Design of duplexer using waveguide filters For GSM applications

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***Abstract*— GSM (Global System for Mobile Communications, is a standard developed by the European Telecommunications Standards Institute (ETSI) to describe protocols for second generation (2G) digital cellular networks used by mobile phones. The GSM transmission and reception bands are closer to each other, hence they may cause interference. Hence a duplexer is required. Duplexer is a device that allows bi-directional (duplex) communication over a single path. In radar and radio communications systems, it isolates the receiver from the transmitter while permitting them to share a common antenna. Hence two frequencies are used, namely Up link(890-915 MHZ) and Downlink (935-960 MHz) in P-GSM 900. Two waveguide bandpass filter is implemented using inductive post, which transmits uplink and downlink bands. The two waveguide filters are joined by a T Junction. The overall system acts as a duplexer, with high return loss, low insertion and reduced interference between GSM bands.**

***Index Terms*— GSM, ETSI, P-GSM 900, 2G**

I. Introduction

The GSM standard was developed as a replacement for first generation (1G) analog cellular networks, and originally described a digital, circuit-switched network optimized for full duplex voice telephony. This was expanded over time to include data communications, first by circuit-switched transport, then packet data transport via GPRS (General Packet Radio Services) and EDGE (Enhanced Data rates for GSM Evolution or EGPRS).

Subsequently, the 3GPP developed third generation (3G) UMTS standards followed by fourth generation (4G) LTE Advanced standards, which are not part of the ETSI GSM standard. P- GSM 900 standard is used Indian urban area. 890-915 MHz is the uplink band. 935-960 MHz is the downlink band. A duplexer is designed to prevent interference between the two bands.

II. OBJECTIVES

The objectives are listed below

1. To reduce interference between uplink and downlink bands of P-GSM 900.
2. To obtain low loss and high power using waveguide filter
3. To get the required bandwidth with high return loss.

Manuscript received April 19, 2014.

VineethV, B.E. in Electronics and communication engineering, from Thiagarajar college of Engineering in 2014.

III. METHODOLOGY

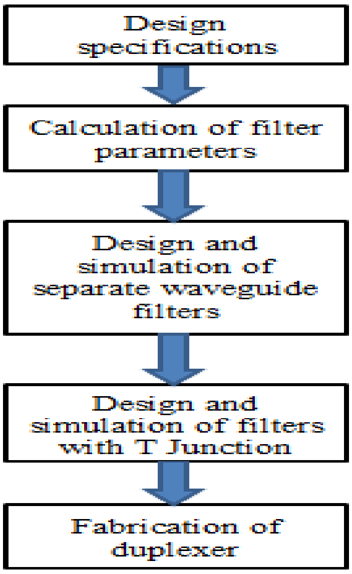


Figure 1. Methodology

Figure 1 shows the design methodology.The problem is identified as unreliability in communication and low insertion loss. The designed specification 890-915 MHz and 935-960 MHz, which corresponds to P-GSM 900 band. They are used for civilian purposes. The chosen fractional bandwidth is 0.02 or 2%, for both of the frequencies. The satisfied waveguide for this frequency range is chosen. The waveguide filters parameters are calculated . After designing, the two waveguide resonators is simulated separately. Then E- Plane T junction is designed for combining the two resonators. The two GSM bands are transmitted without interference. The final simulation result was found to be correct and the process of fabrication is being carried on.

IV. PROPOSED WORK

A. Design specification

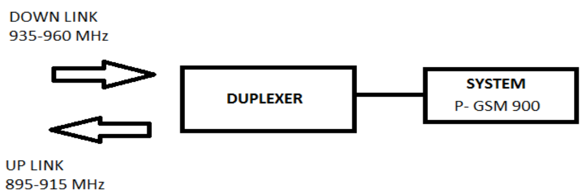


Figure 2.Proposed filter structure

Figure 2.gives the proposed filter structure. The filter must able to transmit both uplink and downlink GSM bands without interference, thus acting as a GSM duplexer. The following table gives the design specifications covering both uplink and downlink bands of proposed design.

	Uplink band	Downlink band
ω'	902.5 MHz	947.5 MHz
ω_1	915 MHz	960 MHz
$L_A(\omega')$	30 dB	30 dB
L_{Ar}	0.1 dB	0.1 dB

A. Calculation of filter parameters

1) Choose type of filter (Maximally flat, equal ripple, etc.).

