High Q Filter Feasibility Study

For Base-Station and Radar Receiver Applications

Author: Duncan Austin

Client: Ofcom

Client Reference: PO4100011216

Isotek Reference: IF26

Rev. No.	Revision details	Date	Checked by
D009	Updated as per Ofcom comments	15/10/09	Dr. Chris Mobbs, Director, Wireless Division

Disclaimer

This report ("report") has been prepared by Isotek Electronics Ltd for Ofcom, in connection with the award of wireless telegraphy licences below 3GHz. This report is intended for information purposes only. This report is not intended to form any part of the basis of any investment decision or other evaluation or any decision to participate in the award process for the Spectrum Bands, and should not be considered as a recommendation by Ofcom or its advisers to any recipient of this report to participate in the award process for the Spectrum Bands. Each recipient of this report must make its own independent assessment of the potential value of a licence after making such investigation as it may deem necessary in order to determine whether to participate in the award process for the Spectrum Bands. All information contained in this report is subject to updating and amendment.

The content of the report, or any other communication by or on behalf of Ofcom or any of its advisers, should not be construed as technical, financial, legal, tax or any other advice or recommendation. Accordingly, any person considering participating in the award process for the Spectrum Bands (either directly or by investing in another enterprise) should consult its own advisers as to these and other matters or in respect of any other assignment of any radio spectrum.

Summary

Ofcom is currently investigating the feasibility of introducing new RF services into the frequency bands detailed below:

1. 790MHz to 862MHz band (a part of the Digital Dividend Review);
2. 872MHz to 876MHz / 917MHz to 921MHz band; and
3. 2500 to 2690MHz band, which is close to the 2700 to 3100MHz band used for radar applications.

One area for major concern is interference between the new services and the existing networks, in particular RF interference created in the wireless front-end equipment. This study determines the optimum RF filter solution to minimise the potential for interference between adjacent RF systems.

Isotek has considerable experience in the design and high volume manufacture of high-Q filters for wireless networks. Estimates are provided on the technical performance capability of practical high-Q metallic cavity filters. In addition pricing information has been included to support a comparison of price vs. technical performance.

Table of contents

1 Introduction

1.1 Background

Among its various responsibilities, Ofcom administers and regulates the civilian use of radio spectrum within the UK to ensure that it is used in the most effective way. Technical progress and market forces result in changing demand for this spectrum, particularly at frequencies below 3 GHz which are well suited for a variety of wireless applications including for mobile and broadcasting communications.

This study investigates a variety of high performance filtering options suitable for use in three areas:

- Transmit filtering within any base-stations operating in the 790-862 MHz band to protect adjacent broadcasting services below 790MHz;

- Transmit and receive filtering in the 872-876MHz / 917-921 MHz band to protect adjacent mobile and other services;

- Receive filters for S-Band Radar 2700-3100MHz band to improve their selectivity performance from emissions within the 2500-2690MHz and 3400-3600MHz bands.

Information is provided on estimated performance of a practical filter to comply with a range of different attenuation and pass-band requirements. Estimates are also provided on the cost, size and complexity of the associated filtering.

This study is limited to filter requirements for base station equipment, radar receivers and high volume manufacture of high-Q filters for wireless networks, which is pertinent to this study. Whereas user equipment is generally very compact and price driven and manufactured in very large quantities, base station and radar receiver applications tend to be high power (for transmit filtering), physically larger, more complex and comparatively more expensive.

<u>Background on Isotek Electronics Limited.</u>

Isotek was founded in 1978 originally to design and manufacture computer based control systems. Subsequently, Isotek has diversified into a wide area of expertise including aerospace, blade welding, sub-sea robotics, telemetry systems, industrial controls and vehicle suspension systems.

Isotek became part of the Filtronic group during the late 1980's until it de-merged in 1998. In 2006 the Filtronic Wireless Infrastructure R&D group left Filtronic and joined Isotek creating two distinct areas of design and manufacture of high performance filters. Further information on Isotek's products and services is contained within the company website[1].

1.2 Filtering Technologies

The role of RF filters is to pass wanted signals (in the 'passband') with a certain maximum insertion loss, while attenuating unwanted signals (in the 'stopband') by a certain minimum level. Many types of filtering technology are used, the choice of which depends on many factors – size available, absolute frequency and bandwidth of consideration, maximum level of insertion loss and minimum attenuation required, power level of signals, etc. In addition to these electrical requirements the choice of technology is also influenced by the environment, particularly the operating temperature range, and by cost considerations.

One key parameter is the Q or 'quality factor' of a filter. This determines how much of the wanted signal is lost as it passes through the filter, and also determines how 'sharp' the filter response will be, i.e. how close the stopband can be to the passband. In the frequency range from 500MHz to 3GHz filter Q values range from a few hundred for filters composed of discrete 'lumped elements' or printed filters a few mm in size, up to more than 50,000 for ceramic resonator filters with dimensions of over 300x300x300mm.

For this study metallic cavity filters (also called combline filters) are considered for the following reasons:

- This technology enables filters to be designed that give a good compromise between performance, size and cost;
- The technology is 'mature' and available from multiple sources;
- Combline filters are suitable for low cost, volume manufacture using high pressure die-casting techniques;
- The Q values achieved result in insertion loss performance that is acceptable for many wireless infrastructure base-station requirements; and
- They exhibit good power handling capability and temperature stability.

[1] http://www.isotek.co.uk/

Interior view of typical combline filter

In each of the applications covered the combline filter performance presented is that which could be readily achieved by a number of suppliers in high volume. This assumes the following:

- Maximum filter Q is limited to that which would be typically used in current wireless infrastructure base-station filters, although lower Q (and hence smaller size & price) filters are used where possible;
- Frequency offsets to account for change in performance over temperature are set to values achievable for a unit in an indoor base-station / radar receiver scenario (range of –10°C to +65°C);
- Margins on attenuation levels are incorporated to allow for assembly, alignment and test variability; and
- Filter designs above nine resonant sections are not considered due to the excessive alignment time involved during the production process.

2 790-862 MHz band (part of the Digital Dividend)

Following the switchover of analogue TV services to digital, the spectrum above 790MHz will be available for new wireless services such as for mobile applications. Representative candidate technologies for mobile applications in these bands are LTE (Long Term Evolution) introduced by 3GPP (3rd Generation Partnership Project) and WiMAX a telecommunications technology based on the IEEE 802.16 standard. This study investigates the filtering requirements to protect adjacent broadcasting receivers below 790MHz. For the purposes of this study emissions based on LTE transmissions is assumed. However, the resulting estimate on the base station filtering requirement is considered to be broadly applicable to other candidate mobile technologies that may be deployed within the 790-862 MHz band. It is assumed that any base-station transmitter already meets the spectrum emissions requirements for LTE, however additional filtering will be required to meet the regulatory limits to be set in the use of the band.

The study examines the filtering requirements to comply with six possible regulatory limits as set out in “Karimi_Specifications_for_Isotek.ppt” (Appendix 1). The requirements are examined under three scenarios of guard bands of 0 MHz, 1 MHz & 2 MHz between new and existing services at 790MHz . In addition, two DVB-T masks at guard bands of 1MHz and 2MHz were examined as described in “Karimi_Specifications_for_Isotek-DVB-T mask.ppt” (Appendix 2). For each of these sets of limits filters are presented which provide the additional attenuation required, and estimate the resultant impact on insertion loss of the first 10MHz above 790MHz.

2.1 Regulatory Limits –59dBm/100kHz to –9dBm/100kHz

As per the study objectives in Appendix 1, it is assumed that the LTE spectrum emissions mask (SEM) has been met by the base-station giving a level of +8dBm at band edge at 790MHz (i.e. corresponding to a passband starting at 792MHz for a 2MHz guard band scenario, 791MHz for 1MHz guard band, and 790MHz for 0MHz guard band). Although this 3GPP requirement reduces slightly as the mask is further separated from band edge, for the purposes of this study it is assumed to be constant at +8dBm across the entire stopband at 790MHz and below. Hence each filter must provide sufficient attenuation to reduce power from +8dBm to the possible six regulatory limit levels under examination. These filtering requirements are as follows:

Regulatory limit (dBm/100kHz)	Filter attenuation required (dB)
-59	67
-49	57
-39	47
-29	37
-19	27
-9	17

In addition, following a request from Ofcom, an additional filter with 7dB attenuation was investigated.

The following general guidelines were assumed in the design of filters. Each filter is designed to achieve the required attenuation with reasonable production margin. A frequency shift of ±150kHz over the operational temperature range is assumed, and this can be seen in the offsets of the passband and stopband frequency markers. Each filter is designed to achieve <1dB insertion loss worst case over the passband. Where this is not achievable the plot shows at what frequency this insertion loss is achieved (loss is minimum in the middle of the passband and increases toward each band edge). Additionally, for 7dB, 17dB and 27dB attenuation cases with 2MHz and 1MHz guard band, results are also presented that estimate the resultant worst-case group delay variation over 200kHz, together with the error vector magnitude (EVM) performance over one mobile channel (see Appendix 3 for background on EVM). EVM is not calculated in cases where the result would be far outside acceptable limits. For example, 3GPP specify that the total EVM of a UMTS (3G) basestation transmitter must not be more than 17.5% EVM for QPSK modulation, or 12.5% for 16QAM modulation. As the filter is one of many components that will contribute to the overall EVM, its performance must be significantly better than the overall requirement. It should be noted that the EVM performance may be improved through equalisation techniques, which is outside the scope of this study.

The following pages show details of the achievable performance, along with size and price indication.

2.1.1 2MHz Guardband Filter Performance

2.1.1.1 67dB Attenuation Required

Notes:

- 1.7dB worst case insertion loss at lower band edge
- 1.1dB insertion loss achieved 1MHz into passband
- Approximate filter size: 210 x 210 x 75mm
- Price indication: £330 (1k volumes), £250 (10k volumes)

2.1.1.2 57dB Attenuation Required

Notes:

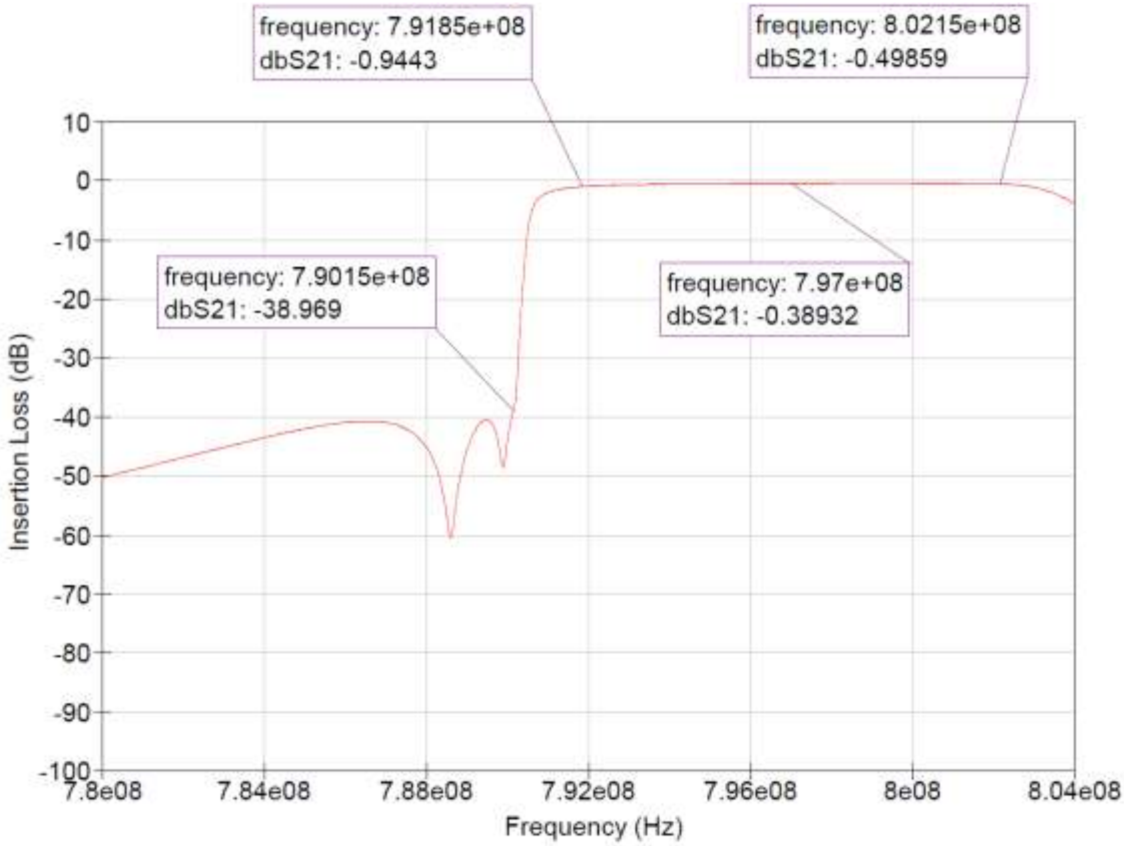
- 1.4dB worst case insertion loss at lower band edge
- 0.8dB insertion loss achieved 1MHz into passband
- Approximate filter size: 140 x 280 x 75mm
- Price indication: £310 (1k volumes), £240 (10k volumes)

2.1.1.3 47dB Attenuation Required

Notes:

- 1.1dB worst case insertion loss at lower band edge
- 0.9dB insertion loss achieved 0.5MHz into passband
- Approximate filter size: 140 x 280 x 75mm
- Price indication: £310 (1k volumes), £240 (10k volumes)

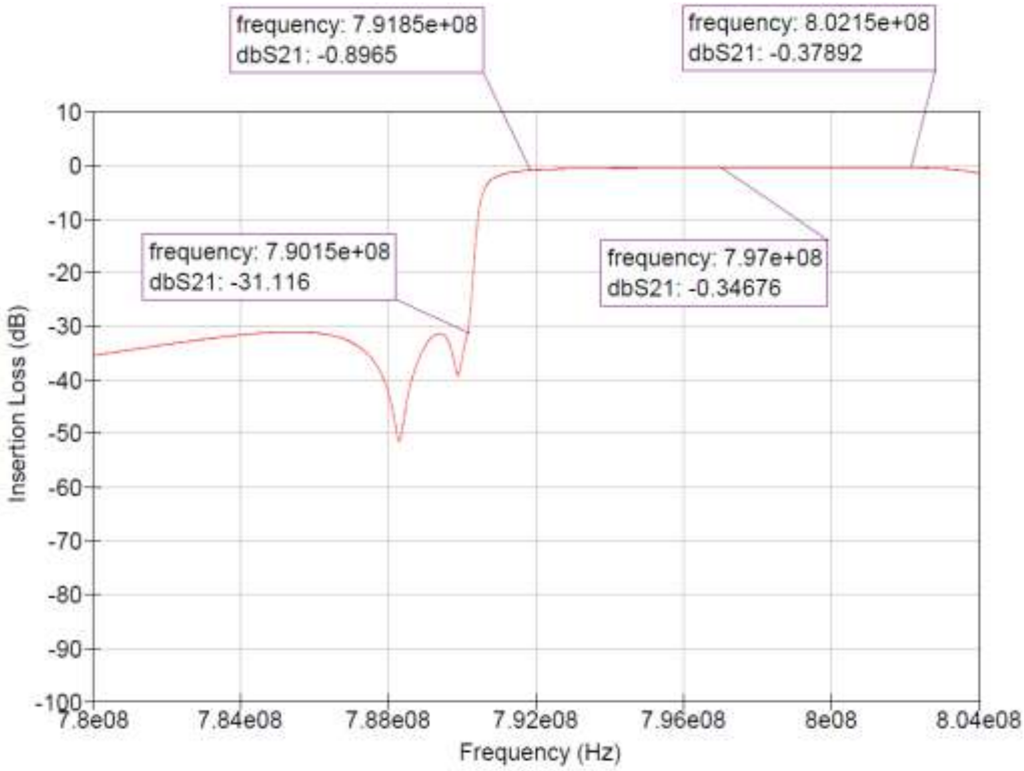
2.1.1.4 37dB Attenuation Required

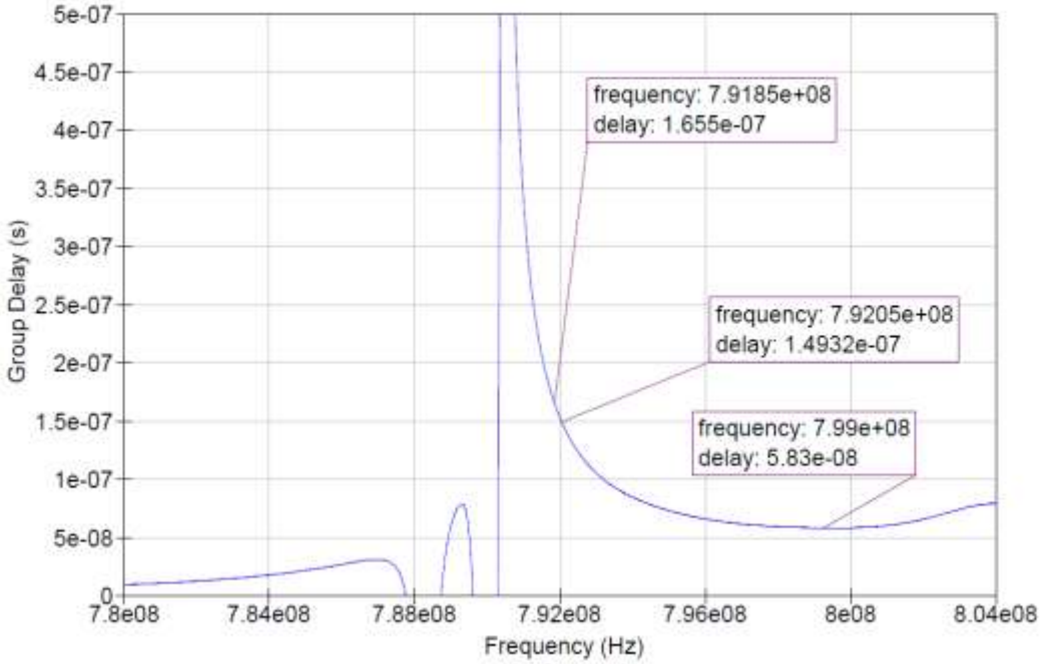


Notes:

- 1.0dB worst case insertion loss at lower band edge
- Approximate filter size: 140 x 280 x 75mm
- Price indication: £310 (1k volumes), £240 (10k volumes)

2.1.1.5 27dB Attenuation Required

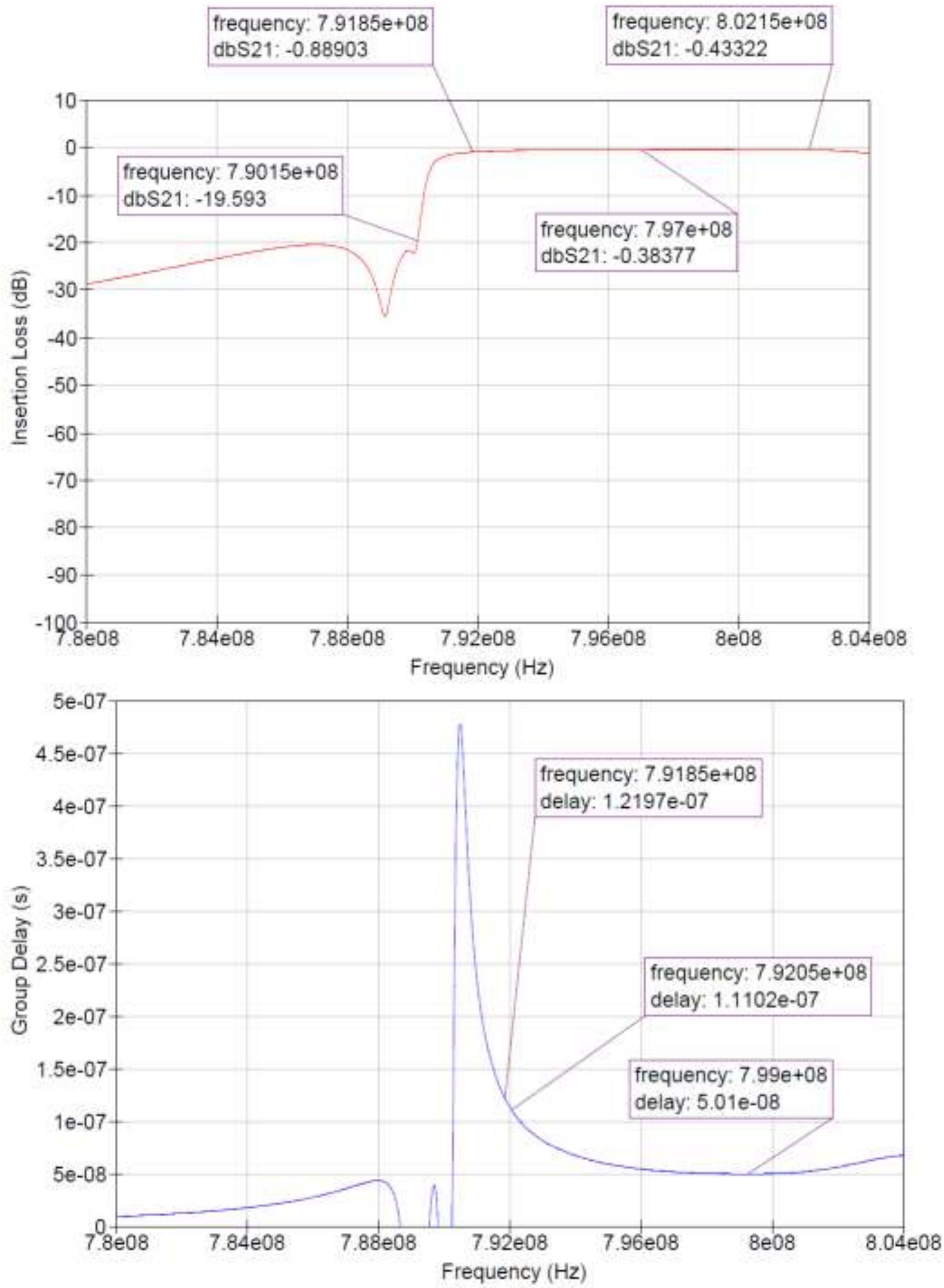




Notes:

- 0.9dB worst case insertion loss at lower band edge
- EVM = 5.2% over worst case 3.84MHz
- Group delay variation = 17ns over worst case 200kHz
- Approximate filter size: 120 x 180 x 75mm
- Price indication: £250 (1k volumes), £200 (10k volumes)

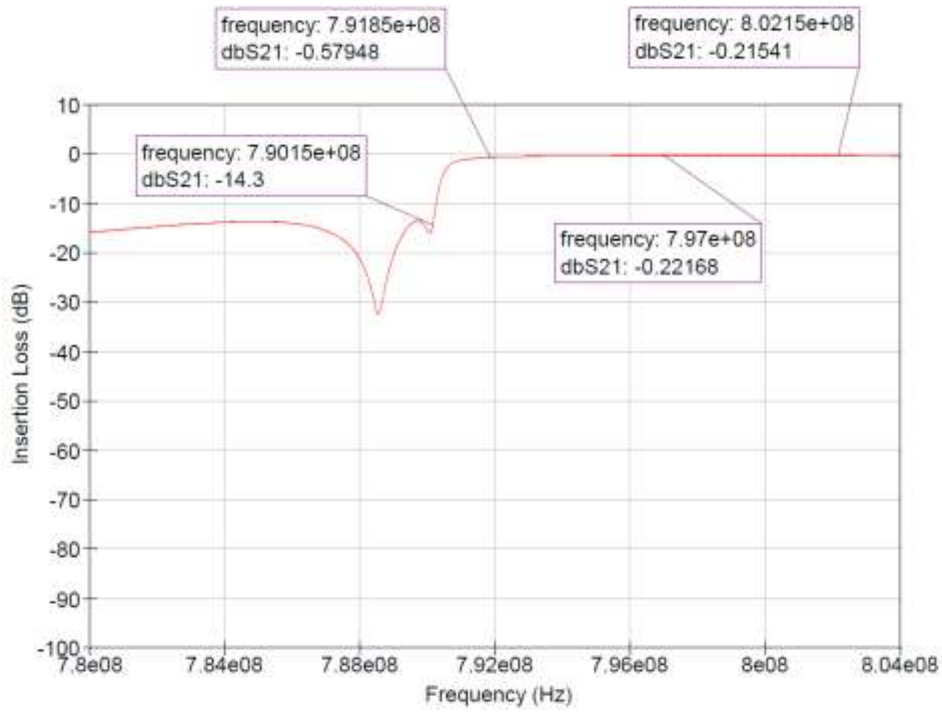
2.1.1.6 17dB Attenuation Required

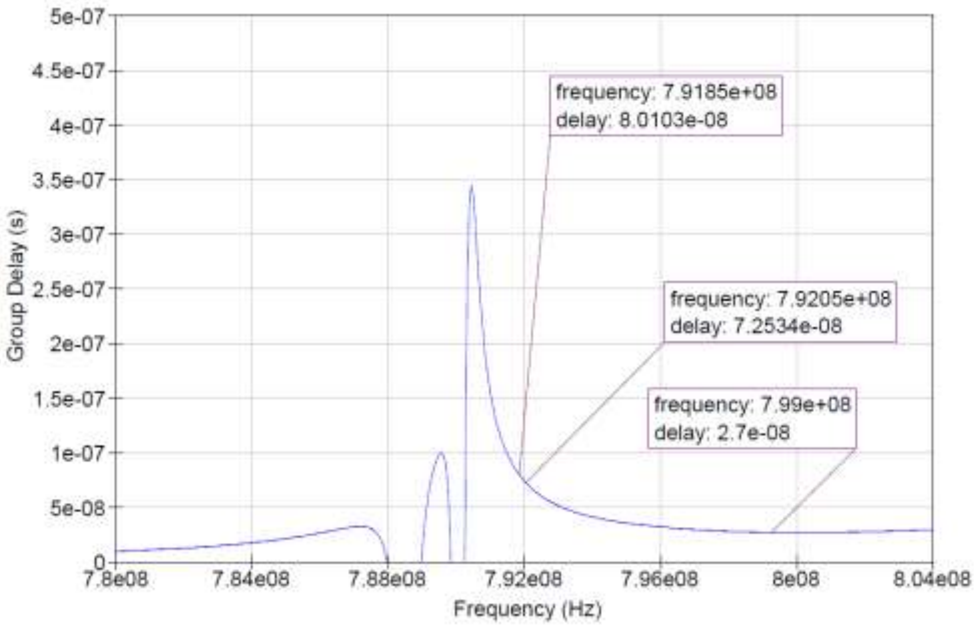


Notes:

- 0.9dB worst case insertion loss at lower band edge
- EVM = 3.6% over worst case 3.84MHz
- Group delay variation = 11ns over worst case 200kHz
- Approximate filter size: 100 x 150 x 75mm
- Price indication: £230 (1k volumes), £180 (10k volumes)

2.1.1.7 7dB Attenuation Required





Notes:

- 0.6 dB worst case insertion loss at lower band edge
- EVM = 2.6% over worst case 3.84MHz
- Group delay variation = 8ns over worst case 200kHz
- Approximate filter size: 120 x130 x 75 mm
- Price indication: £215 (1k volumes), £170 (10k volumes)

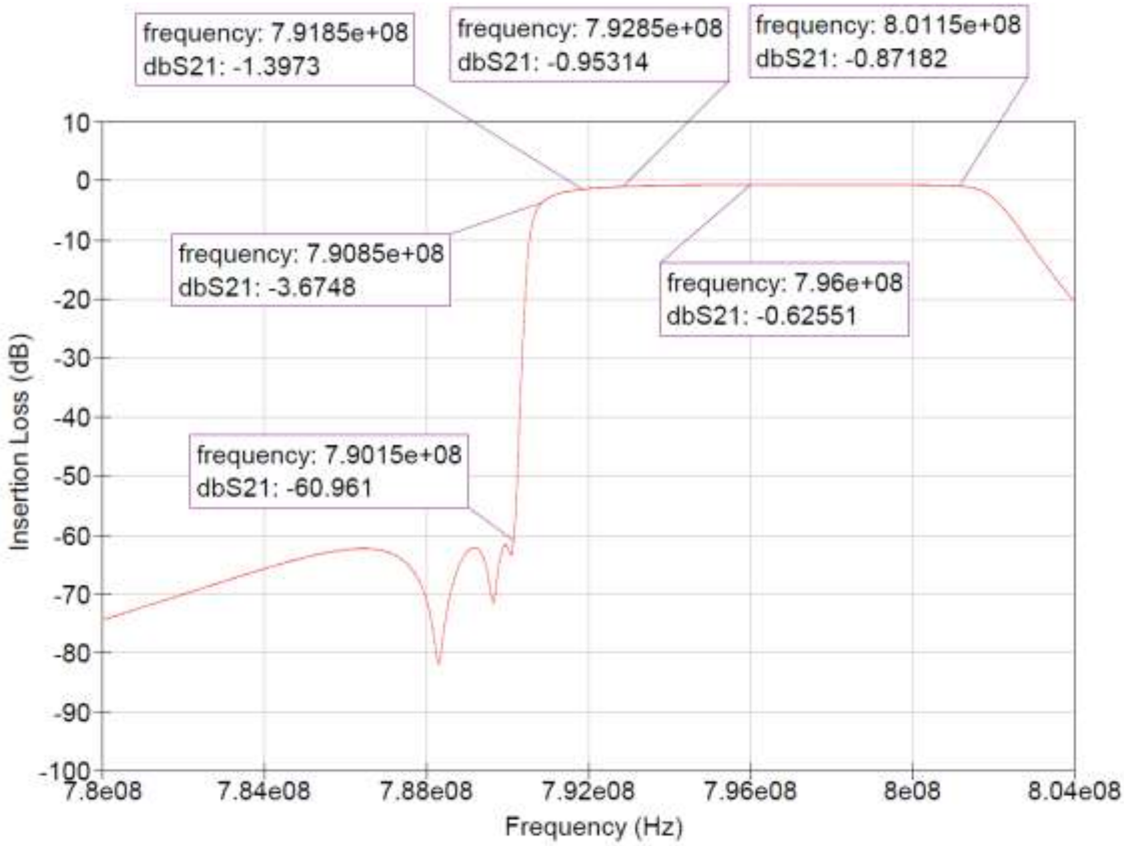
2.1.2 1MHz Guard Band Filter Performance

2.1.2.1 67dB Attenuation Required

Notes:

- 5.1dB worst case insertion loss at lower band edge
- 1.6dB insertion loss achieved 1MHz into passband
- 1.1dB insertion loss achieved 2MHz into passband
- Approximate filter size: 210 x 210 x 75mm
- Price indication: £330 (1k volumes), £250 (10k volumes)

2.1.2.2 57dB Attenuation Required



Notes:

- 3.7dB worst case insertion loss at lower band edge
- 1.4dB insertion loss achieved 1MHz into passband
- 1.0dB insertion loss achieved 2MHz into passband
- Approximate filter size: 210 x 210 x 75mm
- Price indication: £330 (1k volumes), £250 (10k volumes)

2.1.2.3 47dB Attenuation Required

Notes:

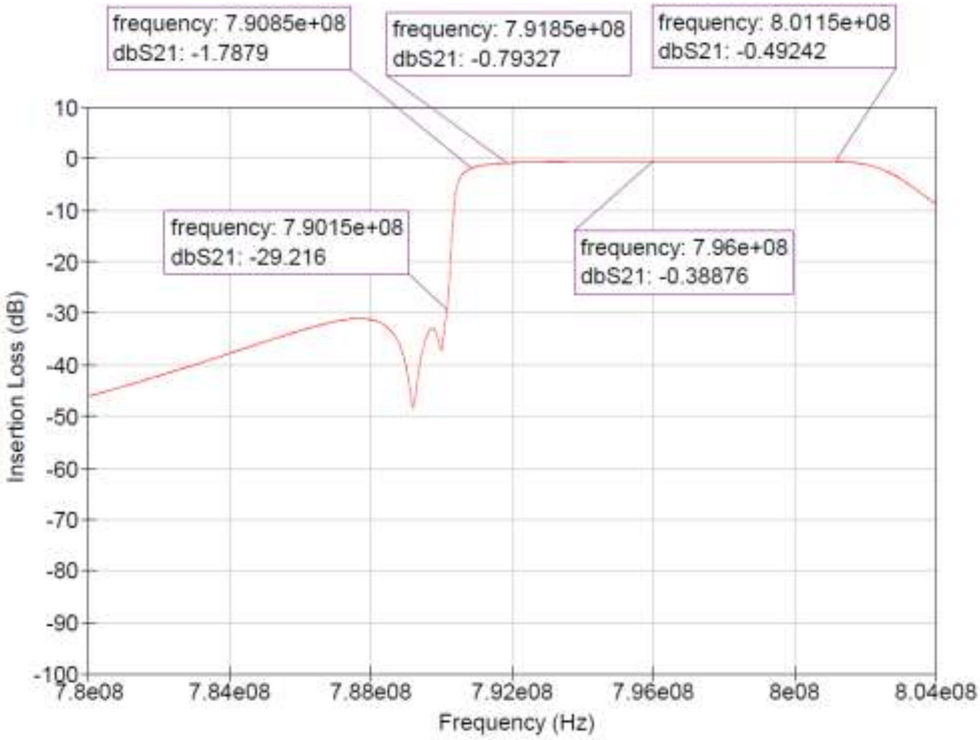
- 2.9dB worst case insertion loss at lower band edge
- 1.1dB insertion loss achieved 1MHz into passband
- 0.8dB insertion loss achieved 2MHz into passband
- Approximate filter size: 210 x 210 x 75mm
- Price indication: £330 (1k volumes), £250 (10k volumes)

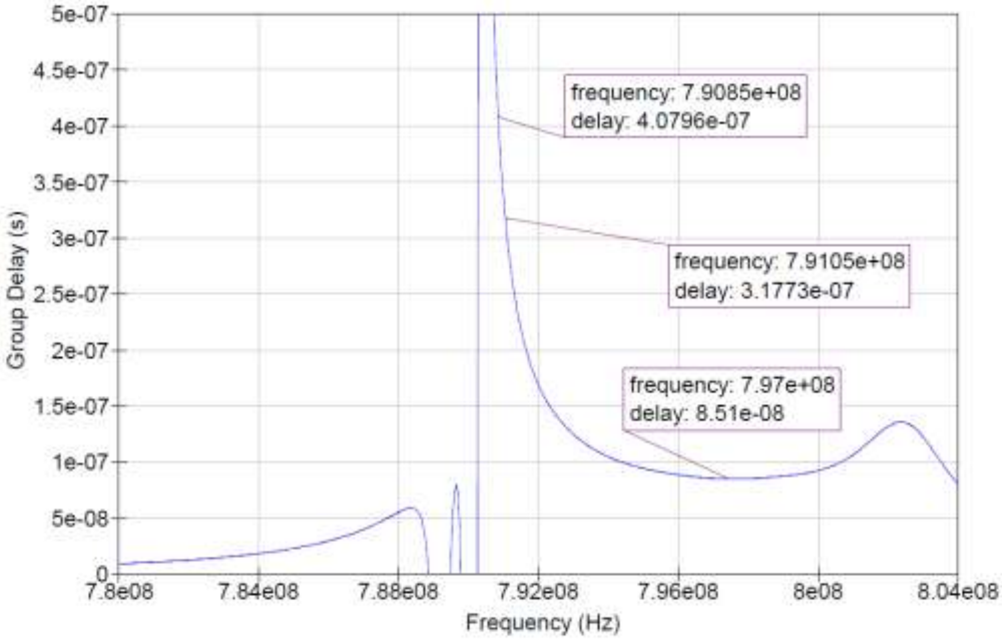
2.1.2.4 37dB Attenuation Required

Notes:

- 2.6dB worst case insertion loss at lower band edge
- 1.0dB insertion loss achieved 1MHz into passband
- Approximate filter size: 140 x 280 x 75mm
- Price indication: £310 (1k volumes), £240 (10k volumes)

2.1.2.5 27dB Attenuation Required



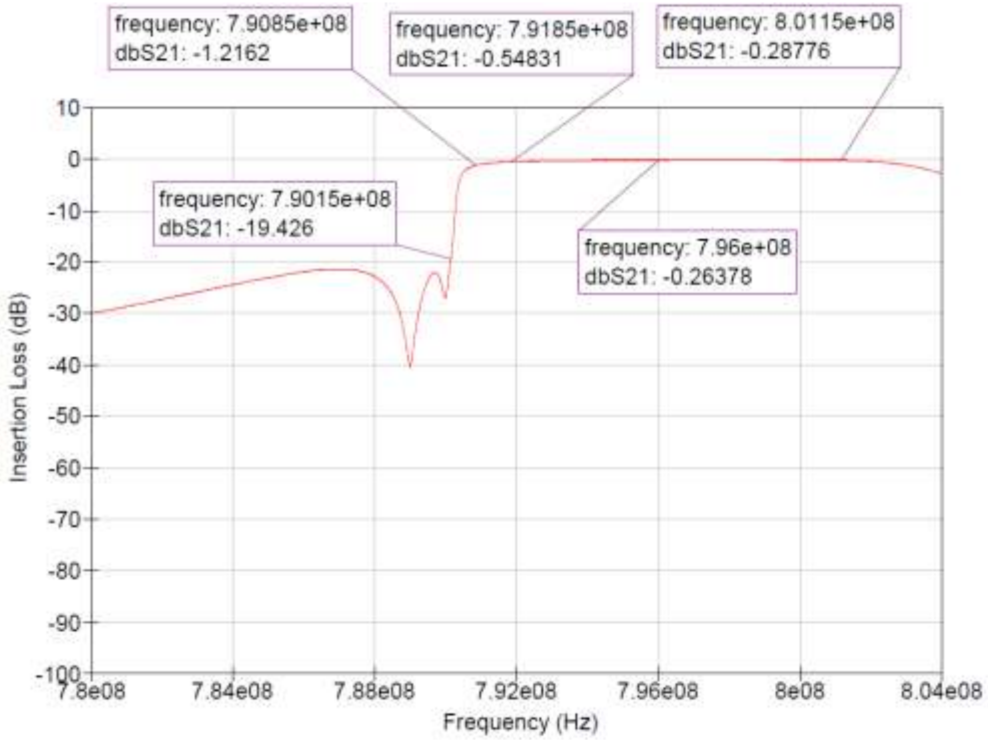


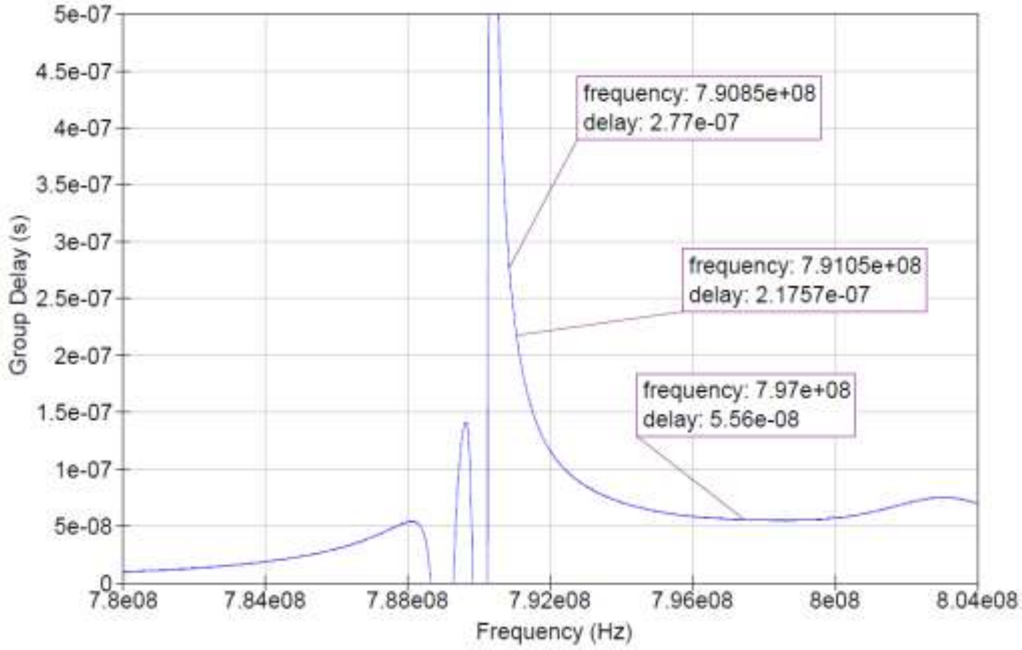
Notes:

- 1.8dB worst case insertion loss at lower band edge
- 0.8dB insertion loss achieved 1MHz into passband
- EVM = 11% over worst case 3.84MHz
- Group delay variation = 91ns over worst case 200kHz
- Approximate filter size: 140 x 280 x 75mm
- Price indication: £310 (1k volumes), £240 (10k volumes)

- For reasons given in section 1.2 only metallic 'combline' filters are considered in this report. However more complex state of the art ceramic filters could improve this performance and reduce the band edge insertion loss to approximately 0.6dB. Size and price would be two to three times that of a standard filter

2.1.2.6 17dB Attenuation Required



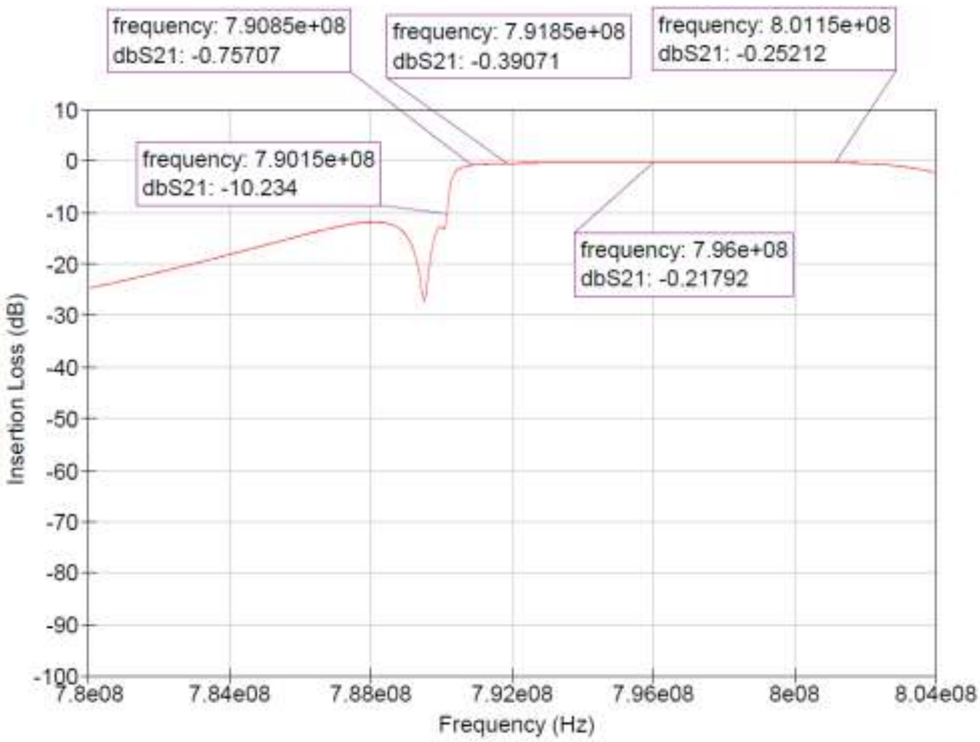


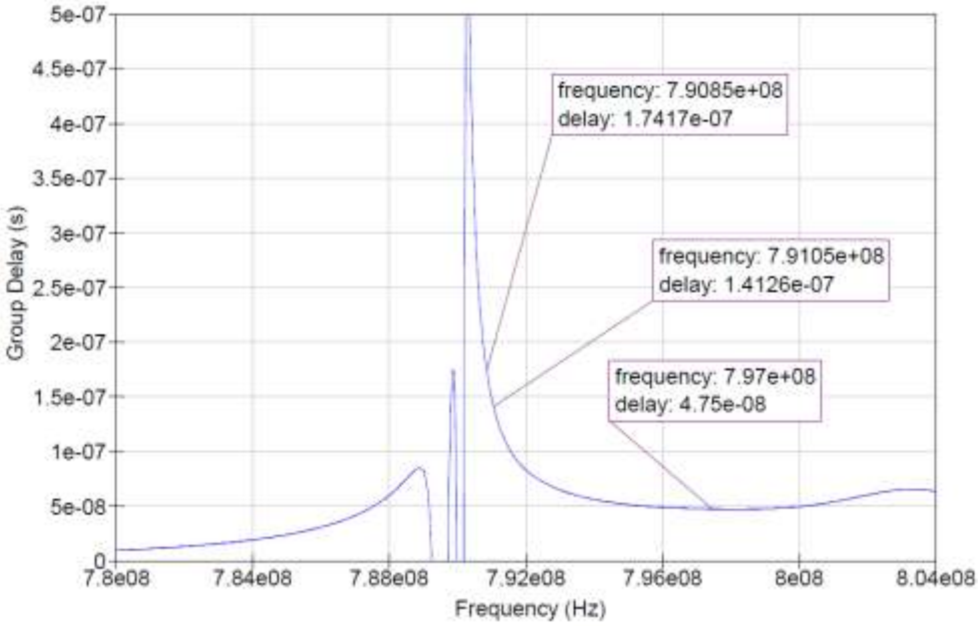
Notes:

- 1.2dB worst case insertion loss at lower band edge

- 0.5dB insertion loss achieved 1MHz into passband
- EVM = 7.5% over worst case 3.84MHz
- Group delay variation = 60ns over worst case 200kHz
- Approximate filter size: 140 x 210 x 75mm
- Price indication: £290 (1k volumes), £210 (10k volumes)
- For reasons given in section 1.2 only metallic ‘combline’ filters are considered in this report. However more complex state of the art ceramic filters could improve this performance and reduce the band edge insertion loss to approximately 0.4dB. Size and price would be two to three times that of a standard filter

2.1.2.7 7dB Attenuation Required



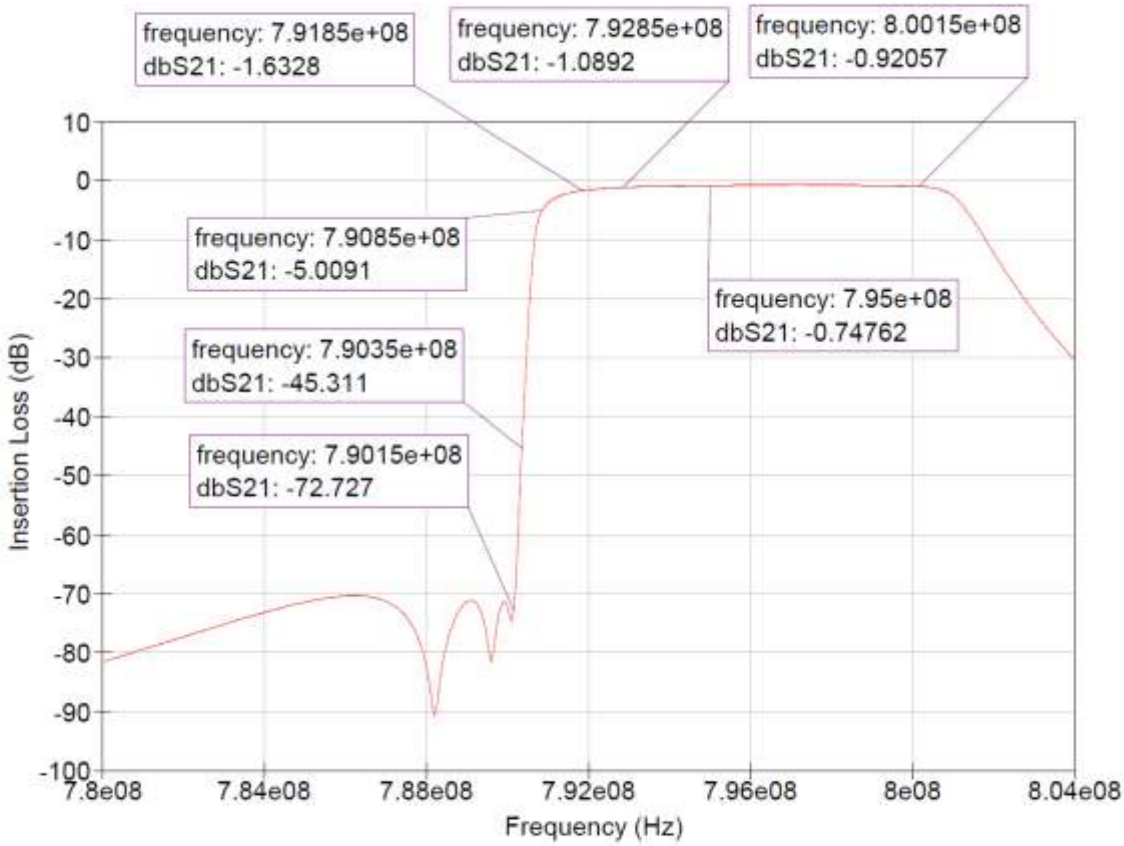


Notes:

- 0.8 dB worst case insertion loss at lower band edge
- 0.4 dB insertion loss achieved 1 MHz into Passband
- EVM = 4.4% over worst case 3.84MHz
- Group delay variation = 34ns over worst case 200kHz
- Approximate filter size: 100 x150 x 75 mm
- Price indication: £275 (1k volumes), £200 (10k volumes)
- For reasons given in section 1.2 only metallic ‘combline’ filters are considered in this report. However more complex state of the art ceramic filters could improve this performance and reduce the band edge insertion loss to approximately 0.3dB. Size and price would be two to three times that of a standard filter

2.1.3 0MHz Guard Band Filter Performance

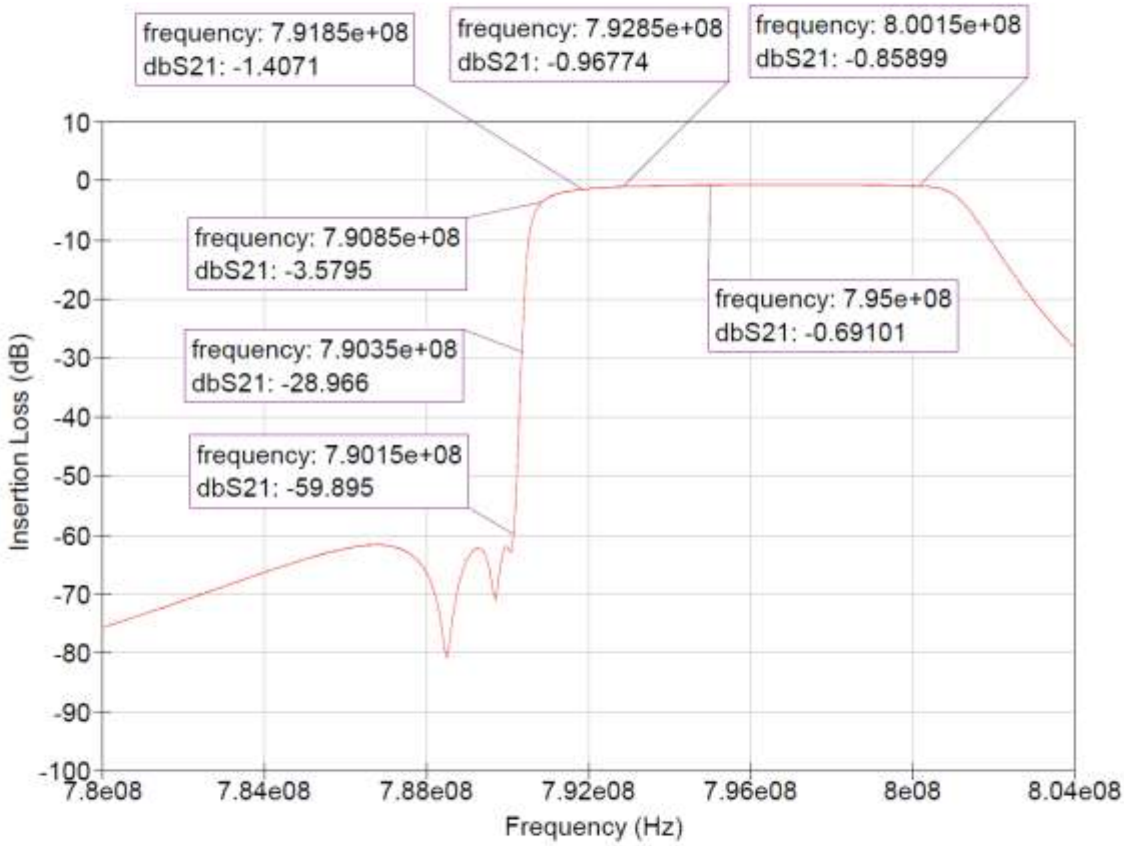
2.1.3.1 67dB Attenuation Required



Notes:

- 45dB insertion loss achieved 0.5MHz into passband
- 5.0dB insertion loss achieved 1MHz into passband
- 1.6dB insertion loss achieved 1.5MHz into passband
- 1.1dB insertion loss achieved 0.5MHz into passband
- Approximate filter size: 210 x 210 x 75mm
- Price indication: £330 (1k volumes), £250 (10k volumes)

2.1.3.2 57dB Attenuation Required



Notes:

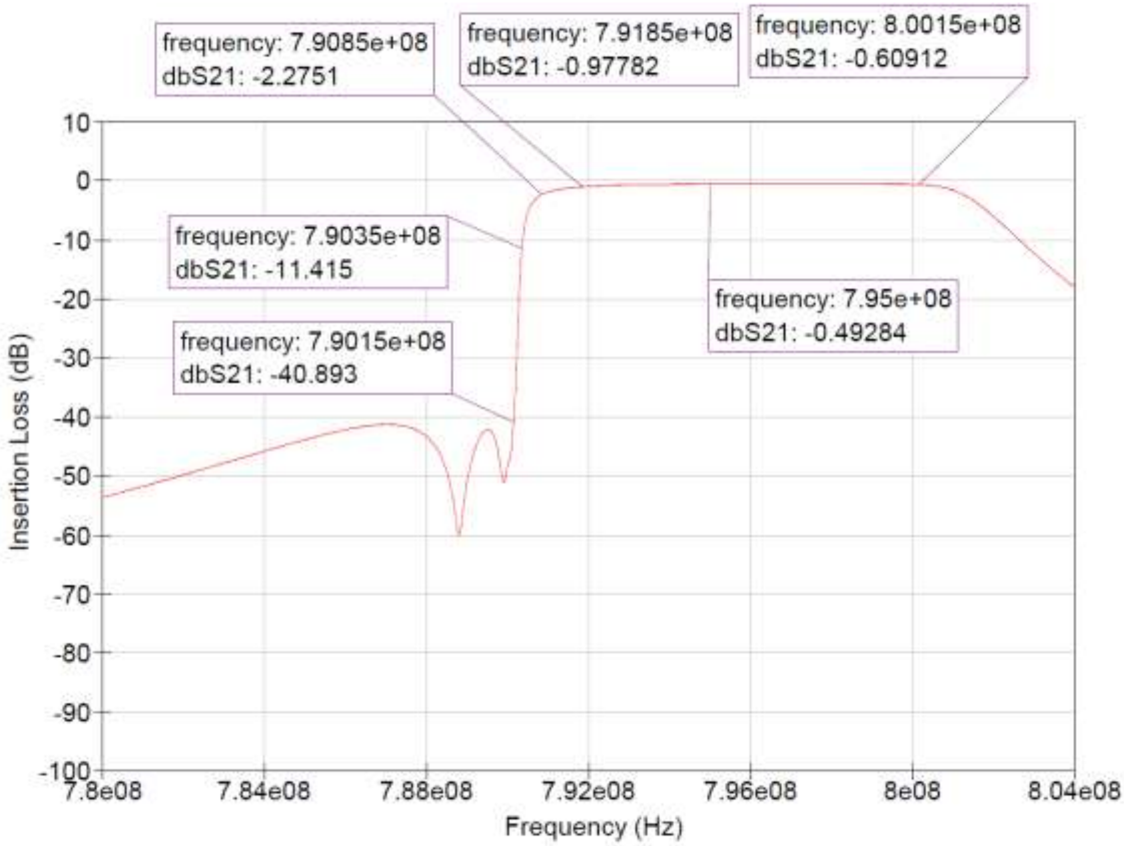
- 29dB insertion loss achieved 0.5MHz into passband
- 3.6dB insertion loss achieved 1MHz into passband
- 1.4dB insertion loss achieved 1.5MHz into passband
- 1.0dB insertion loss achieved 0.5MHz into passband
- Approximate filter size: 210 x 210 x 75mm
- Price indication: £330 (1k volumes), £250 (10k volumes)

2.1.3.3 47dB Attenuation Required

Notes:

- 17dB insertion loss achieved 0.5MHz into passband
- 2.9dB insertion loss achieved 1MHz into passband
- 1.2dB insertion loss achieved 1.5MHz into passband
- 0.9dB insertion loss achieved 0.5MHz into passband
- Approximate filter size: 210 x 210 x 75mm
- Price indication: £330 (1k volumes), £250 (10k volumes)

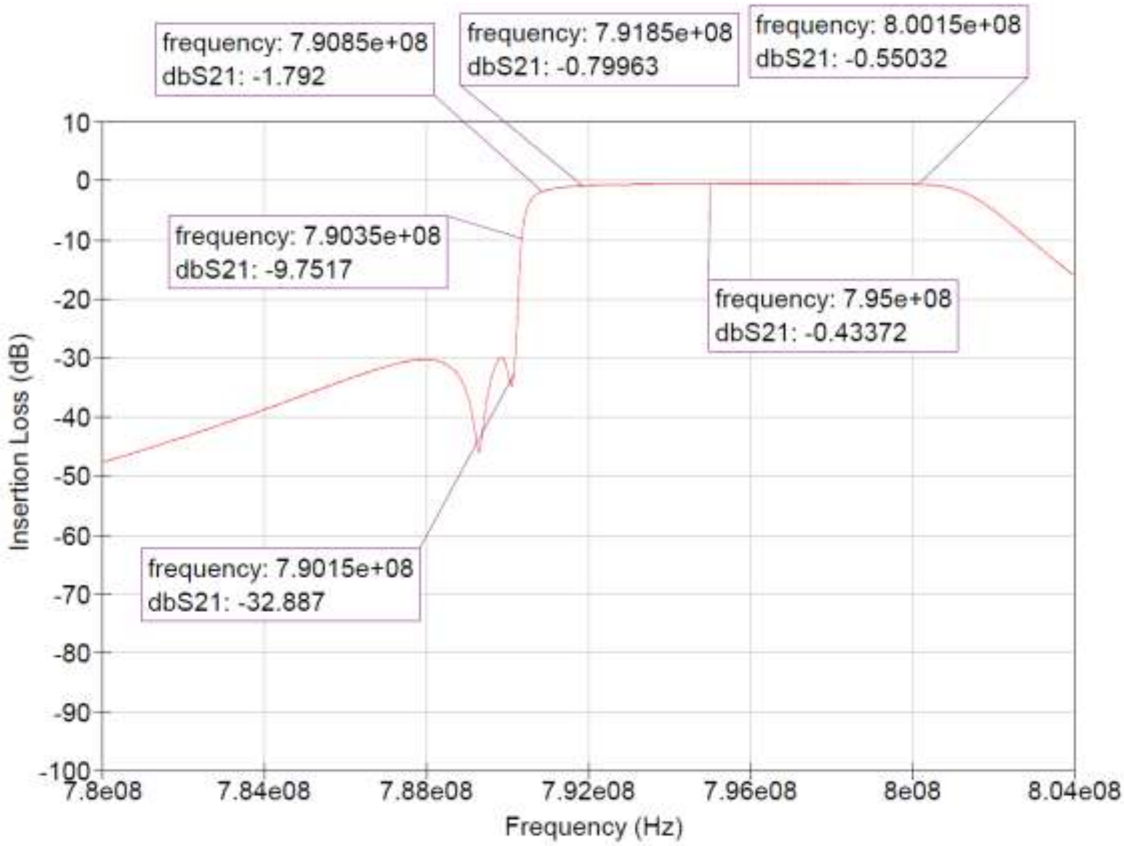
2.1.3.4 37dB Attenuation Required



Notes:

- 11dB insertion loss achieved 0.5MHz into passband
- 2.3dB insertion loss achieved 1MHz into passband
- 1.0dB insertion loss achieved 1.5MHz into passband
- Approximate filter size: 140 x 280 x 75mm
- Price indication: £310 (1k volumes), £240 (10k volumes)

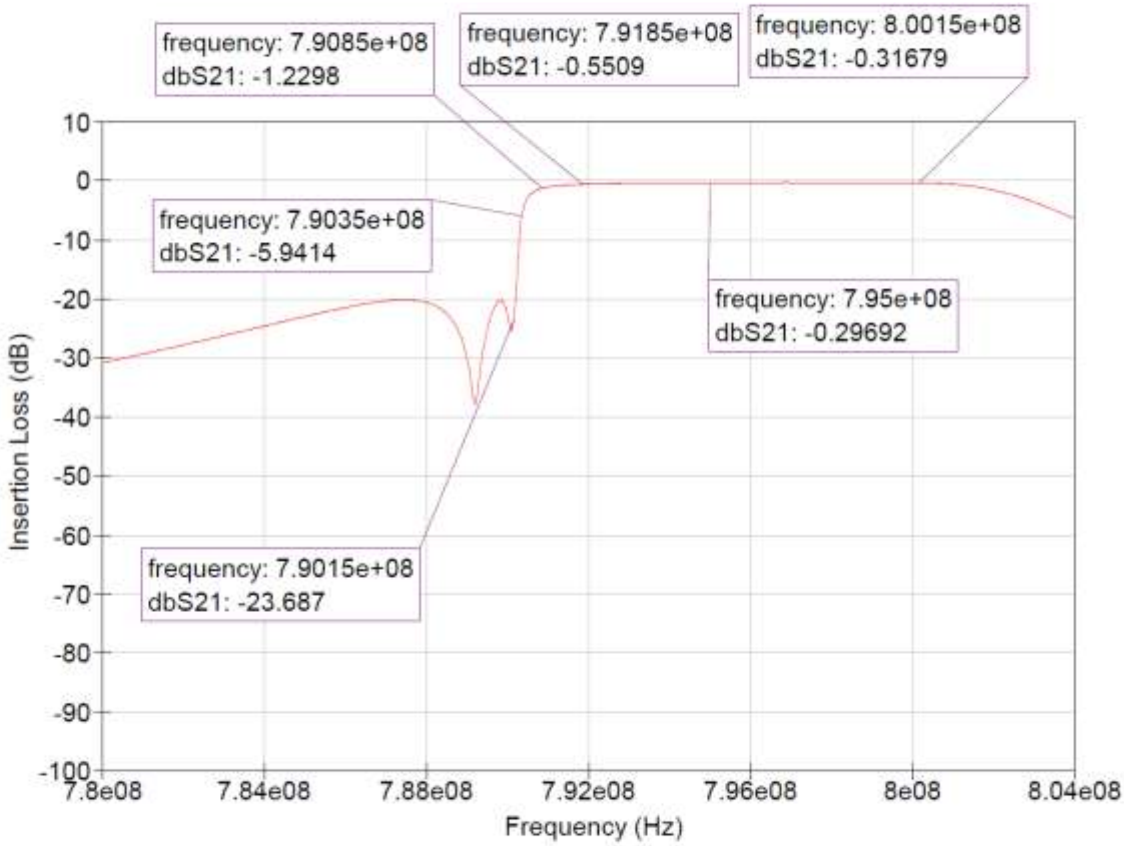
2.1.3.5 27dB Attenuation Required



Notes:

- 10dB insertion loss achieved 0.5MHz into passband
- 1.8dB insertion loss achieved 1MHz into passband
- 0.8dB insertion loss achieved 1.5MHz into passband
- Approximate filter size: 140 x 280 x 75mm
- Price indication: £310 (1k volumes), £240 (10k volumes)

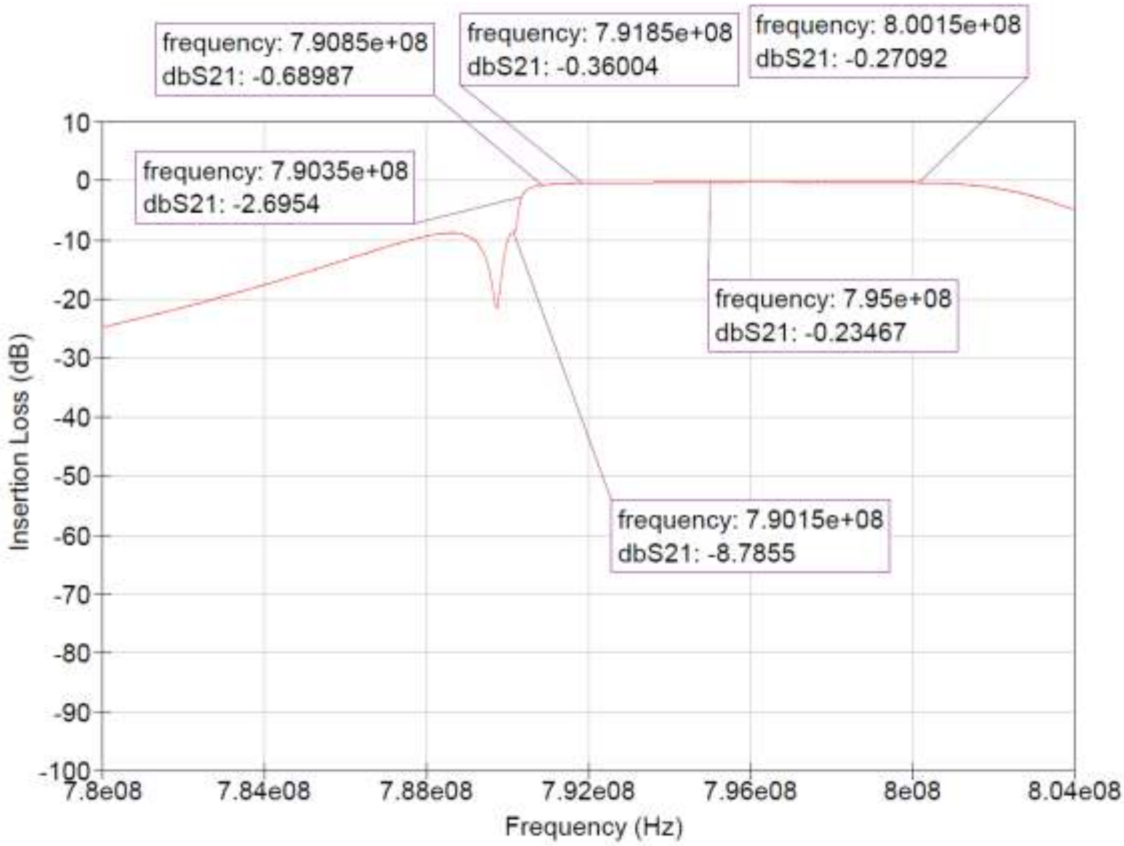
2.1.3.6 17dB Attenuation Required



Notes:

- 6dB insertion loss achieved 0.5MHz into passband
- 1.2dB insertion loss achieved 1MHz into passband
- 0.5dB insertion loss achieved 1.5MHz into passband
- Approximate filter size: 140 x 210 x 75mm
- Price indication: £290 (1k volumes), £220 (10k volumes)

2.1.3.7 7dB Attenuation Required



Notes:

- 2.7 dB insertion loss achieved 0.5 MHz into passband
- 0.7 dB insertion loss achieved 1 MHz into passband
- 0.4 dB insertion loss achieved 1.5 MHz into passband
- Approximate filter size: 100 x 150 x 75 mm
- Price indication: £275 (1k volumes), £205 (10k volumes)

2.1.4 Summary (790 – 862MHz)

The table below summarises the data presented in sections 2.1.1 to 2.1.3. Data in **bold** indicates where design goals were not met through the use of the high-Q metallic cavity filter technology under consideration.

Filter Description	Band Edge Loss (dB)	Approx. size (mm)	Approx. price for 1k volumes (£)	Approx. price for 10k volumes (£)
2MHz Guardband				
67dB attenuation	**1.7**	210 x 210 x 75	330	250
57dB attenuation	**1.4**	140 x 280 x 75	310	240
47dB attenuation	**1.1**	140 x 280 x 75	310	240
37dB attenuation	1.0	140 x 280 x 75	310	240
27dB attenuation	0.9	120 x 180 x 75	250	200
17dB attenuation	0.9	100 x 150 x 75	230	180
7dB attenuation	0.6	100 x 130 x 75	215	170
1MHz Guardband				
67dB attenuation	**5.1**	210 x 210 x 75	330	250
57dB attenuation	**3.7**	210 x 210 x 75	330	250
47dB attenuation	**2.9**	210 x 210 x 75	330	250
37dB attenuation	**2.6**	140 x 280 x 75	310	240
27dB attenuation	**1.8**	140 x 280 x 75	310	240
17dB attenuation	**1.2**	140 x 210 x 75	290	220
7dB attenuation	0.8	100 x 150 x 75	230	180
0MHz Guardband				
67dB attenuation	**45**	210 x 210 x 75	330	250
57dB attenuation	**29**	210 x 210 x 75	330	250
47dB attenuation	**17**	210 x 210 x 75	330	250
37dB attenuation	**11**	140 x 280 x 75	310	240
27dB attenuation	**10**	140 x 280 x 75	310	240
17dB attenuation	**6**	140 x 210 x 75	290	220
7dB attenuation	**2.7**	100 x 150 x 75	230	180

2.2 DVB-T Critical and Non-Critical Masks (790-862MHz band)

Table 2 contained in the study objectives in Appendix 2 shows terrestrial Digital Video Broadcasting (DVB-T) critical and non-critical spectrum masks. As per section 2.1 it is assumed that the LTE SEM has been met by the base-station, giving a level of +8dBm at band edge. Although this level changes slightly as the mask moves away from band edge, for this study it is assumed to be +8dBm across the stopband. Hence each filter must provide sufficient attenuation to reduce power from +8dBm to the DVB-T critical and non-critical spectrum mask requirements. This results in the following filtering requirements:

Frequency (MHz)	Filter attenuation required – critical case (dB)	Filter attenuation required – non critical case (dB)
784	51.2	41.2
787	38.7	28.7
790	26.2	16.2
791	19.5	9.5

Each filter is designed to achieve the required attenuation with a reasonable production margin. A frequency shift of 150kHz over the operational temperature range is assumed, which can be seen in the offsets of the passband and stopband frequency markers. Each filter is designed to achieve <1dB insertion loss worst case over the passband. Where this is not achievable the plot shows at what frequency this insertion loss is achieved (loss is minimum in the middle of the passband and increases toward each band edge).

The following figures show details of the estimated achievable performance, along with the estimated size and price indication.

2.2.1 2MHz Guard Band Filter Performance

2.2.1.1 DVB-T Critical Mask

Notes:

- 1.1dB worst case insertion loss at lower band edge
- Approximate filter size: 140 x 280 x 75mm
- Price indication: £310 (1k volumes), £240 (10k volumes)

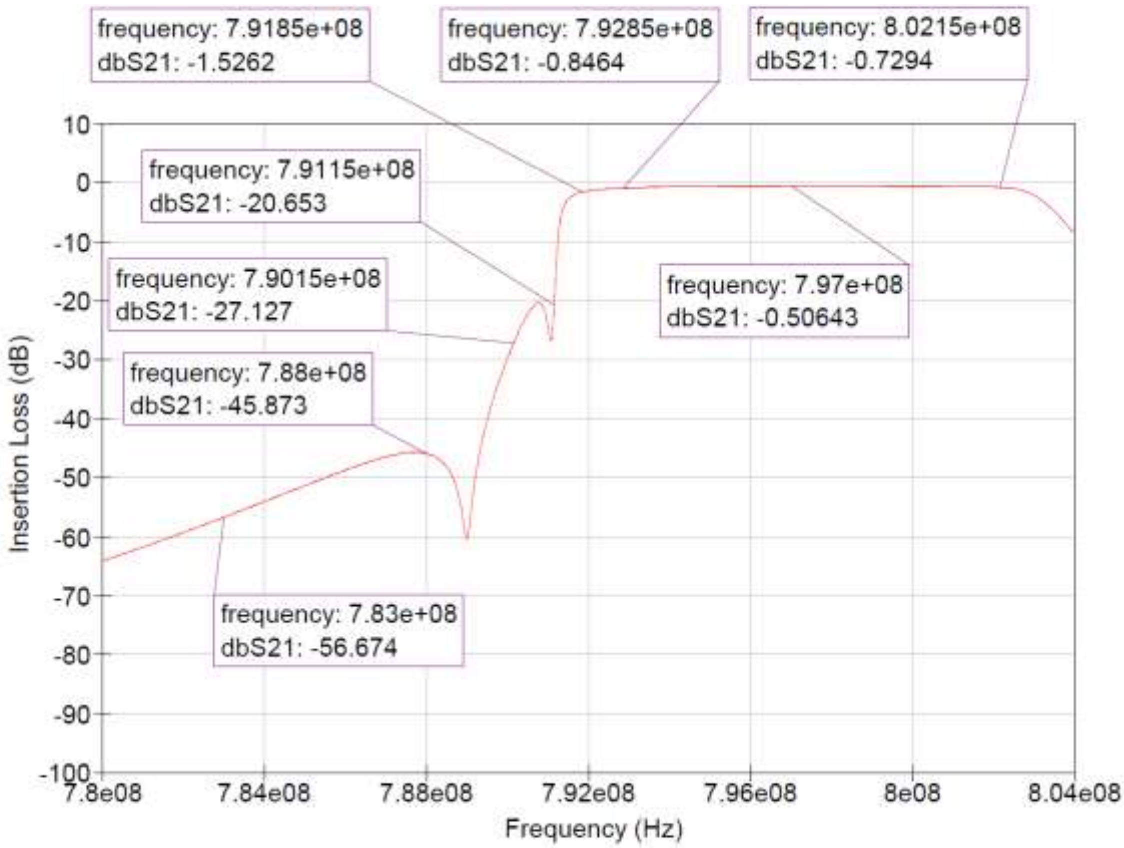
2.2.1.2 DVB-T Non-Critical Mask

Notes:

- 0.9dB worst case insertion loss at lower band edge
- Approximate filter size: 120 x 180 x 75mm
- Price indication: £250 (1k volumes), £200 (10k volumes)

2.2.2 1MHz Guard Band Filter Performance

2.2.2.1 DVB-T Critical Mask



Notes:

- 1.5dB worst case insertion loss at lower band edge
- 0.8dB insertion loss achieved 1MHz into passband
- Approximate filter size: 140 x 280 x 75mm
- Price indication: £310 (1k volumes), £240 (10k volumes)

2.2.2.2 DVB-T Non-Critical Mask

Notes:

- 1.1dB worst case insertion loss at lower band edge
- Approximate filter size: 140 x 280 x 75mm
- Price indication: £310 (1k volumes), £240 (10k volumes)

2.2.3 Summary (DVB-T Critical and Non-Critical Masks / 790-862MHz band)

The table below summarises the data presented in sections 2.2.1 to 2.2.2. Data in **bold** indicates where design goals were not met through the use of the high-Q metallic cavity filter technology under consideration.

Filter Description	Band Edge Loss (dB)	Approx. size (mm)	Approx. price for 1k volumes (£)	Approx. price for 10k volumes (£)
2MHz Guardband				
Critical mask	**1.1**	140 x 280 x 75	310	240
Non-critical mask	0.9	120 x 180 x 75	250	200
1MHz Guardband				
Critical mask	**1.5**	140 x 280 x 75	310	240
Non-critical mask	1.1	140 x 280 x 75	310	240

2.3 Conclusions

Simulations show that with the use of the high-Q metallic cavity filter technology under consideration, less than 1dB passband insertion loss can be achieved in four out of the seven 2MHz guardband cases, and in one out of the seven 1MHz cases. None of the 0MHz guardband cases achieve acceptable performance. DVB-T non-critical masks could be met, with filters for critical masks having slightly high insertion loss compared to the design goals. Hence using either a 2MHz or 1MHz guardband would be reasonably practical.

Filters would be comparable in size to ‘standard’ GSM900 filtering equipment currently used in the field. It can be seen that filters that achieve higher levels of attenuation are larger than those with less stringent attenuation requirements. These 790MHz filters are also larger than would be seen in higher frequency systems i.e. GSM1800 and UMTS, as some aspects of the filter dimensions are related to the wavelength of the signal, which reduces as the frequency increases.

3 872 to 876 MHz paired with 917 to 921MHz Frequency Band

Ofcom is undergoing consultation on the release of spectrum in the bands 872MHz to 876MHz paired with 917MHz to 921MHz. The RF services for use in these bands are at present undefined, but one option is for FDD applications.

Filtering may be required to prevent interference between this new service and the existing service in the paired bands 880MHz to 915MHz and 925MHz to 960MHz. These bands are currently used by GSM services, but may be used for other services in the future.

The following filters are considered:

- Filtering to be added to existing base stations to prevent interference from transmitted power in the range 917MHz to 921MHz;

- Filtering required by the new systems for both receive (RX) and transmit (TX) channels to ensure sufficient TX to RX isolation, and to prevent interference from transmitted power in the range 925MHz to 960MHz

The following figures show details of the estimated achievable performance based on a number of assumptions (stated in each section), along with size and price indication.

3.1 Filters for existing Base Station Receive equipment

Transmitted powers in the range 917MHz to 921MHz have the potential to interfere into cellular base station receivers operating in the frequency band 880-915 MHz. To minimise this potential for interference two filter options are considered – a bandpass filter, which passes a specific range of frequencies and attenuates all others, and a bandstop filter, which attenuates a specific range of frequencies and passes all others.

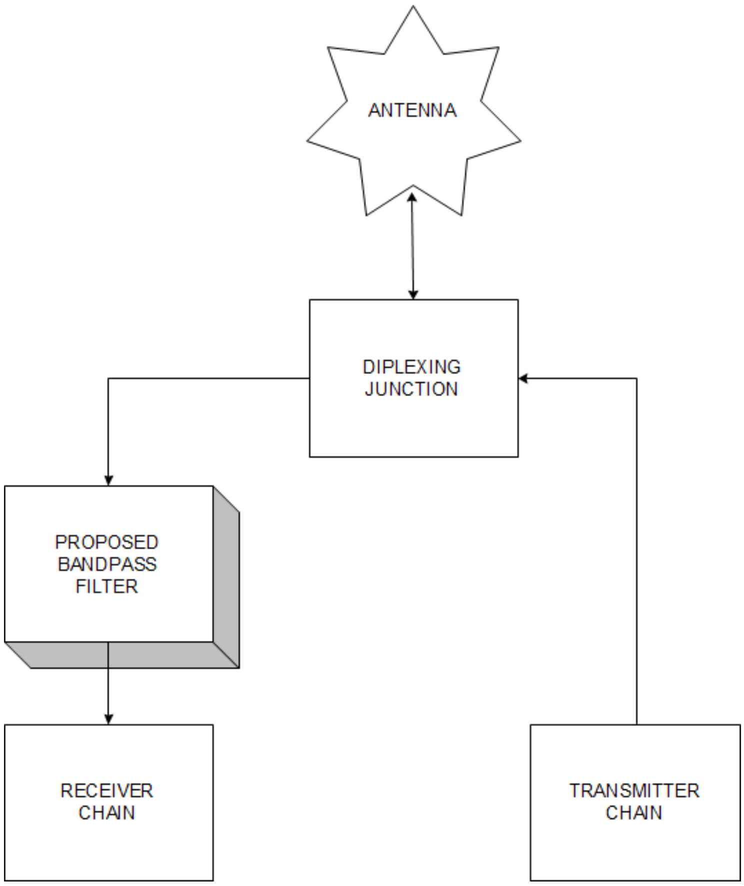
3.1.1 Bandpass Filter for Existing System

Passband 880-915 MHz, stopband 917-921 MHz

This filter could be positioned between the diplexing junction and the receiver chain. Three designs were considered, each with various levels of attenuation of the band 917-921MHz. A frequency shift of ±150kHz over the operational temperature range is assumed, and this can be seen in the offsets of the passband and stopband frequency markers. For each filter the resultant worst-case insertion loss, group delay variation over 200kHz, and EVM over one mobile channel is shown (see appendix 3 for background on EVM).

