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ภาคผนวก ก

โปรแกรมการออกแบบไดเรกชันแนลคัปเปลอร์

แบบเซมิเชฟ มีจำนวน 7 รูป

โปรแกรมออกแบบไดเรกชันแนลคัปเปลอร์ในช่วงความถี่ 8-12GHz

โปรแกรมต่อไปนี้เป็นโปรแกรมที่เขียนด้วยรูปแบบ(Format) ของ Mathcad PLUS version 6.0 ซึ่งเป็นโปรแกรมที่ง่ายและใกล้เคียงกับรูปแบบการเขียนทางคณิตศาสตร์ที่ใช้กันอยู่ทั่วไปดังนั้นจึงเป็นการ-ง่ายต่อบุคคลทั่วไปที่จะเข้าใจโดยไม่จำเป็นต้องมีความรู้ทางภาษาคอมพิวเตอร์มาก่อน

โปรแกรมออกแบบไดเรกชันแนลคัปเปลอร์ด้วยวิธี Chebyshev

$f_{lower} := 8 \cdot GHz$ $f_{upper} := 12 \cdot GHz$ ช่วงความถี่ที่สนใจ

$D_m := 40$ $C_o := 20$ ค่า Directivity ต่ำสุด และค่า Couplingที่ต้องการ

นำข้อมูลมาคำนวณหาขนาดของเวกเตอร์การแพร่ในท่อนำคลื่นขนาดมาตรฐาน

$c := 3 \cdot 10^{8} \cdot \frac{m}{sec}$ $\lambda_{lower} := \frac{c}{f_{lower}}$ $\lambda_{upper} := \frac{c}{f_{upper}}$

$k_{lower} := \frac{2 \cdot \pi}{\lambda_{lower}}$ $k_{lower} = 167.55160819 \cdot m^{-1}$

$k_{upper} := \frac{2 \cdot \pi}{\lambda_{upper}}$ $k_{upper} = 251.32741229 \cdot m^{-1}$

ขนาดของเวกเตอร์การแพร่ในสูญญากาศ

ขนาดของเวกเตอร์การแพร่ในท่อนำคลื่นที่เป็นฟังก์ชั่นของความกว้างของท่อนำคลื่น โดยที่ a คือความกว้างของท่อและ b คือความสูงของท่อ

$$\beta_{lower}(a) := \left[k_{lower}^{2} - \left(\frac{\pi}{a} \right)^{2} \right]^{\frac{1}{2}} \qquad \beta_{upper}(a) := \left[k_{upper}^{2} - \left(\frac{\pi}{a} \right)^{2} \right]^{\frac{1}{2}}$$

$$\beta_{o}(a) := \frac{\beta_{lower}(a) + \beta_{upper}(a)}{2}$$

ขนาดของเวกเตอร์การแพร่กลางที่เราต้องการนำมาออกแบบที่ความถี่ของความถี่กลาง-นี้

$a := 22.90 \cdot mm$ $b := 10.2 \cdot mm$ ความกว้าง a และความสูง b

$f_c := \frac{c}{2 \cdot a}$ $f_c = 6.55 \cdot GHz$ ความถี่ cutoff ของ TE_{10} ในท่อมาตรฐาน

จากขนาดของท่อนำคลื่นดังกล่าวจะได้ขนาดของเวกเตอร์การแพร่ดังต่อไปนี้

$\beta_o(a) = 153.388 \cdot m^{-1}$ $\beta_{lower}(a) = 96.193 \cdot m^{-1}$ $\beta_{upper}(a) = 210.583 \cdot m^{-1}$

$d := \frac{\pi}{2 \cdot \beta_o(a)}$ $d = 10.24067 \cdot mm$ ระยะห่างระหว่างรู

$H := 7$ จำนวนรู

$N := H - 1$ $N = 6$

$$k_o := \left[\beta_o(a)^2 + \left(\frac{\pi}{a} \right)^2 \right]^{\frac{1}{2}}$$

$\lambda_o := \frac{2 \cdot \pi}{k_o}$ $\lambda_o = 3.053 \cdot cm$ $\frac{c}{\lambda_o} = 9.8256 \cdot GHz$

$x_o := \left(\frac{a}{\pi} \right) \cdot \operatorname{asin}\left(\frac{\lambda_o}{\sqrt{6} \cdot a} \right)$ $x_o = 4.19552 \cdot mm$ ระยะห่างของรูจากผนังท่อ

สัมประสิทธิ์ความสัมพันธ์ระหว่าง d_n และรัศมีของรู

$$T_f := \frac{-2i \cdot k_o^2}{3 \cdot \beta_o(a) \cdot a \cdot b} \cdot \sin\left(\frac{\pi \cdot x_o}{a} \right)^2 + \frac{4i}{3 \cdot a \cdot b} \cdot \left(\beta_o(a) \cdot \sin\left(\frac{\pi \cdot x_o}{a} \right)^2 + \frac{\pi^2}{\beta_o(a) \cdot a^2} \cdot \cos\left(\frac{\pi \cdot x_o}{a} \right)^2 \right)$$

$|T_f| = 5.188 \cdot 10^{5} \cdot m^{-3}$

$n := 0, 1 .. N$

$$g_{w1} := \frac{10^{\frac{-C_0}{20}}}{|T_f|} \qquad g_{max} := \frac{10^{\frac{-C_0 - D_m}{20}}}{|T_f|}$$

$$\theta_m := \operatorname{acos}\left[\frac{1}{\cos\left(\frac{\operatorname{acos}\left(\frac{g_{w1}}{g_{max}}\right)}{N}\right)}\right] \qquad \theta_m = 0.786582$$

$$\psi(n) := -2 \cdot \operatorname{acos}\left[\cos(\theta_m) \cdot \cos\left[\frac{(2 \cdot n - 1) \cdot \pi}{2 \cdot N}\right]\right]$$

$$d_n(w) := \left[\prod_{n=1}^{N} \left(w - e^{i \cdot \psi(n)}\right)\right] \qquad d_n(1) = 24.82285$$

$$f_N := \frac{g_{w1}}{d_n(1)} \qquad f_N = 7.765 \cdot 10^{-9} \cdot m^{3}$$

$n := 1, 2 .. N$

$$w_n(n) := e^{\left(i \cdot \psi(n)\right)} \qquad g(w) := f_N \cdot d_n(w)$$

$w_n(n)$

-0.069 − 0.998i
-0.501 − 0.865i
-0.933 − 0.359i
-0.933 + 0.359i
-0.501 + 0.865i
-0.069 + 0.998i