Chebyshev filter of Type II is chosen

2) Find "fractional bandwidth" Δ

$\Delta = \omega_{BW}/\omega_o$
$\omega_{BW} = \omega_1 - \omega_2$
ω_O = center frequency ω_o

3)Convert frequency where attenuation is specified(ω) to normalized low pass form

4) Find the filter order N that ishigher than the required attenuation at the frequency.

5) Use the tablesto find the "g" valuesof the filter(Chebyshev or binomial)

6) Use equations to find Z_{oJn} for n=1,2……N+1

The order of the filter can be found out using these formula

$$L_A(\omega') = 10\log_{10}\left\{1 + \epsilon\cos^2\left[n\cos^{-1}\left(\frac{\omega'}{\omega'_1}\right)\right]\right\}_{\omega'\leq\omega'_1}$$

$$L_A(\omega') = 10\log_{10}\left\{1 + \epsilon\cosh^2\left[n\cosh^{-1}\left(\frac{\omega'}{\omega'_1}\right)\right]\right\}_{\omega'\geq\omega'_1}$$

where

$$\epsilon = \left[\operatorname{antilog}_{10}\left(\frac{L_{Ar}}{10}\right)\right] - 1$$

n is the order of the filter

ω' is the cutoff frequency

ω_1' is the pass edge frequency

$L_{Ar}$is the pass band ripple attenuation

L_A (ω') is the pass band attenuation

For both the cases, the order is calculated as three, the 'g' values can be found, for Chebyshev filter with pass band attenuation 0.1 dB, considered.

'g' values are 1.0325, 1.1474, 1.0315, 1.000

B. Design and simulation of waveguide filter

The waveguide dimensions are taken from waveguide charts, corresponding to P-GSM 900 band. The start and stop frequencies are used for further calculations

Waveguide Band-pass filter

$l = \lambda_g/2$ …………eqn(1)

$= \lambda_0/2[1-(\omega_c/\omega_0)^2]^{1/2}$

………………………eqn(2)

$\omega_c$is the cutoff frequency

$\omega_0$is the centre frequency

$\lambda_g$is the guide wavelength

$= \lambda_0/2[1-(\lambda_0/2a)^2]^{1/2}$ …………eqn(3)

The above formula is used to calculate length of waveguide for corresponding frequency.

$\lambda_g = \lambda_0/[1-(\omega_c/\omega_0)^2]^{½}$ ………eqn(4)

The above formula is used to find the waveguide wavelength and

$\lambda_{g0} \approx (\lambda_{g1} + \lambda_{g2})/2$

…………………eqn(5)

$\alpha = [(\lambda_{g1}/\lambda_{g0})\sin(\pi\lambda_{g0}/\lambda_{g1})]^{-1}$

…………………eqn(6)

α for uplink band is 12.9 and downlink band is 14.332

The above formula is used to calculate an intermediate value to find Zr.

$z_r = (2\alpha/\eta)\sin[(2r-1)\pi/2^N]$

$- (1/4\eta\alpha)\{ [\eta^2+\sin^2(r\ \pi/N)]/\sin[(2r + 1)\ \pi/2^N]$
$+ (\eta^2+\sin^2[(r-1)\ \pi/N])/\sin[(2r - 3)\ \pi/2^N]\}$
……………………eqn(7)

for r = 1,…………N, and

$K_{r,r+1} = [\eta^2+\sin^2(r\ \pi/N)]^{1/2}/\ \eta$ ……….eqn(8)
for r = 0,…………N,

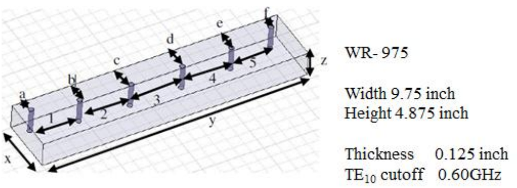
Here
$\eta = \sinh[(1/N)\ \sinh^{-1}(1/\epsilon)]$
……………………eqn(9)
η for both uplink and downlink band are 0.6362
These formulas are used to find impedance Zr, Impedance inverter values K r,r+1.