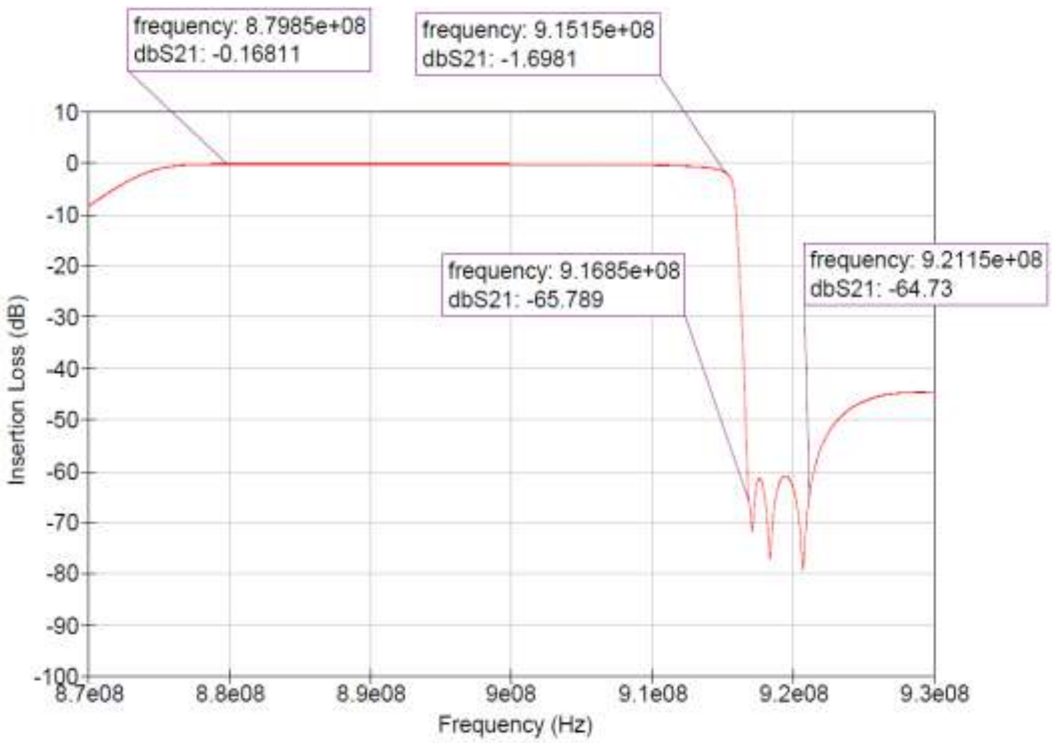
EVM is not calculated in cases where the result would be far outside acceptable limits. For example, 3GPP specify that the total EVM of a UMTS basestation transmitter must not be more than 17.5% EVM for QPSK modulation, or 12.5% for 16QAM modulation. As the filter is one of many components that will contribute to the overall EVM, we assume that its performance must be significantly better than the overall requirement. It should be noted that the EVM performance may well be improved through equalisation techniques, which was outside the scope of this study.

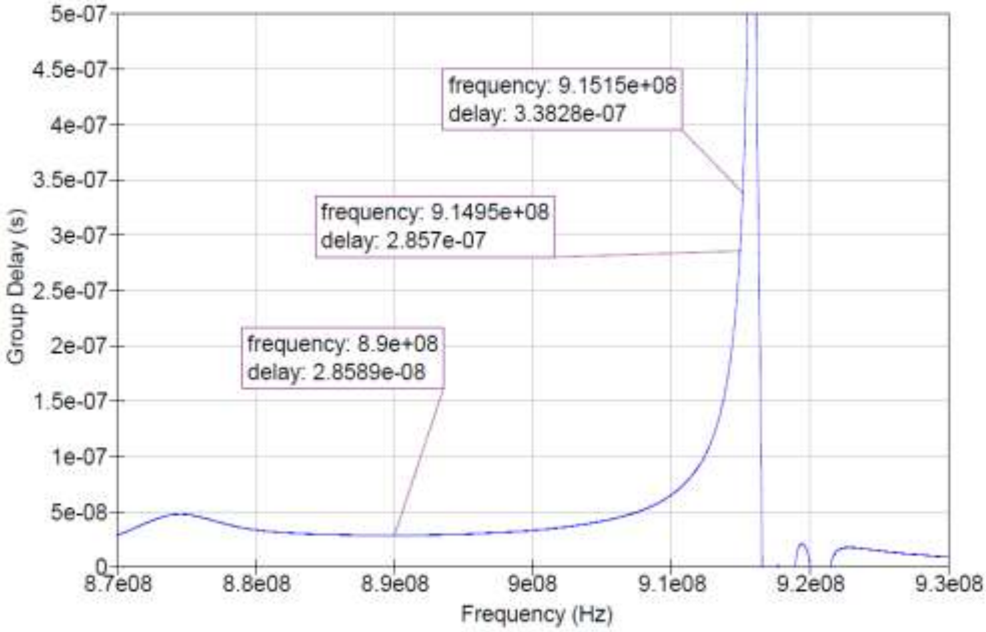
It is noted from the channel arrangement for UMTS (ETS 125 104) that the highest frequency UMTS channel extends from 909.9 to 914.9MHz, which would give an additional 100kHz guard band between the award band and a UMTS base station receiver. This additional 100kHz guard band was not taken into account within the results of base station filtering presented in this document.



Block diagram

3.1.1.1 60dB Attenuation

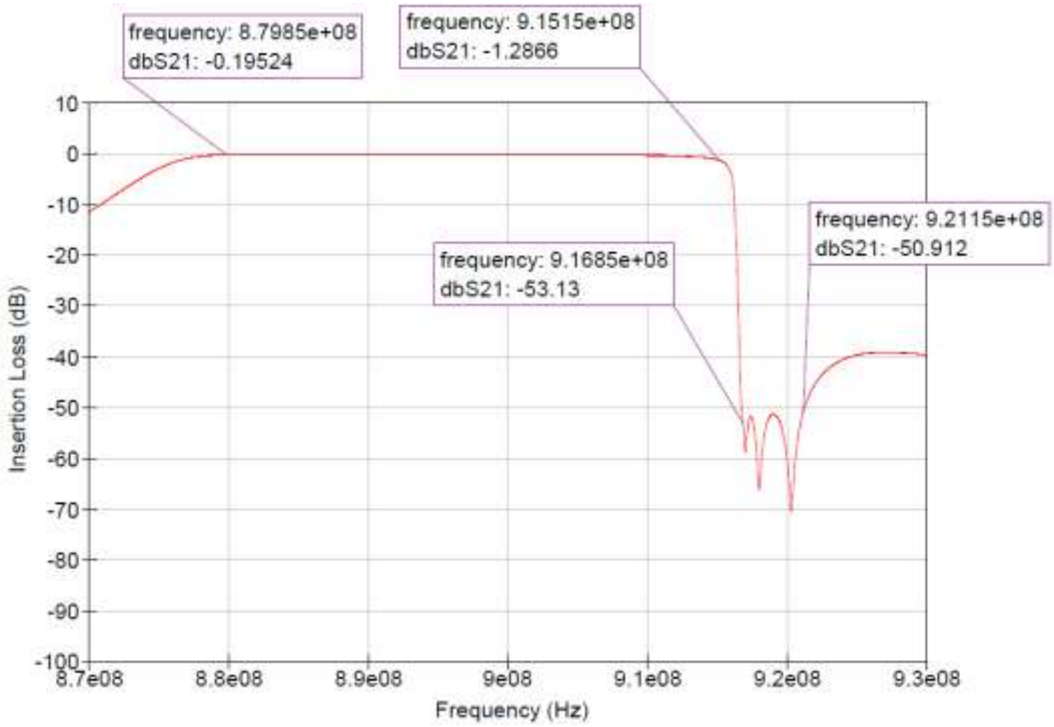


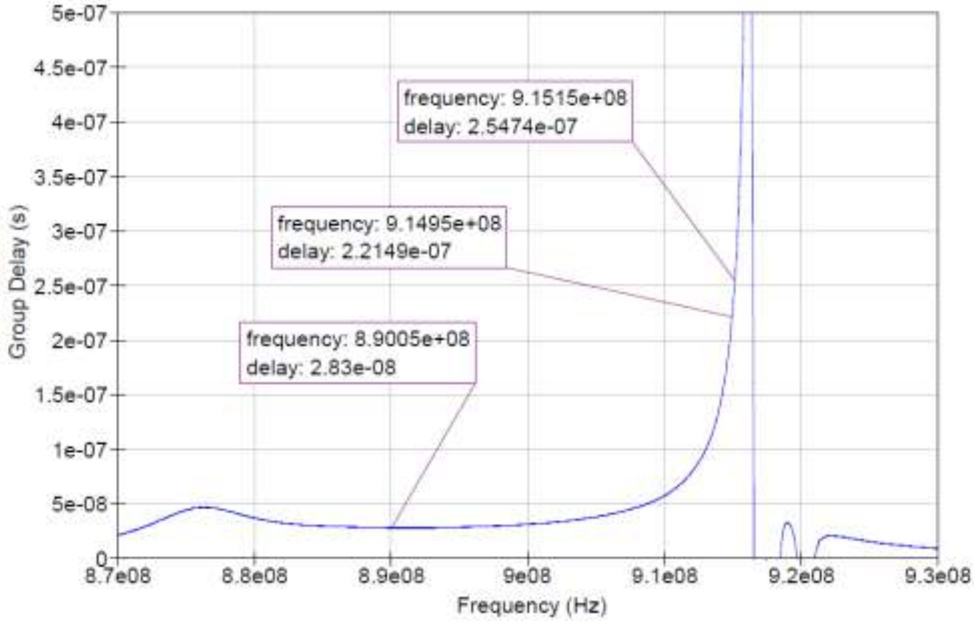


Notes:

- 1.7dB worst case insertion loss at lower band edge
- EVM = 12.6% over worst case 3.84MHz
- Group delay variation = 54ns over worst case 200kHz
- Approximate filter size: 140 x 280 x 75mm
- Price indication: £370 (500-off volumes), £310 (1k volumes)

3.1.1.2 50dB Attenuation

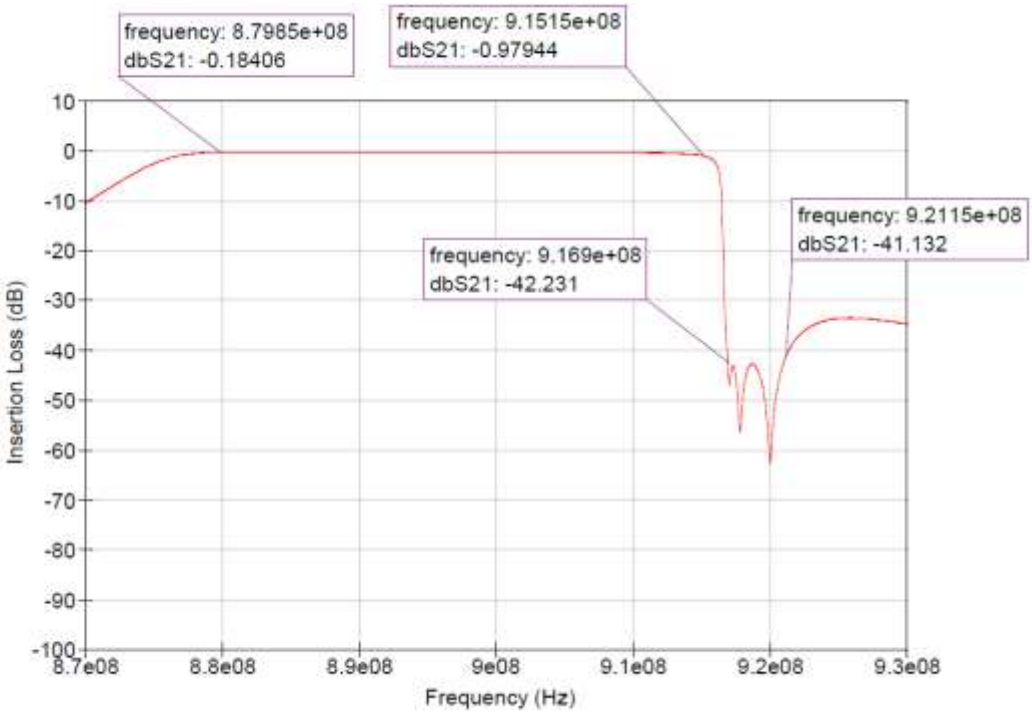


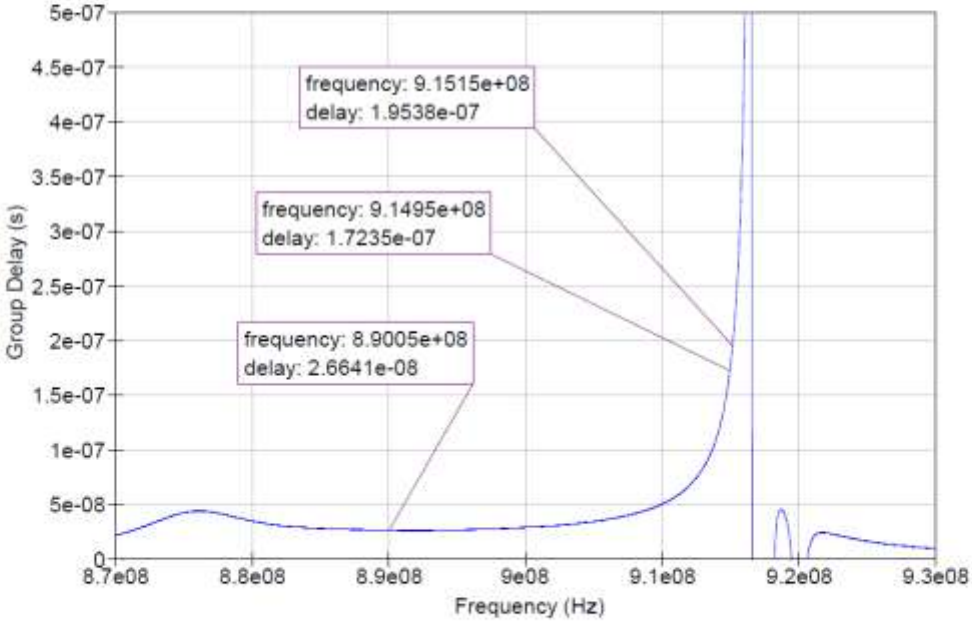


Notes:

- 1.3dB worst case insertion loss at lower band edge
- EVM = 9.7% over worst case 3.84MHz
- Group delay variation = 34ns over worst case 200kHz
- Approximate filter size: 140 x 280 x 75mm
- Price indication: £370 (500-off volumes), £310 (1k volumes)

3.1.1.3 40dB Attenuation





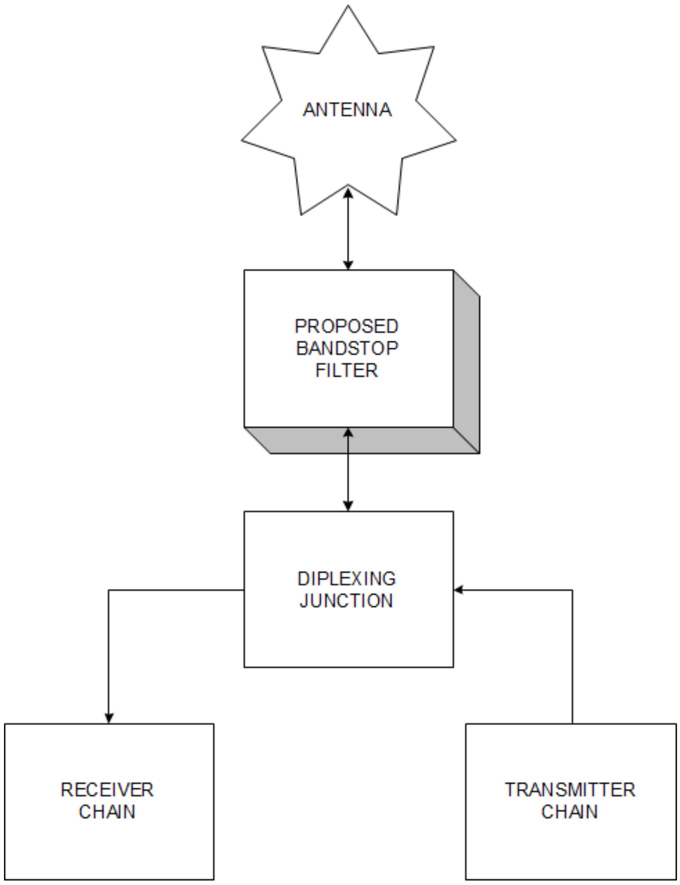
Notes:

- 1.0dB worst case insertion loss at lower band edge
- EVM = 7.5% over worst case 3.84MHz
- Group delay variation = 24ns over worst case 200kHz
- Approximate filter size: 140 x 280 x 75mm
- Price indication: £370 (500-off volumes), £310 (1k volumes)

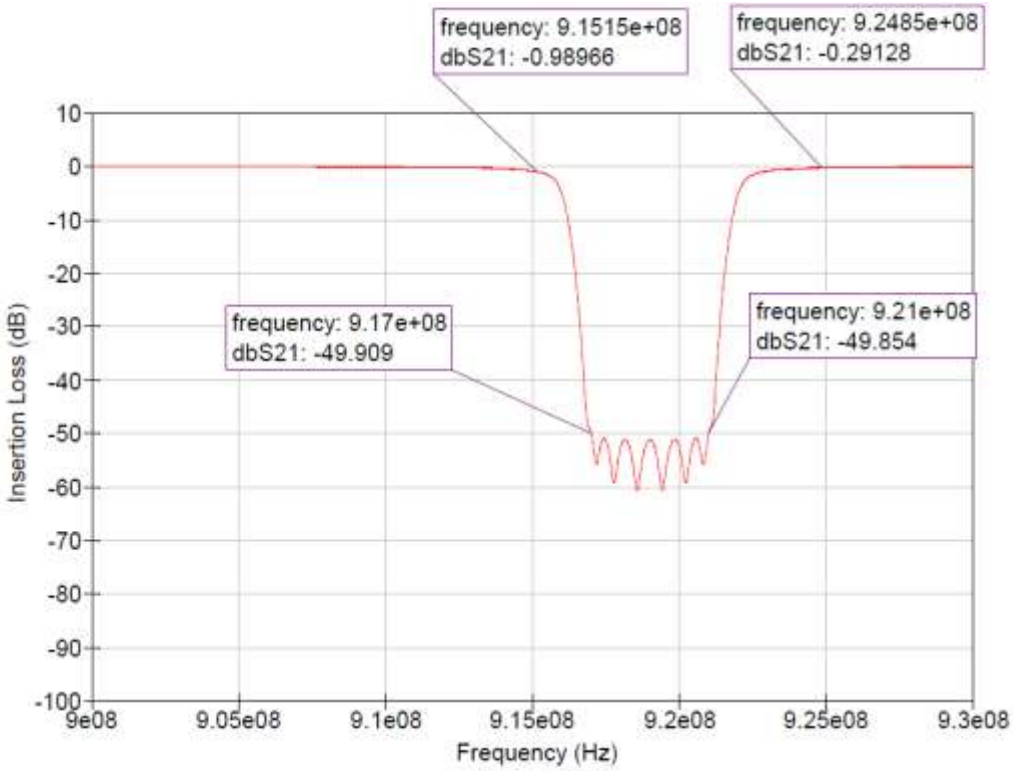
3.1.2 Band stop filter

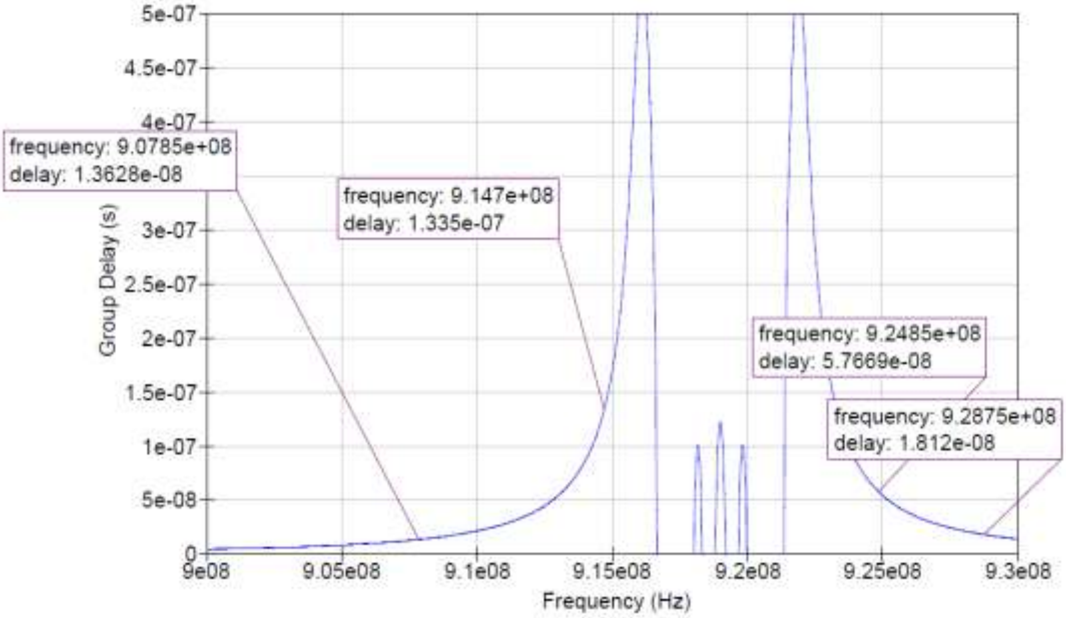
Stopband 917-921 MHz

This filter could be positioned between the antenna and the diplexing junction. The design shown attenuates the band 917-921MHz by 50dB. A frequency shift of ±150kHz over the operational temperature range is assumed, and this can be seen in the offsets of the passband and stopband frequency markers.



Block diagram





Notes:

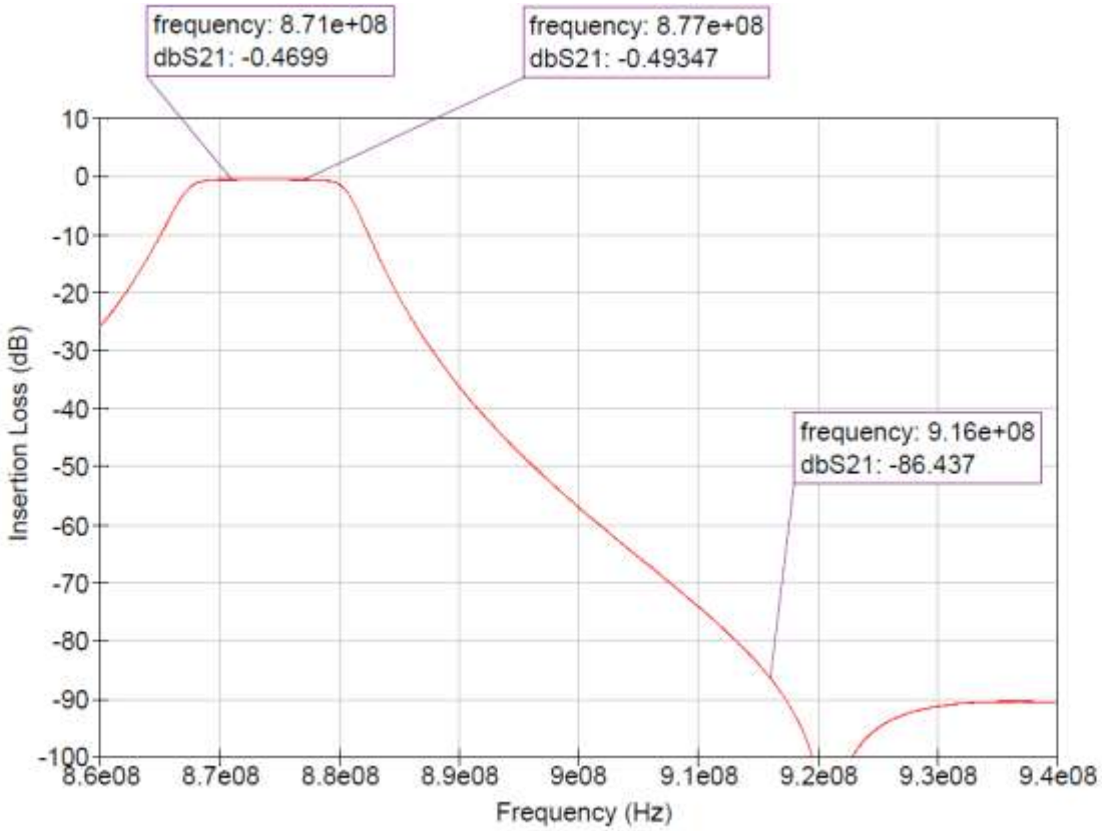
- 1dB worst case insertion loss over band 880MHz to 915MHz
- 0.3dB worst case insertion loss over band 925MHz to 960MHz
- EVM = 8.2% over worst case 3.84MHz
- Group delay variation = 24ns over worst case 200kHz
- Approximate filter size: 140 x 280 x 75mm
- Price indication: £370 (500-off volumes), £310 (1k volumes)

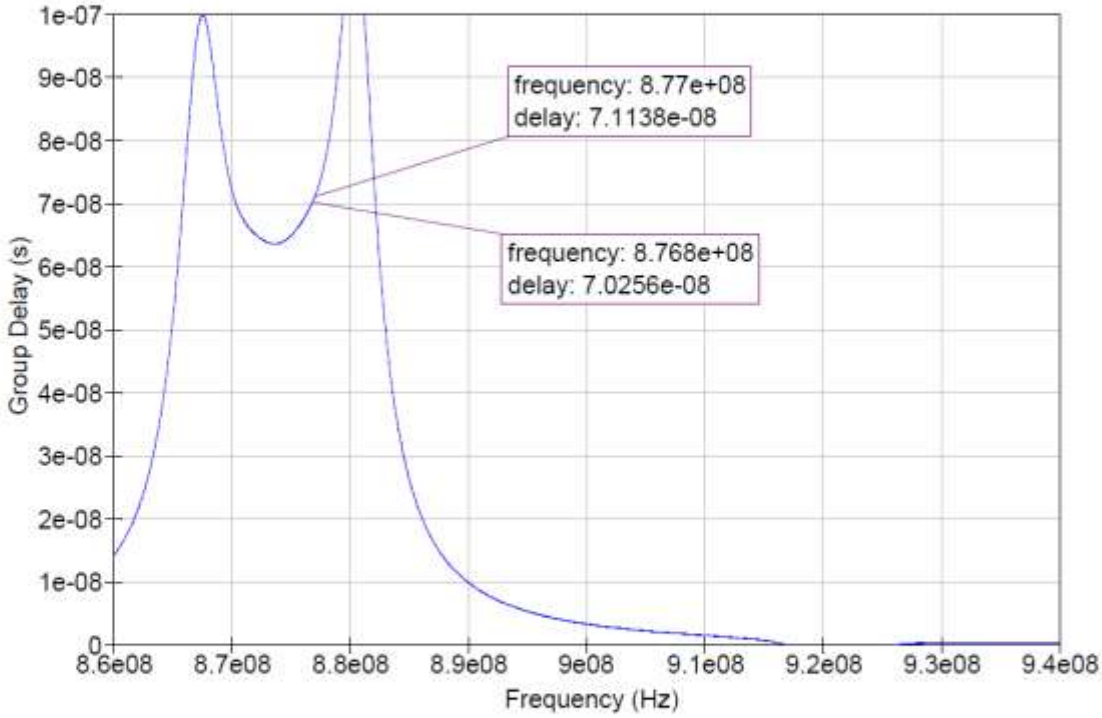
3.2 Possible Filters for a New System operating in the bands 872-876 MHz & 917-921 MHz

3.2.1 RX

This filter is required to pass the receive band 872- 876MHz with minimum insertion loss while providing over 85dB of isolation from its paired transmit channel, 917-921 MHz. In addition the filter must also provide high attenuation to base station transmitters over the EGSM transmit band 925-960 MHz

Given the absence of close-in attenuation requirements the design passband can be widened to reduce the filter complexity & setting tolerances, as reflected in the frequency shift provision of ±1MHz.