$$t_N = 7.76465 \cdot 10^{-9} \cdot m^3$$

$\psi(n)$

-1.64
-2.096
-2.774
-3.509
-4.187
-4.643

$$2.333994160205938086 \cdot 10^{-8} \cdot m^3 \cdot w + 4.8683949719391 \cdot 10^{-8} \cdot m^3 \cdot w^3 + 4.087992719805 \cdot 10^{-8} \cdot m^3 \cdot w^4$$

$$+ 4.08838431709123062 \cdot 10^{-8} \cdot m^3 \cdot w^2 + 7.76465 \cdot 10^{-9} \cdot m^3 \cdot w^6 + 7.7596838380450959542 \cdot 10^{-9} \cdot m^3$$

$$+ 2.33405379 \cdot 10^{-8} \cdot m^3 \cdot w^5$$

จะได้รัศมีของแต่ละรูปดังต่อไปนี้

$$r_7 := \left(7.7645 \cdot 10^{-9} \cdot m^3\right)^{\frac{1}{3}} \qquad r_7 = 1.98018 \cdot mm$$

$$r_6 := \left(2.33405379 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_6 = 2.85783 \cdot mm$$

$$r_5 := \left(4.087992719805 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_5 = 3.44485 \cdot mm$$

$$r_4 := \left(4.8683949719391 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_4 = 3.65142 \cdot mm$$

$$r_3 := \left(4.088384317091230 62 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_3 = 3.44496 \cdot mm$$

$$r_2 := \left(2.333994160205938086 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_2 = 2.85781 \cdot mm$$

$$r_1 := \left(7.759683830450959542 \cdot 10^{-9} \cdot m^3\right)^{\frac{1}{3}} \qquad r_1 = 1.97977 \cdot mm$$

$$v := 7.0\cdot GHz, 7.01\cdot GHz .. 14\cdot GHz$$

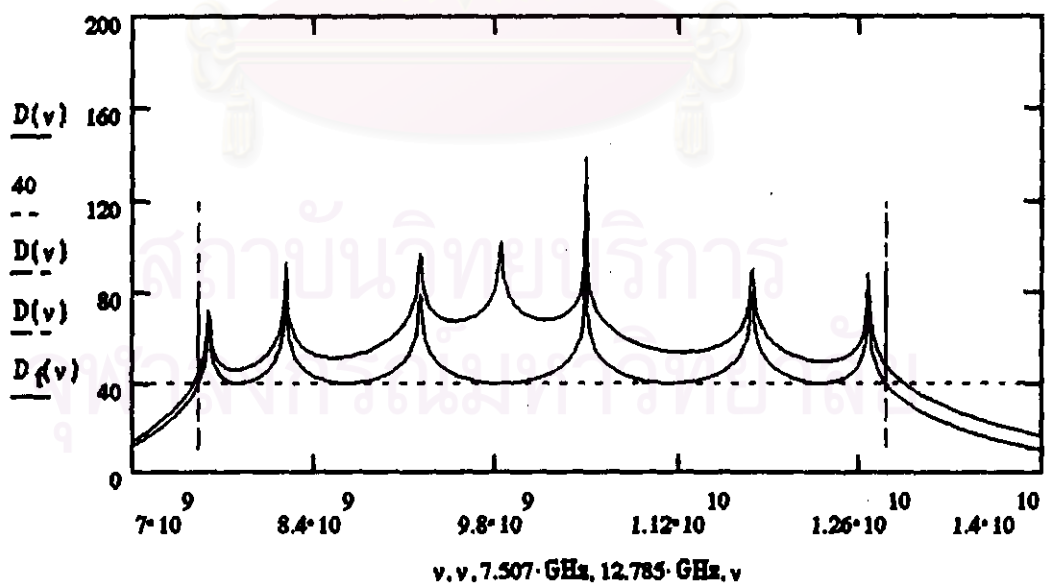
$$\beta(v) := \left[\left(2\cdot\pi\cdot\frac{v}{c}\right)^2 - \left(\frac{\pi}{a}\right)^2\right]^{\frac{1}{2}}$$

$$T_f(v) := \frac{-2\cdot k_o^{\,2}}{3\cdot\beta(v)\cdot a\cdot b}\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{4}{3\cdot a\cdot b}\cdot\left(\beta(v)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{\pi^2}{\beta(v)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right)$$

$$T_b(v) := \frac{-2\cdot k_o^{\,2}}{3\cdot\beta(v)\cdot a\cdot b}\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 - \frac{4}{3\cdot a\cdot b}\cdot\left(\beta(v)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 - \frac{\pi^2}{\beta(v)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right)$$

$$\psi(v) := -2\cdot\beta(v)\cdot d \qquad w(v) := e^{i\cdot\psi(v)}$$

$$D(v) := 20\cdot\log\left(\frac{|g(1)|}{|g(w(v))|}\right) \qquad D_f(v) := 20\cdot\log\left(\frac{|T_f(v)|}{|T_b(v)|}\right) + D(v)$$



กราฟความสัมพันธ์ระหว่าง Directivity และความถี่

$$\beta_{lwEdge} := \frac{\theta_m}{d} \qquad \beta_{upEdge} := \frac{\pi - \theta_m}{d}$$

$$k_{lower} := \left[\beta_{lwEdge}^{2} + \left(\frac{\pi}{a}\right)^{2} \right]^{\frac{1}{2}} \qquad f_{lwEdge} := \frac{c}{2 \cdot \pi} \cdot k_{lower} \qquad f_{lwEdge} = 7.507 \cdot GHz$$

$$k_{upper} := \left[\beta_{upEdge}^{2} + \left(\frac{\pi}{a}\right)^{2} \right]^{\frac{1}{2}} \qquad f_{upEdge} := \frac{c}{2 \cdot \pi} \cdot k_{upper} \qquad f_{upEdge} = 12.785 \cdot GHz$$

$$A := \frac{k_o^{\,2}}{\beta_o(a)\cdot a\cdot b}\cdot \sin\left(\frac{\pi\cdot x_o}{a}\right)^2 \qquad A = 3.502\cdot 10^{5}\cdot m^{-3}$$

$$B := \frac{1}{a\cdot b}\cdot\left(\beta_o(a)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{\pi^{2}}{\beta_o(a)\cdot a^{2}}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right) \qquad B = 5.642\cdot 10^{5}\cdot m^{-3}$$

$$T_f := \frac{-2i\cdot k_o^{\,2}}{3\cdot\beta_o(a)\cdot a\cdot b}\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{4i}{3\cdot a\cdot b}\cdot\left(\beta_o(a)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{\pi^{2}}{\beta_o(a)\cdot a^{2}}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right)$$

$$r_7 = 1.98\cdot mm \qquad c_n := |T_f|\cdot r_6^{\,3}$$

$r := 1\cdot mm$

given

$$\left[\frac{2}{3}\cdot A\cdot e^{-2.405\cdot\left(\frac{1\cdot mm}{r}\right)} + \frac{4}{3}\cdot B\cdot e^{-1.841\cdot\left(\frac{1\cdot mm}{r}\right)}\right]\cdot r^{3} = c_n \qquad \text{find}(r) = 3.35525\cdot mm$$