$B_{r,r+1} = [(Z_{r,r+1})^{1/2}/(K_{r,r+1})]-[(K_{r,r+1})/(Z_{r,r+1})^{1/2}]$
………….eqn(10)

The above formula is used to find Susceptance.
$\Psi_r = \pi - (1/2)[\cot^{-1}(B_{r-1,r}/2) + \cot^{-1}(B_{r,r+1}/2)]$
……………….eqn(11)

The above formula is used to find the phase length in radians.
$l_r = (\Psi_r/\ \pi)(\lambda_{g0}/2)$
……………………eqn(12)

The above formula is used to find the physical length



ForUplink 890-915 MHzWaveguide standard WR-975
All measurements in mm.
By using equations 1 to 12, the dimensions and phase lengths are calculated.

1	2	3	
180.31	181.42	180.31	
a	b	c	D
36.00	127.73	127.73	36
Width	Height	Length	
243.75	121.87	1135.6	
Radius of post	17.8		

Table 1 .Waveguide filter dimensions for uplink band

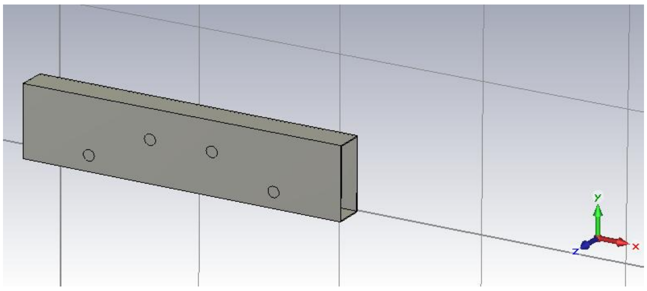


Figure 3. Waveguide filter design for uplink band

Table 1.shows the Waveguide filterdimensions for uplink band. Figure 3.shows the Waveguide filter design for uplink band. Normally waveguide acts as a highpassfilter, it is converted into bandpass filter by introducing discontinuities such as posts. The phase lengths are calculated according to the given formulas. The dimensions of waveguide are adjusted to get specified frequencies, and the radius is tuned to get specified bandwidth.

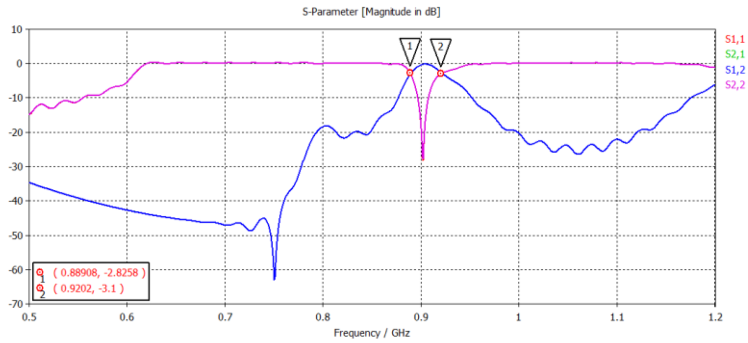


Figure 4.Simulation result for first resonator (895-915MHz)

Figure 4.shows the S parameters of uplink resonator . Fewer

changes were made, such as changing the radius of post for tuning the bandwidth and adjusting the position of post for tuning the frequency. Insertion loss of nearly 0 dB is obtained. . Frequency of range 889 -920 MHz is transmitted.

Return loss $S_{11,}$ S_{22} = -29.014 dB
Insertion loss $S_{12,}$ S_{21} = -0.336 dB

For Downlink 935-960 MHz Waveguide standard WR-975
All measurements in mm.
By using equations 1 to 12, the dimensions and phase lengths are calculated.

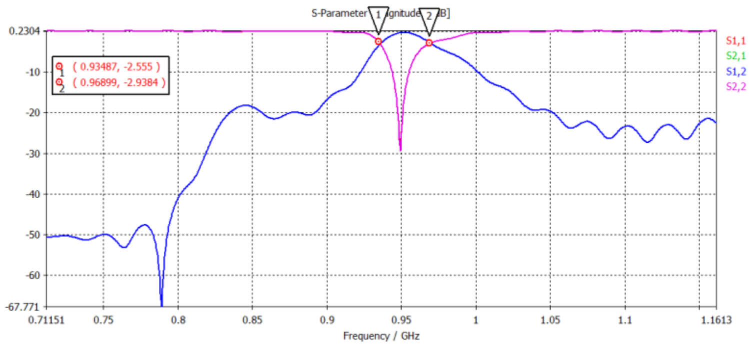


Figure 6.Simulation result for second resonator (935-960 MHz)

Figure 6.shows the S parameters of downlink resonator.

