rect\left[\frac{f+f_c}{2B}\right] \otimes \tau\, Sinc\,(\tau f)\right\}\right\} e^{j(-2\pi f t_o)} \qquad (9)$$

or equivalently

$$H_W(f) = \left(\frac{1}{\pi}\right)\{Si\,[\tau\pi(f - f_c + B)] - Si[\tau\pi(f - f_c - B)] + Si\,[\tau\pi(f + f_c + B)] - Si[\tau\pi(f + f_c - B)]\} e^{j(-2\pi f t_o)} \qquad (10)$$

Where $\otimes$ is the convolution notation and Si(u) is the Sinc integral function shown in fig.3., which is given by

$$Si(u) = \int_0^u \frac{\sin(x)}{x}\, dx \qquad (11)$$

Equation (10) shows the transfer function of the ideal distortionless SAW band pass filter in terms of sine integral function Si (u) and is derived by the convolution technique

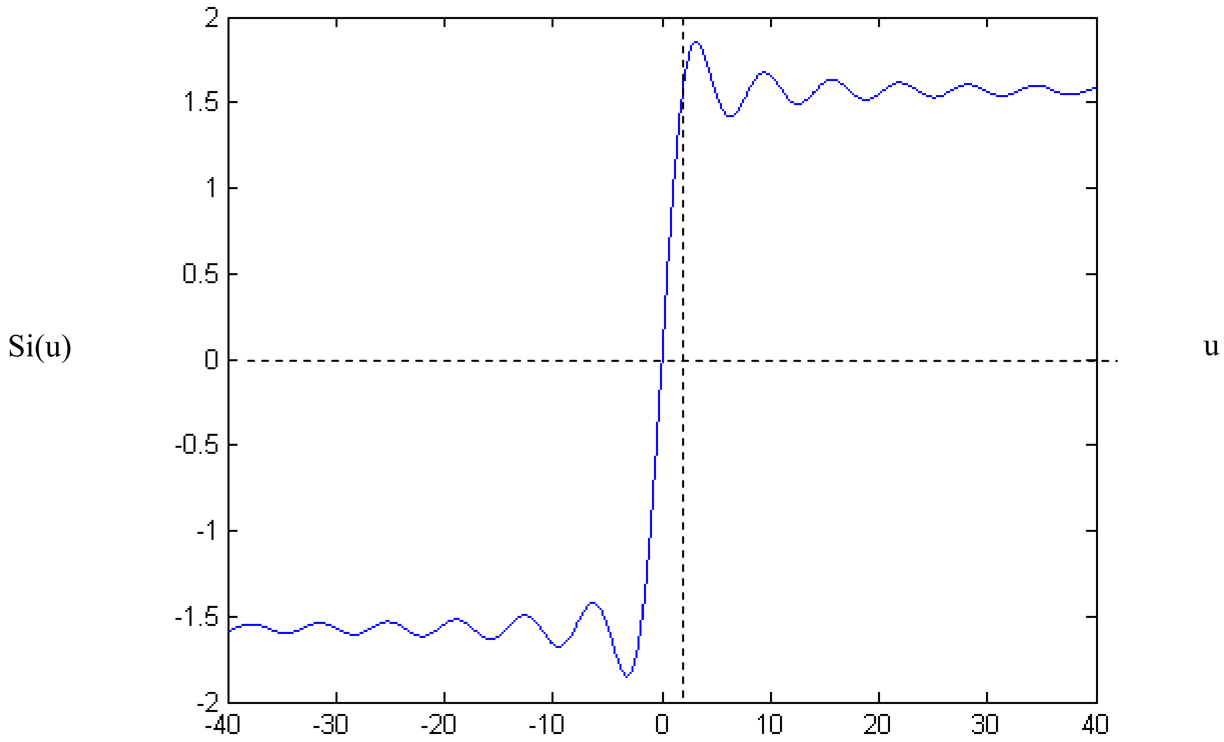

Fig.3. Sinc Integral function

V. The Transfer Function of the distortionless SAW duplexer for IS'95, GSM and UMTS mobile systems

1- The transfer functions of the transmitter and receiver, equation (10) are plotted for different mobile systems using different window lengths (0.2 μ sec and 2 μ sec) where Fig.4. represents Transmitter and Receiver of GSM mobile system for the mentioned window lengths, while Fig.5. represents Transmitter and Receiver of IS'95 mobile system for the mentioned window lengths and Fig.6. represents Transmitter and Receiver of UMTS mobile system for the same window lengths.

