Microstrip Filter Design

Jia-Sheng Hong

Heriot-Watt University
Edinburgh, UK
J.Hong@hw.ac.uk

Outline

- Introduction
- Design considerations
- Design examples
- Summary

Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

Introduction- Driving forces

Recent development of microstrip filters has been driven by applications -

- **Wireless communications**
- **Wireless sensor/radar systems**
- **…….**

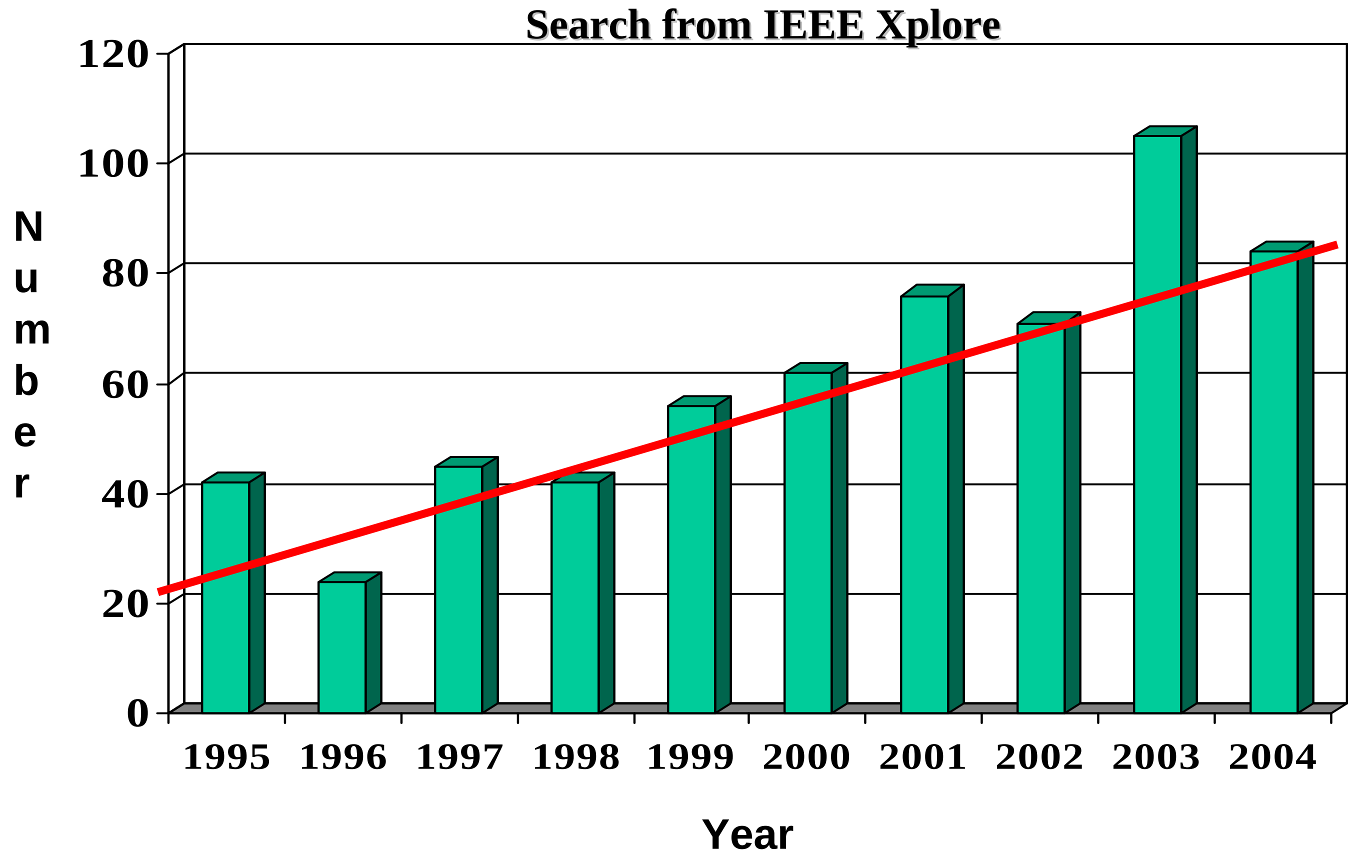
Driven by technologies -

- **High temperature superconducting**
- **Micromachining**
- **LTCC**
- **Ferroelectric**
- **…….**

HERIOT WATT UNIVERSITY
Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

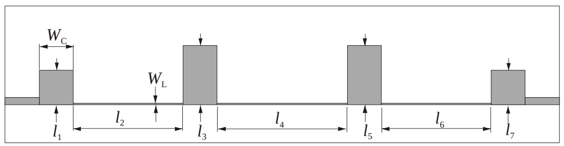
Introduction- Microstrip Filter Publications

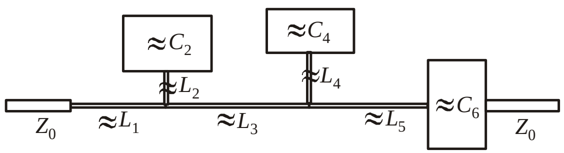
Total 600+ in recent 10 years

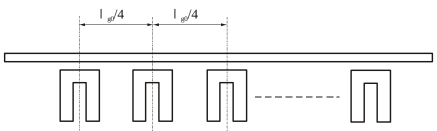


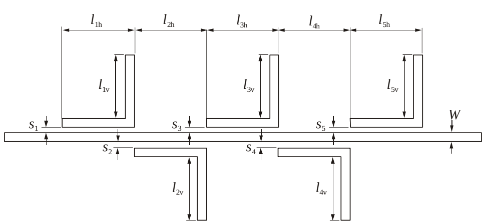
Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

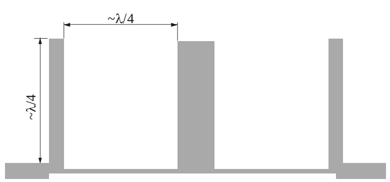
Design Considerations- Topologies

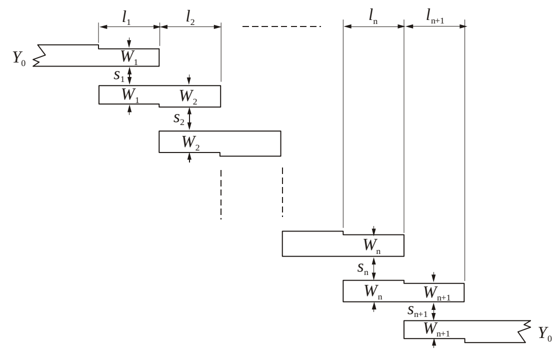


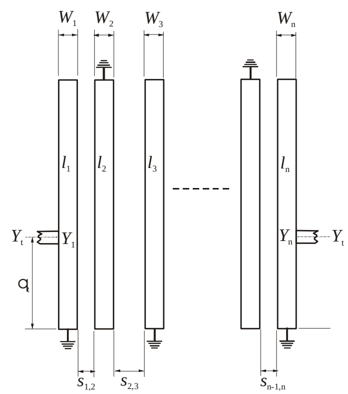


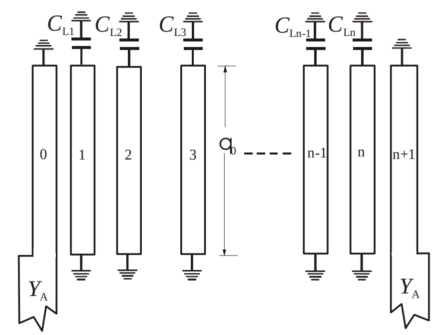


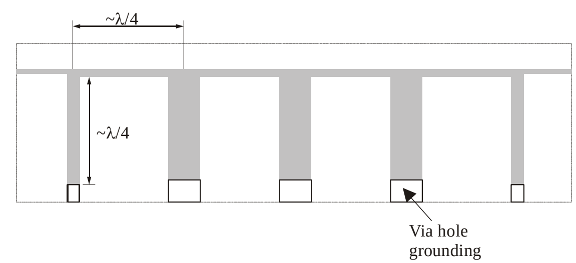












Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

Design Considerations- Topologies

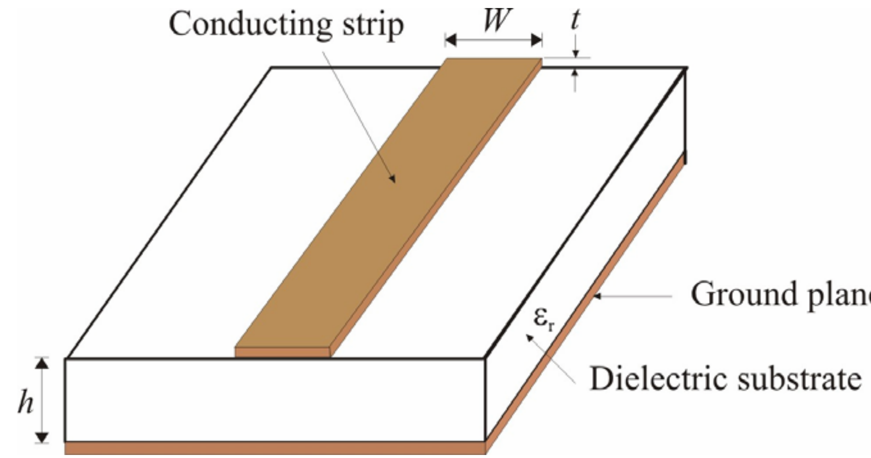
The choice of a topology depends on

- ✓ Characteristics of filters, such as chebyshev or elliptic
- ✓ Bandwidth
- ✓ Size
- ✓ Power handling

HERIOT WATT UNIVERSITY

Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

Design Considerations- Substrates



The choice of a substrate depends on

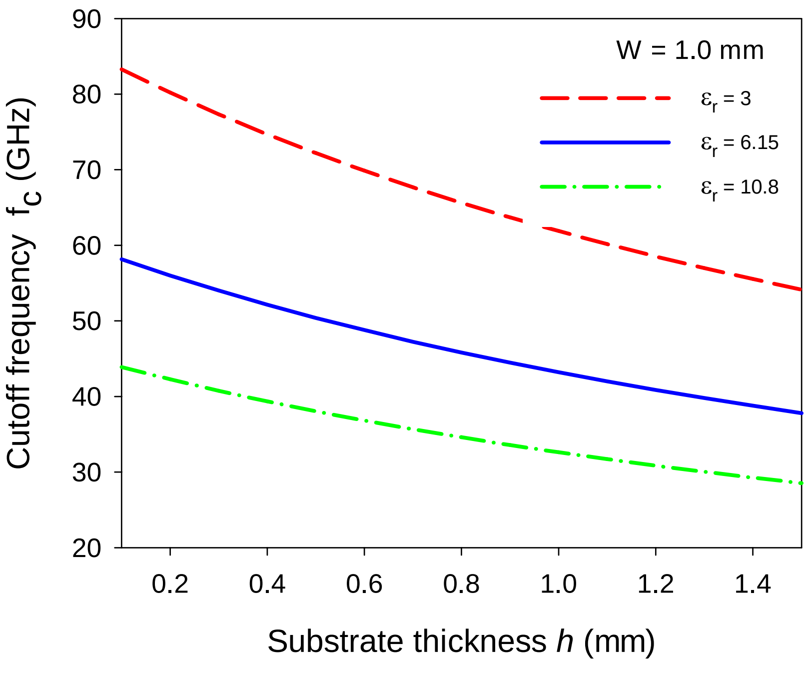
- ✓ Size
- ✓ Higher-order modes
- ✓ Surface wave effects
- ✓ Implementations – couplings, line/spacing tolerances, …
- ✓ Dielectric loss
- ✓ Temperature stability
- ✓ Power handling – dielectric strength (breakdown), thermal conductivity