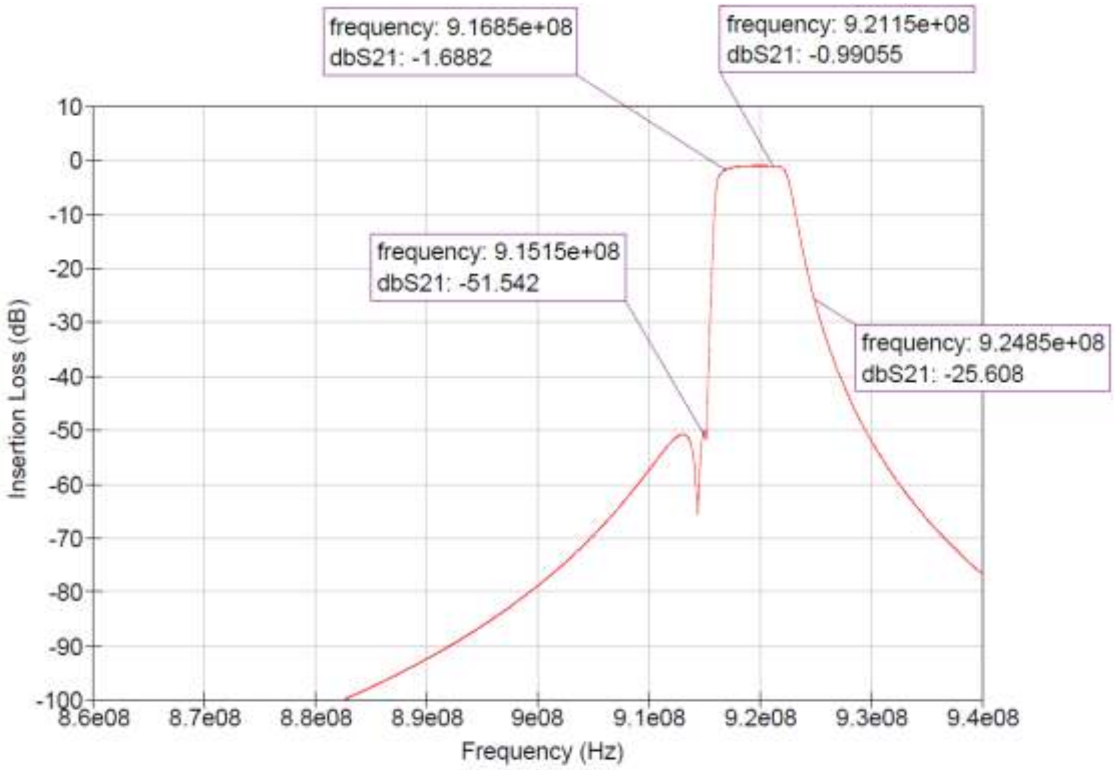


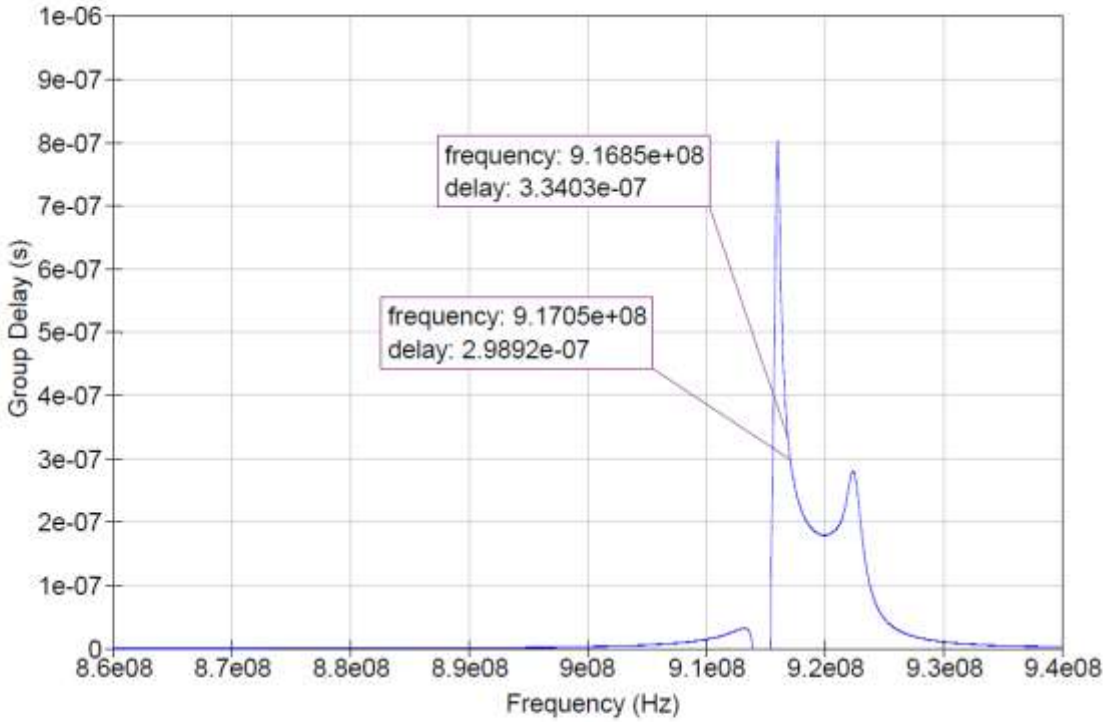
Notes:

- 0.5dB worst case insertion loss over band 872MHz to 876MHz
- EVM = <1% over worst case 3.85MHz
- Group delay variation = 1ns over worst case 200kHz
- Approximate filter size: 110 x 110 x 75mm
- Price indication: £280 (500-off volumes), £230 (1k volumes)

3.2.2 Transmit Filter

This filter must have a minimum insertion loss over the transmit band 917-921MHz and provide 85dB of isolation from its paired receive channel, 872-876 MHz. It must also attenuate the EGSM transmit band 925-960 MHz, and receive band 880-915 MHz to minimise the potential for out of band emissions in interfering with the EGSM system. A frequency shift of ±150kHz over the operational temperature range is assumed, and this can be seen in the offsets of the passband and stopband frequency markers.





Notes:

- 1.7dB worst case insertion loss over band 917MHz to 921MHz
- EVM = 8% over worst case 3.85MHz
- Group delay variation = 35ns over worst case 200kHz
- Approximate filter size: 140 x 210 x 75mm
- Price indication: £350 (500-off volumes), £290 (1k volumes)

3.3 Conclusions (872 to 876 MHz / 917 to 921MHz bands)

Simulations have been presented for possible filtering designs to minimise the potential for interference to existing EGSM900 systems from transmit signals in the range 917MHz to 921MHz. Of these the bandstop filter designs seems more favourable than the corresponding bandpass filter designs. Electrical performance is better, and implementation would be easier as it can be fitted between the existing basestation and antenna. In contrast, the bandpass solution would need to be positioned within the receive chain of the existing basestation.

Receive and transmit filters for base-station installations in the 872-876MHz / 917 – 921 MHz bands are shown as feasible and are considered of reasonably simple design.

4 Filtering Requirement options in the 2700MHz to 3100 MHz Band

A number of Civil and MoD radars currently deployed within the UK in the 2700-3100MHz band may well receive interference when the 2.6GHz spectrum is made available for new RF applications due to inadequate selectivity performance of radar receivers. In such cases receiver filtering at the radar may be required to improve the selectivity performance of radar and reduce the possibility of receiving transmissions originating within adjacent bands. Filter designs are presented for the following nine combinations of passband relative to overall operating band:

		Pass band (MHz)		
		100	200	300
Frequency offset (in MHz) to 2690 MHz	10	2750	2800	2850
	30	2770	2820	2870
	60	2800	2850	2900

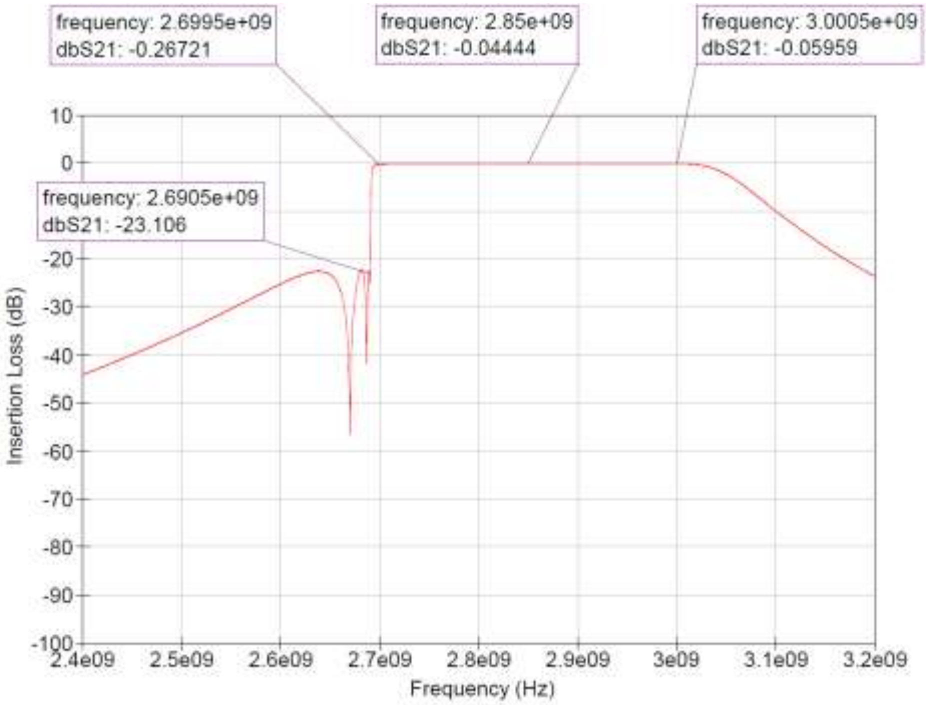
The filters are designed to comply with a linearity spec of 0.4°/MHz over any 10MHz region of the pass band, and the resultant attenuation achievable is shown. A frequency shift of ±500kHz over the operational temperature range is assumed, which is indicated in the offsets of the passband and stopband frequency markers. It should be noted the target phase linearity and minimum attenuation parameters were based on requirements proposed by a radar manufacturer for a single older radar type. As such, they may not be applicable as target filter design objectives for other types of radar which may require more stringent phase and/or attenuation requirements, or have other technical considerations such as group delay that might need to be taken into account in the design of filters. It should also be noted a frequency shift allowance of less than this amount would be difficult to achieve at these frequencies and bandwidths.

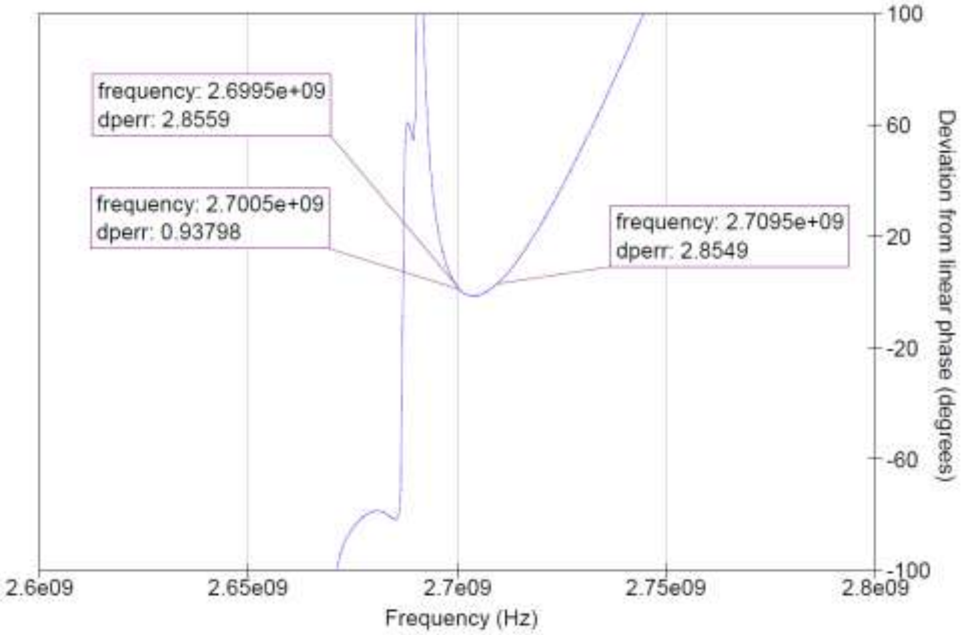
In addition to the nine combinations shown above, a possible parallel filter design is shown. This comprises two 10MHz wide filters in a parallel configuration separated by 50MHz.

Note: In some cases the linearity specification cannot be met with the high-Q metallic filter designs under consideration. These cases are denoted in **bold** in the notes section below each graph.

4.1 10MHz Frequency Offset

4.1.1 300MHz Bandwidth

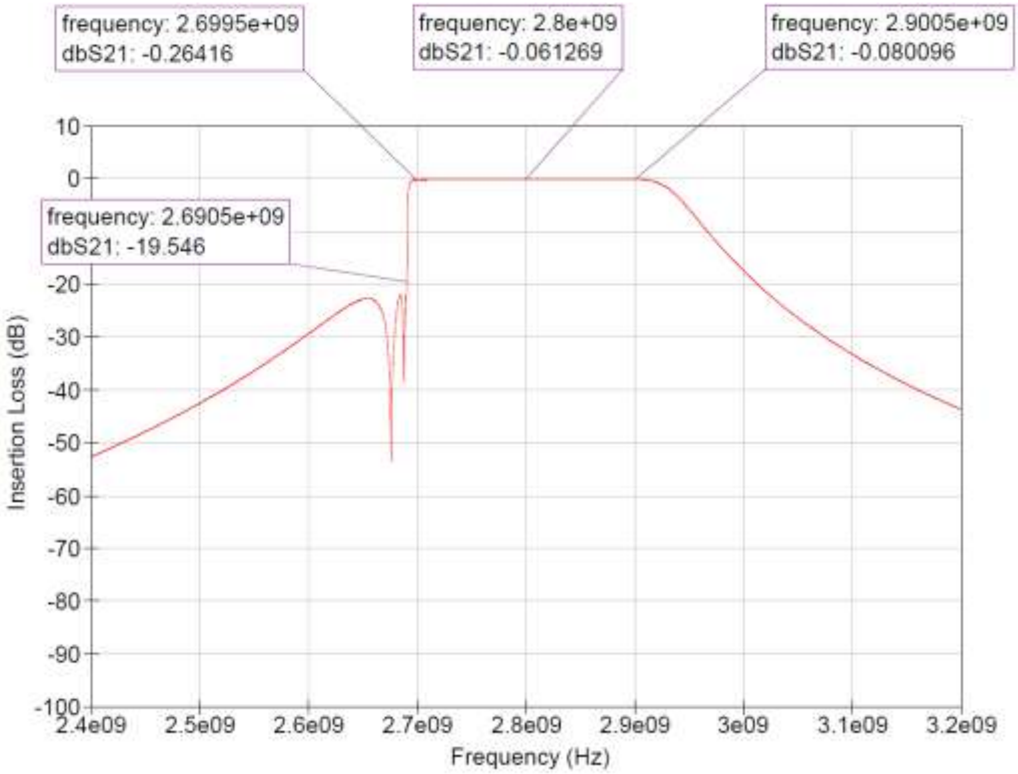


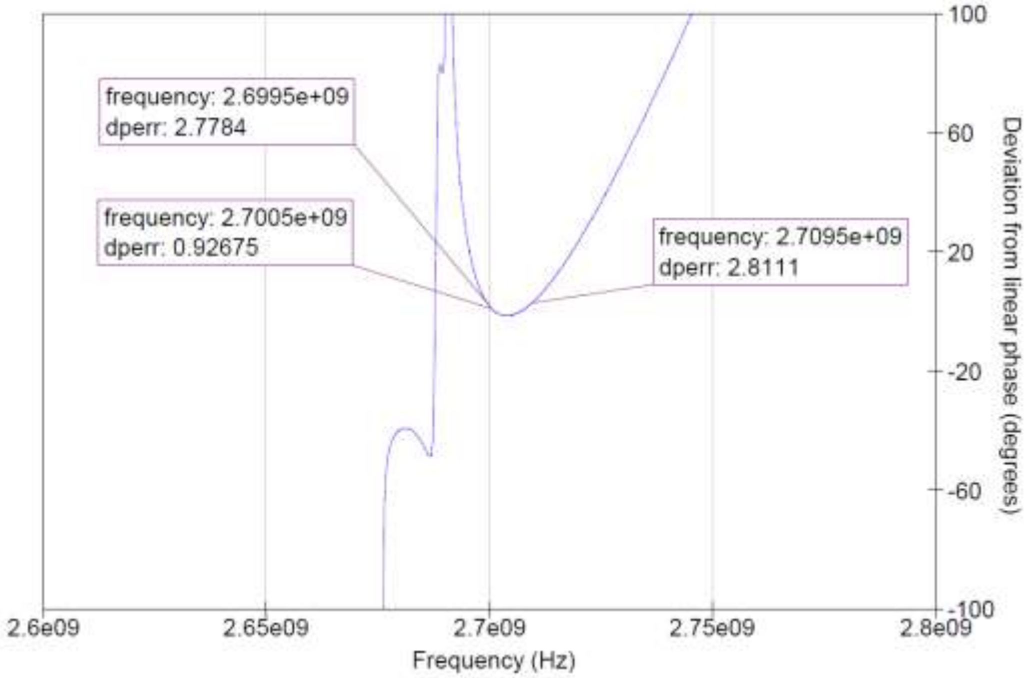


Notes:

- 0.27dB worst case insertion loss over band
- Attenuation = 23dB @ 2690MHz
- **Deviation from linear phase = 1.92° over worst case 1MHz**
- Approximate filter size: 215 x 100 x 40mm
- Price indication: £1300 (50-off volumes)

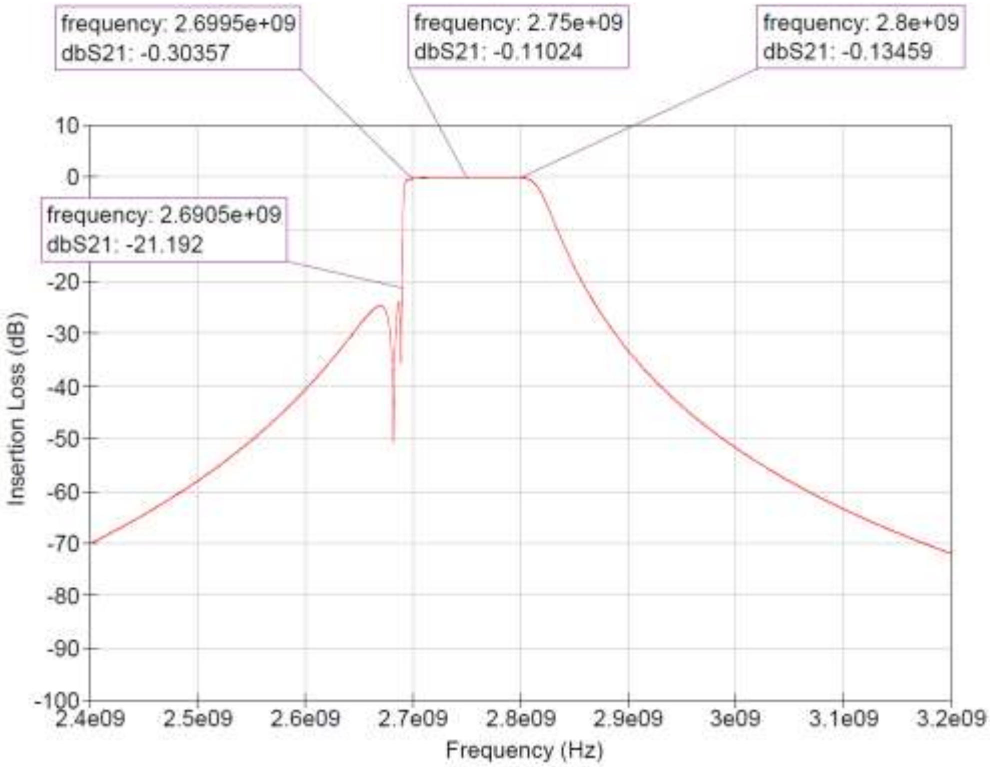
4.1.2 200MHz Bandwidth

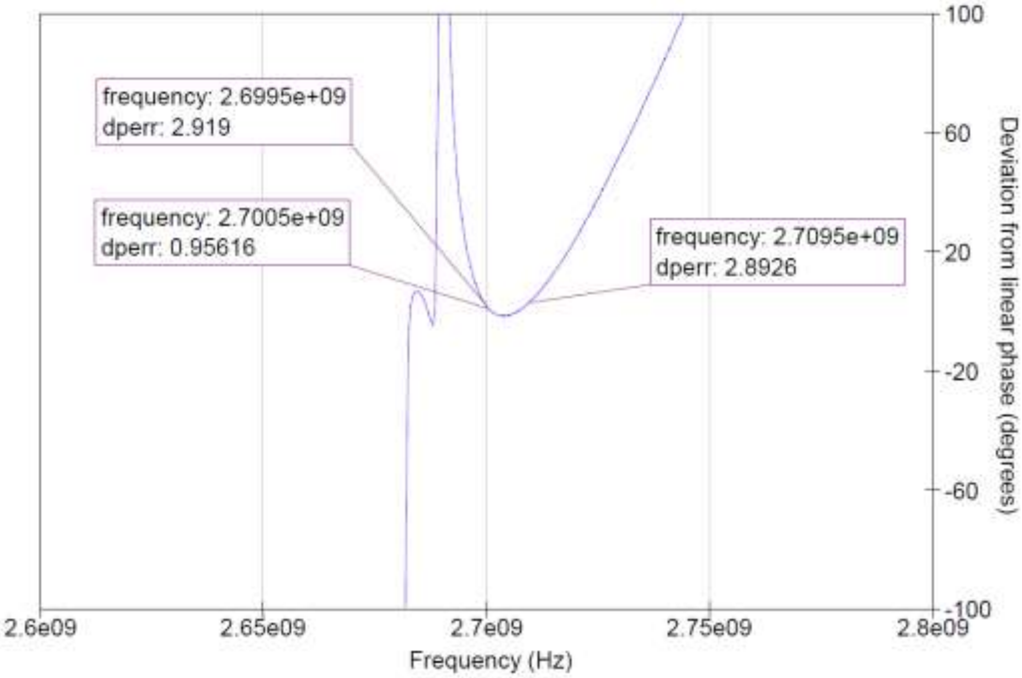




- 0.26dB worst case insertion loss over band
- Attenuation = 20dB @ 2690MHz
- **Deviation from linear phase = 1.85° over worst case 1MHz**
- Approximate filter size: 215 x 100 x 40mm
- Price indication: £1300 (50-off volumes)

4.1.3 100MHz Bandwidth

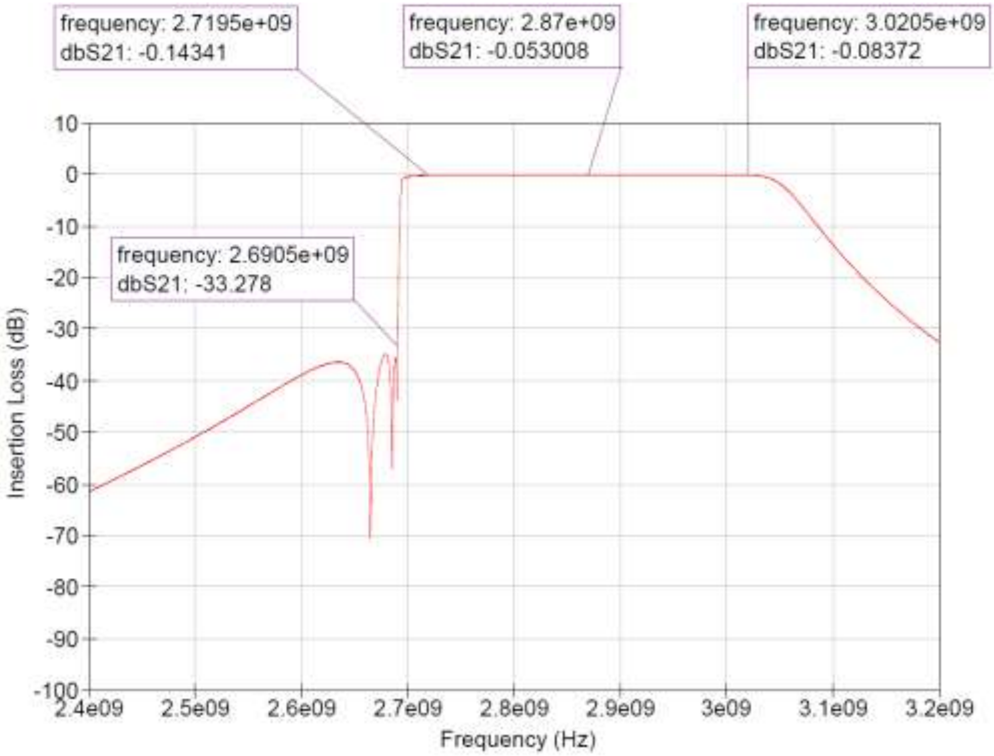


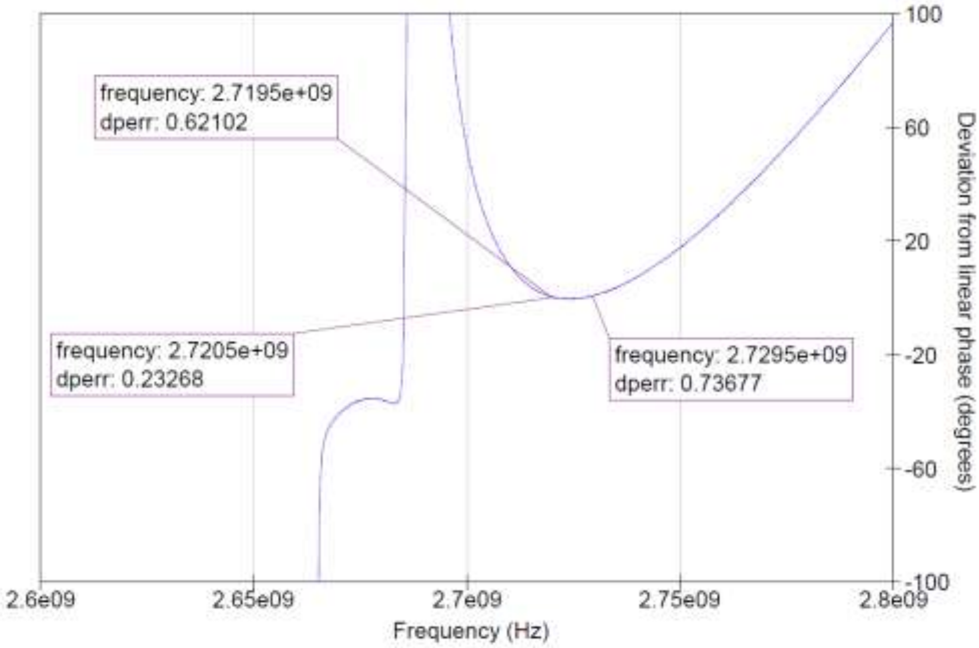


- 0.30dB worst case insertion loss over band
- Attenuation = 21dB @ 2690MHz
- **Deviation from linear phase = 1.85° over worst case 1MHz**
- Approximate filter size: 215 x 100 x 40mm
- Price indication: £1300 (50-off volumes)