VI. The Insertion Loss of the distortionless SAW duplexer For IS'95, GSM and UMTS mobile systems

The Insertion Loss of surface wave filters is made up of several contributions: 1) Loss at the input transducer, 2) Loss at the output transducer, 3) Surface wave propagation loss, and 4) Loss due to beam spreading. The first two are the most significant while the last two are relatively small [10]. The Insertion Loss is the logarithmic ratio of the power delivered to the load impedance before the filter is inserted to the power delivered to the load impedance after the filter is inserted. Unit of Insertion loss in is dB [11]. Fig.7 Shows the Insertion loss of the IS-95, GSM and UMTS surface acoustic wave duplexer for transducer length $\tau = 1$ μ sec. The Insertion loss can be calculated from the following equation [12].

$$IL = 10 \log_{10} |H_{Tr}(f)|^2$$

VII. Conclusion

The surface acoustic wave duplexer is considered the main part of the mobile communication devices because of its advantages (small size, high reliability, low cost, high quality factor, temperature stability, wide dynamic range, linear phase response, ruggedness, high stability, reproducibility and achieve superior performance bandwidth). It can be shown from Fig.4, Fig.5, and Fig.6 for the GSM, IS-95 and UMTS mobile systems that the transfer function approaches the ideal distortionless transfer function while the Fresnel ripples in the pass bands and Gibbs ripples in the stop bands are decreased by increasing the window length (SAW transducer time length). Also, Fig.7 shows the Insertion Loss of the three mobile communication systems, illustrating the Amplitude of the Insertion Loss in the pass bands and stop bands of the Transmitter and Receiver of the surface acoustic wave duplexer for the ideal theoretical distortionless systems.

VIII. References

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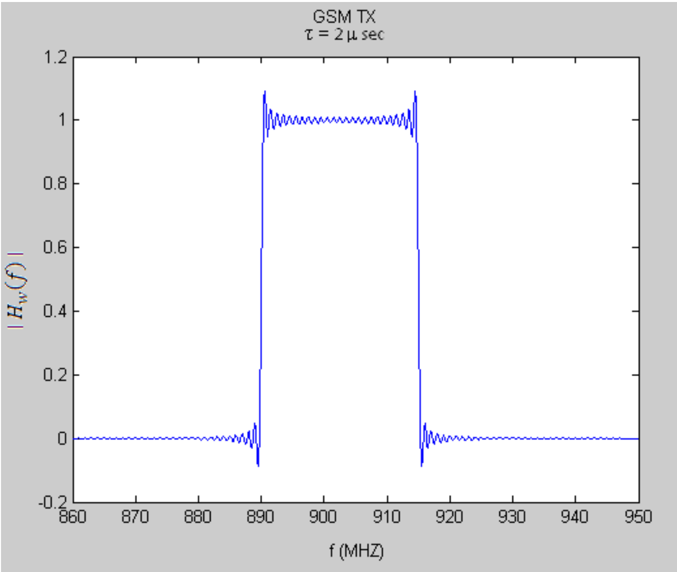

Fig.4a.

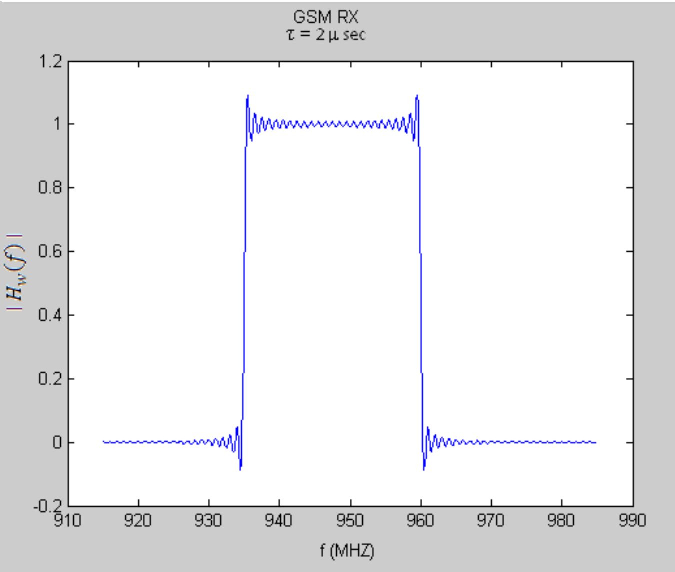

Fig.4b.