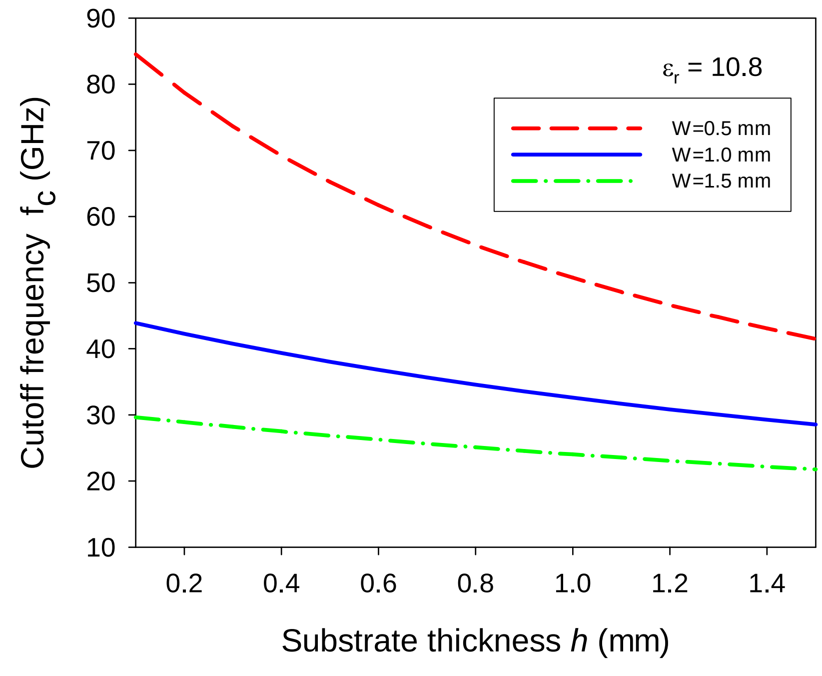
HERIOT WATT UNIVERSITY

Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

Design Considerations- Higher-order modes

✓ Keep operating frequencies below the cutoff frequency of the 1st higher-order mode,
$$f_c = \frac{c}{\sqrt{\varepsilon_r}(2W + 0.8h)}$$





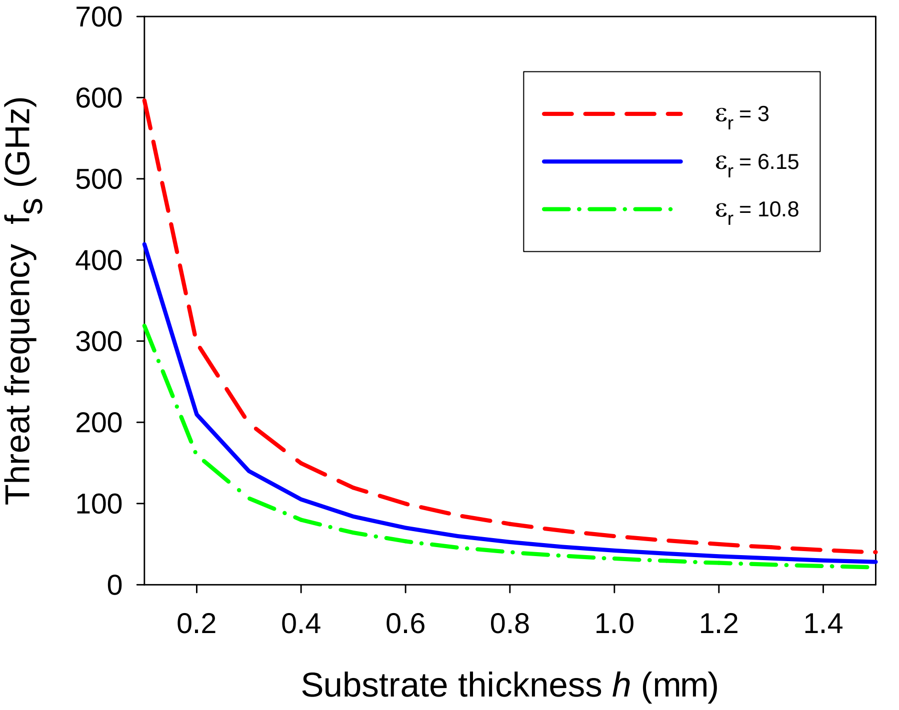
Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

Design Considerations- Surface waves

✓ Keep operating frequencies below the threat frequency of the lowest surface wave mode,

$$f_s = \frac{c \tan^{-1} \varepsilon_r}{\sqrt{2}\pi h \sqrt{\varepsilon_r - 1}}$$

at which the surface mode couples strongly to the dominant mode of microstrip because the phase velocities of the two modes are close.



Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

Design Considerations- Losses

There are three major losses in a microstrip resonator:

- Conductor loss $$Q_c \propto \pi \left(\frac{h}{\lambda}\right) \cdot \left(\frac{377\Omega}{R_s}\right)$$
- Dielectric loss $$Q_d \propto \frac{1}{\tan\delta}$$
- Radiation loss

$$\frac{1}{Q_u} = \frac{1}{Q_c} + \frac{1}{Q_d} + \frac{1}{Q_r}$$

HERIOT WATT UNIVERSITY
Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

Design Considerations- Power handling

- Peak power handling capability –

  when the breakdown occurs in substrate

$$P_p \propto \frac{V_o^2}{2Z_c}$$

V_o is the maximum breakdown voltage of the substrate

Z_c is the characteristic impedance of the microstrip

Narrower band filters result in higher electric field density, leading to a lower peak power handling

HERIOT WATT UNIVERSITY

Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

Design Considerations- Temperature effect

Temperature characteristic of a microstrip half-wavelength resonator on RT/Duroid substrate with ε_r = 10.2, h = 1.27 mm

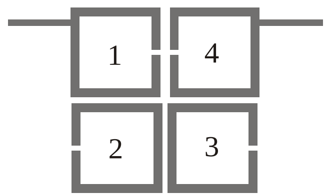
Copper CTE (coefficient of thermal expansion) = 17 ppm/^{o}C
Substrate CTE = 24 ppm/^{o}C
Substrate TCK (thermal coefficient of ε_r) = –425 ppm/^{o}C

At 23 ^{o}C	f0 = 1929.8 MHz	Δf = 0
At 73 ^{o}C for copper CTE only	f0 = 1928.1 MHz	Δf = –1.7 MHz
At 73 ^{o}C for substrate thickness CTE only	f0 = 1929.9 MHz	Δf = 0.1 MHz
At 73 ^{o}C for substrate TCK only	f0 = 1949.4 MHz	Δf = 19.6 MHz
At 73 ^{o}C (consider all)	f0 = 1947.8 MHz	Δf = 18.0 MHz

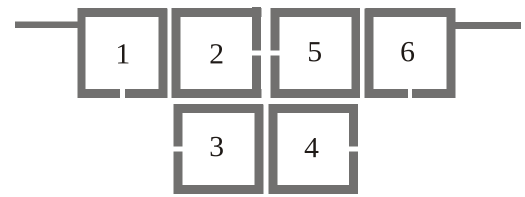
- ✓ **Frequency variation versus temperature is mainly due to dielectric constant change vs temperature**

HERIOT WATT UNIVERSITY
Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

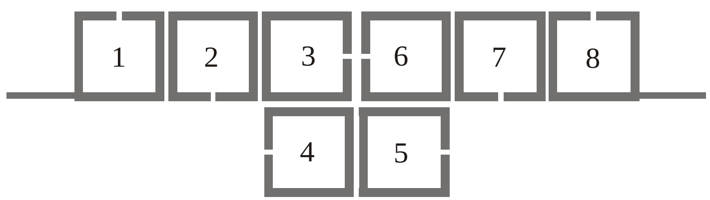
Design Examples- Open-loop filters



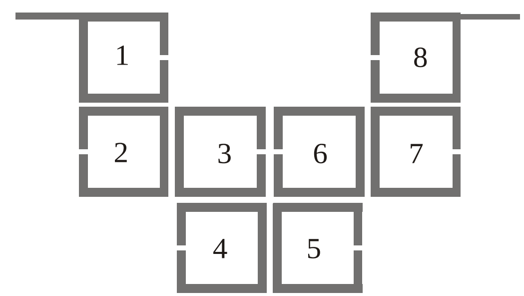
(*a*)



(*b*)



(*c*)



(*d*)

From: Jia-Sheng Hong and M.J.Lancaster, *Microstrip Filters for RF/Microwave Applications*, John Wiley & Sons. Inc. New York, 2001

Design Examples- Open-loop filters

- Specifications:

Center frequency	985MHz
Fractional Bandwidth	10.359%
40dB-Rejection Bandwidth	125.5MHz
Passband Return loss	–20dB

- Design parameters for an 8-pole filter:

$$M_{1,2} = M_{7,8} = 0.08441 \qquad M_{2,3} = M_{6,7} = 0.06063$$

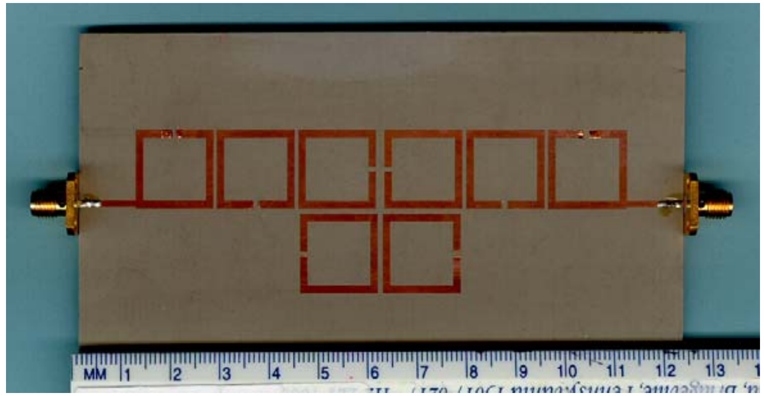
$$M_{3,4} = M_{5,6} = 0.05375 \qquad M_{4,5} = 0.0723$$

$$M_{3,6} = -0.01752 \qquad Q_{ei} = Q_{eo} = 9.92027$$

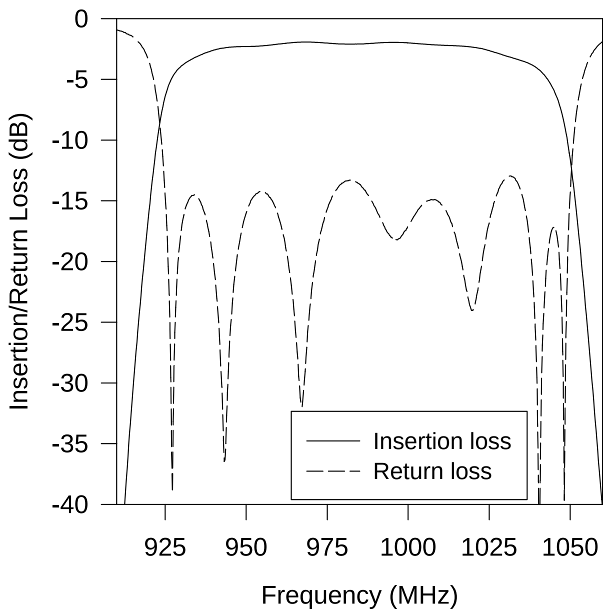
Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

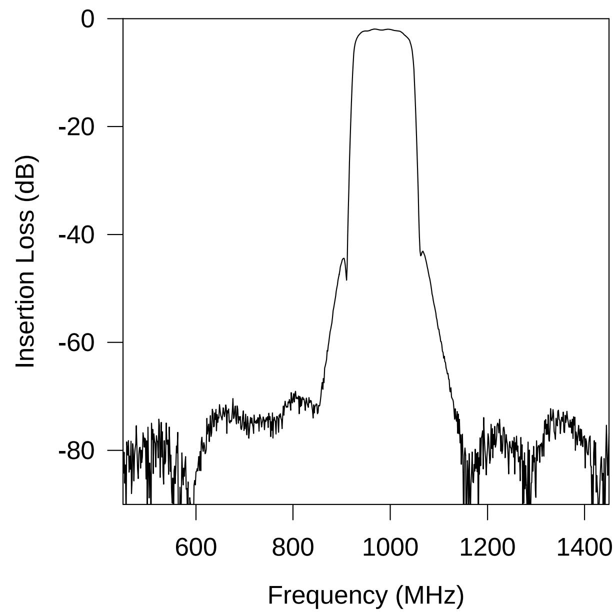
Design Examples- Open-loop filters

Realisation 1



On RT/Duroid substrate with a relative dielectric constant of 10.8 and a thickness of 1.27mm. Each resonator has a size of 16 by 16 mm.