$n := 0..6$

$r_n :=$

2.46621·mm
3.35525·mm
3.94701·mm
4.15494·mm
3.94712·mm
3.35522·mm
2.4658·mm

$d_n :=$

2.46621·mm
3.35525·mm
3.94701·mm
4.15494·mm
3.94712·mm
3.35522·mm
2.4658·mm

$$\beta(v) := \left[\left(\frac{2\cdot\pi\cdot v}{c}\right)^2 - \left(\frac{\pi}{a}\right)^2\right]^{\frac{1}{2}}$$

$$A(v) := \frac{k_o^2}{\beta(v)\cdot a\cdot b}\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 \qquad B(v) := \frac{1}{a\cdot b}\cdot\left(\beta(v)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{\pi^2}{\beta(v)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right)$$

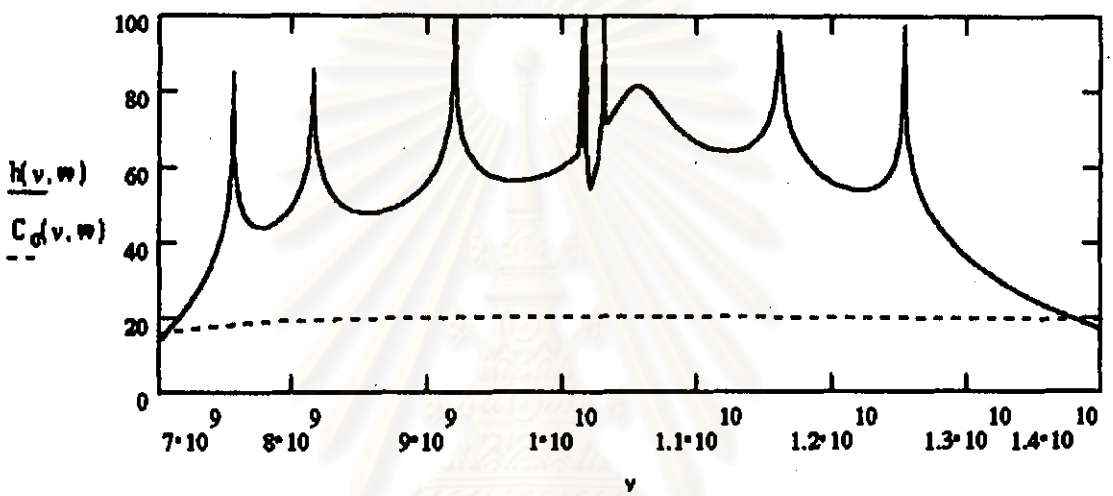
$$C(v) := \frac{1}{a\cdot b}\cdot\left(\beta(v)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 - \frac{\pi^2}{\beta(v)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right) \qquad w := 1\cdot mm$$

$$f(v,w) := \left[\sum_{n=0}^{6}\left[\left|\frac{2}{3}\cdot A(v)\cdot e^{-2.405\cdot\left(\frac{w}{r_n}\right)} + \frac{4}{3}\cdot B(v)\cdot e^{-1.841\cdot\left(\frac{w}{r_n}\right)}\right|\cdot\left(r_n\right)^3\right]\right]$$

$$g(v,w) := \left[\sum_{n=0}^{6}\left[\left|\frac{2}{3}\cdot A(v)\cdot e^{-2.405\cdot\left(\frac{w}{r_n}\right)} - \frac{4}{3}\cdot C(v)\cdot e^{-1.841\cdot\left(\frac{w}{r_n}\right)}\right|\cdot\left(r_n\right)^3\cdot e^{i\cdot\psi(v)\cdot n}\right]\right]$$

$$h(v,w) := 20\cdot\log\left(\frac{|f(v,w)|}{|g(v,w)|}\right) \qquad C_o(v,w) := -20\cdot\log(|f(v,w)|)$$

$v := 7.00\cdot GHz, 7.01\cdot GHz .. 14.00\cdot GHz$



แบบเซปิเชฟ มีจำนวน 10 รู

โปรแกรมออกแบบไดเรกชันแนลคัปเปลอร์ในช่วงความถี่ 8-12GHzด้วยวิธี Chebyshev

$f_{lower} := 8 \cdot GHz$ $f_{upper} := 12 \cdot GHz$ ช่วงความถี่ที่สนใจ

$D_m := 40$ $C_o := 20$ ค่า Directivity ต่ำสุด และค่า Coupling ที่ต้องการ

นำข้อมูลมาคำนวณหาขนาดของเวกเตอร์การแพร่ในท่อนำคลื่นขนาดมาตรฐาน

$c := 3 \cdot 10^{8} \cdot \frac{m}{sec}$ $\lambda_{lower} := \frac{c}{f_{lower}}$ $\lambda_{upper} := \frac{c}{f_{upper}}$

$k_{lower} := \frac{2 \cdot \pi}{\lambda_{lower}}$ $k_{lower} = 167.55160819 \cdot m^{-1}$

$k_{upper} := \frac{2 \cdot \pi}{\lambda_{upper}}$ $k_{upper} = 251.32741229 \cdot m^{-1}$

ขนาดของเวกเตอร์การแพร่ในสูญญากาศ

ขนาดของเวกเตอร์การแพร่ในท่อนำคลื่นที่เป็นฟังก์ชั่นของความกว้างของท่อนำคลื่น โดยที่ a คือความกว้างของท่อและ b คือความสูงของท่อ

$$\beta_{lower}(a) := \left[k_{lower}^{2} - \left(\frac{\pi}{a}\right)^{2}\right]^{\frac{1}{2}} \qquad \beta_{upper}(a) := \left[k_{upper}^{2} - \left(\frac{\pi}{a}\right)^{2}\right]^{\frac{1}{2}}$$

$$\beta_o(a) := \frac{\beta_{lower}(a) + \beta_{upper}(a)}{2}$$

ขนาดของเวกเตอร์การแพร่กลางที่เราต้องการนำมาออกแบบที่ความถี่ของความถี่กลางนี้

$a := 22.90 \cdot mm$ $b := 10.2 \cdot mm$ ความกว้าง a และความสูง b

$f_c := \frac{c}{2 \cdot a}$ $f_c = 6.55 \cdot GHz$ ความถี่ cutoff ของ TE_{10} ในท่อมาตรฐาน