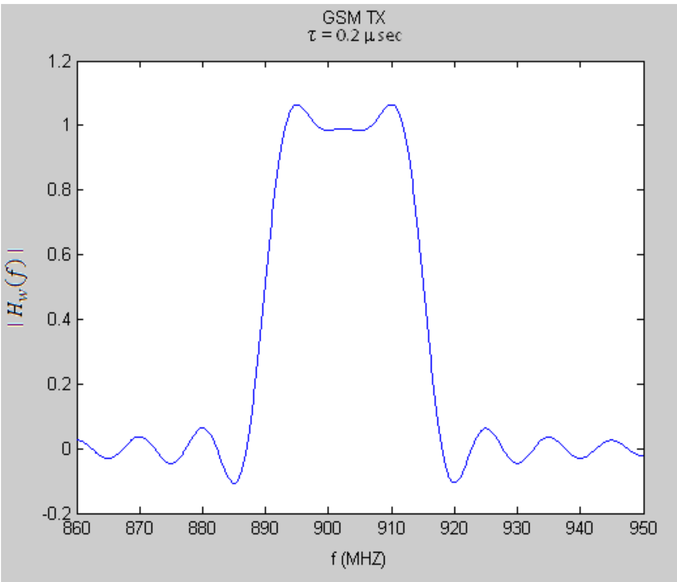

Fig.4c.

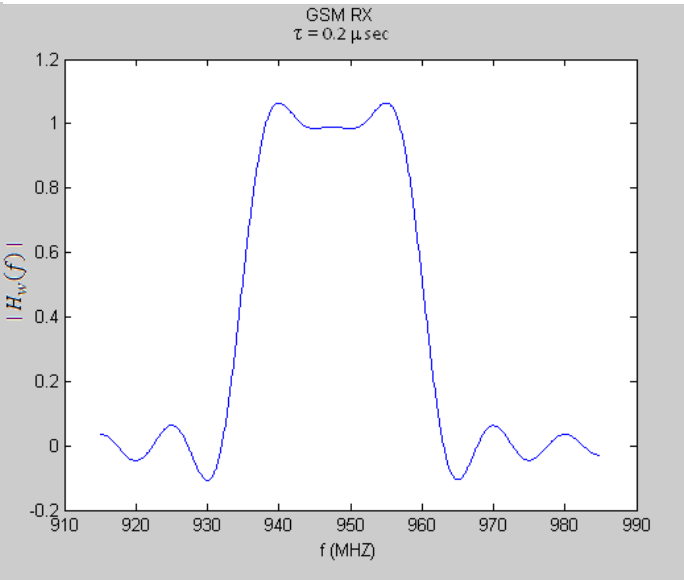

Fig.4d.

Fig.4. The magnitude of the Transfer Function of the distortionless duplexer for GSM mobile System for τ = 0.2 μ sec and τ=2 μ sec

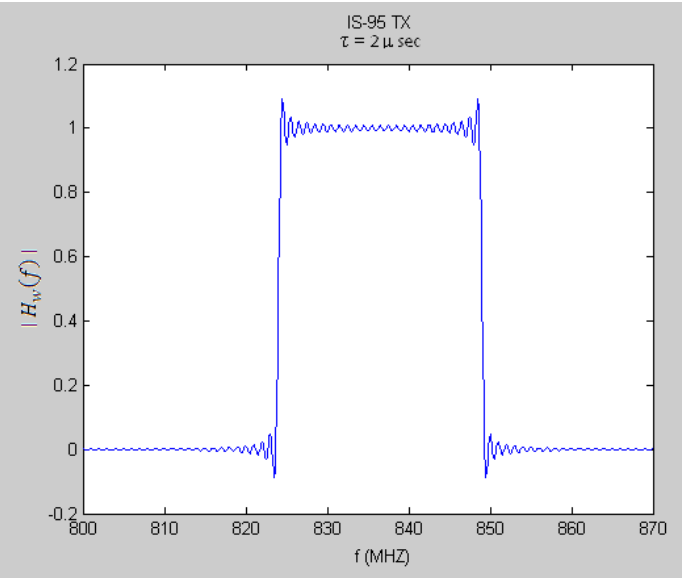

Fig.5a.