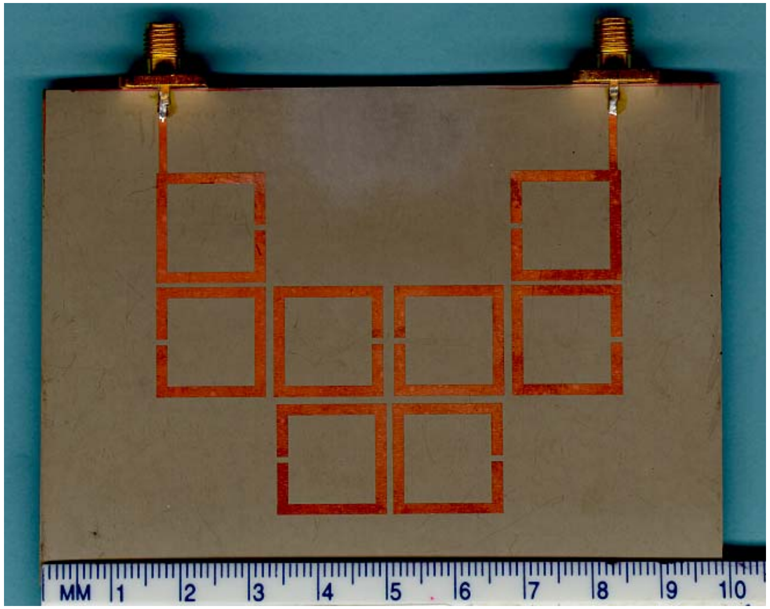


HERIOT WATT UNIVERSITY

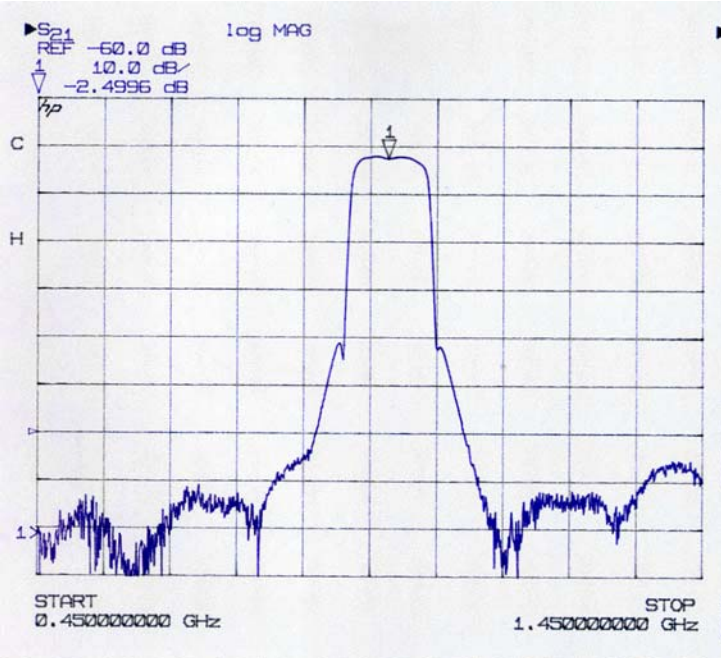
Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

Design Examples- Open-loop filters

Realisation 2



On RT/Duroid substrate with a relative dielectric constant of 10.8 and a thickness of 1.27mm



Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

Design Examples- Trisection open-loop filters

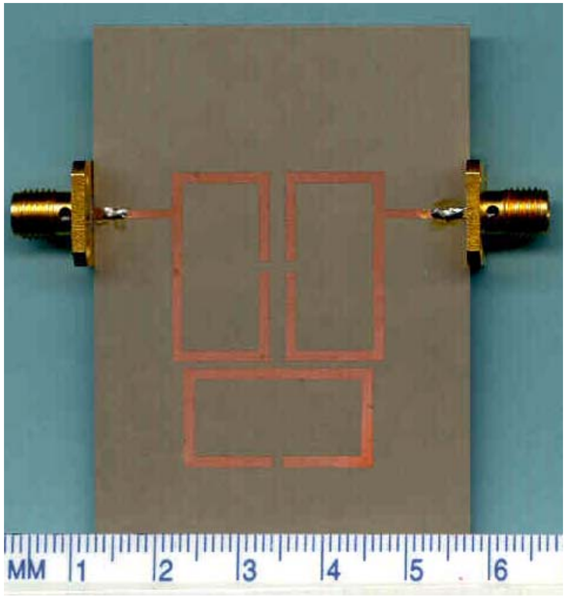
Midband or centre frequency : 905MHz

Bandwidth of pass band : 40MHz

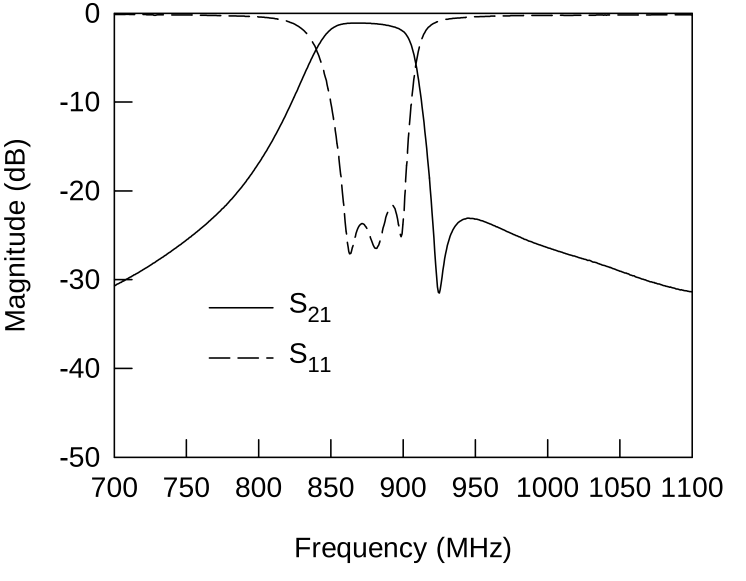
Return loss in the pass band : < –20dB

Rejection : > 20dB for frequencies ≥ 950MHz

$$f_{01} = f_{03} = 899.471\,\text{MHz}$$
$$f_{02} = 914.713\,\text{MHz}$$
$$Q_{ei} = Q_{eo} = 15.7203$$
$$M_{12} = M_{23} = 0.04753$$
$$M_{13} = -0.02907$$



On RT/Duroid substrate with a relative dielectric constant of 10.8 and a thickness of 1.27mm



Measured response

Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

Design Examples- Trisection open-loop filters

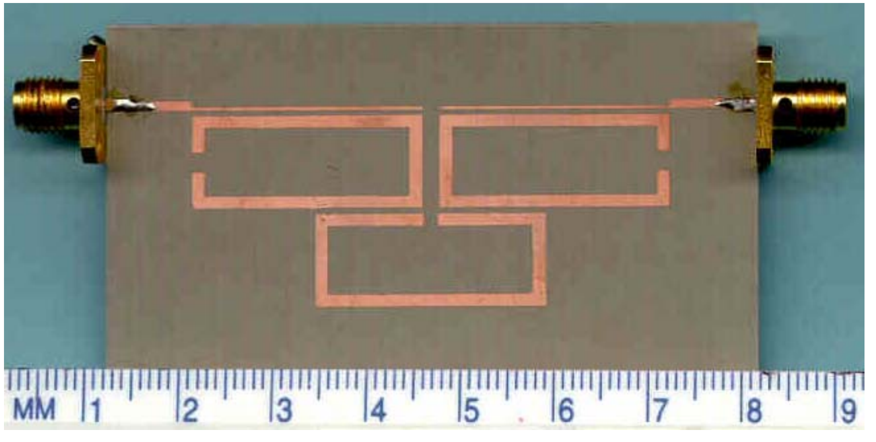
Midband or centre frequency : 910MHz

Bandwidth of pass band : 40MHz

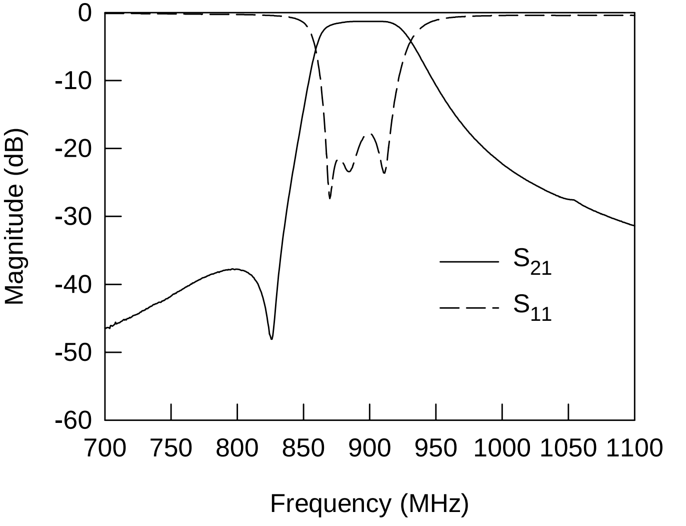
Return loss in the pass band : < –20dB

Rejection : > 35dB for frequencies ≤ 843MHz

$$f_{01} = f_{03} = 916.159 \text{ MHz}$$
$$f_{02} = 905.734 \text{ MHz}$$
$$Q_{ei} = Q_{eo} = 14.6698$$
$$M_{12} = M_{23} = 0.05641$$
$$M_{13} = 0.01915$$



On RT/Duroid substrate with a relative dielectric constant of 10.8 and a thickness of 1.27mm

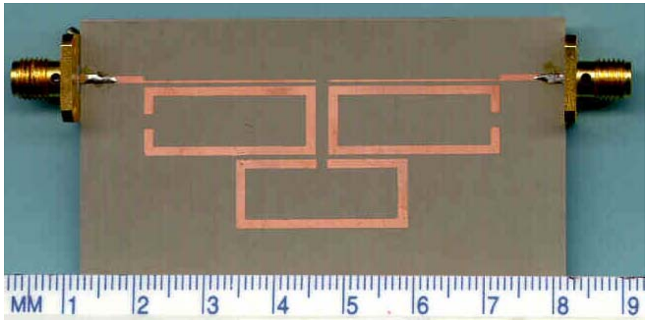


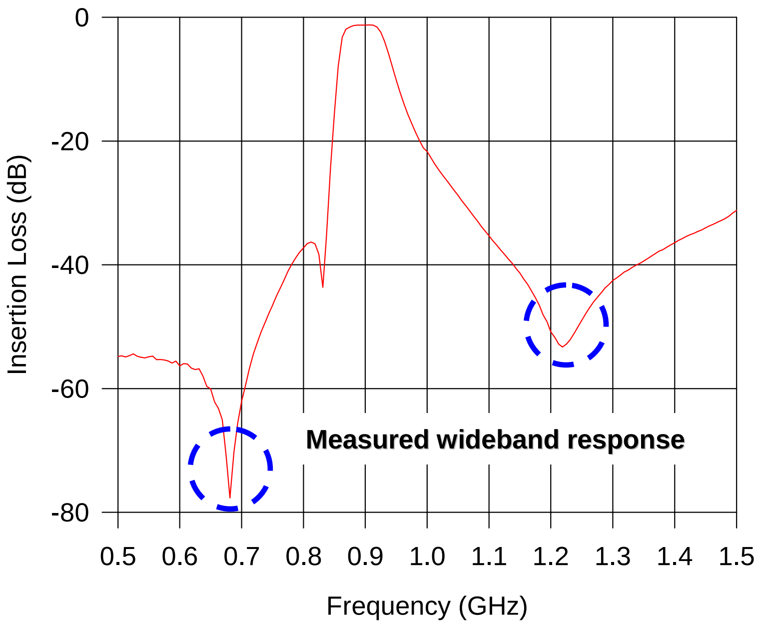
Measured response

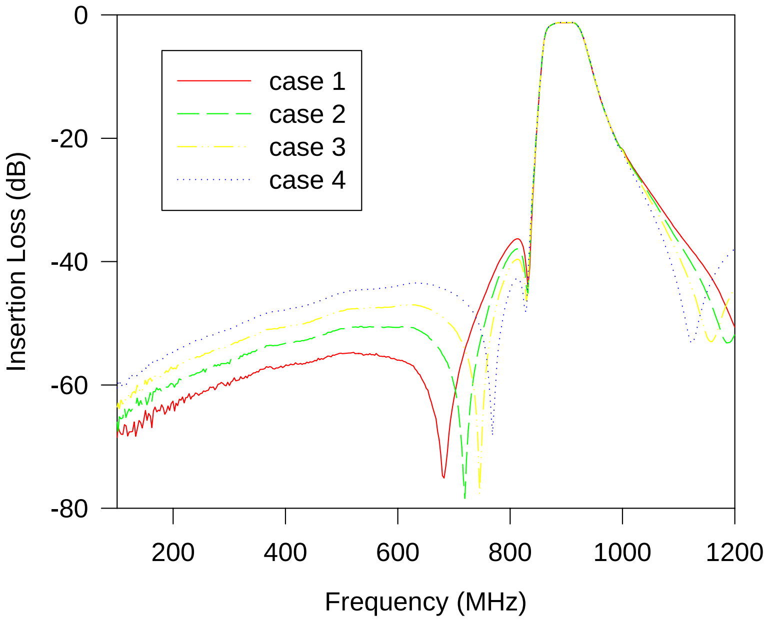
HERIOT WATT UNIVERSITY

Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

Design Examples- Trisection open-loop filters



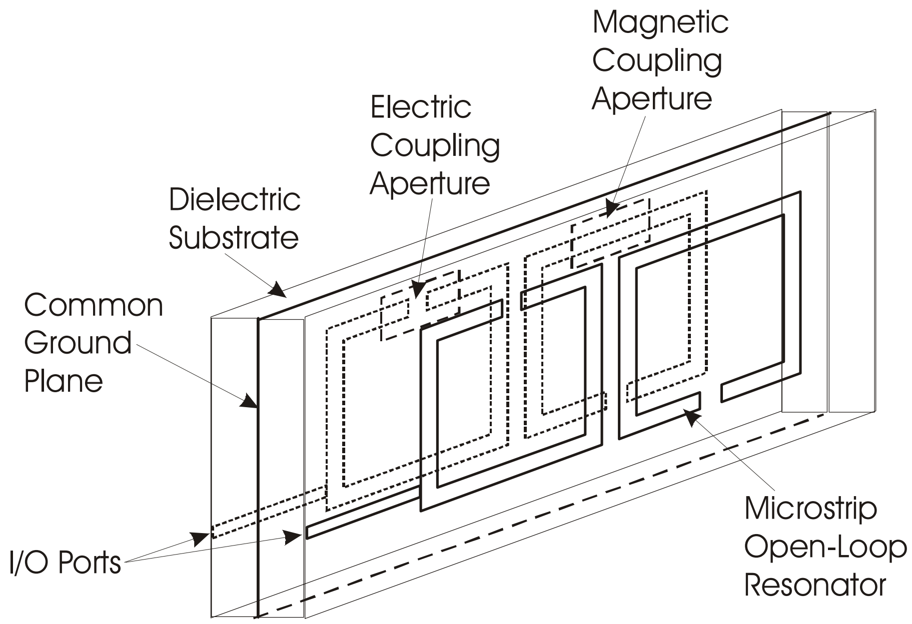




Experimental results on extra transmission zeros, where case 1 to 4 indicate the increase of direct coupling between the two feed lines.