จากขนาดของท่อนำคลื่นดังกล่าวจะได้ขนาดของเวกเตอร์การแพร่ดังต่อไปนี้

$\beta_o(a) = 153.388 \cdot m^{-1}$ $\beta_{lower}(a) = 96.193 \cdot m^{-1}$ $\beta_{upper}(a) = 210.583 \cdot m^{-1}$

$d := \frac{\pi}{2 \cdot \beta_o(a)}$ $d = 10.24067 \cdot mm$ ระยะห่างระหว่างรู

$H := 10$ จำนวนรู

$N := H - 1$ $N = 9$

$$k_o := \left[\beta_o(a)^2 + \left(\frac{\pi}{a} \right)^2 \right]^{\frac{1}{2}}$$

$\lambda_o := \frac{2 \cdot \pi}{k_o}$ $\lambda_o = 3.053 \cdot cm$ $\frac{c}{\lambda_o} = 9.8256 \cdot GHz$

$x_o := \left(\frac{a}{\pi} \right) \cdot \operatorname{asin}\left(\frac{\lambda_o}{\sqrt{6} \cdot a} \right)$ $x_o = 4.19552 \cdot mm$ ระยะห่างของรูจากผนังท่อ

ค่าประสิทธิ์ความสัมพันธ์ระหว่าง d_n และรัศมีของรู

$$T_f := \frac{-2i \cdot k_o^2}{3 \cdot \beta_o(a) \cdot a \cdot b} \cdot \sin\left(\frac{\pi \cdot x_o}{a} \right)^2 + \frac{4i}{3 \cdot a \cdot b} \cdot \left(\beta_o(a) \cdot \sin\left(\frac{\pi \cdot x_o}{a} \right)^2 + \frac{\pi^2}{\beta_o(a) \cdot a^2} \cdot \cos\left(\frac{\pi \cdot x_o}{a} \right)^2 \right)$$

$$|T_f| = 5.188 \cdot 10^{5} \cdot m^{-3}$$

$$n := 0, 1 .. N$$

$$g_{w1} := \frac{10^{\frac{-C_0}{20}}}{|T_f|} \qquad g_{max} := \frac{10^{\frac{-C_0 - D_m}{20}}}{|T_f|}$$

$$\theta_m := \operatorname{acos}\left[\frac{1}{\cos\left(\frac{\operatorname{acos}\left(\frac{g_{w1}}{g_{max}}\right)}{N}\right)}\right] \qquad \theta_m = 0.5573739$$

$$\psi(n) := -2 \cdot \operatorname{acos}\left[\cos(\theta_m) \cdot \cos\left[\frac{(2 \cdot n - 1) \cdot \pi}{2 \cdot N}\right]\right]$$

$$d_n(w) := \left[\prod_{n=1}^{N} \left(w - e^{i \cdot \psi(n)}\right)\right] \qquad d_n(1) = 45.66405$$

$$f_N := \frac{g_{w1}}{d_n(1)} \qquad f_N = 4.221 \cdot 10^{-9} \cdot m^{3}$$

$$n := 1, 2 .. N$$

$$w_n(n) := e^{\left(i \cdot \psi(n)\right)} \qquad g(w) := f_N \cdot d_n(w)$$

$w_n(n)$

0.397 − 0.918i
0.08 − 0.997i
-0.405 − 0.914i
-0.832 − 0.556i
-1
-0.832 + 0.556i
-0.405 + 0.914i
0.08 + 0.997i
0.397 + 0.918i

$\psi(n)$

-1.163
-1.49
-1.988
-2.553
-3.142
-3.731
-4.296
-4.793
-5.121

$$1.0646943083316982976\cdot 10^{-8}\cdot m^3\cdot w - 8.442\cdot 10^{-29}\cdot i\cdot m^3\cdot w^2 + 4.2274282781635255707\cdot 10^{-9}\cdot m^3$$

$$+ 1.9586017538002600463\cdot 10^{-8}\cdot m^3\cdot w^2 + 2.8318491490364618657\cdot 10^{-8}\cdot m^3\cdot w^3$$

$$+ 3.37463329416125346\cdot 10^{-8}\cdot m^3\cdot w^4 + 3.3744814737889059\cdot 10^{-8}\cdot m^3\cdot w^5$$

$$+ 2.8303980300792\cdot 10^{-8}\cdot m^3\cdot w^6 + 1.9569429747\cdot 10^{-8}\cdot m^3\cdot w^7 + 1.063692\cdot 10^{-8}\cdot m^3\cdot w^8$$

$$+ 4.221\cdot 10^{-9}\cdot m^3\cdot w^9$$

จะได้รัศมีของแต่ละรูดังต่อไปนี้

$$r_{10} := \left(4.221\cdot 10^{-9}\cdot m^3\right)^{\frac{1}{3}} \qquad r_{10} = 1.61611\cdot mm$$

$$r_9 := \left(1.063692\cdot 10^{-8}\cdot m^3\right)^{\frac{1}{3}} \qquad r_9 = 2.19924\cdot mm$$

$$r_8 := \left(1.9569429747 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_8 = 2.6948 \cdot mm$$

$$r_7 := \left(2.8303980300792 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_7 = 3.04754 \cdot mm$$

$$r_6 := \left(3.3744814737889059 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_6 = 3.23149 \cdot mm$$

$$r_5 := \left(3.37463329416125346 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_5 = 3.23153 \cdot mm$$

$$r_4 := \left(2.8318491490364618657 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_4 = 3.04806 \cdot mm$$

$$r_3 := \left(1.9586017538002600463 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_3 = 2.69556 \cdot mm$$

$$r_2 := \left(1.0646943083316982976 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_2 = 2.19993 \cdot mm$$

$$r_1 := \left(4.2274282781635255707 \cdot 10^{-9} \cdot m^3\right)^{\frac{1}{3}} \qquad r_1 = 1.61693 \cdot mm$$