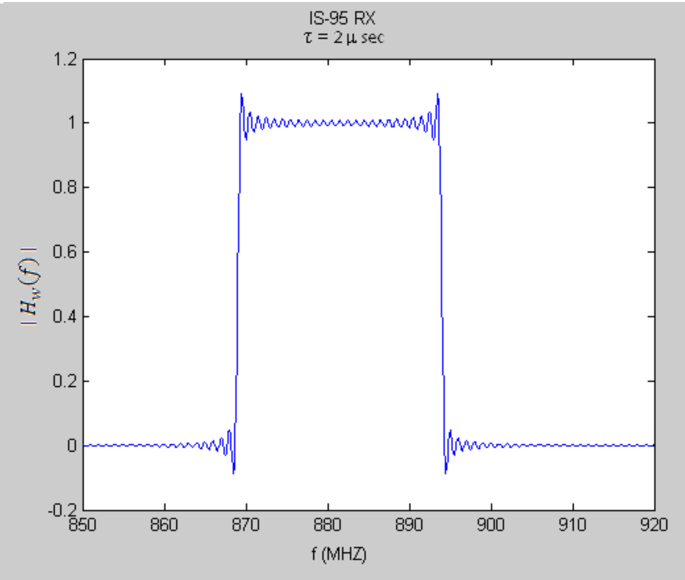

Fig.5b.

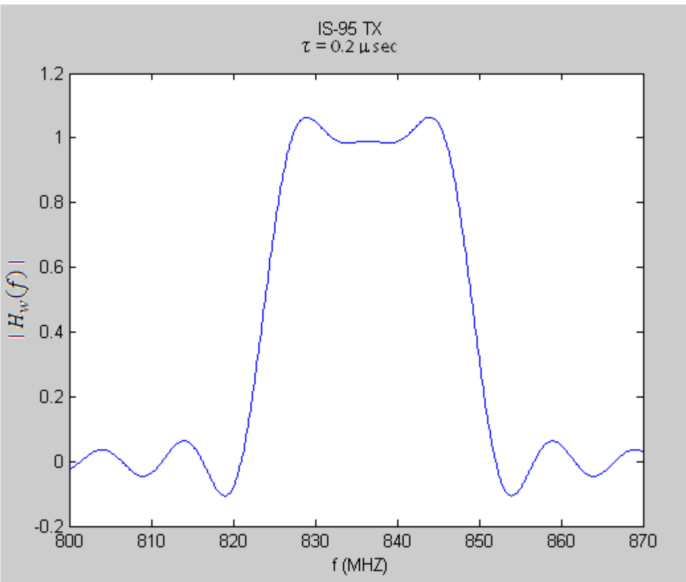

Fig.5c.

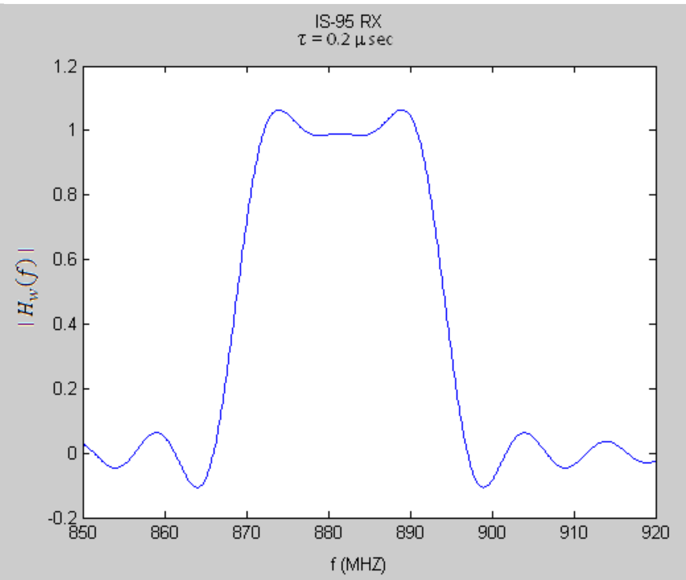

Fig.5d.