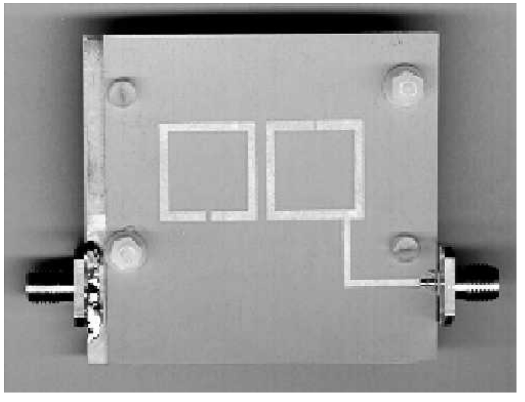
Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

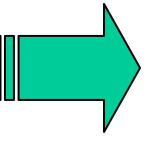
Design Examples- Multi-layer filters

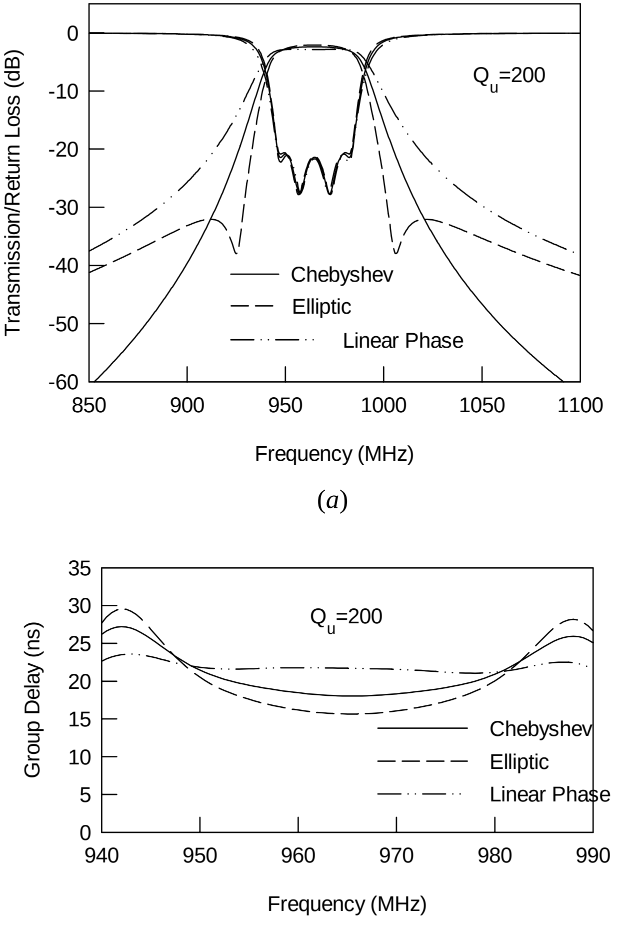


Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

Design Examples- Multi-layer filters







(*a*)

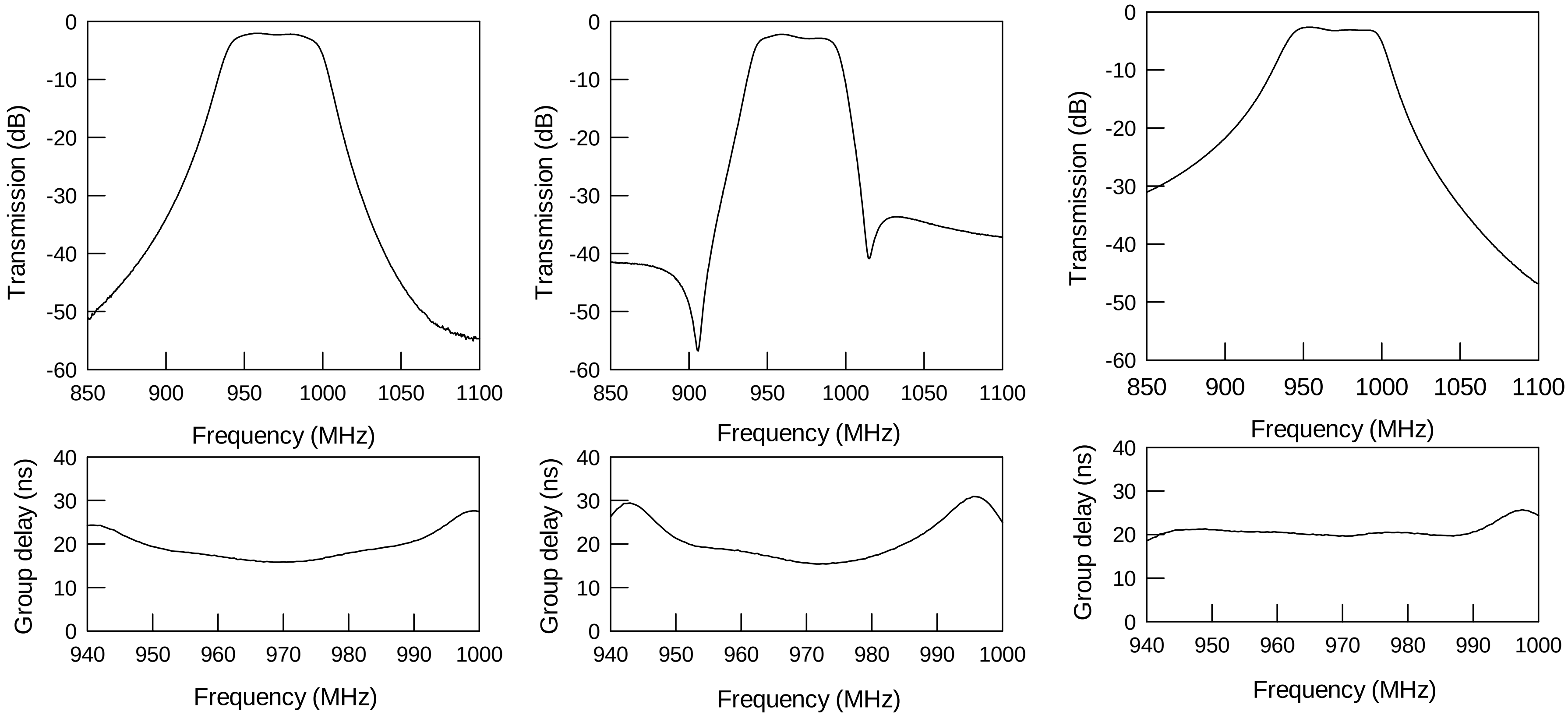
(*b*)

HERIOT WATT UNIVERSITY

Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

Design Examples- Multi-layer filters

Experimental results

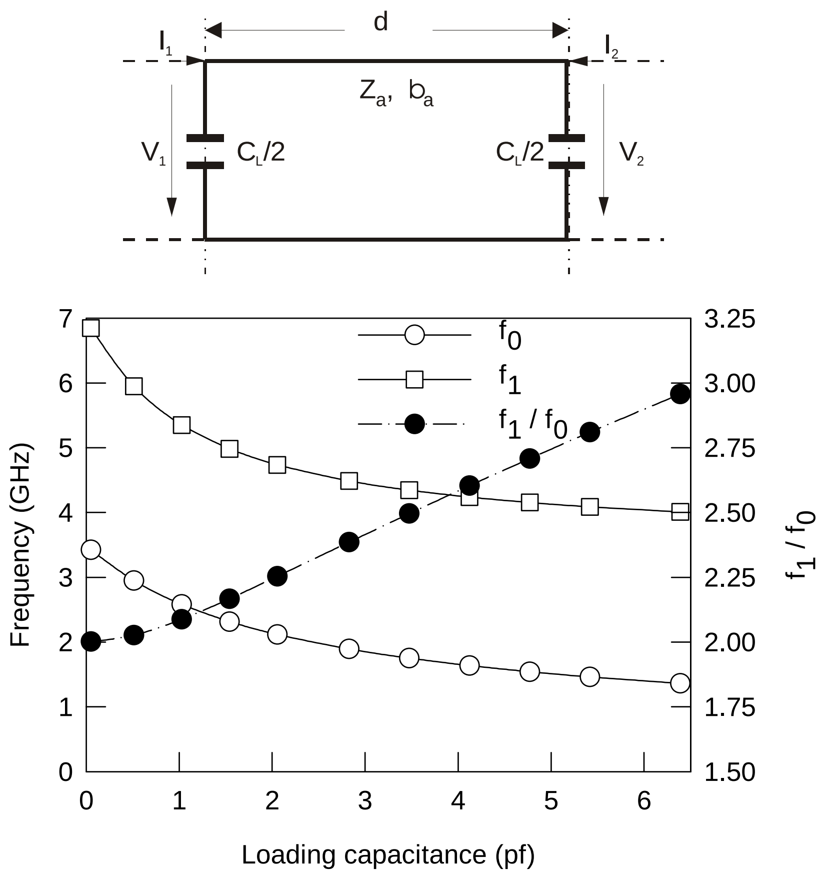


(*a*) (*b*) (*c*)

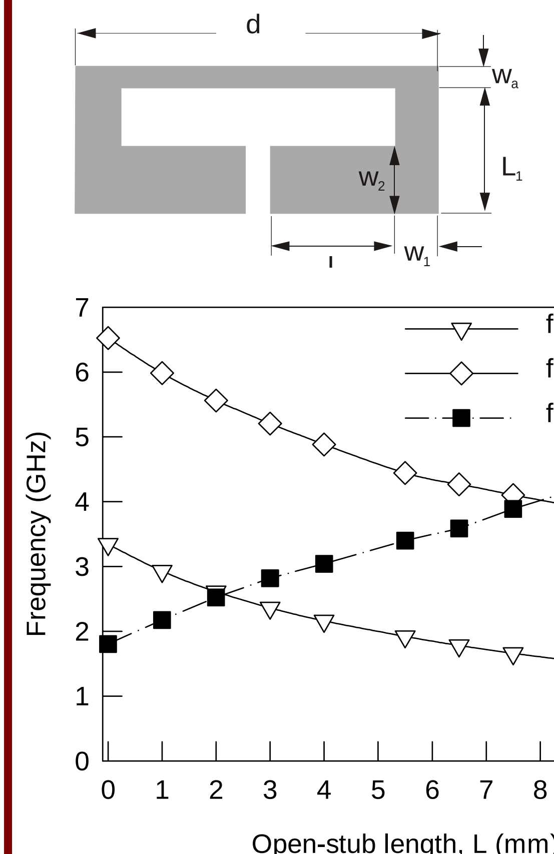
Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

Design Examples- Slow-wave filters

Capacitively loaded line resonator



Microstrip slow wave resonator (I)



Wa=1 mm, w1=2 mm, w2=3 mm, d=16 mm on RT/Duroid 6010

HERIOT WATT UNIVERSITY

Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

Design Examples- Slow-wave filters

Centre Frequency : 1335 MHz

3dB Bandwidth : 30 MHz

passband Loss : 3dB Max.