$$\nu := 7.0\cdot GHz, 7.01\cdot GHz .. 14\cdot GHz$$

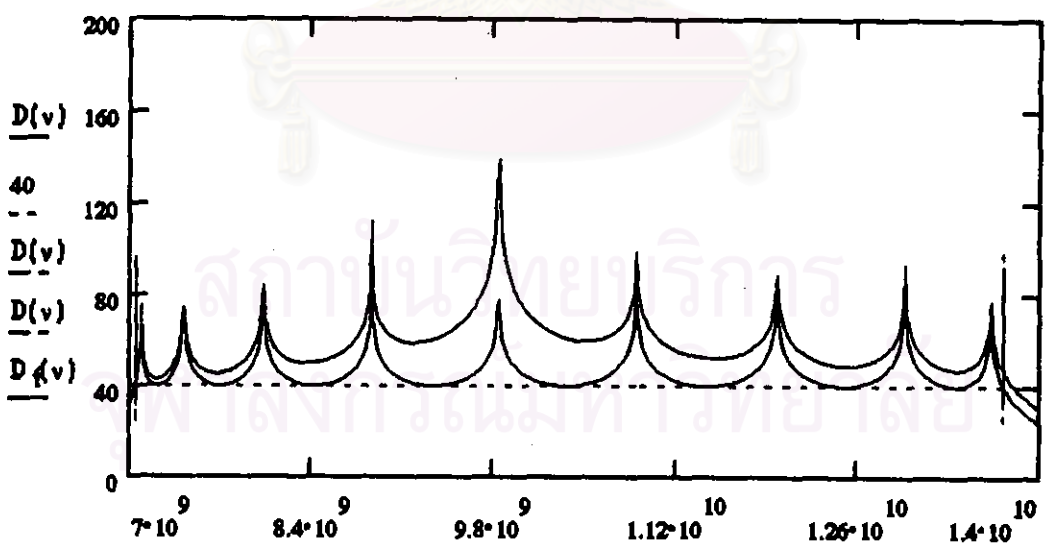
$$\beta(\nu) := \left[\left(2\cdot\pi\cdot\frac{\nu}{c}\right)^2 - \left(\frac{\pi}{a}\right)^2\right]^{\frac{1}{2}}$$

$$T_f(\nu) := \frac{-2\cdot k_o^{\,2}}{3\cdot\beta(\nu)\cdot a\cdot b}\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{4}{3\cdot a\cdot b}\cdot\left(\beta(\nu)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{\pi^2}{\beta(\nu)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right)$$

$$T_b(\nu) := \frac{-2\cdot k_o^{\,2}}{3\cdot\beta(\nu)\cdot a\cdot b}\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 - \frac{4}{3\cdot a\cdot b}\cdot\left(\beta(\nu)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 - \frac{\pi^2}{\beta(\nu)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right)$$

$$\psi(\nu) := -2\cdot\beta(\nu)\cdot d \qquad w(\nu) := e^{i\cdot\psi(\nu)}$$

$$D(\nu) := 20\cdot\log\left(\frac{|g(1)|}{|g(w(\nu))|}\right) \qquad D_f(\nu) := 20\cdot\log\left(\frac{|T_f(\nu)|}{|T_b(\nu)|}\right) + D(\nu)$$



กราฟความสัมพันธ์ระหว่าง Directivity และความถี่

$$\beta_{lwEdge} := \frac{\theta_m}{d} \qquad \beta_{upEdge} := \frac{\pi - \theta_m}{d}$$

$$k_{lower} := \left[\beta_{lwEdge}^{2} + \left(\frac{\pi}{a} \right)^{2} \right]^{\frac{1}{2}} \qquad f_{lwEdge} := \frac{c}{2 \cdot \pi} \cdot k_{lower} \qquad f_{lwEdge} = 7.047 \cdot GHz$$

$$k_{upper} := \left[\beta_{upEdge}^{2} + \left(\frac{\pi}{a} \right)^{2} \right]^{\frac{1}{2}} \qquad f_{upEdge} := \frac{c}{2 \cdot \pi} \cdot k_{upper} \qquad f_{upEdge} = 13.714 \cdot GHz$$

$$A := \frac{k_o^2}{\beta_o(a)\cdot a\cdot b}\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 \qquad A = 3.502\cdot 10^5\cdot m^{-3}$$

$$B := \frac{1}{a\cdot b}\cdot\left(\beta_o(a)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{\pi^2}{\beta_o(a)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right) \qquad B = 5.642\cdot 10^5\cdot m^{-3}$$

$$T_f := \frac{-2i\cdot k_o^2}{3\cdot\beta_o(a)\cdot a\cdot b}\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{4i}{3\cdot a\cdot b}\cdot\left(\beta_o(a)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{\pi^2}{\beta_o(a)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right)$$

$r := 1\cdot mm$

$c_n := |T_f|\cdot r_8^3$

given

$$\left[\frac{2}{3}\cdot A\cdot e^{-2.405\cdot\left(\frac{1\cdot mm}{r}\right)} + \frac{4}{3}\cdot B\cdot e^{-1.841\cdot\left(\frac{1\cdot mm}{r}\right)}\right]\cdot r^3 = c_n \qquad \text{find}(r) = 3.19058\cdot mm$$

$n := 0..9$

$r_n :=$

2.09458·mm
2.68882·mm
3.19058·mm
3.54666·mm
3.7321·mm
3.7321·mm
3.54719·mm
3.19135·mm
2.68952·mm
2.09542·mm

$dd_n :=$

1.61611·mm
2.19924·mm
2.6948·mm
3.04754·mm
3.23149·mm
3.23153·mm
3.04806·mm
2.69556·mm
2.19993·mm
1.61693·mm

$$\beta(v) := \left[\left(\frac{2\cdot\pi\cdot v}{c}\right)^2 - \left(\frac{\pi}{a}\right)^2\right]^{\frac{1}{2}}$$

$$A(v) := \frac{k_o^2}{\beta(v)\cdot a\cdot b}\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 \qquad B(v) := \frac{1}{a\cdot b}\cdot\left(\beta(v)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{\pi^2}{\beta(v)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right)$$

$$C(v) := \frac{1}{a\cdot b}\cdot\left(\beta(v)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 - \frac{\pi^2}{\beta(v)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right)$$