4.2 30MHz Frequency Offset

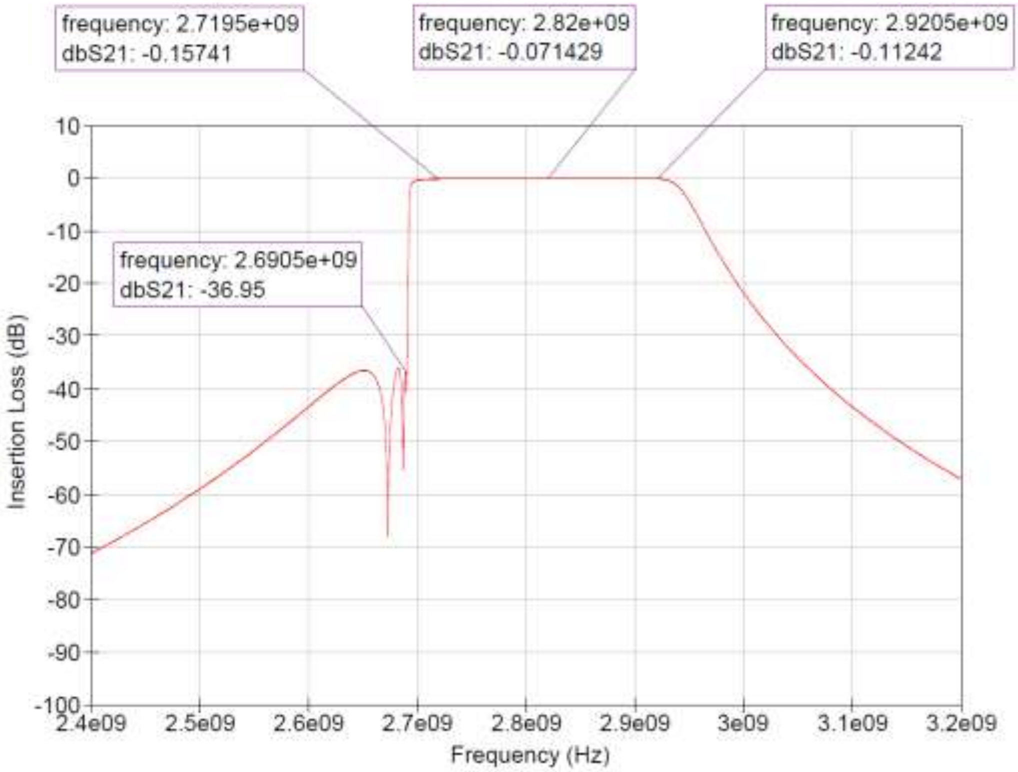
4.2.1 300MHz Bandwidth

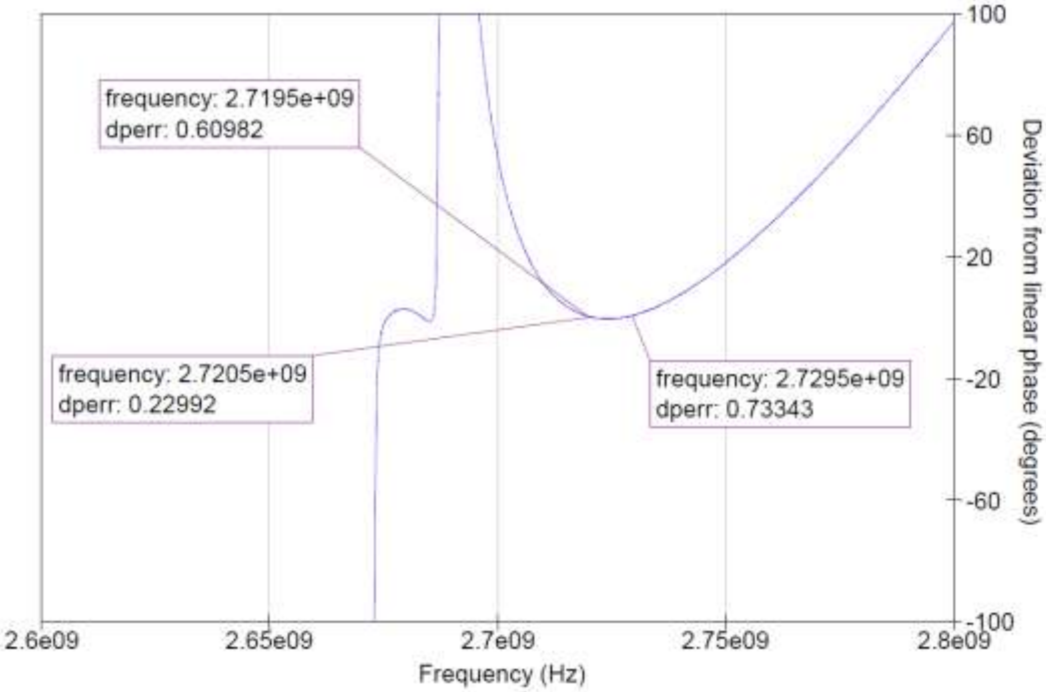




- 0.14dB worst case insertion loss over band
- Attenuation = 33dB @ 2690MHz
- Deviation from linear phase = 0.39° over worst case 1MHz
- Approximate filter size: 215 x 100 x 40mm
- Price indication: £1300 (50-off volumes)

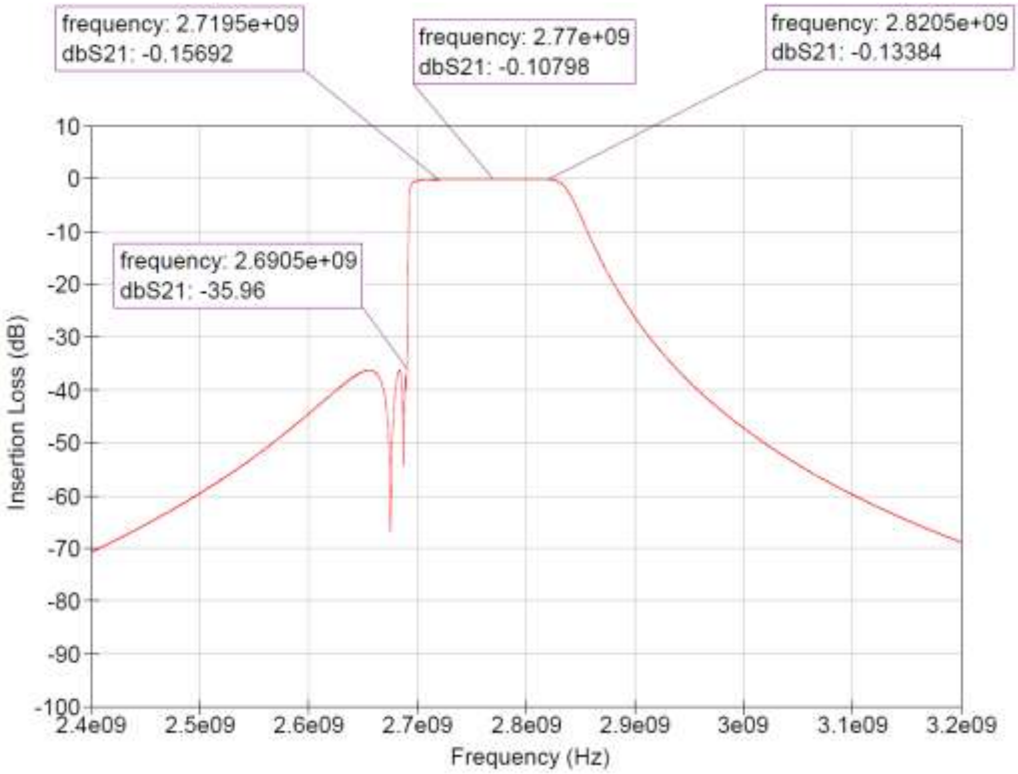
4.2.2 200MHz Bandwidth

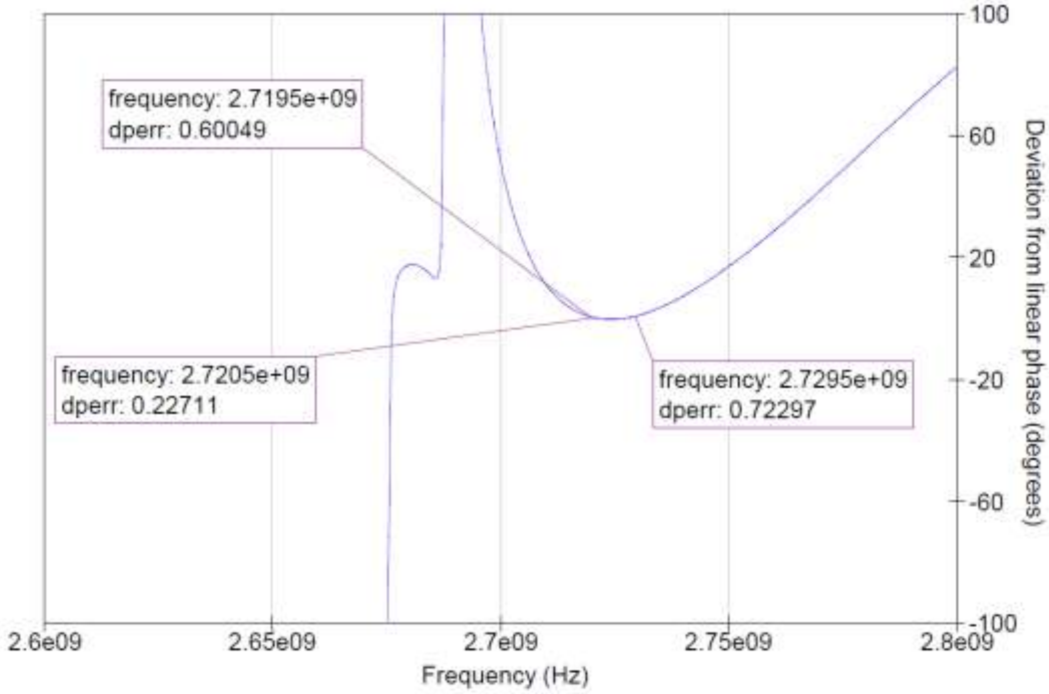




- 0.16dB worst case insertion loss over band
- Attenuation = 37dB @ 2690MHz
- Deviation from linear phase = 0.39° over worst case 1MHz
- Approximate filter size: 215 x 100 x 40mm
- Price indication: £1300 (50-off volumes)

4.2.3 100MHz Bandwidth

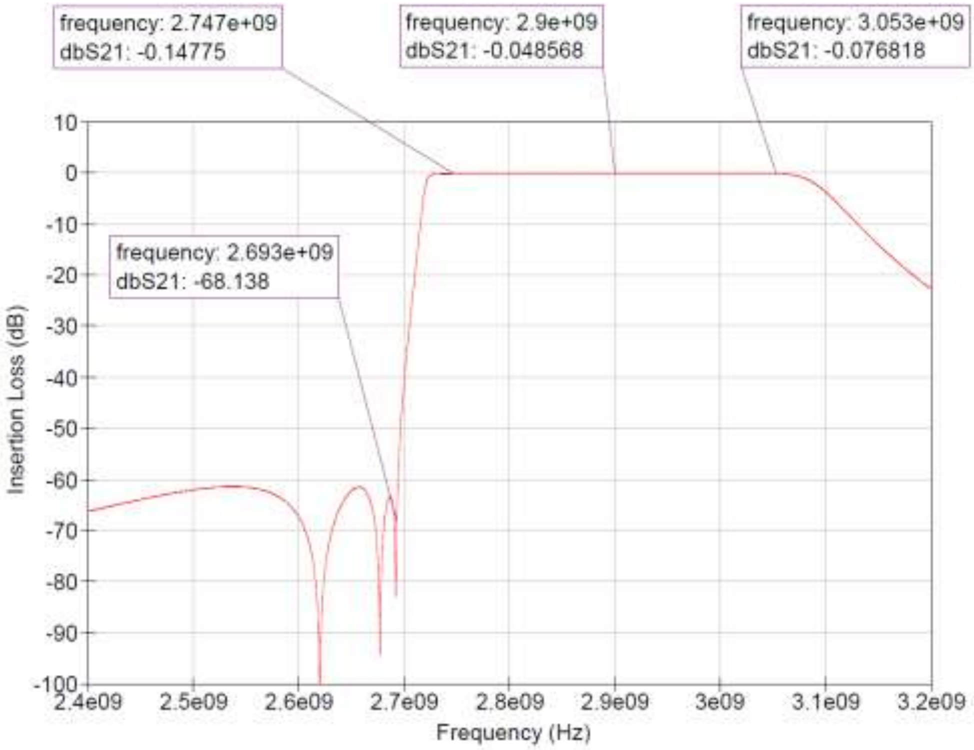


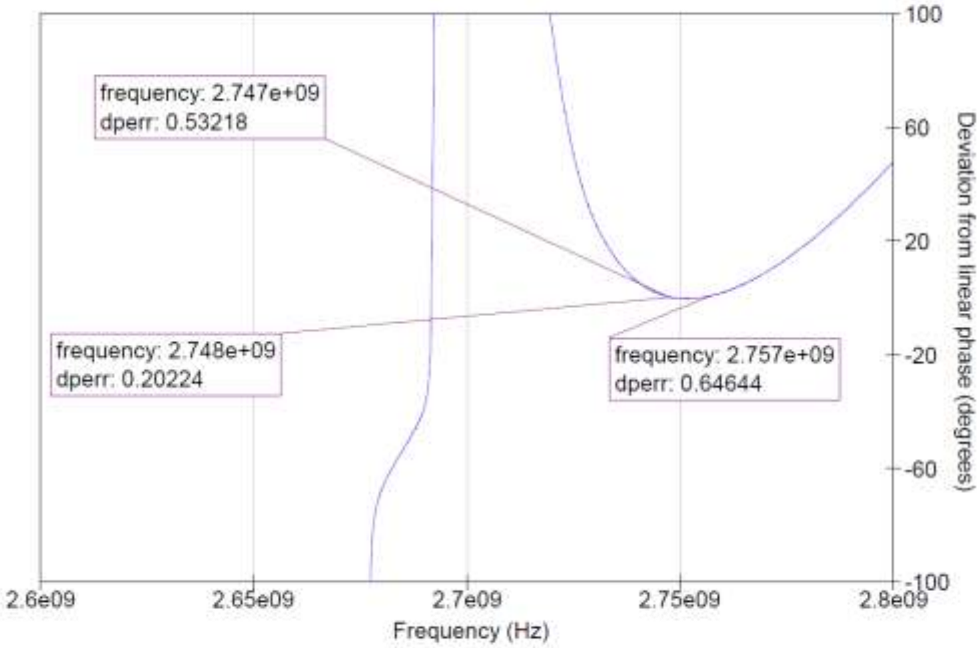


- 0.14dB worst case insertion loss over band
- Attenuation = 35dB @ 2690MHz
- Deviation from linear phase = 0.39° over worst case 1MHz
- Approximate filter size: 215 x 100 x 40mm
- Price indication: £1300 (50-off volumes)

4.3 60MHz Frequency Offset

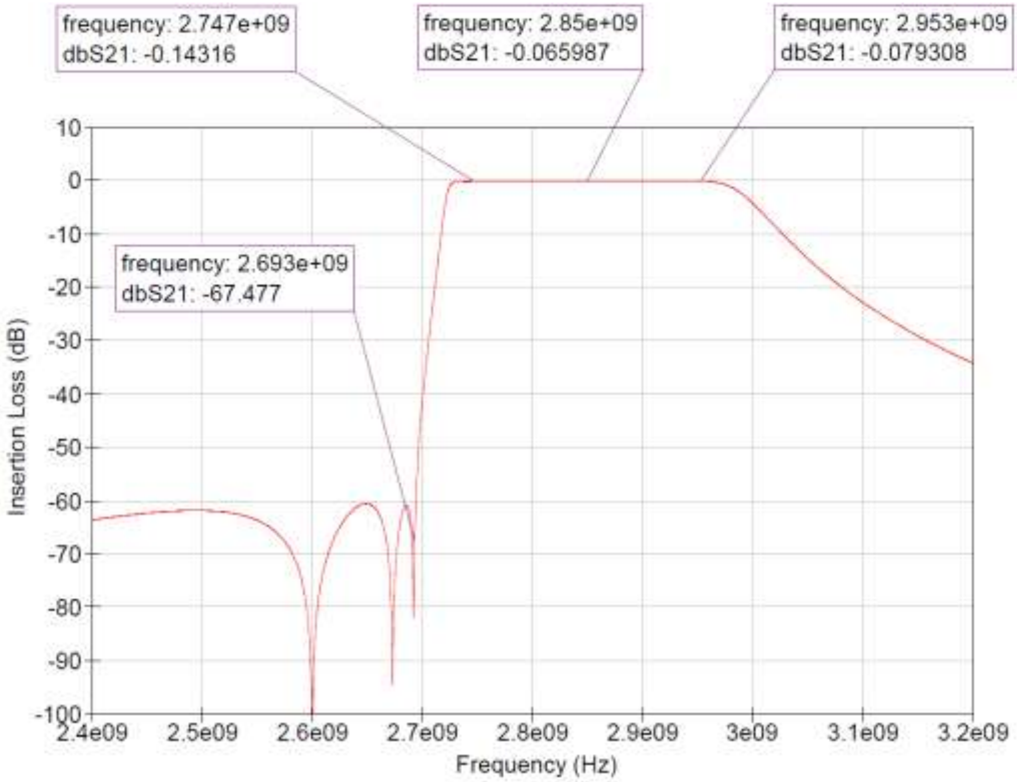
4.3.1 300MHz Bandwidth

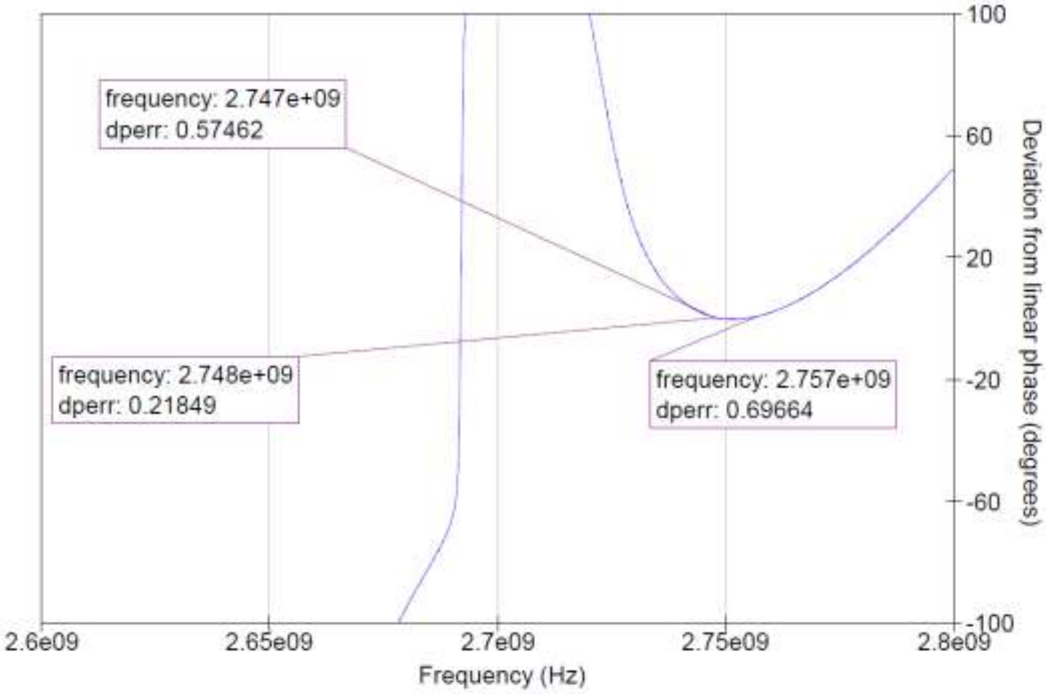




- 0.15dB worst case insertion loss over band
- Attenuation = 62dB @ 2690MHz
- Deviation from linear phase = 0.33° over worst case 1MHz
- Approximate filter size: 215 x 100 x 40mm
- Price indication: £1300 (50-off volumes)

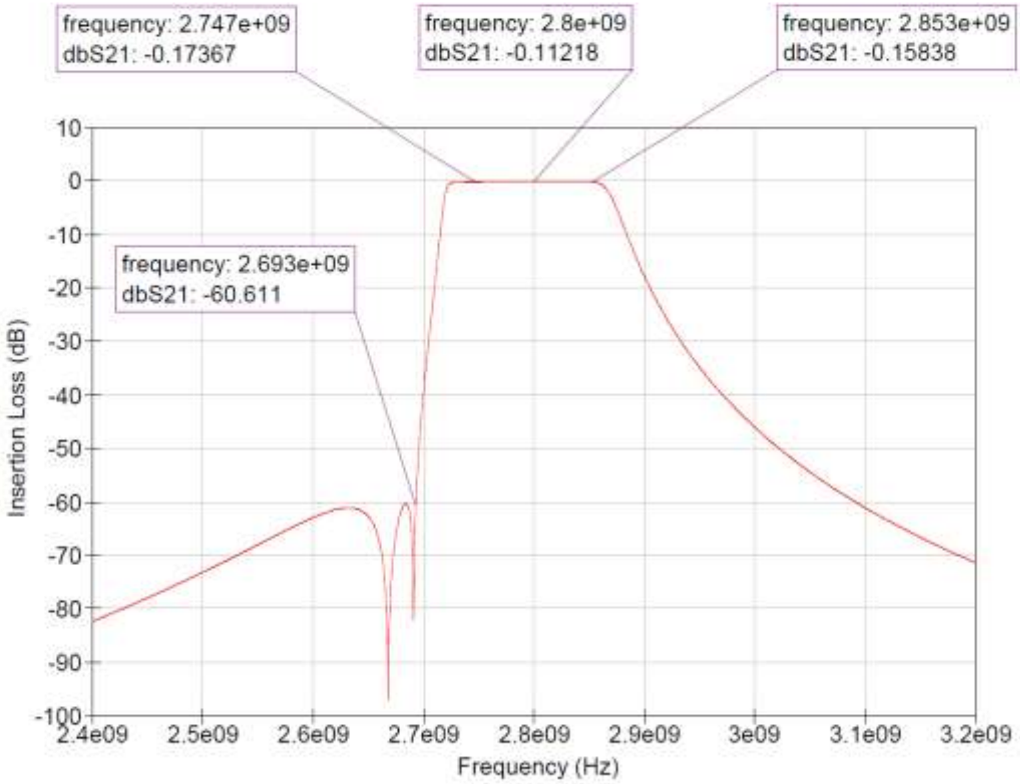
4.3.2 200MHz Bandwidth

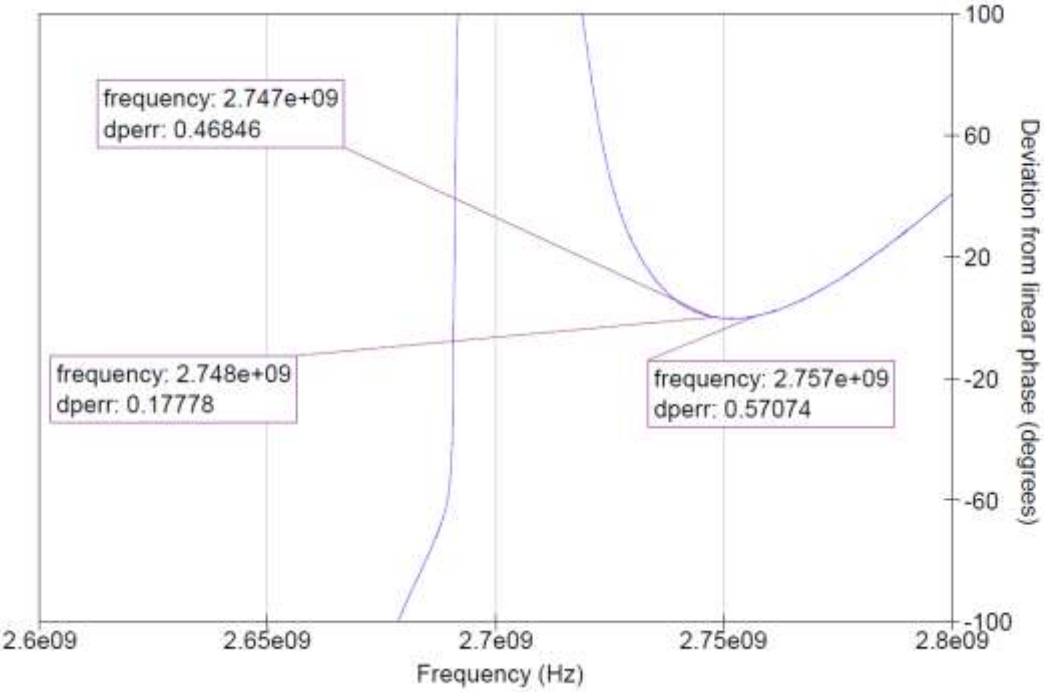




- 0.14dB worst case insertion loss over band
- Attenuation = 60dB @ 2690MHz
- Deviation from linear phase = 0.35° over worst case 1MHz
- Approximate filter size: 165 x 100 x 40mm
- Price indication: £1000 (50-off volumes)

4.3.3 100MHz Bandwidth





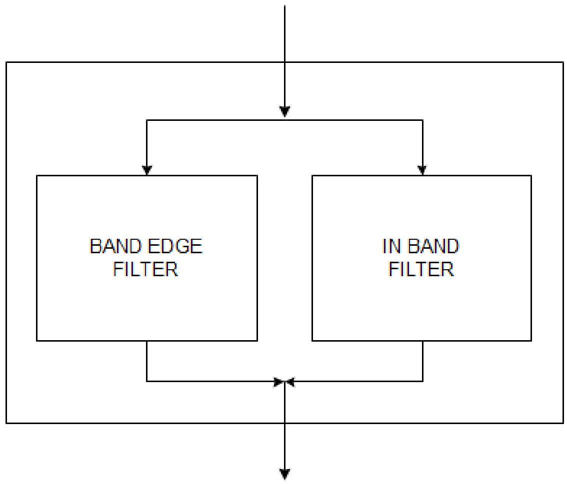
- 0.17dB worst case insertion loss over band
- Attenuation = 60dB @ 2690MHz
- Deviation from linear phase = 0.29° over worst case 1MHz
- Approximate filter size: 165 x 100 x 40mm
- Price indication: £1000 (50-off volumes)

4.4 10 MHz Frequency Offset – Parallel Filter Configuration (Case 1).