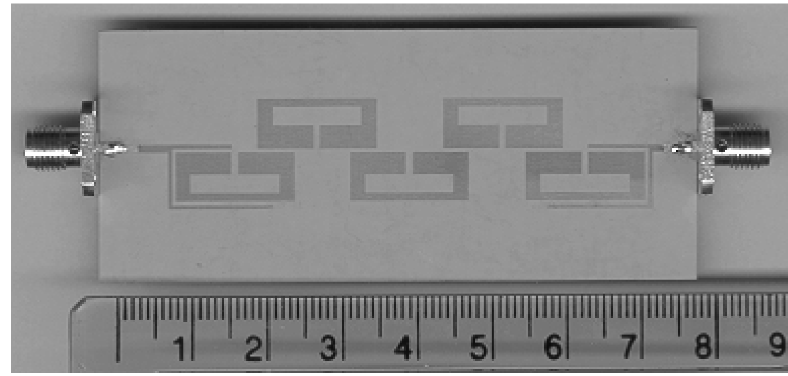
Min. stopband rejection :

D.C. to 1253 MHz 60dB

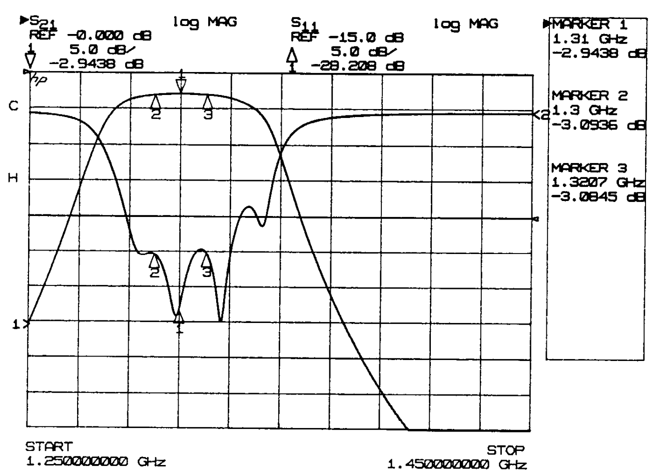
1457 to 2650 MHz 60dB

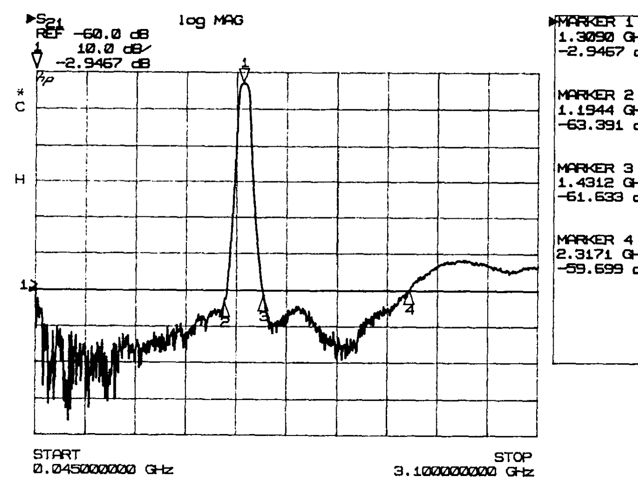
2650 to 3100 MHz 30dB

60dB Bandwidth : 200 MHz Max.



