notch filter design
requirements

- $F_0 = 2.4\,GHz$, $F_{s_1} = 2.4125\,GHz$, $F_{s_2} = 2.3875\,GHz$

- $BW = 50\,MHz = \frac{50\times10^6}{2.4\times10^9} = 2.08\,\% = FBW$

- min attenuation $= 30\,dB = A_s$, $Z_0 = 50\Omega$

we will design for a pass band $BW = 2\times BW = 100\,MHz$

So $F_{p_1} = 2.425\,GHz$, $F_{p_2} = 2.375\,GHz$

For a 0.5 dB equal ripple

$$A_p = 10\log\left(1+\varepsilon^2\cosh^2(n\cosh^{-1}(r))\right)$$

as $\varepsilon = \sqrt{10^{A_p/10}-1} = 0.349$ (ripple factor) , $r = \frac{\Omega_s}{\Omega_p} = 2$

$$\Omega_p = \frac{BW}{F_{p_1}-F_{p_2}} = 1 \quad , \quad \Omega_s = \frac{BW}{F_{s_1}-F_{s_2}} = 2$$

$$n \geq \frac{\cosh^{-1}\sqrt{\frac{10^{A_s/10}-1}{\varepsilon^2}}}{\cosh^{-1}(r)} = 3.947$$

So $n \approx 4$ (order)

$$Z_{on} = \frac{4 Z_0}{\pi g_n \Delta} \quad , \quad Z_0 = 50\,\Omega$$

$\Delta = 0.0208$

n	g_n	Z_{on}
1	1.6703	1832.408
2	1.1926	2566.386
3	2.3661	1293.55
4	0.8419	3635.434
5	1.9841	1542.599

$$Q = \frac{F_0}{BW} = \frac{2.4\times10^9}{50\times10^6} = 48 \ \#$$

We will choose a substrate with $\varepsilon_r = 4.4$

$h = 1.6$ mm

We assume $\frac{W}{d} < 2$

For $Z_0 = 50$ $A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right)$

$= 1.5298$

$$\frac{W}{d} = \frac{8e^{A}}{e^{2A}-2} = 1.91185 \checkmark$$

$$L = \frac{\lambda_{eff}}{4} = \frac{C}{4 f_0 \sqrt{\varepsilon_{eff}}}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2} \frac{1}{\sqrt{1+12d/W}}$$

$$= \frac{4.4+1}{2} + \frac{4.4-1}{2} \frac{1}{\sqrt{1+\frac{12}{1.91185}}}$$

$$= 3.33$$

$$L = \frac{3\times10^{8}}{4\times24\times10^{9}\times\sqrt{3.33}} = 17.11\ mm$$

$$W = d\times1.91185 = 1.6\times1.91185 = 3.05896\ mm$$

For the Smallest Z_0 of a stub hence ($\uparrow W$)

$$A = \frac{1293.55}{60}\sqrt{\frac{4.4+1}{2}} + \frac{4.4-1}{4.4+1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right)$$

$$= 35.5844$$

$$\frac{W}{d} = 2.8116\times10^{-15} \Rightarrow W = 4.3\times10^{-18}\ m$$:)

using Coupled line, (as shown before)

n = 4

$$Z_{oe} = Z_0\left[1 + JZ_0 + (JZ_0)^2\right]$$

$$Z_{oo} = Z_0\left[1 - JZ_0 + (JZ_0)^2\right]$$

Knowing that

$Z_0 J_1 = \sqrt{\dfrac{\pi\Delta}{2g_1}}$, $Z_0 J_n = \dfrac{\pi\Delta}{2\sqrt{g_{n-1}\, g_n}}$, $Z_0 J_{N+1} = \sqrt{\dfrac{\pi\Delta}{2 g_N g_{N+1}}}$

$\Delta = 0.0208$

n	g_n	$Z_0 J_n$	Z_{oe}	Z_{oo}	h (mm)	W (mm)
1	1.6703	0.13986	57.97	43.983	1.6	3.009
2	1.1926	0.02315	51.184	48.869	〃	3.057
3	2.3661	0.01944	50.99	49.047	〃	3.058
4	0.8419	0.02314	51.184	48.869	〃	3.057
5	1.9841	0.13985	57.97	43.983	〃	3.009