Fig.5. The magnitude of the Transfer Function of the distortionless duplexer for IS'95 mobile System for $\tau = 0.2\ \mu$ sec and $\tau=2\ \mu$ sec

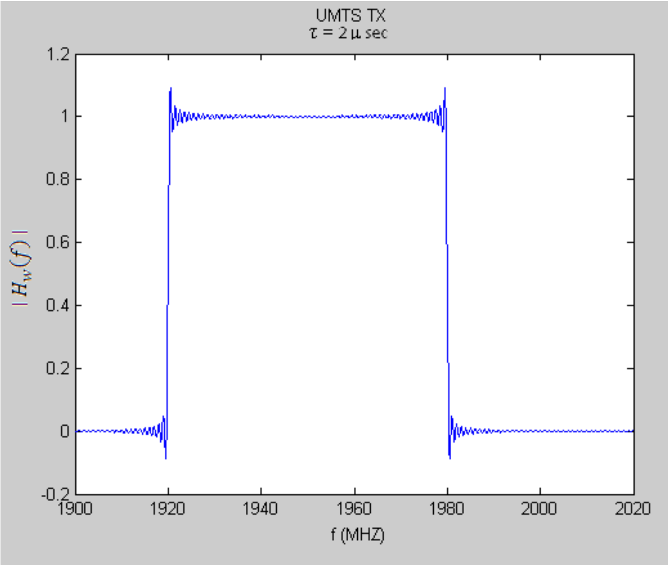

Fig.6a.

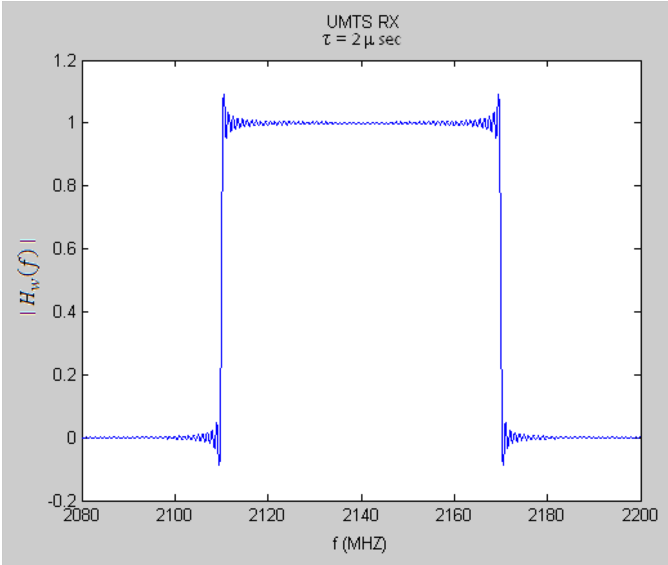

Fig.6b.

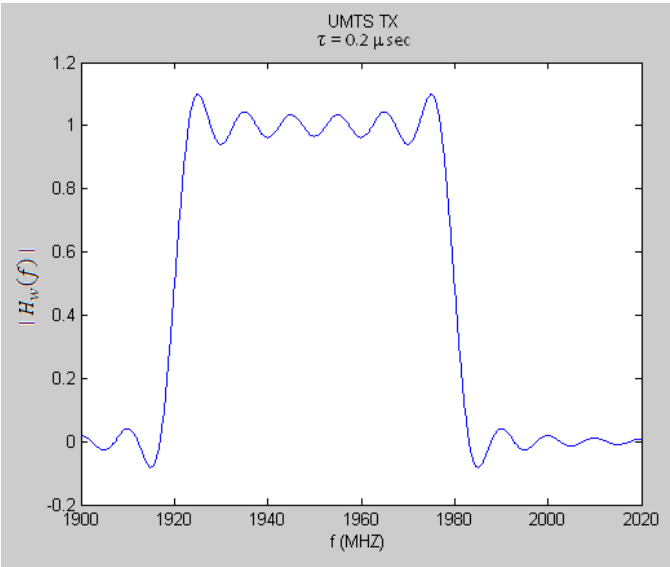

Fig.6c.

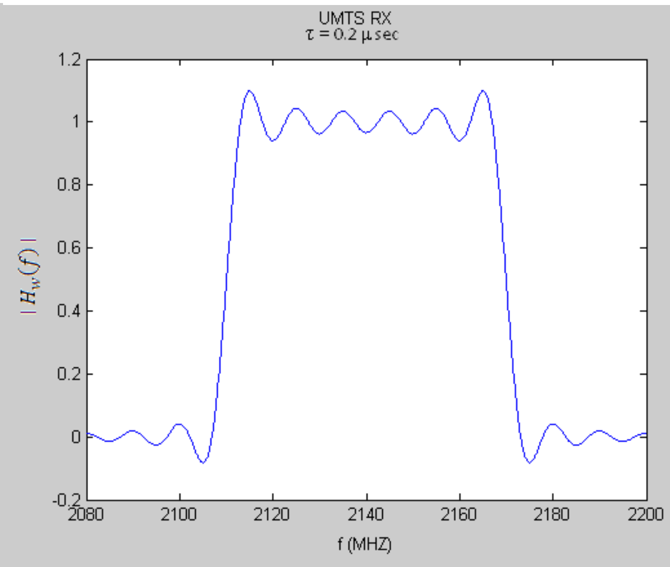

Fig.6d.