Section 4.1 shows that a phase linearity of 0.4°/MHz is not achievable for a 10MHz offset with a filter bandwidth of 100MHz through use of high-Q metallic filter designs under consideration. Ofcom therefore requested that Isotek provide details of a dual band filter that passes two 10MHz wide carriers, separated by 50MHz. Physically this would still be a 2-port device, but would house two parallel filters within a single unit, with the input and outputs connected to both of the parallel filters.

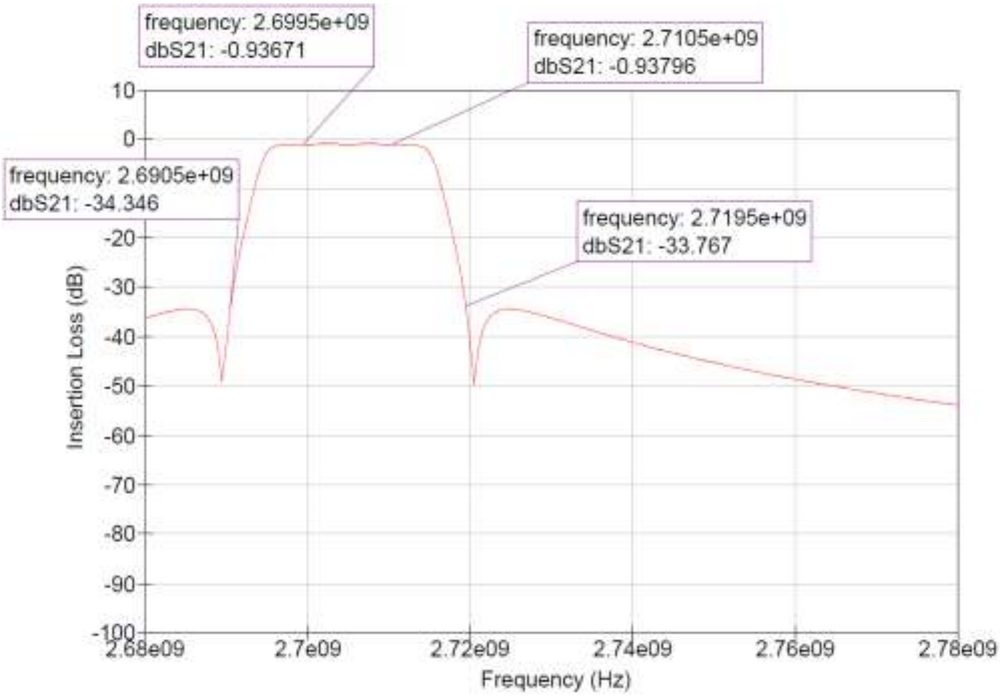
The units would house the following filters:

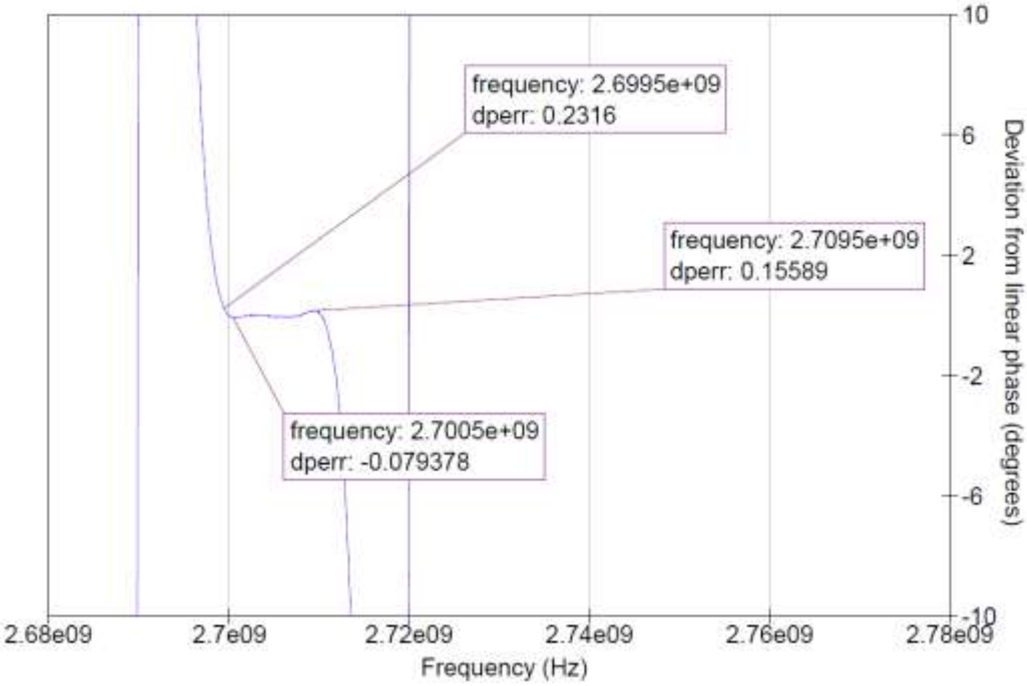
1) A ‘band edge’ filter, capable of passing a 10MHz carrier but providing rejection 10MHz away from band edge; and
2) An ‘in band’ filter, which simply passes a 10MHz carrier and provides sufficient rejection of the band edge filter to prevent interaction between the two parallel filters.



Block diagram

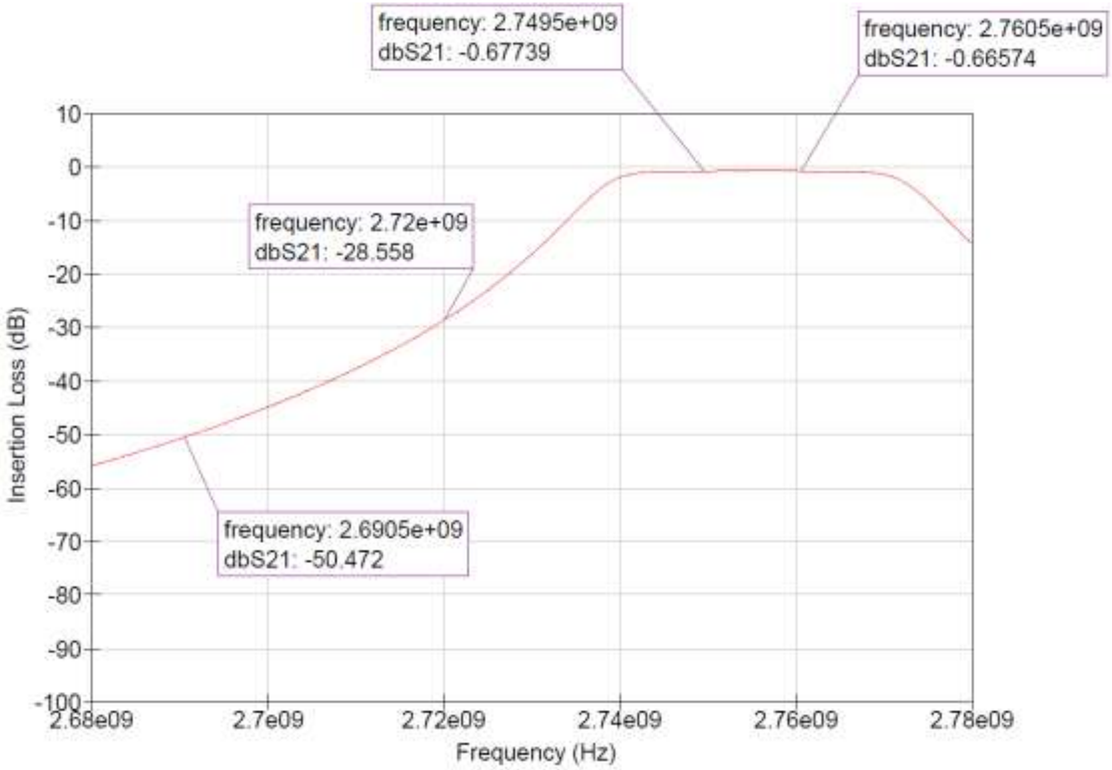
4.4.1 Band Edge Filter

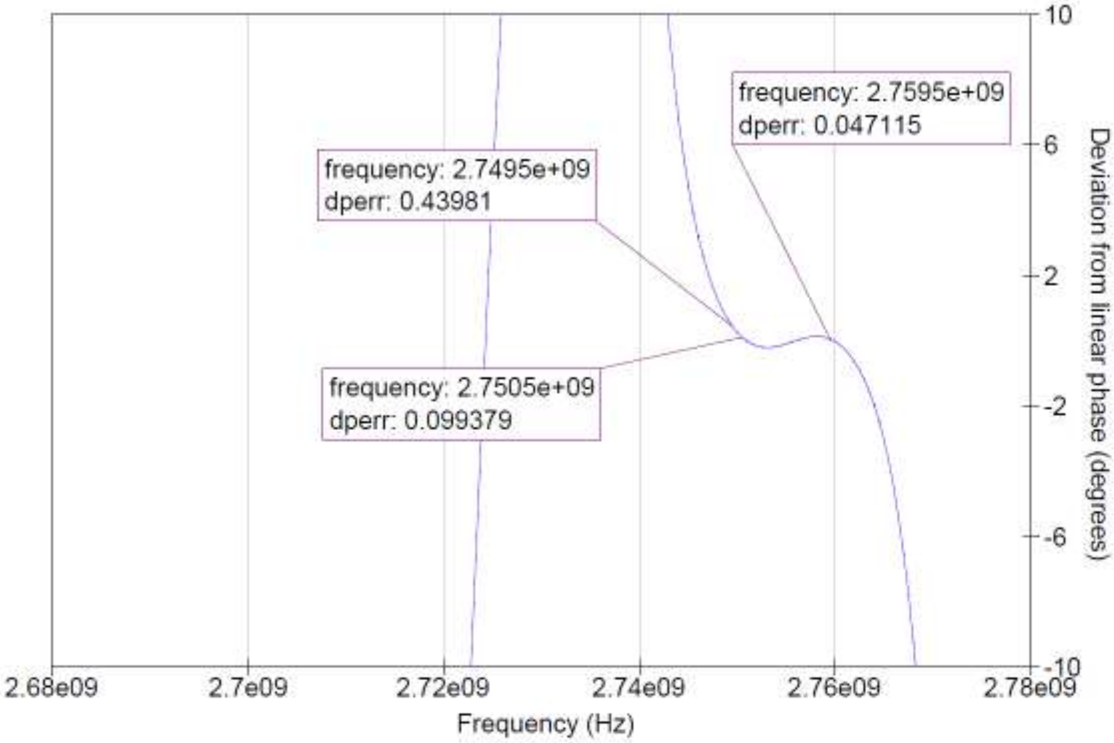




- 0.94dB worst case insertion loss over band
- Attenuation = 34dB @ 2690MHz
- Deviation from linear phase = 0.31° over worst case 1MHz
- Approximate filter size: 165 x 100 x 40mm

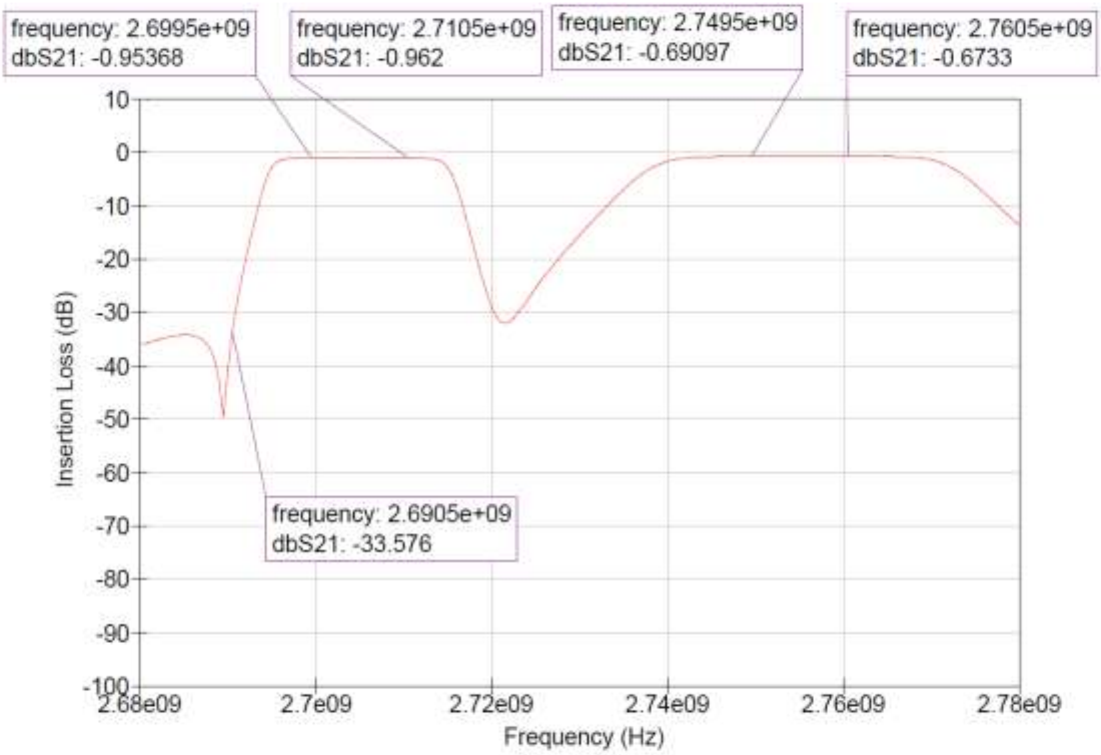
4.4.2 In Band Filter





- 0.68dB worst case insertion loss over band
- Attenuation = 50dB @ 2690MHz
- Deviation from linear phase = 0.34° over worst case 1MHz
- Approximate filter size: 70 x 70 x 40mm

4.4.3 Full Unit



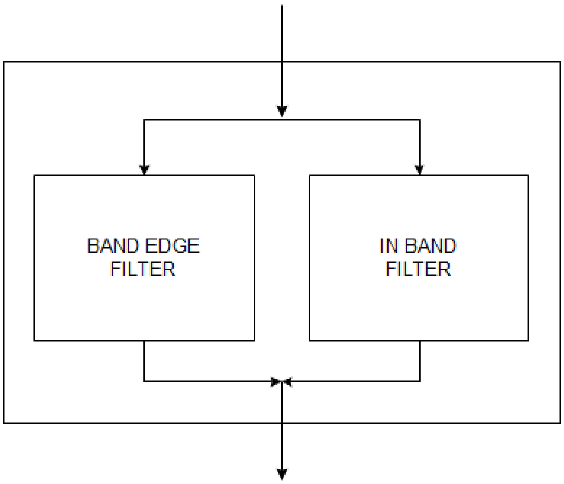
- Approximate full unit size: 230 x 100 x 40mm
- Price indication: £1400 (50-off volumes)

4.5 10 MHz Frequency Offset – Parallel Filter Configuration (Case 2) – Increased Bandwidth 'in band' Filter

Section 4.4 shows that a parallel filter configuration enables the use of a 10MHz wide frequency band starting at 2.7GHz, with another 10MHz wide band at some higher frequency. This study was then extended to define the performance of a parallel filter unit with a much wider 'in-band filter' bandwidth. Ideally the 'in-band filter' would extend over the full 150MHz from 2.75GHz to 2.9GHz.

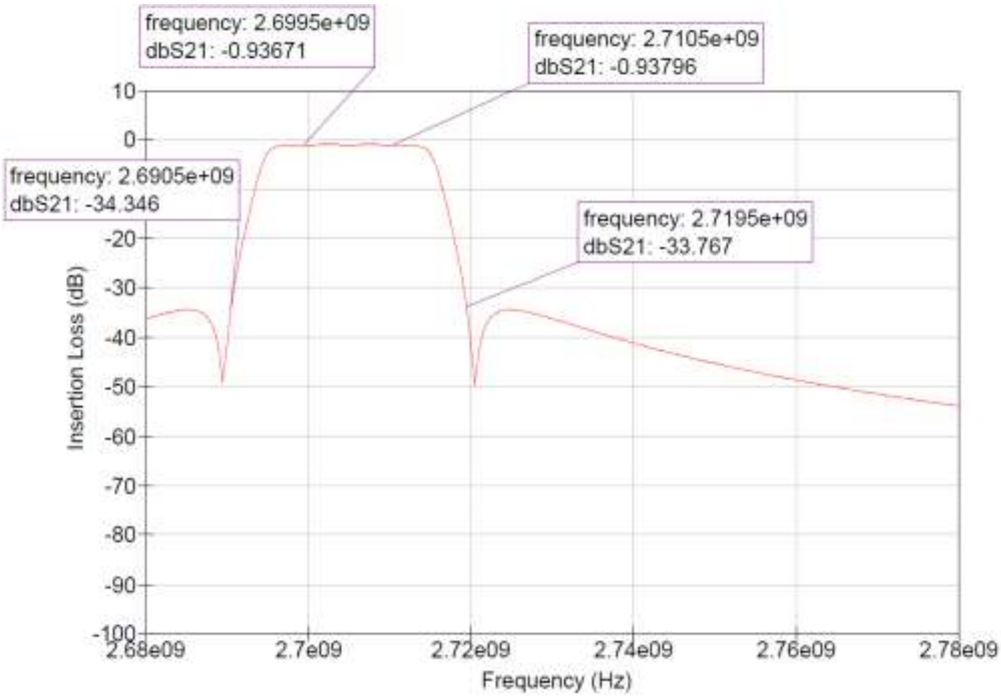
The units would house the following filters:

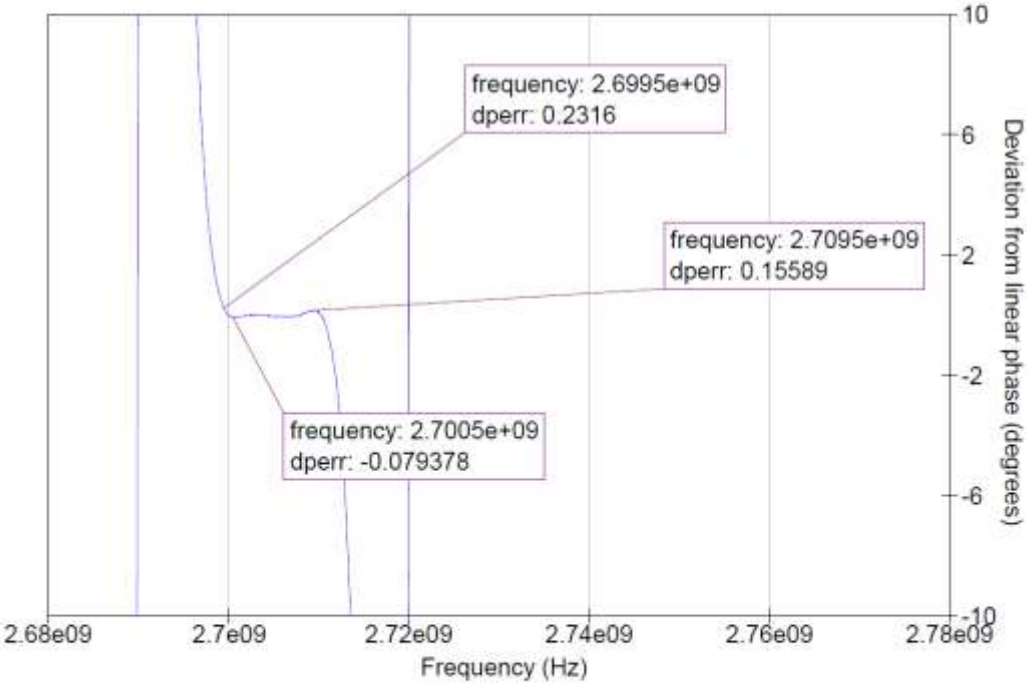
3) A 'band edge' filter, capable of passing a 10MHz carrier but providing rejection 10MHz away from band edge;
4) An 'in band' filter, which simply passes a 150MHz carrier and provides sufficient rejection of the band edge filter to prevent interaction between the two



Block diagram

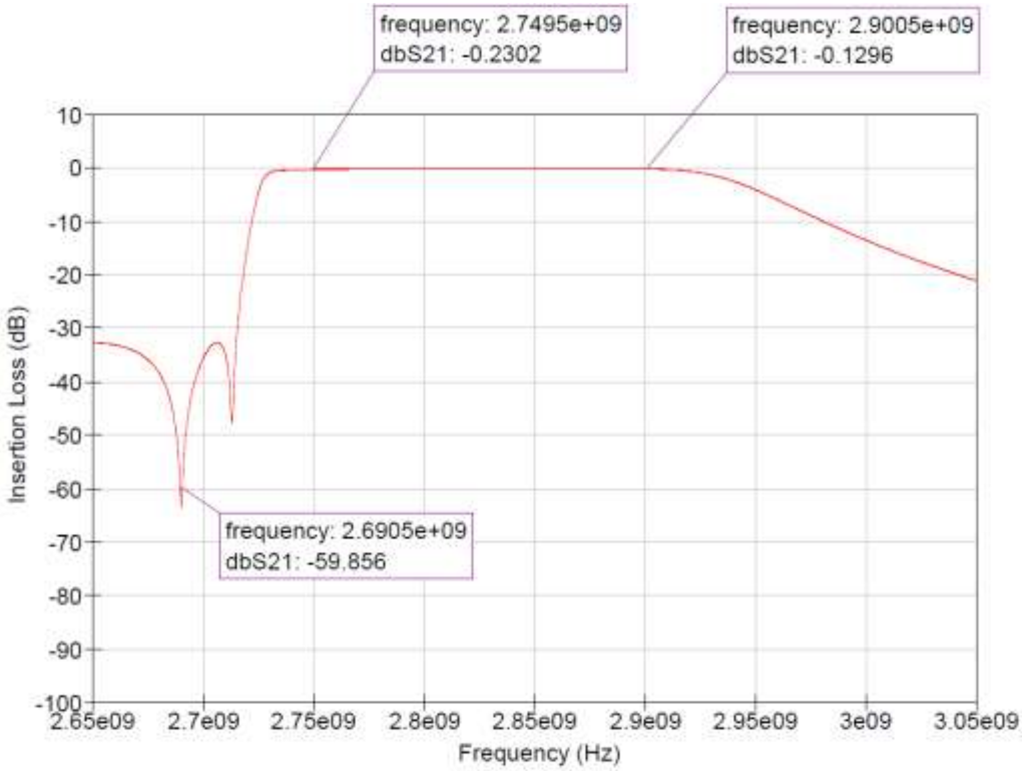
4.5.1 Band Edge Filter

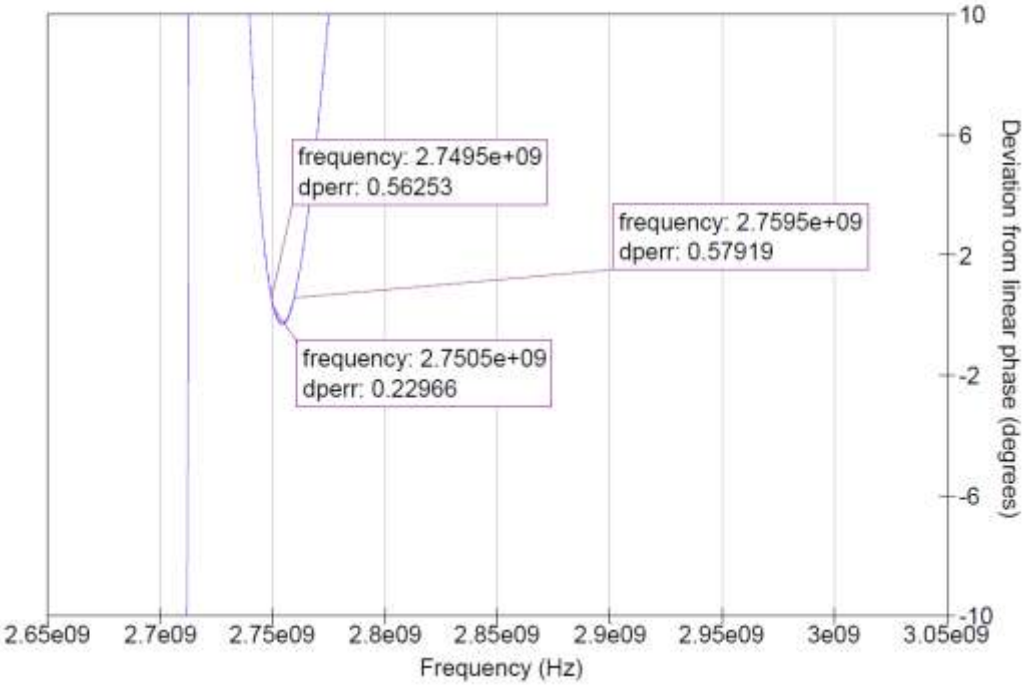




- 0.94dB worst case insertion loss over band
- Attenuation = 35dB @ 2690MHz
- Deviation from linear phase = 0.31° over worst case 1MHz
- Approximate filter size: 165 x 100 x 40mm