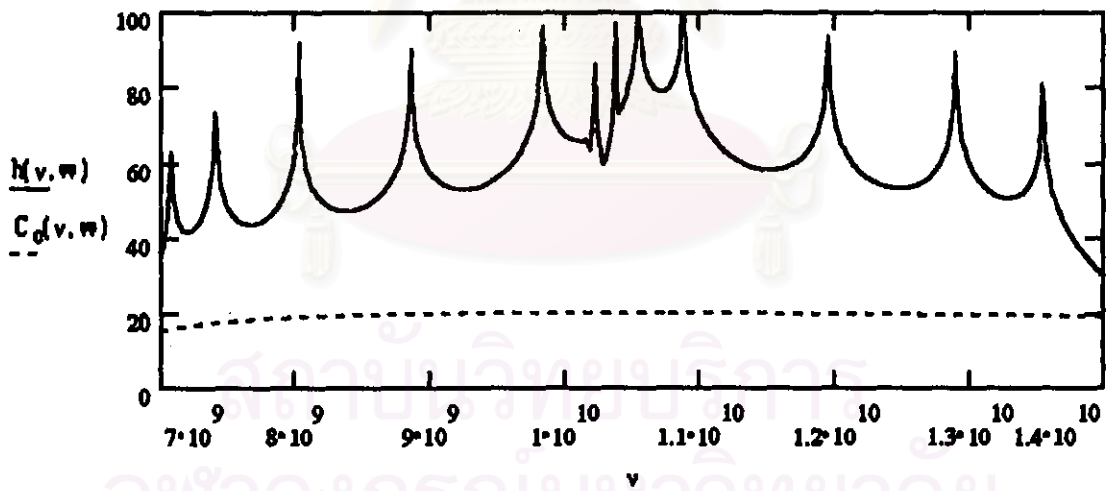
$w := 1 \cdot mm$

$$f(v,w) := \left[\sum_{n=0}^{9} \left[\left| \frac{2}{3} \cdot A(v) \cdot e^{-2.405 \cdot \left(\frac{w}{r_n} \right)} + \frac{4}{3} \cdot B(v) \cdot e^{-1.841 \cdot \left(\frac{w}{r_n} \right)} \right| \cdot (r_n)^3 \right] \right]$$

$$g(v,w) := \left[\sum_{n=0}^{9} \left[\left| \frac{2}{3} \cdot A(v) \cdot e^{-2.405 \cdot \left(\frac{w}{r_n} \right)} - \frac{4}{3} \cdot C(v) \cdot e^{-1.841 \cdot \left(\frac{w}{r_n} \right)} \right| \cdot (r_n)^3 \cdot e^{i \cdot \psi(v) \cdot n} \right] \right]$$

$$h(v,w) := 20 \cdot \log\left(\frac{|f(v,w)|}{|g(v,w)|} \right) \qquad C_o(v,w) := -20 \cdot \log(|f(v,w)|)$$

$v := 7.00 \cdot GHz, 7.01 \cdot GHz .. 14.00 \cdot GHz$



แบบไบโนมี่ยล มีจำนวน 10 รู

โปรแกรมออกแบบไดเรกชันแนลคัปเปลอร์ในช่วงความถี่ 8-12GHz ด้วยวิธี Binomial

$f_{lower} := 8 \cdot GHz$ $f_{upper} := 12 \cdot GHz$ ช่วงความถี่ที่สนใจ

$D_m := 40$ $C_o := 20$ ค่า Directivity ต่ำสุด และค่า Coupling

นำข้อมูลมาคำนวณหาขนาดของเวกเตอร์การแพร่ในท่อนำคลื่นขนาดมาตรฐาน

$$c := 3 \cdot 10^{8} \cdot \frac{m}{sec} \qquad \lambda_{lower} := \frac{c}{f_{lower}} \qquad \lambda_{upper} := \frac{c}{f_{upper}}$$

$$k_{lower} := \frac{2 \cdot \pi}{\lambda_{lower}} \qquad k_{lower} = 167.55160819 \cdot m^{-1}$$

ขนาดของเวกเตอร์การแพร่ในสุญญากาศ

$$k_{upper} := \frac{2 \cdot \pi}{\lambda_{upper}} \qquad k_{upper} = 251.32741229 \cdot m^{-1}$$

ขนาดของเวกเตอร์การแพร่ในท่อนำคลื่นที่เป็นฟังก์ชั่นของความกว้างของท่อนำคลื่น โดยที่ a คือความกว้างของท่อและ b คือความสูงของท่อ

$$\beta_{lower}(a) := \left[k_{lower}^{2} - \left(\frac{\pi}{a} \right)^{2} \right]^{\frac{1}{2}} \qquad \beta_{upper}(a) := \left[k_{upper}^{2} - \left(\frac{\pi}{a} \right)^{2} \right]^{\frac{1}{2}}$$

$$\beta_o(a) := \frac{\beta_{lower}(a) + \beta_{upper}(a)}{2}$$

ขนาดของเวกเตอร์การแพร่กลางที่เราต้องการนำมาออกแบบที่ความถี่ของความถี่กลางนี้

$a := 22.90 \cdot mm$ $b := 10.2 \cdot mm$ ความกว้าง a และความสูง b

$f_c := \frac{c}{2 \cdot a}$ $f_c = 6.55 \cdot GHz$ ความถี่ cutoff ของ TE_{10} ในท่อมาตรฐาน

จากขนาดของท่อนำคลื่นดังกล่าวจะได้ขนาดของเวกเตอร์การแพร่ดังต่อไปนี้

$\beta_o(a) = 153.388 \cdot m^{-1}$ $\beta_{lower}(a) = 96.193 \cdot m^{-1}$ $\beta_{upper}(a) = 210.583 \cdot m^{-1}$

$d := \frac{\pi}{2 \cdot \beta_o(a)}$ $d = 10.24067 \cdot mm$ ระยะห่างระหว่างรู

$H := 10$ จำนวนรู

$N := H - 1$ $N = 9$

$$k_o := \left[\beta_o(a)^2 + \left(\frac{\pi}{a} \right)^2 \right]^{\frac{1}{2}}$$

$\lambda_o := \frac{2 \cdot \pi}{k_o}$ $\lambda_o = 3.053 \cdot cm$ $\frac{c}{\lambda_o} = 9.8256 \cdot GHz$

$x_o := \left(\frac{a}{\pi} \right) \cdot \operatorname{asin}\left(\frac{\lambda_o}{\sqrt{6} \cdot a} \right)$ $x_o = 4.19552 \cdot mm$ ระยะห่างของรูจากผนังท่อ

$$T_f := \frac{-2i \cdot k_o^2}{3 \cdot \beta_o(a) \cdot a \cdot b} \cdot \sin\left(\frac{\pi \cdot x_o}{a} \right)^2 + \frac{4i}{3 \cdot a \cdot b} \cdot \left(\beta_o(a) \cdot \sin\left(\frac{\pi \cdot x_o}{a} \right)^2 + \frac{\pi^2}{\beta_o(a) \cdot a^2} \cdot \cos\left(\frac{\pi \cdot x_o}{a} \right)^2 \right)$$