Fig.6. The magnitude of the Transfer Function of the distortionless duplexer for UMTS mobile System for $\tau = 0.2\ \mu$ sec and $\tau=2\ \mu$ sec

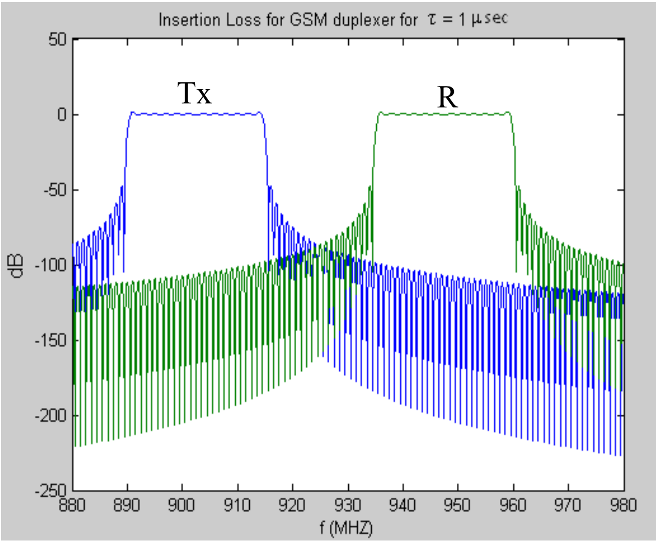

Fig.7a.

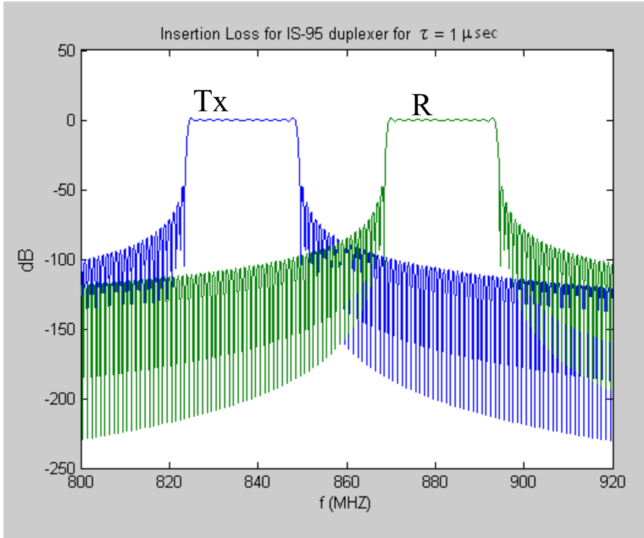

Fig.7b.

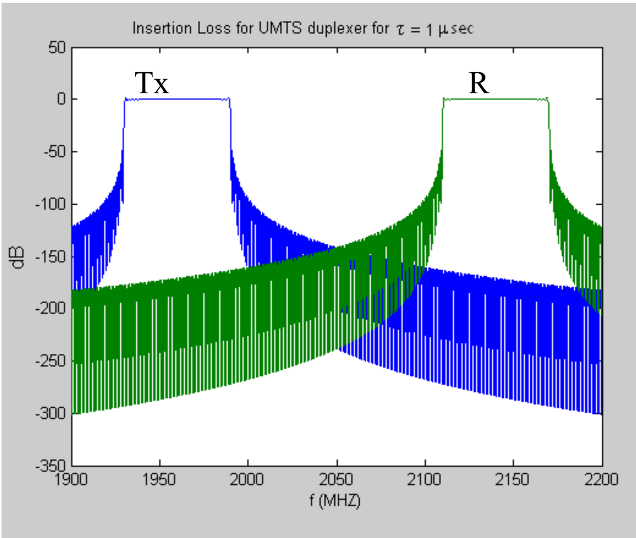

Fig.7c.

Fig.7. Insertion loss of the distortionless duplexer for IS'95, GSM and UMTS mobile Systems for $\tau = 1$ μ sec