<table>
<tr><td colspan="4">1</td><td colspan="4">2</td><td colspan="4">3</td></tr>
<tr><td colspan="4">171.29</td><td colspan="4">172.35</td><td colspan="4">171.29</td></tr>
<tr><td colspan="3">a</td><td colspan="3">b</td><td colspan="3">c</td><td colspan="3">D</td></tr>
<tr><td colspan="3">34.20</td><td colspan="3">121.34</td><td colspan="3">121.34</td><td colspan="3">34.20</td></tr>
<tr><td colspan="4">Width</td><td colspan="4">Height</td><td colspan="4">Length</td></tr>
<tr><td colspan="4">243.75</td><td colspan="4">121.87</td><td colspan="4">1078.82</td></tr>
<tr><td colspan="6">Radius of post</td><td colspan="6">17.8</td></tr>
</table>

Table 2. Waveguide filter dimensions for downlink band

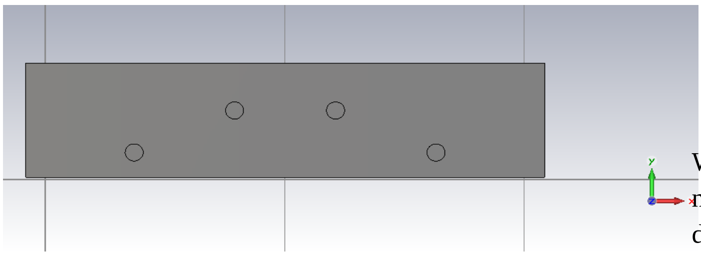


Figure 5. Waveguide filter design for down link band

Table 2.shows the Waveguide filter dimensions for uplink band. Figure 5.shows the Waveguide filter design for uplink band. Normally waveguide acts as a highpassfilter, it is converted into bandpass filter by introducing discontinuities such as posts. The phase lengths are calculated according to the given formulas. The dimensions of waveguide are adjusted to get specified frequencies, and the radius is tuned to get specified bandwidth.

Fewer changes were made, such as changing the radius of post for tuning the bandwidth and adjusting the position of post for tuning the frequency. Insertion loss of nearly 0 dB isobtained. Frequency of range 934-968 MHz is transmitted.

Return loss $S_{11,}$ S_{22}= -28.322dB
Insertion loss $S_{12,}$ S_{21} = -0.2304dB

C. Design and simulation of t junction

Waveguide junctions are used when power in a waveguide needs to be split or some extracted. There are a number of different types of waveguide junction that can be use, each type having different properties - the different types of waveguide junction affect the energy contained within the waveguide in different ways.

T Junction and types

There are a number of different types of waveguide junction. The major types are listed below:

- **H-type T Junction:** This type of waveguide junction gains its name because top of the "T" in the T junction is parallel to the plane of the magnetic field, H lines in the waveguide.
- **E-Type T Junction:** This form of waveguide junction gains its name as an E- type T junction

because the tope of the "T" extends from the main waveguide in the same plane as the electric field in the waveguide.

- **Magic T waveguide junction:** The magic T waveguide junction is effectively a combination of the E-type and H-type waveguide junctions.
- **Hybrid Ring Waveguide Junction:** This form of waveguide junction is another form of waveguide junction that is more complicated than either the basic E-type or H-type waveguide junction.

D. *E-Type waveguide junction*

B.

C. *It is called an E-type T junction because the junction arm, i.e. the topof the "T" extends fromthe main waveguide in the same direction as the E field. It is characterized by the fact that the outputs of this form of waveguide junction are 180° out of phase with each other.*

The basic construction of the waveguide junction shows the three port waveguide device. Although it may be assumed that the input is the single port and the two outputs are those on the top section of the "T", actually any port can be used as the input, the other two being outputs.

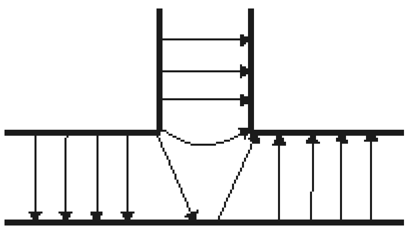


Figure 7.Electric field in E type T junction

From figure 7., It can be seen from the electric field that when it approaches the T junction itself, the electric field lines become distorted and bend. They split so that the "positive" end of the line remains with the top side of the right hand section in the diagram, but the "negative" end of the field lines remain with the top side of the left hand section. In this way the signals appearing at either section of the "T" are out of phase.