Can be fabricated
with short circuit
needed for each
Coupler @ Port 4
Open Circuit @ Port 3

Planar notch Filter

requirments $F_0 = 2.4\,GHz$

BW @ $A_s = 30\,dB \Rightarrow 25\,MHz \rightarrow F_{s_1} = 2.3875\,GHz$

$F_{s_2} = 2.4125\,GHz$

BW @ $A_p = 0.5\,dB \Rightarrow 50\,MHz \rightarrow F_{p_1} = 2.375\,GHz$

$F_{p_2} = 2.425\,GHz$

chebyshev (equal ripple) , $Z_0 = 50\,\Omega$

Substrate requirements $\varepsilon_r = 3.48$, $d = 1.524\,mm$

(Roger RO4350B) $\tan\delta = 37 \times 10^{-4}$

Conductor " $t = 35\,\mu m$, $\sigma_c = 5.813 \times 10^7$

$$FBW = \Delta = \frac{BW}{F_0} = \frac{50 \times 10^6}{2.4 \times 10^9} = 0.02083 = 2.083\%$$

Calculate order for equal ripple = 5

First method (quarter wave resonator O.C)

n	g_n	$Z_{on} = (4 Z_0 / \pi g_n \Delta)$
1	1.7058	1791.69
2	1.2296	2485.5757
3	2.5408	1202.87
4	1.2296	2485.5757
5	1.7058	1791.69
6	1	3056.26

second method (Coupled lines)

n	g_n	$Z_0 J_n$	Z_{oe}	Z_{oo}
1	1.7058	0.1385	57.884	44.034
2	1.2296	0.02259	51.155	48.896
3	2.5408	0.0185	50.942	49.092
4	1.2296	0.0185	50.942	49.092
5	1.7058	0.02259	51.55	48.896
6	1	0.1385	57.884	44.034

as $Z_0 J_1 = \sqrt{\dfrac{\pi\Delta}{2g_1}}$, $Z_0 J_n = \dfrac{\pi\Delta}{2\sqrt{g_{n-1}g_n}}$, $Z_0 J_{N+1} = \sqrt{\dfrac{\pi\Delta}{2g_N g_{N+1}}}$

$$Z_{oe} = Z_0\left[1 + J Z_0 + (J Z_0)^2\right] , \quad Z_{oo} = Z_0\left[1 - J Z_0 + (J Z_0)^2\right]$$

third method (L-Resonator)

$Z_n = Z_0 / g_n \times FBW$

n	g_n
1	1.7058
2	1.2296
3	2.5408
4	1.2296
5	1.7058

1^{st} method For $F_{P_1} = 2.3\,GHz$, $F_{P_2} = 2.5\,GHz$
$F_{S_1} = 2.33\,GHz$, $F_{S_2} = 2.45\,GHz$

$BW = 200\,MHz$

$\Delta = FBW = \frac{0.2}{2.4} = 0.0833 = 8.33\%$

n	g_n	$Z_{on} = 4Z_o/\pi g_n \Delta$
1	1.7058	448.0299
2	1.2296	621.54
3	2.5408	300.79
4	1.2296	621.54
5	1.7058	448.0299

2^{nd} method

n	g_n	$Z_o J_n$	Z_{oe}	Z_{oo}
1	1.7058	0.27696	67.68	39.987
2	1.2296	0.0903	54.9255	45.89
3	2.5408	0.074	53.975	46.57
4	1.2296	0.074	53.975	46.57
5	1.7058	0.0903	54.9255	45.89
6	1	0.27696	67.68	39.987

3^{rd} method

n	g_n	$Z_{on} = Z_o/g_n \Delta$
1	1.7038	351.8818
2	1.2296	448.1588
3	2.5408	256.24
4	1.2296	448.1588
5	1.7058	351.8818