$|T_f| = 5.188 \cdot 10^5 \cdot m^{-3}$

$$f_{19} := \frac{10^{-\frac{C_0}{20}}}{|T_f| \cdot 2^N}$$

$f_{19} = 3.76447 \cdot 10^{-10} \cdot m^3$

$$f(w) := f_{19} \cdot \left[\prod_{n=1}^{N} \left(w + 1 \right) \right] \qquad f(w) := f_{19} \cdot \left(w + 1 \right)^{N}$$

$$3.76447 \cdot 10^{-10} \cdot m^{3} \cdot \left(w + 1 \right)^{9}$$

$$3.76447 \cdot 10^{-10} \cdot m^{3} \cdot w^{9} + 3.388023 \cdot 10^{-9} \cdot m^{3} \cdot w^{8} + 1.3552092 \cdot 10^{-8} \cdot m^{3} \cdot w^{7} + 3.1621548 \cdot 10^{-8} \cdot m^{3} \cdot w^{6}$$

$$+ 4.7432322 \cdot 10^{-8} \cdot m^{3} \cdot w^{5} + 4.7432322 \cdot 10^{-8} \cdot m^{3} \cdot w^{4} + 3.1621548 \cdot 10^{-8} \cdot m^{3} \cdot w^{3}$$

$$+ 1.3552092 \cdot 10^{-8} \cdot m^{3} \cdot w^{2} + 3.388023 \cdot 10^{-9} \cdot m^{3} \cdot w + 3.76447 \cdot 10^{-10} \cdot m^{3}$$

$$r_{10} := \left(3.76447 \cdot 10^{-10} \cdot m^{3} \right)^{\frac{1}{3}} \qquad r_{10} = 0.72205 \cdot mm$$

$$r_{9} := \left(3.388023 \cdot 10^{-9} \cdot m^{3} \right)^{\frac{1}{3}} \qquad r_{9} = 1.50193 \cdot mm$$

$$r_{8} := \left(1.3552092 \cdot 10^{-8} \cdot m^{3} \right)^{\frac{1}{3}} \qquad r_{8} = 2.38416 \cdot mm$$

$$r_{7} := \left(3.1621548 \cdot 10^{-8} \cdot m^{3} \right)^{\frac{1}{3}} \qquad r_{7} = 3.16224 \cdot mm$$

$$r_6 := \left(4.7432322 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_6 = 3.61986 \cdot mm$$

$$r_5 := \left(4.7432322 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_5 = 3.61986 \cdot mm$$

$$r_4 := \left(3.1621548 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_4 = 3.16224 \cdot mm$$

$$r_3 := \left(1.3552092 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_3 = 2.38416 \cdot mm$$

$$r_2 := \left(3.388023 \cdot 10^{-9} \cdot m^3\right)^{\frac{1}{3}} \qquad r_2 = 1.50193 \cdot mm$$

$$r_1 := \left(3.76447 \cdot 10^{-10} \cdot m^3\right)^{\frac{1}{3}} \qquad r_1 = 0.72205 \cdot mm$$

$$\nu := 7.0\cdot GHz, 7.01\cdot GHz .. 14\cdot GHz$$

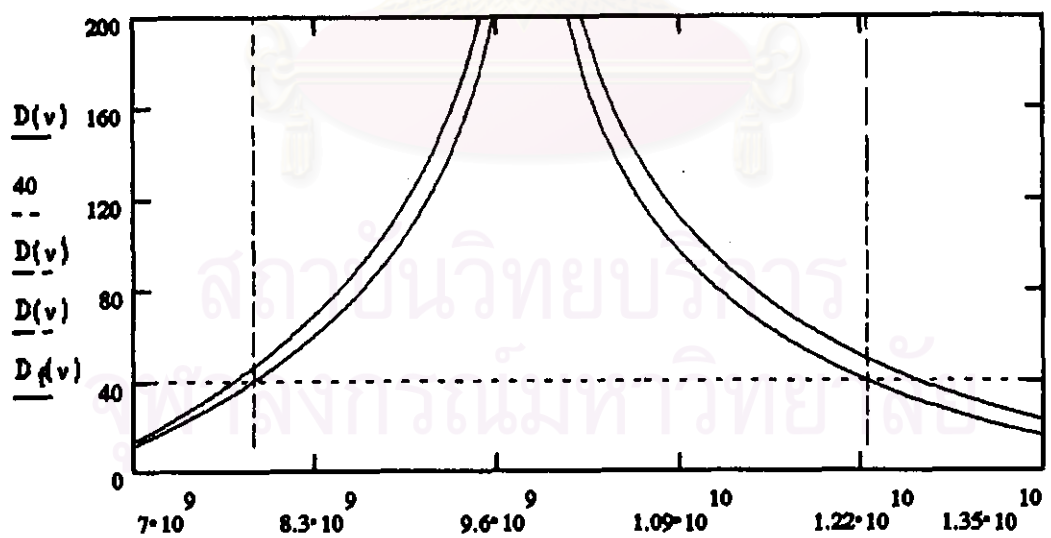
$$\beta(\nu) := \left[\left(\frac{2\cdot\pi\cdot\nu}{c}\right)^2 - \left(\frac{\pi}{a}\right)^2\right]^{\frac{1}{2}}$$

$$T_f(\nu) := \frac{-2\cdot k_0^{\,2}}{3\cdot\beta(\nu)\cdot a\cdot b}\cdot\sin\left(\frac{\pi\cdot x_0}{a}\right)^2 + \frac{4}{3\cdot a\cdot b}\cdot\left(\beta(\nu)\cdot\sin\left(\frac{\pi\cdot x_0}{a}\right)^2 + \frac{x^2}{\beta(\nu)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_0}{a}\right)^2\right)$$

$$T_b(\nu) := \frac{-2\cdot k_0^{\,2}}{3\cdot\beta(\nu)\cdot a\cdot b}\cdot\sin\left(\frac{\pi\cdot x_0}{a}\right)^2 - \frac{4}{3\cdot a\cdot b}\cdot\left(\beta(\nu)\cdot\sin\left(\frac{\pi\cdot x_0}{a}\right)^2 - \frac{x^2}{\beta(\nu)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_0}{a}\right)^2\right)$$

$$\psi(\nu) := -2\cdot\beta(\nu)\cdot d \qquad w(\nu) := e^{i\cdot\psi(\nu)}$$

$$D(\nu) := 20\cdot\log\left(\frac{|f(1)|}{|f(w(\nu))|}\right) \qquad D_f(\nu) := 20\cdot\log\left(\frac{|T_f(\nu)|}{|T_b(\nu)|}\right) + D(\nu)$$