These phase relationships are preserved if signals enter from either of the other ports.

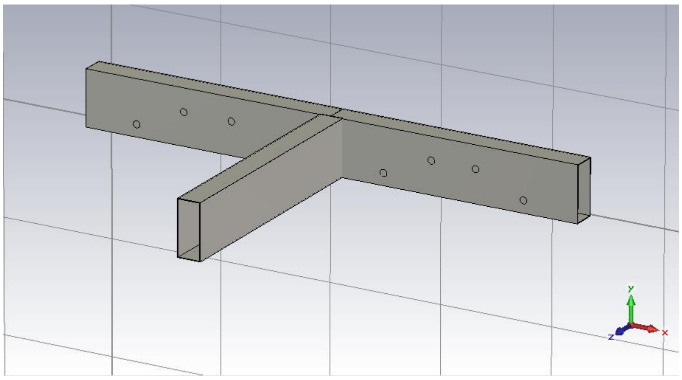


Figure 8.Designed E-type T junction

Figure 8.shows the designed E-type T junction. The T Junction was designed by joining the two waveguide resonators, and adding a third waveguide of WR 975 standards. The first and second waveguide act as input ports.The third waveguide act as output port.

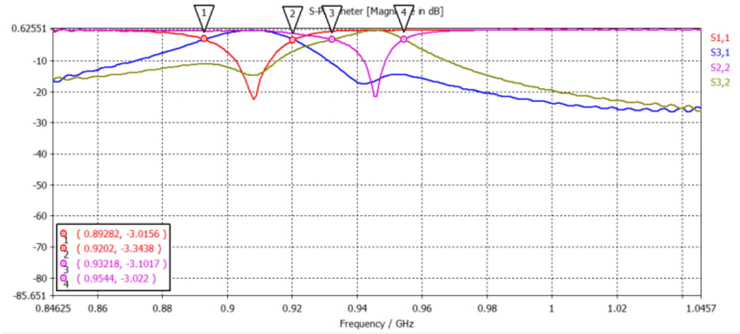


Figure 9.Simulation of duplexer with E type T Junction

Figure 9.shows the S parameters of duplexer with E Type T Junction. The two waveguide resonators are joined using a E- type T junction. On simulating the design in CST, the above results are obtained. Initially the downlink band was not transmitted properly. It was rectified by increasing the radius of post in second resonator.

The S_{12} and S_{33} parameters are insignificant and are not shown here.

Return losses S_{11} -22.36 dB
S_{22} -21.12 dB

Insertion losses S_{13} -0.62dB
S_{23} -0.45dB

I. RESULTS

The simulation result of uplink band (890-915 MHz) is shown in figure 5.2.

During initial trials, a very large bandwidth was obtained. The bandwidth is reduced by increasing the radius of the post. The bandwidth could not be reduced below 30 MHz. However return loss of -29 dB and insertion loss of is obtained.

The simulation result of downlink band (935-960 MHz) is shown in figure 5.4.

Initially the frequency response was shifted about 10 MHz away from the desired frequency range. It was shifted to the original position by increasing the length of waveguide. Return loss of dB and insertion loss of dB is obtained.

The result of simulating the duplexer is shown in the figure 5.7. The two frequency bands are transmitted. The return losses are good, However the insertion losses S_{13} and S_{23} have not got perfect responses. During downlink transmission, 30 dB return loss is not achieved at port one. Similiarly, during uplink transmission, 30 dB return loss is not achieved at port two. This is due to the fact that, the designed pass edge frequency (ω_1) is much smaller than the actual pass edge frequency.

Future work

The duplexer designed with E Type T junction will be fabricated. It will be tested in real time.

II. CONCLUSION

The thesis has proposed a duplexer for GSM transmission system with standard P-GSM 900 for uplink and downlink bands, with centre frequencies 902.5,947.5 MHz and bandwidth 25 MHz. The filter provides good rejection and insertion loss S_{11} and S_{12}. . Thus, a GSM duplexer was successfully designed and simulated using waveguide filter, in CST. The simulation result shows a very low insertion loss at the pass band, high return loss at the pass band and high insertion loss at the stop band.The uplink and downlink bands are trans mitted without interference. The filter will be fabricated in the near future and analysis will be made between the simulated and measured results

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