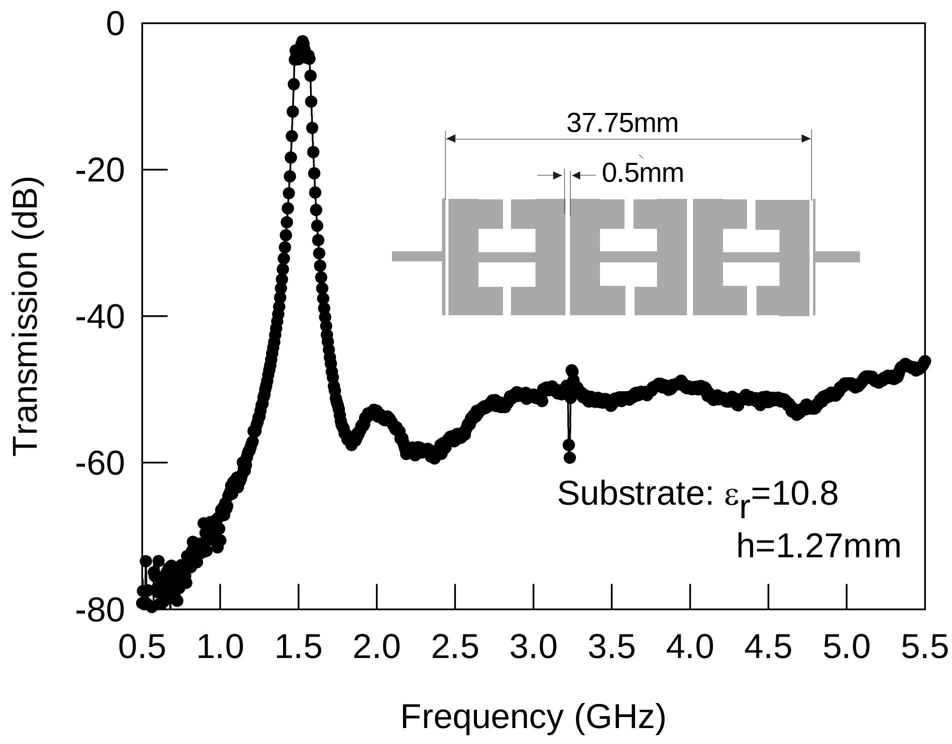
On RT/Duroid 6010 substrate





Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

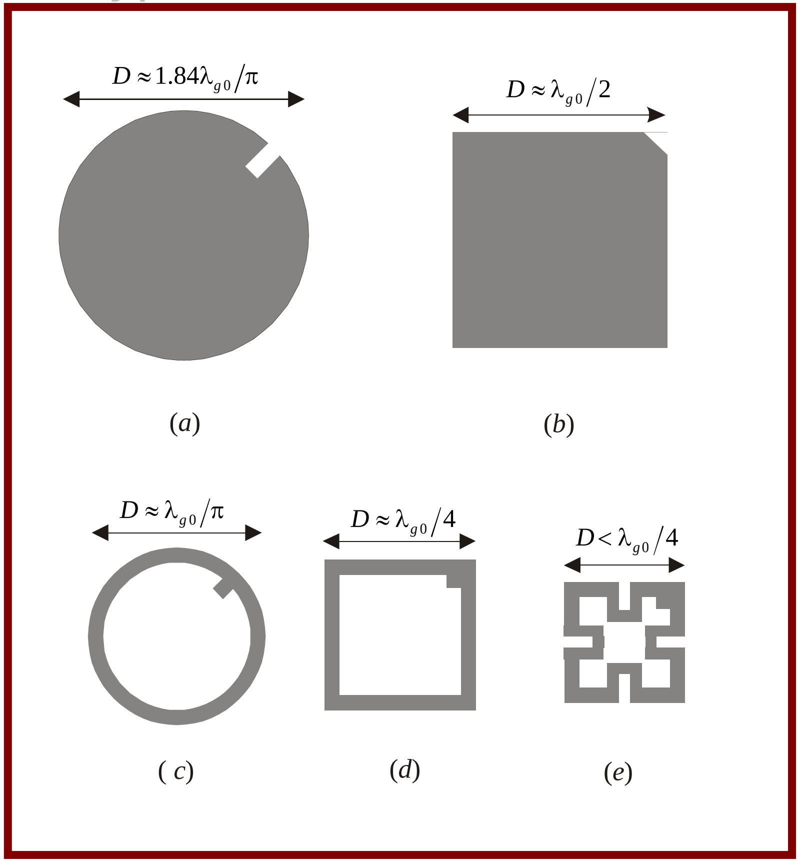
Design Examples- Slow-wave filters

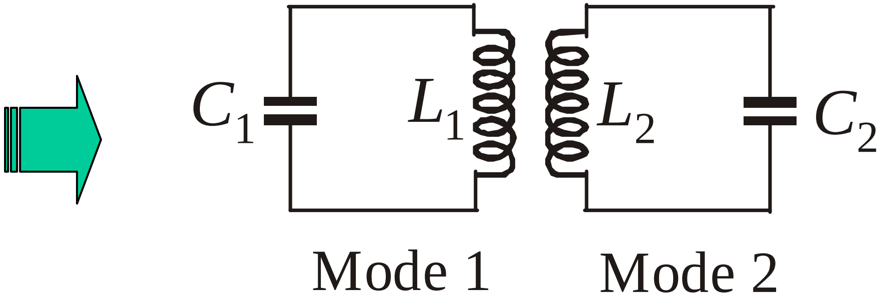


Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

Design Examples- Dual-mode filters

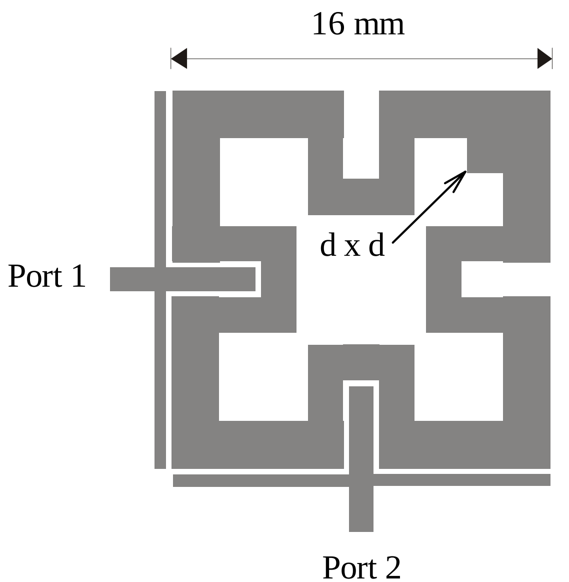
Type I dual-mode resonator

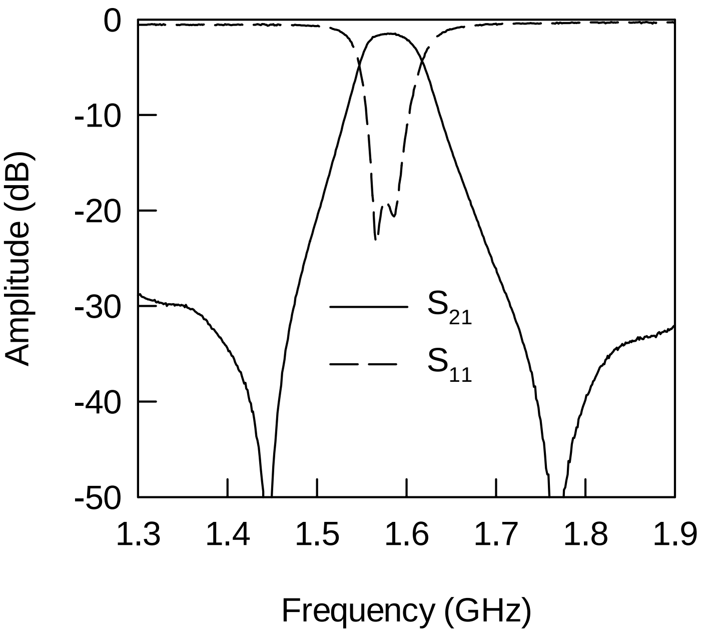




Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

Design Examples- Dual-mode filters



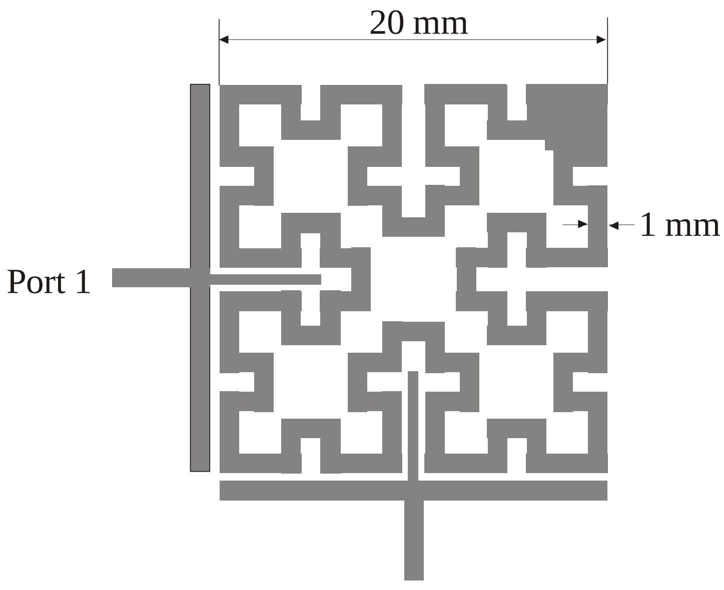


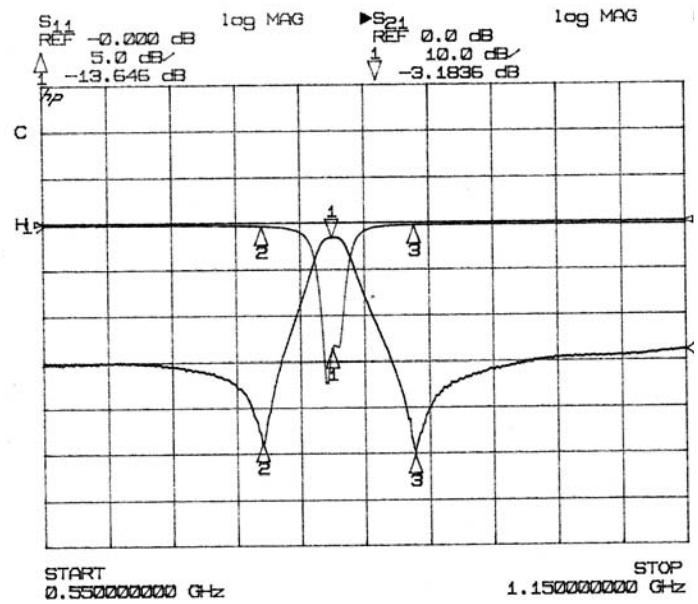
d =2 mm on RT/Duroid 6010 substrate

2.5% bandwidth at 1.58 GHz

HERIOT WATT UNIVERSITY
Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

Design Examples- Dual-mode filters





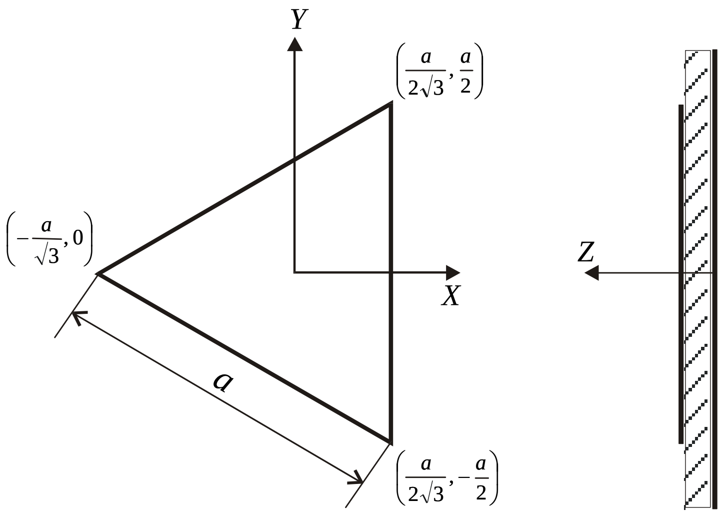
On RT/Duroid 6010 substrate

Centred at 820 MHz

Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

Design Examples- Dual-mode filters

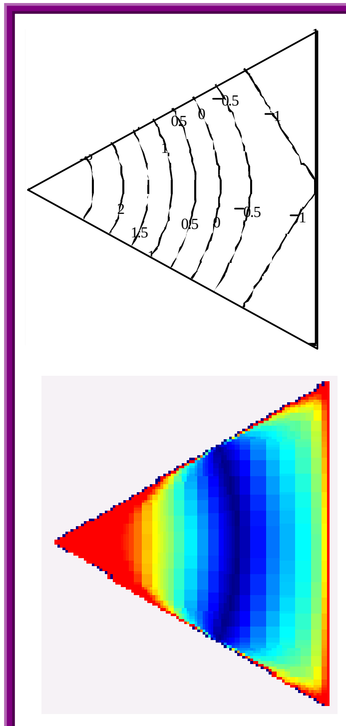
Type II dual-mode resonator



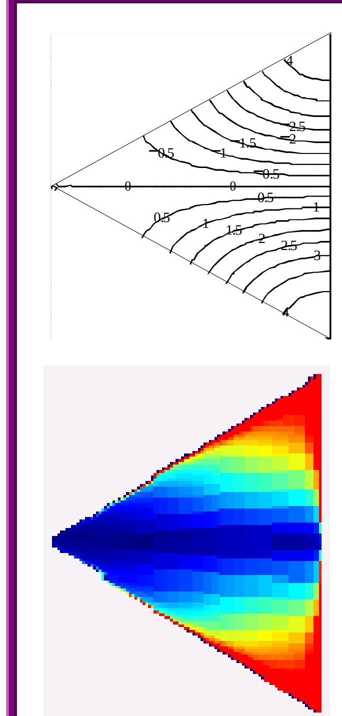
Equilateral triangular microstrip patch resonator

Electric Field Pattern

@ Mode 1

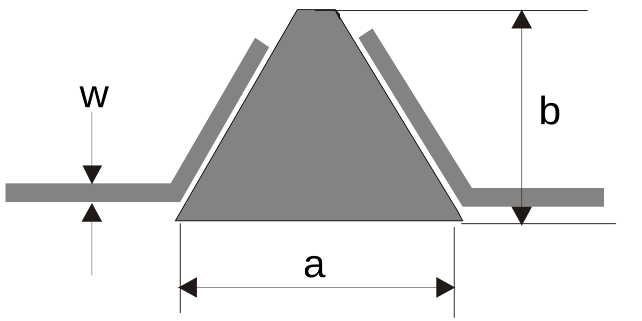


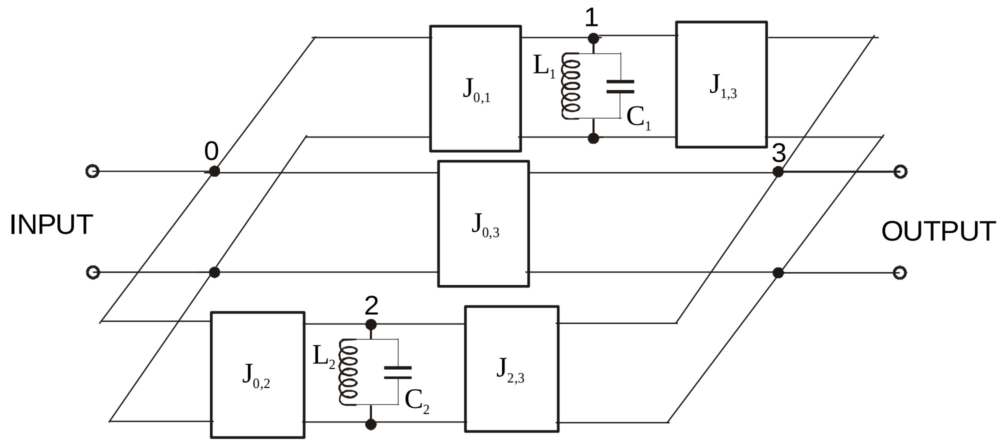
@ Mode 2



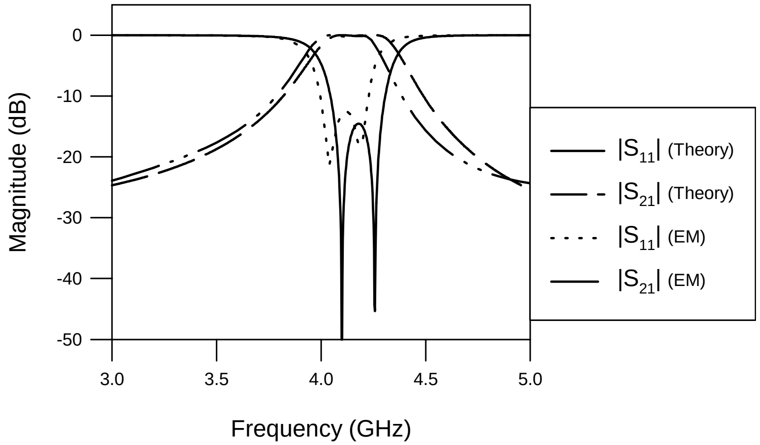
Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

Design Examples- Dual-mode filters





Circuit model (No coupling between the two modes)



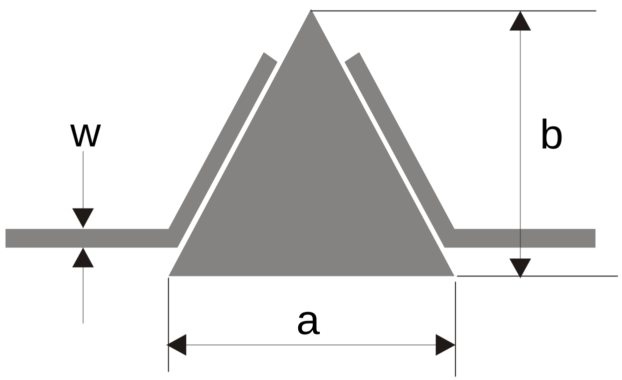
Frequency response

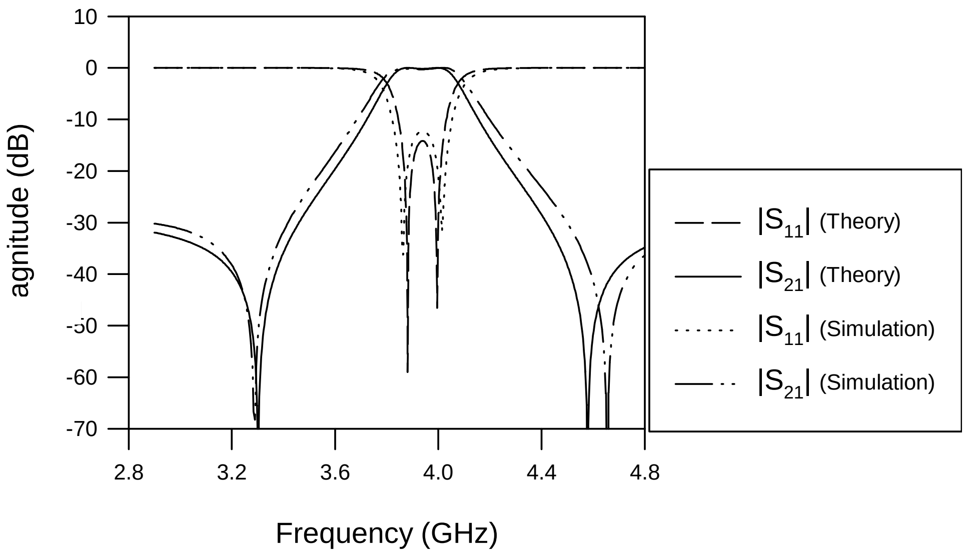
(a = 15 mm and b = 11.25 mm on a 1.27mm thick dielectric substrate with a relative dielectric constant of 10.8)

HERIOT WATT UNIVERSITY

Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

Design Examples- Dual-mode filters





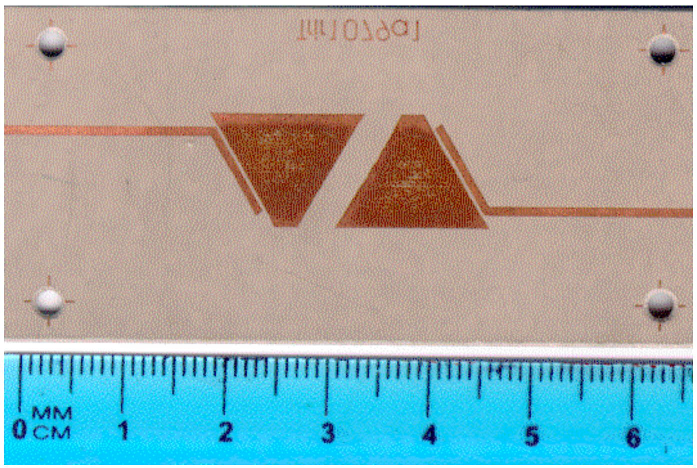
a = 15 mm and b = 14 mm on a 1.27mm thick dielectric substrate with a relative dielectric constant of 10.8

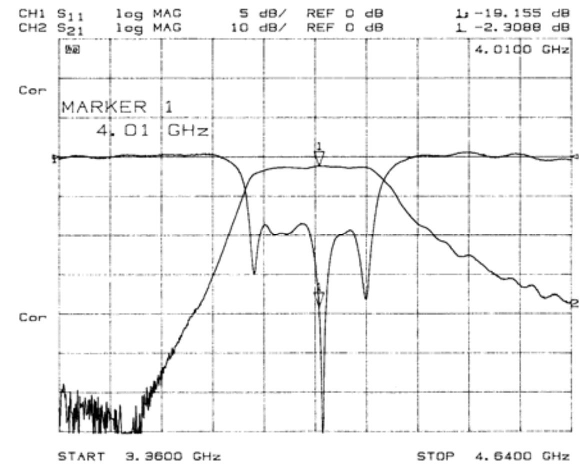
Frequency response

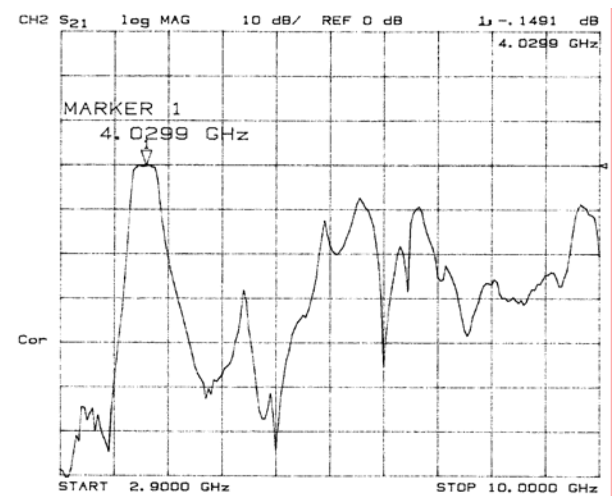
Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