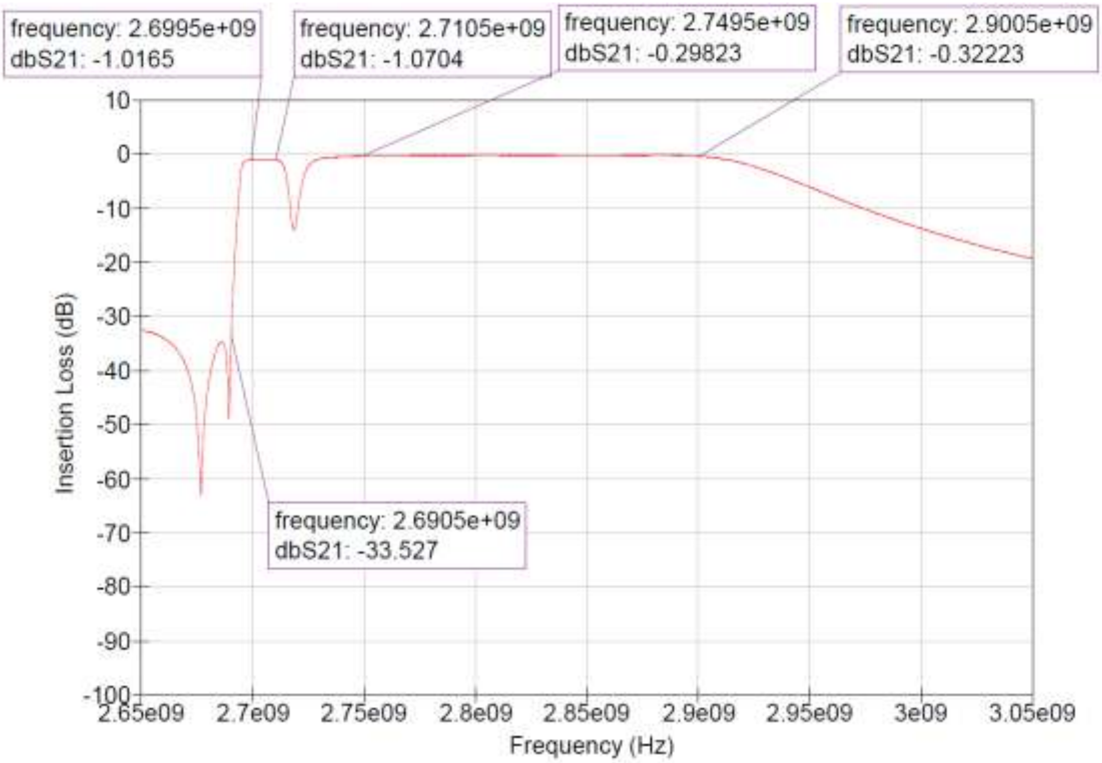
4.5.2 In Band Filter





- 0.68dB worst case insertion loss over band
- Attenuation = 32dB @ 2690MHz
- Deviation from linear phase = 0.34° over worst case 1MHz
- Approximate filter size: 70 x 100 x 40mm

4.5.3 Full Unit

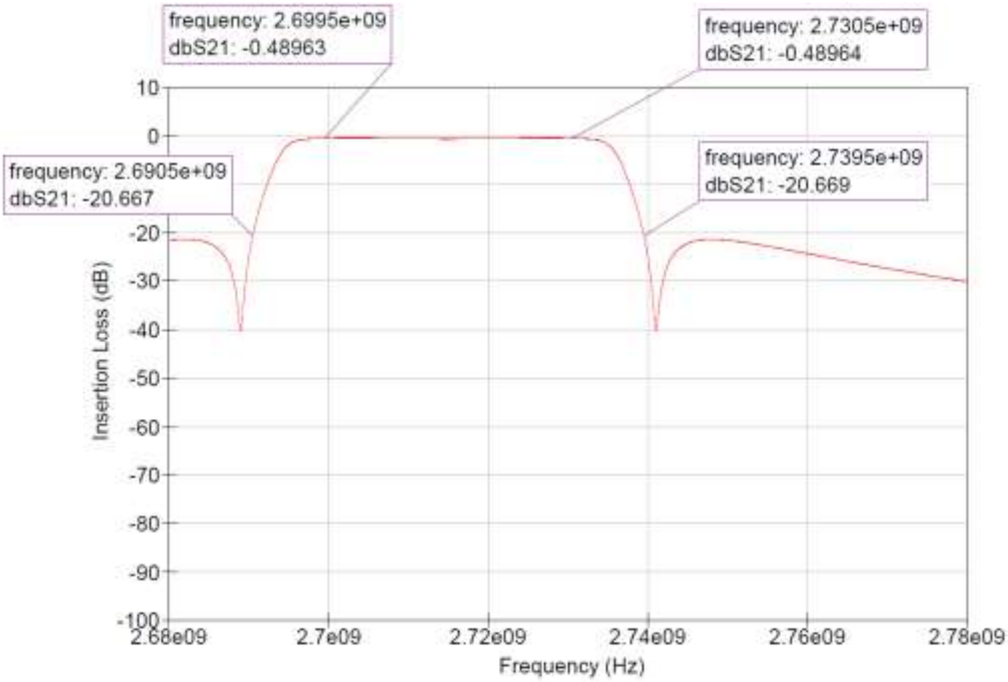


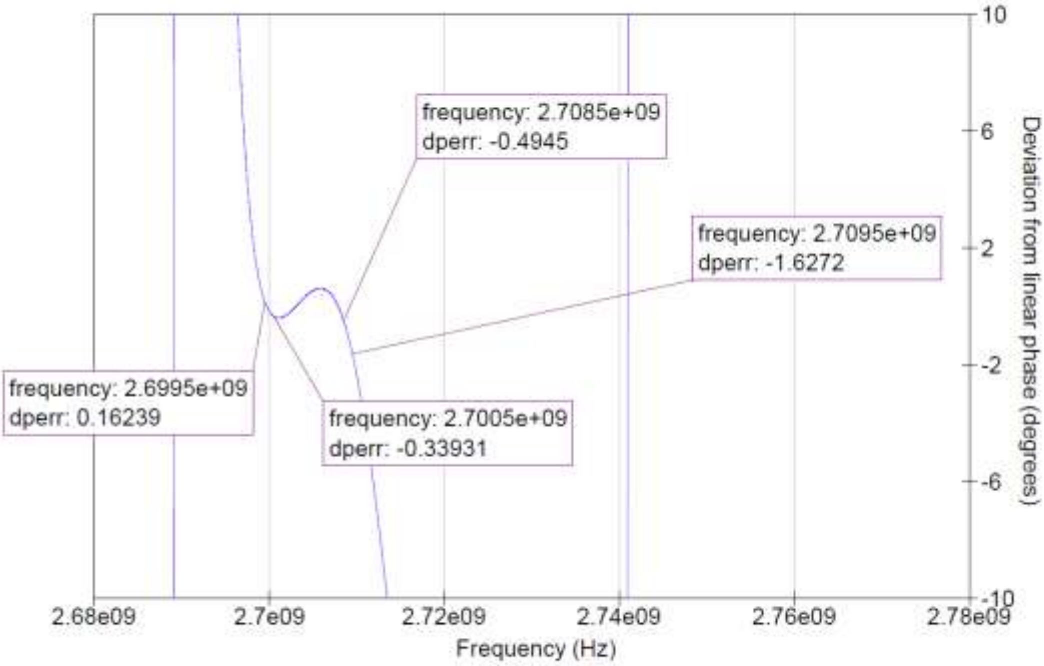
- Approximate full unit size: 230 x 100 x 40mm
- Price indication: £1400 (50-off volumes)

4.6 10 MHz Frequency Offset – Parallel Filter Configuration (Case 3) – Increased Bandwidth 'band edge' Filters

This study was then extended to define the performance of a parallel filter unit with a wider 'band-edge filter' bandwidth. Bandwidths of 30MHz and 50MHz were considered. An accompanying 'in-band filter' could be designed which would extend over the remainder of the band, except for a 10MHz section between the band-edge filter and the in-band filter. Performance of the in-band filters would be similar to that shown in section 4.5.2.

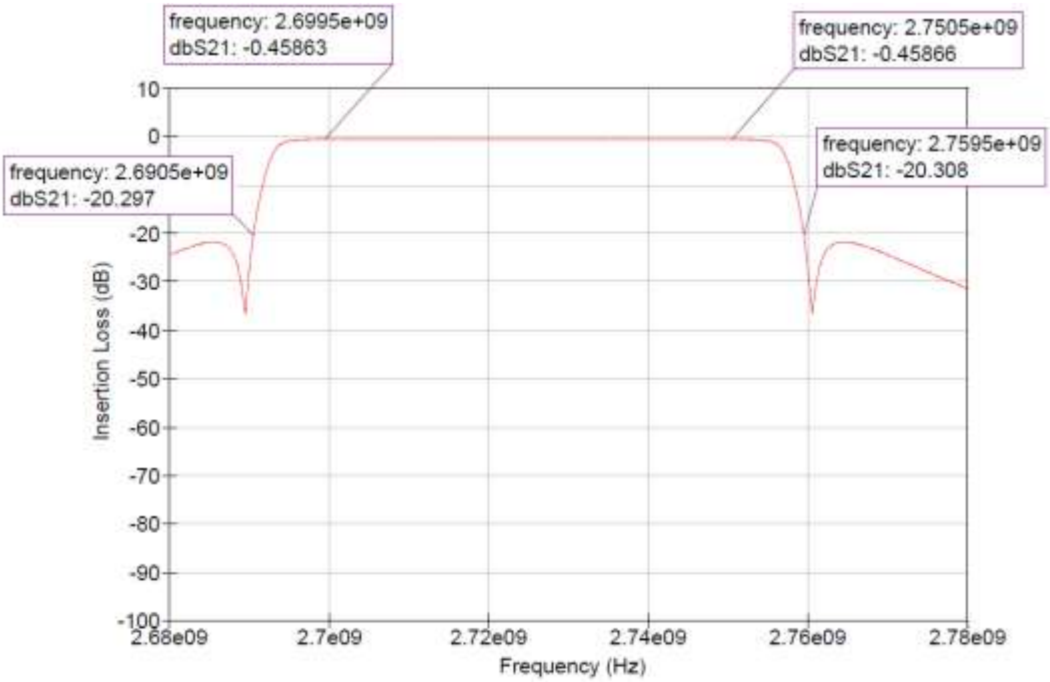
4.6.1 Band Edge Filter – 30MHz Bandwidth

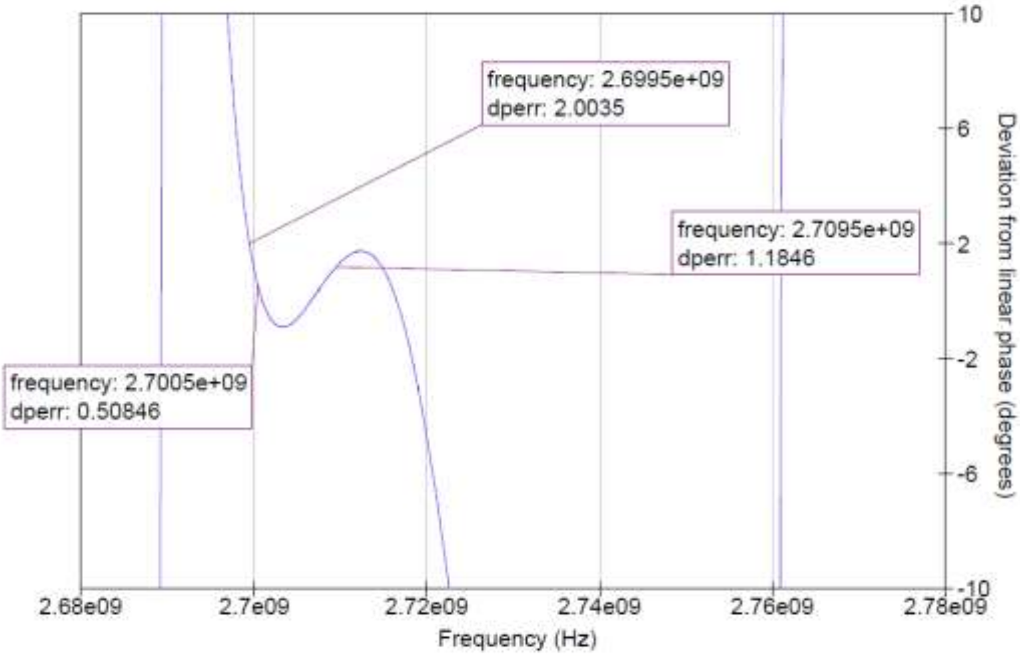




- 0.49dB worst case insertion loss over band
- Attenuation = 20dB @ 2690MHz
- Deviation from linear phase = 1.13° over worst case 1MHz
- Approximate filter size: 165 x 100 x 40mm

4.6.2 Band Edge Filter – 50MHz Bandwidth





- 0.46dB worst case insertion loss over band
- Attenuation = 20dB @ 2690MHz
- Deviation from linear phase = 1.50° over worst case 1MHz
- Approximate filter size: 215 x 100 x 40mm

4.7 Summary (filtering options for the 2700 - 3100 MHz band)

The table below summarises the data presented in sections 4.1 to 4.4. Data in **bold** indicates where design goals were not met through the use of the high-Q metallic cavity filter technology under consideration.

Filter Description	Band Edge Loss (dB)	Attenuation @ 2690MHz (dB)	Deviation from linear phase (°)	Approx. size (mm)	Approx. price for 50-off volumes (£)
10MHz Offset					
300MHz band	0.27	22	**1.92**	215 x 100 x 40	1300
200MHz band	0.28	22	**1.85**	215 x 100 x 40	1300
100MHz band	0.30	23	**1.96**	215 x 100 x 40	1300
30MHz Offset					
300MHz band	0.14	35	0.39	215 x 100 x 40	1300
200MHz band	0.16	37	0.39	215 x 100 x 40	1300
100MHz band	0.16	36	0.29	215 x 100 x 40	1300
60MHz Offset					
300MHz band	0.15	62	0.33	215 x 100 x 40	1300
200MHz band	0.14	60	0.35	165 x 100 x 40	1000
100MHz band	0.17	60	0.29	165 x 100 x 40	1000
Parallel Filter Configuration (10MHz Offset)	0.94 / 0.64	35	0.31 / 0.34	230 x 100 x 40	1400
Parallel Filter Configuration (10MHz Offset) Increased In-band Bandwidth	1.00 / 0.37	33	0.31 / 0.34	230 x 100 x 40	1400
Parallel Filter Configuration (10MHz Offset) 30MHz Band-edge Bandwidth	0.49	20	**1.13**	230 x 100 x 40	1400
Parallel Filter Configuration (10MHz Offset) 50MHz Band-edge Bandwidth	0.46	20	**1.50**	280 x 100 x 40	1800

4.8 Conclusions (filtering options for the 2700 - 3100 MHz band)

Simulations have been presented on possible filter designs which can improve the selectivity of radar receivers operating in the 2700 – 3100MHz band. The objective of the study was to minimise the potential for receipt of unacceptable interference due to inadequate radar selectivity from new telecommunications systems operating within the 2500 - 2690MHz and 3400 – 3600MHz bands.

Results of the analysis show that it should be possible to realise a practical 'generic' filtering design for radar systems operating in the 2700-3100MHz band (based on a standard single receiver RF chain) and having carriers centre frequencies assigned with a minimum of 30MHz from the 2690MHz band edge. The target filter design objective assumed within this study was a linearity specification of 0.4°/MHz over any 10MHz region of the pass band, a minimum target attenuation of 20dB at 2690MHz and a maximum frequency shift of ±500 kHz over the operational temperature range. It should be noted the target phase linearity and minimum attenuation parameters were based on requirements proposed by a radar manufacturer for a single older radar type. As such, they may not be applicable as target filter design objectives for other types of radar which may require more stringent phase and/or attenuation requirements, or have other technical considerations such as group delay that might need to be taken into account in the design of filters.

However, it was found with a 10MHz offset the phase linearity specification requirements could not be met by any of the single filter design considered (based on the use of high Q metallic cavity filters). Instead the study found a parallel filter configuration could be used for the 10MHz offset case which met the study design objectives of the filter. However it is recognised under the filtering scenario considered, the design of such a filter would need to be tailored to the individual operating frequency / frequencies of the radars. It is therefore considered radars having carriers assigned approximately within the 2700-2720 MHz band may need to make use of a bespoke filter design that is tailored to assigned carrier frequencies of the radar, in order to improve their receiver selectivity performance. This may not be the case for radars with carriers assigned above 2720MHz (i.e., having 30MHz offset to the 2690MHz band), where a generic filter design having a wide pass band and conforming with the target filter design requirements may well be practical.

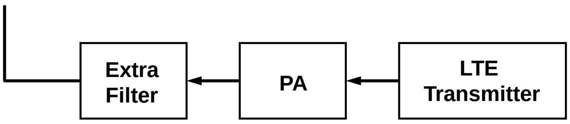
It should also be noted that filters with additional attenuation above the passband i.e. at 3400MHz could also be designed with similar performance.

5 Appendices

5.1 Appendix 1: Ofcom DDR Presentation 1

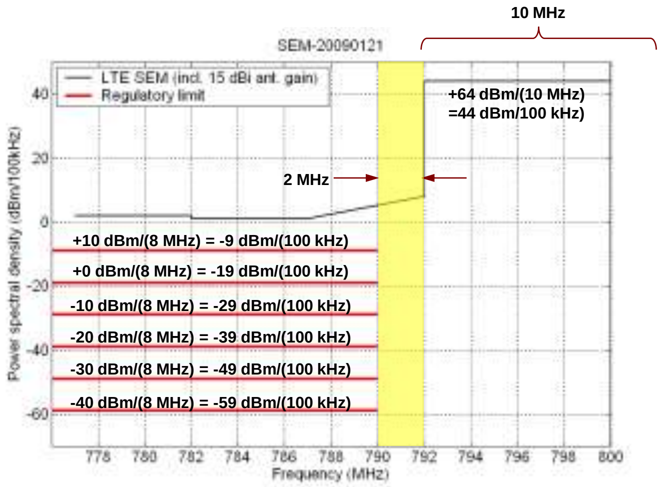
Problem formulation

- In practice, a base station's emission mask is a function of all the filtering in the transmitter and the spectral re-growth in the PA.
- For our purposes, we assume that the base station already meets the spectrum emission mask (SEM) specifications for LTE.
- In order to meet the additional regulatory limits, extra filtering is then needed post-PA. These will require low insertion loss and be able to deal with high powers.
- **Question:** What is the unit cost (in volumes for the EU market) of the simplest filter design/technology which would meet specific regulatory limits?
- The following slides describe the regulatory limits.



©Ofcom Reza Karimi 0 (4)

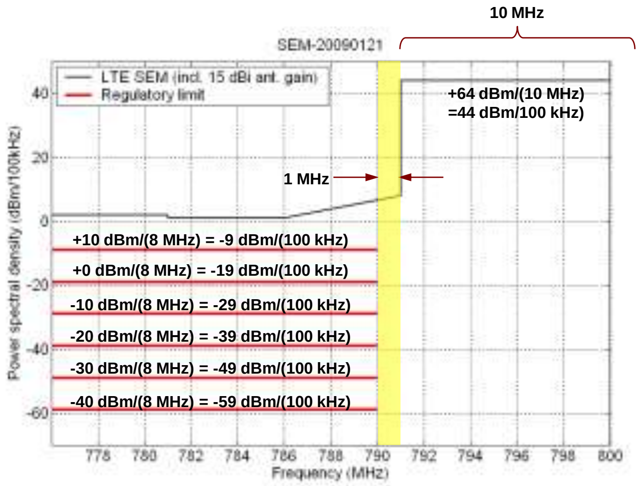
2 MHz guard-band



©Ofcom Reza Karimi 1 (4)

Ofcom

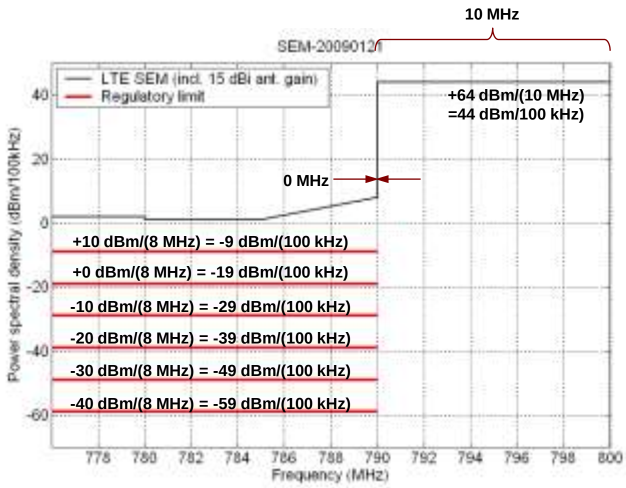
1 MHz guard-band



©Ofcom Reza Karimi 2 (4)

Ofcom

0 MHz guard-band



©Ofcom Reza Karimi 3 (4)

Ofcom

LTE SEM from 3GPP TS 36.104 V8.4.0 (2008-12)

For E-UTRA BS operating in Bands 5, 6, 8, 12, 13, 14, 17 emissions shall not exceed the maximum levels specified in Tables 6.6.3.1-1 to 6.6.3.1-3.

Table 6.6.3.1-3: General operating band unwanted emission limits for 5, 10, 15 and 20 MHz channel bandwidth (E-UTRA bands <1GHz) for Category A

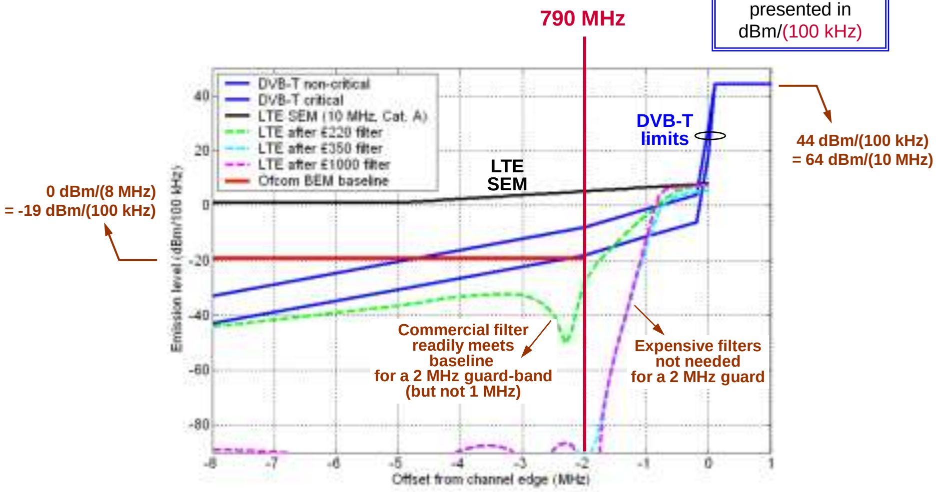
Frequency offset of measurement filter -3dB point, Δf	Frequency offset of measurement filter centre frequency, f_offset	Minimum requirement	Measurement bandwidth (Note 1)
0 MHz ≤ Δf < 5 MHz	0.05 MHz ≤ f_offset < 5.05 MHz	$-7dBm-\frac{7}{5}\left(\frac{f\_offset}{MHz}-0.05\right)dB$	100 kHz
5 MHz ≤ Δf < 10 MHz	5.05 MHz ≤ f_offset < 10.05 MHz	-14 dBm	100 kHz
10 MHz ≤ Δf ≤ Δf_{max}	10.05 MHz ≤ f_offset < f_offset_{max}	-13 dBm	100 kHz

- To derive EIRP, add 15 dB antenna gain (including cable loss).

5.2 Appendix 2: Ofcom DDR Presentation 2

Comparison of BEM baseline and SEMs

Note: All masks are presented in dBm/(100 kHz)



The LTE out-of-block SEM is from TS 36.104 for a 10 MHz channel bandwidth,
and for an antenna gain (including cable loss) of 15 dB.
The assumed LTE in-block emission level is consistent with an EIRP of 64 dBm/(10 MHz).

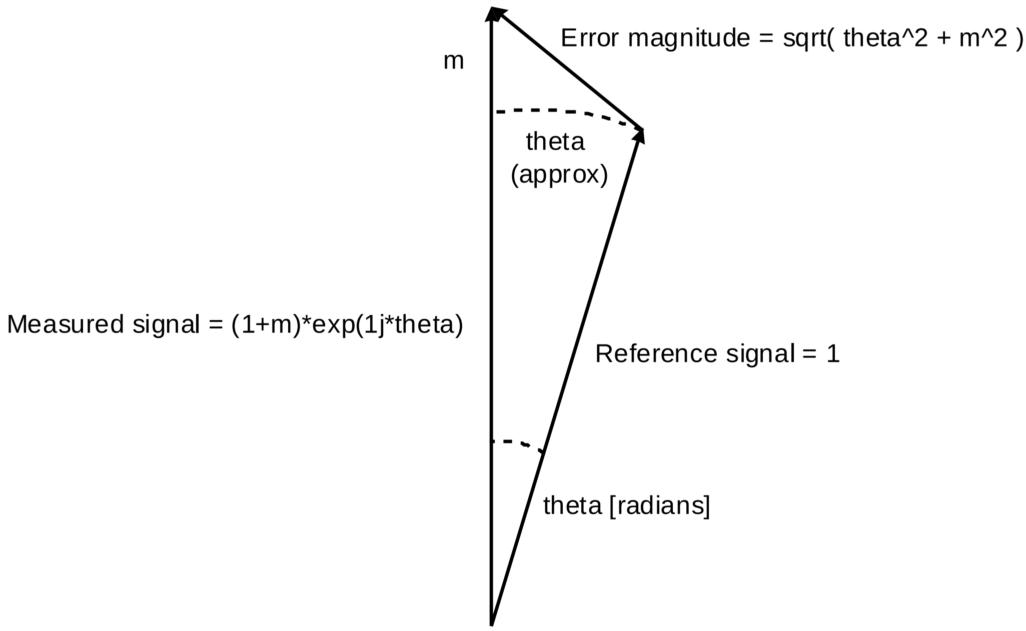
DVB-T critical and non-critical masks

Table 2: DVB-T spectrum masks for 8 MHz channel spacing
(GE06 Final Acts, section 3.6.2)
(Power level measured in a 4kHz bandwidth,
where 0dB corresponds to the total output power)

Relative frequency (DVB-T) (MHz)	DVB-T Non critical case (dB)	DVB-T critical case (dB)
-12	-110	-120
-9	-97.5	-107.5
-6	-85	-95
-5	-78.3	-88.3
-4.2	-73	-83
-4	-48	-58
-3.9	-32.8	-32.8
0	-32.8	-32.8

5.3 Appendix 3: EVM Background

EVM is the square root of ratio of error power to reference power expressed as a percentage. For a filter it is possible to measure the EVM that would be added to a reference signal by looking separately at the phase and magnitude of the filter over the band occupied by the signal. Useful EVM figures are small and therefore the magnitude and phase errors are approximately orthogonal and the error vector is the hypotenuse of a triangle with the magnitude error and theta as the other two sides (see figure below).



For the magnitude error, basic loss simply attenuates the signal and does not contribute to the EVM so the root mean squared (rms) deviation from a unit amplitude is calculated after the signal has been scaled to account for loss (across the bandwidth occupied by the signal). Similarly phase distortion is the rms deviation from the best-fit straight line through the phase because linear phase is only a delay and therefore does not distort the signal either. The total error is then calculated as in the figure above. Generally for most filters the phase distortion dominates the EVM and a good estimate can be obtained from looking at phase only.

The EVM estimate should be weighted across the signal band to account for the roll-off in the shape of the signal and the measurement filter. This typically makes very little difference for WCDMA and OFDM signals and omitting it will produce a very slight over-estimate of EVM for filters. For EDGE and GSM however the effect is greater.