Design Examples- Dual-mode filters

Four-pole dual-mode filters



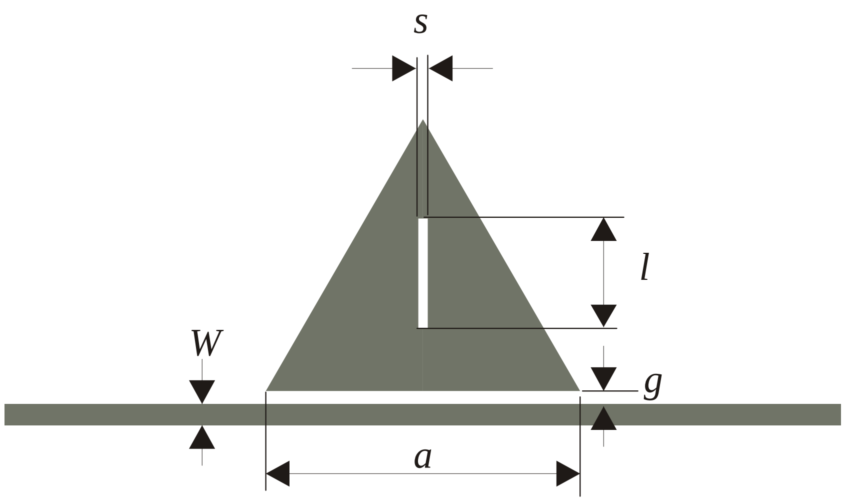


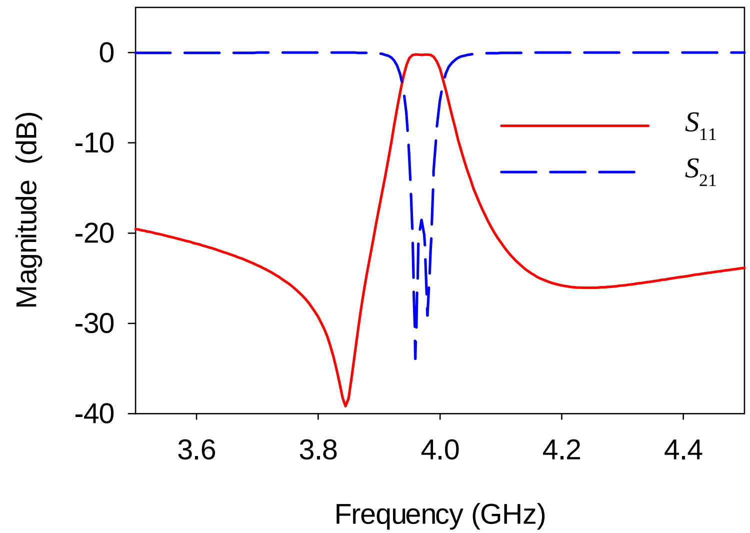


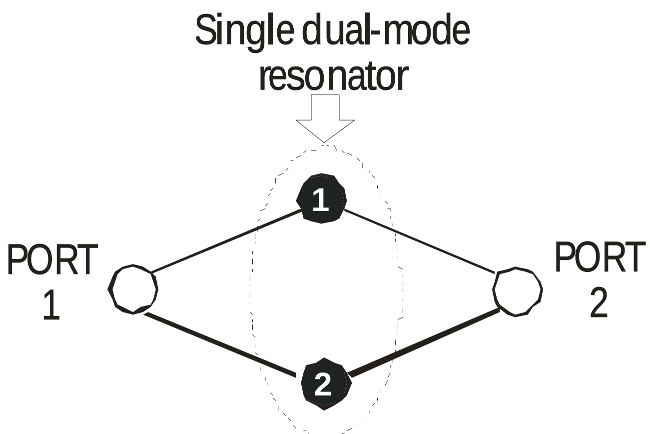
On a substrate with a relative constant of 10.8 and a thickness of 1.27 mm

Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

Design Examples- Dual-mode reject filters



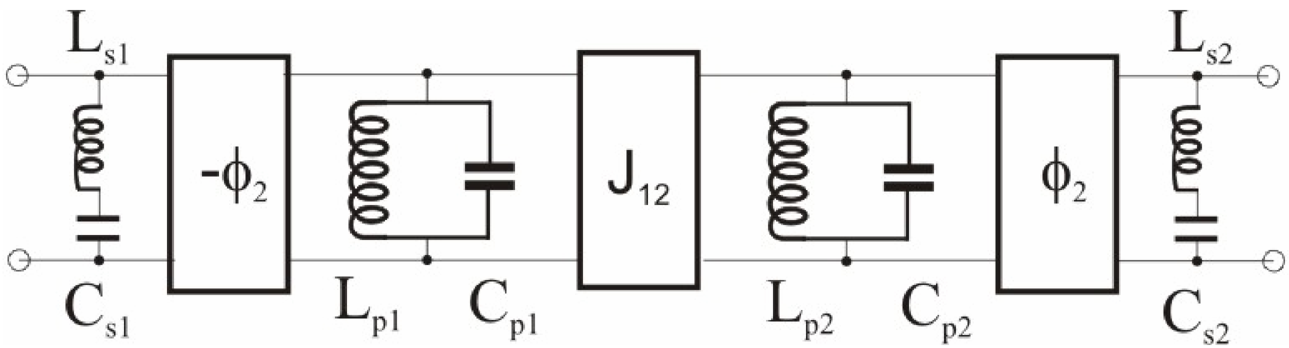


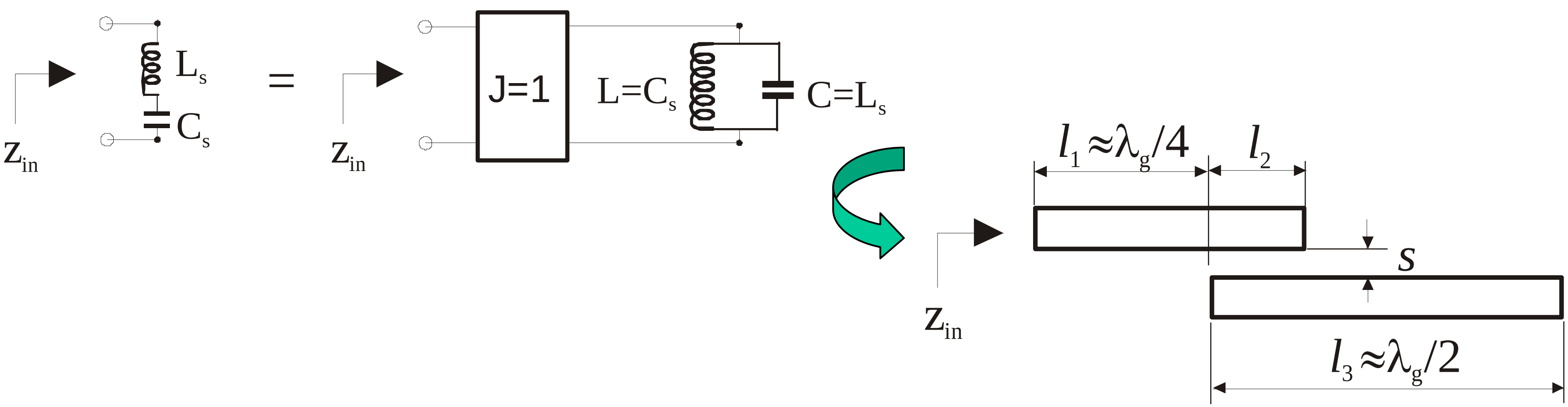


The details to be presented in another session (WE4C) at IMS2005

Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

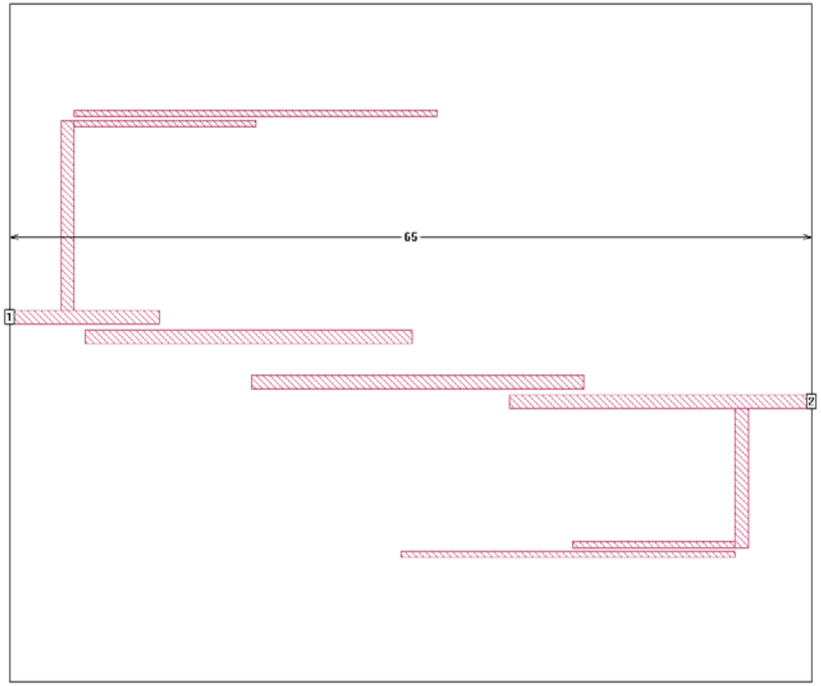
Design Examples- Extract-pole filters

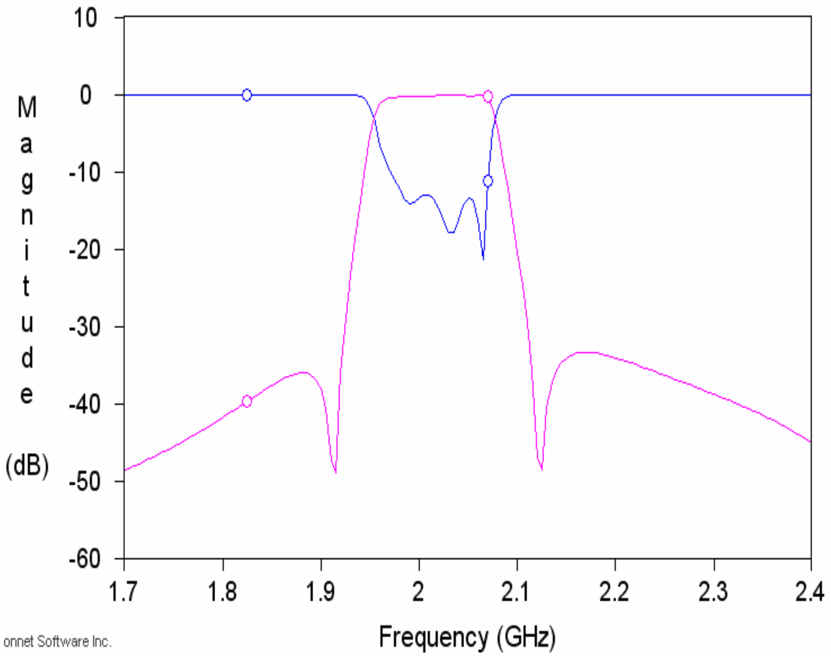




Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

Design Examples- Extract-pole filters



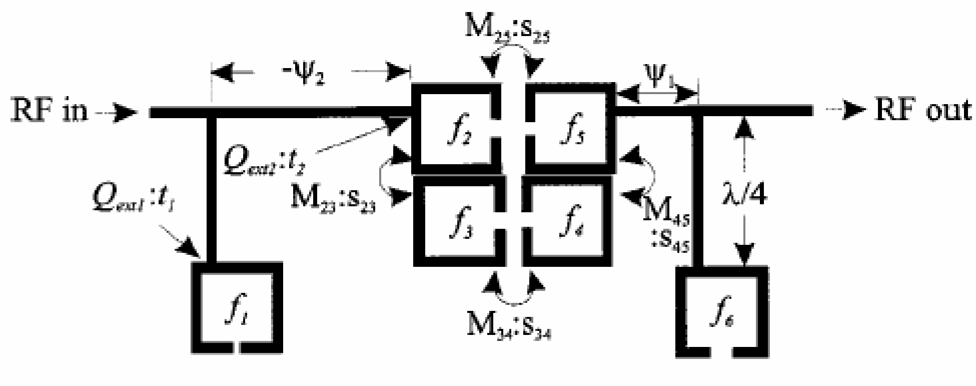


On RT/Duroid 6010 substrate

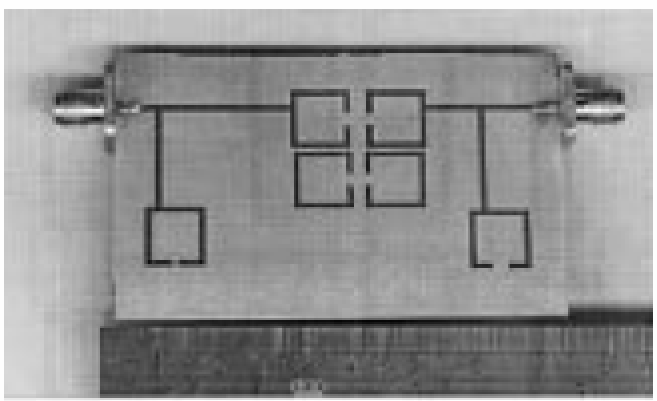
EM simulated performance

Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

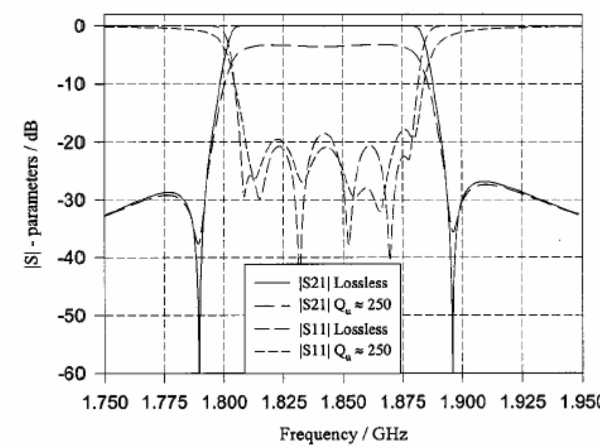
Design Examples- Extract-pole filters

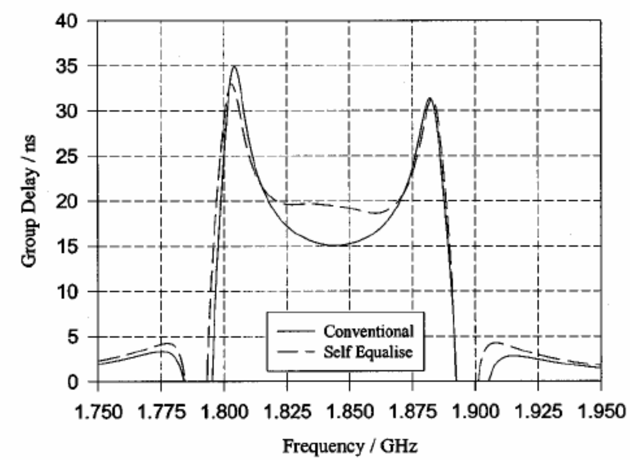


(a)



(b)

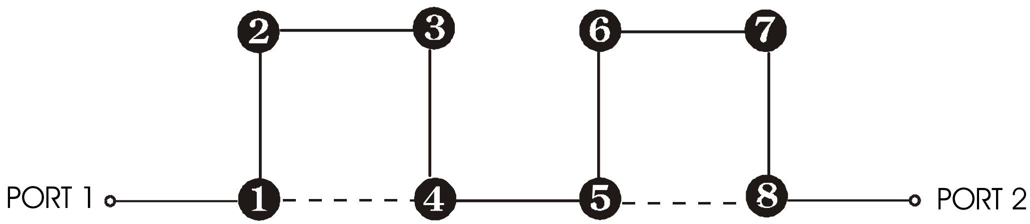


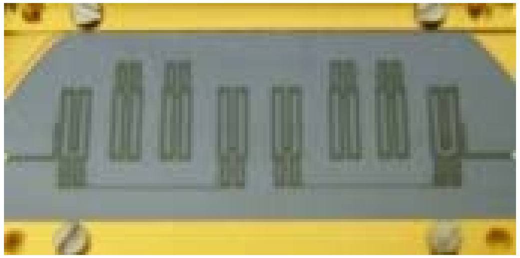


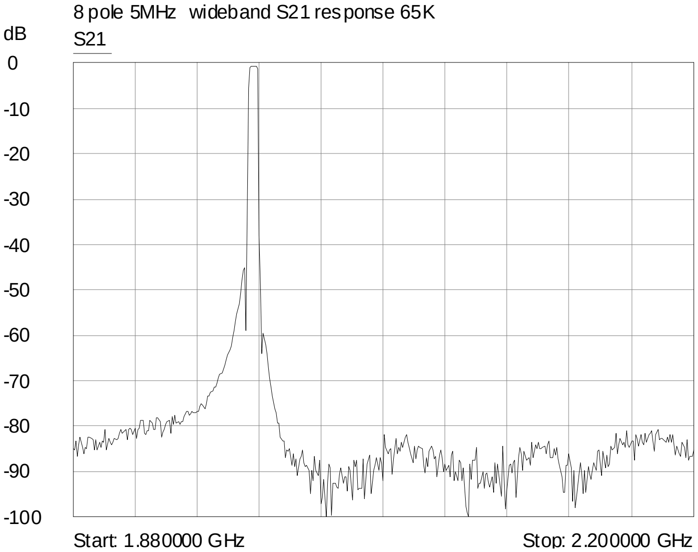
On RT/Duroid 6010 substrate

Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

Design Examples- CQ filters



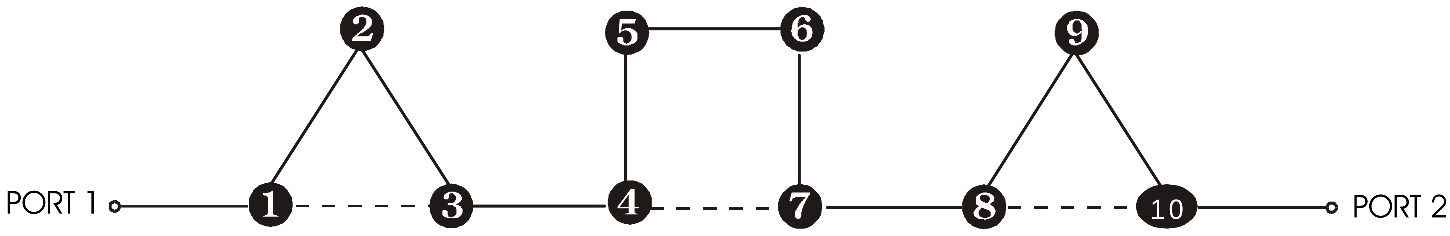


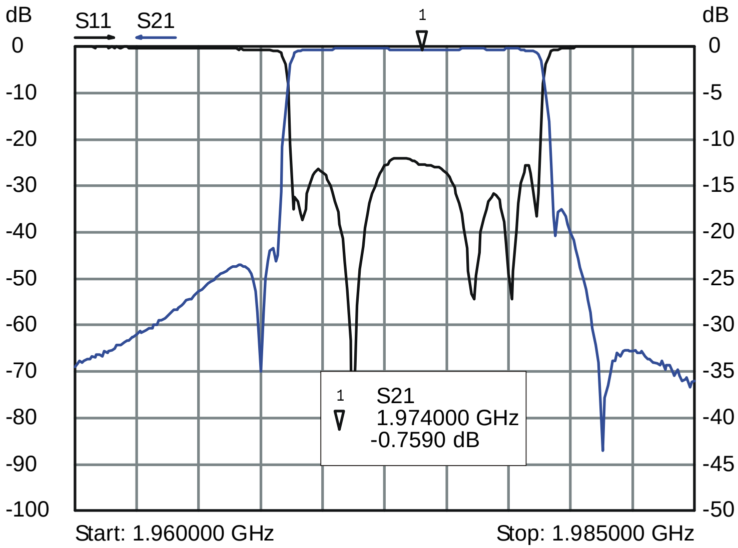


Another 18-pole filter of this type with group delay equalisation will be presented in TH1F session at IMS2005

Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

Design Examples- CQT filters

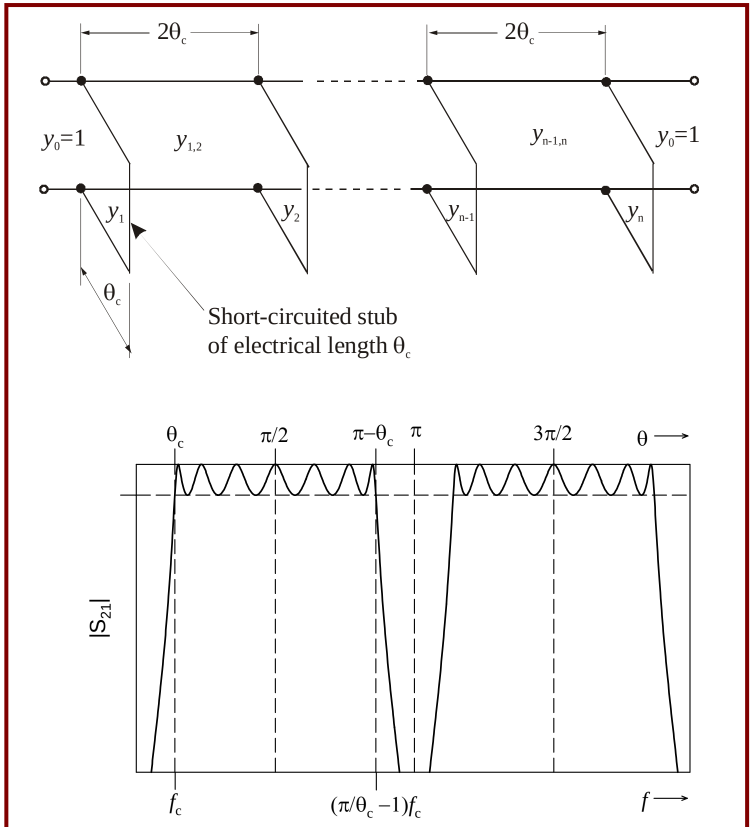


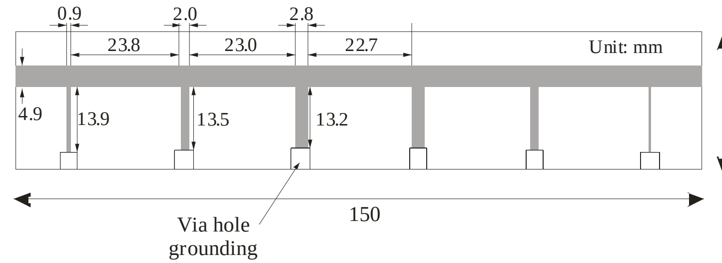


Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

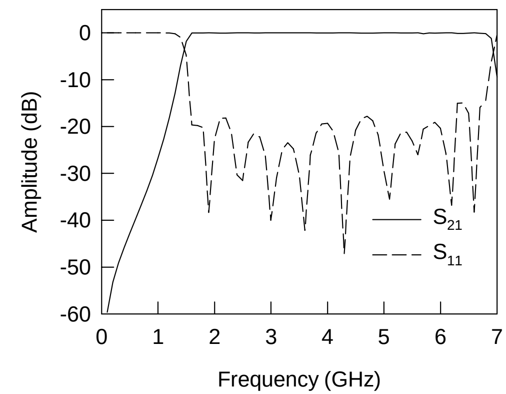
Design Examples- Wideband filters

Optimum stub bandpass or pseudo highpass





On substrate: ε_r = 2.2, h = 1.57 mm



EM simulated performance

From: Jia-Sheng Hong and M.J.Lancaster, *Microstrip Filters for RF/Microwave Applications*,

John Wiley & Sons. Inc. New York, 2001

Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk

Summary

- ✓ Microstrip filter designs involve a number of considerations, including careful choice of topologies and substrates.
- ✓ Some design examples of new topologies with advanced filtering characteristics have been described, including –
  - Open-loop resonator filters
  - Multilayer filters
  - Slow-wave filters
  - Dual-mode filters
  - Extract pole, Trisection, CQ and CQT filters
  - Optimum wideband stub filters
- ✓ Driven by applications and emerging device technologies, many new and advanced microstrip filters have been developed and their designs are available in open literatures.

HERIOT WATT UNIVERSITY

Dr. Jia-Sheng Hong
Department of Electrical, Electronic and Computer Engineering
Heriot-Watt University, UK
J.Hong@hw.ac.uk