กราฟความสัมพันธ์ระหว่าง Directivity และความถี่

$$\beta(f) := \left[\left(\frac{2\cdot\pi\cdot f}{c}\right)^2 - \left(\frac{\pi}{a}\right)^2\right]^{\frac{1}{2}} \qquad -20\cdot\log\left[\left(|\cos(x\cdot d)|\right)^{19}\right] = D_m$$

$$x_1 := \frac{\operatorname{acos}\left[10^{-\left(\frac{D_m}{20\cdot N}\right)}\right]}{d} \qquad \left[\left(\frac{2\cdot\pi\cdot f}{c}\right)^2 - \left(\frac{\pi}{a}\right)^2\right]^{\frac{1}{2}} = x_1$$

$$\begin{bmatrix} \frac{1}{(2\cdot\pi)}\cdot c\cdot\frac{\sqrt{\pi^2 + x_1^2\cdot a^2}}{a} \\ \frac{-1}{(2\cdot\pi)}\cdot c\cdot\frac{\sqrt{\pi^2 + x_1^2\cdot a^2}}{a} \end{bmatrix} \qquad f_{lower} := \frac{1}{(2\cdot\pi)}\cdot c\cdot\frac{\sqrt{\pi^2 + x_1^2\cdot a^2}}{a} \qquad f_{lower} = 7.85\cdot GHz$$

$$x_2 := \frac{\pi - \operatorname{acos}\left[10^{-\left(\frac{40}{20\cdot N}\right)}\right]}{d} \qquad \left[\left(\frac{2\cdot\pi\cdot f}{c}\right)^2 - \left(\frac{\pi}{a}\right)^2\right]^{\frac{1}{2}} = x_2$$

$$\begin{bmatrix} \frac{1}{(2\cdot\pi)}\cdot c\cdot\frac{\sqrt{\pi^2 + x_2^2\cdot a^2}}{a} \\ \frac{-1}{(2\cdot\pi)}\cdot c\cdot\frac{\sqrt{\pi^2 + x_2^2\cdot a^2}}{a} \end{bmatrix}$$

$$f_{upper} := \frac{1}{(2\cdot\pi)}\cdot c\cdot\frac{\sqrt{\pi^2 + x_2^2\cdot a^2}}{a} \qquad f_{upper} = 12.224\cdot GHz$$

$$A := \frac{k_o^2}{\beta_o(a)\cdot a\cdot b}\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 \qquad A = 3.502\cdot 10^5\cdot m^{-3}$$

$$B := \frac{1}{a\cdot b}\cdot\left(\beta_o(a)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{\pi^2}{\beta_o(a)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right) \qquad B = 5.642\cdot 10^5\cdot m^{-3}$$

$$T_f := \frac{-2i\cdot k_o^2}{3\cdot\beta_o(a)\cdot a\cdot b}\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{4i}{3\cdot a\cdot b}\cdot\left(\beta_o(a)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{\pi^2}{\beta_o(a)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right)$$

$r_{10} = 0.722\cdot mm \qquad c_n := |T_f|\cdot r_8^3$

$r := 1\cdot mm$

given

$$\left[\frac{2}{3}\cdot A\cdot e^{-2.405\cdot\left(\frac{1\cdot mm}{r}\right)} + \frac{4}{3}\cdot B\cdot e^{-1.841\cdot\left(\frac{1\cdot mm}{r}\right)}\right]\cdot r^3 = c_n \qquad \text{find}(r) = 2.87631\cdot mm$$

$r_{10} = 0.72205\cdot mm \qquad c_n := |T_f|\cdot r_9^3$

$r := 1\cdot mm$

given

$$\left[-(0.55)\cdot A\cdot e^{-2.405\cdot\left(\frac{1\cdot mm}{r}\right)} + (1.12)\cdot B\cdot e^{-1.841\cdot\left(\frac{1\cdot mm}{r}\right)}\right]\cdot r^3 = c_n \qquad \text{find}(r) = 2.06667\cdot mm$$

$n := 0..9$

$r_n :=$

1.16·mm
1.97·mm
2.87·mm
3.66·mm
4.12·mm
4.12·mm
3.66·mm
2.87·mm
1.97·mm
1.61·mm

$d_n :=$

0.72205·mm
1.50193·mm
2.38416·mm
3.16224·mm
3.61986·mm
3.61986·mm
3.16224·mm
2.38416·mm
1.50193·mm
0.72205·mm

$$\beta(v) := \left[\left(\frac{2\cdot\pi\cdot v}{c}\right)^2 - \left(\frac{\pi}{a}\right)^2\right]^{\frac{1}{2}}$$

$$A(v) := \frac{k_o^{\,2}}{\beta(v)\cdot a\cdot b}\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 \qquad B(v) := \frac{1}{a\cdot b}\cdot\left(\beta(v)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{\pi^2}{\beta(v)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right)$$

$$C(v) := \frac{1}{a\cdot b}\cdot\left(\beta(v)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 - \frac{\pi^2}{\beta(v)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right)$$

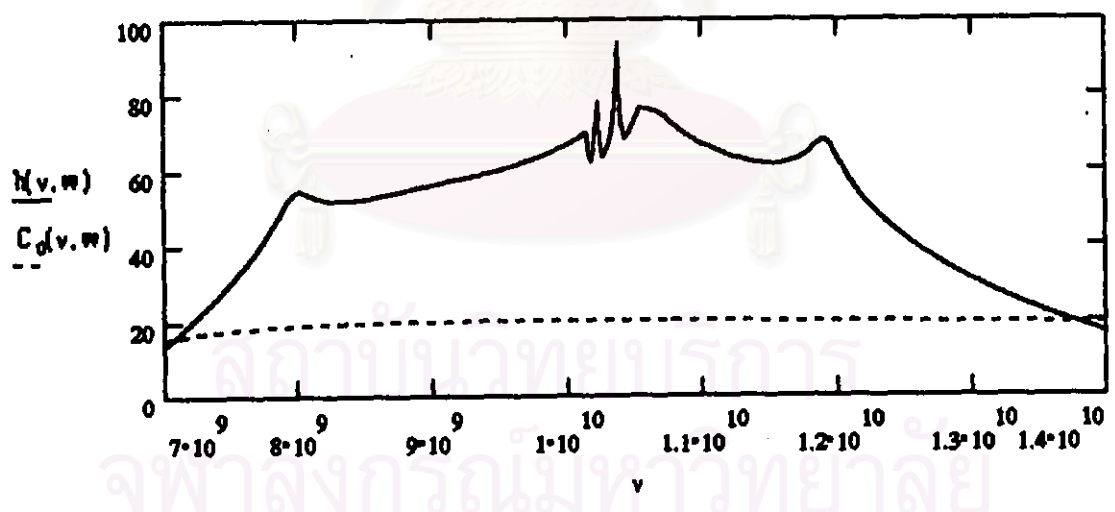
$w := 1 \cdot mm$

$$f(v,w) := \sum_{n=0}^{9} \left[\left| \frac{2}{3} \cdot A(v) \cdot e^{-2.405 \cdot \left(\frac{w}{r_n}\right)} + \frac{4}{3} \cdot B(v) \cdot e^{-1.841 \cdot \left(\frac{w}{r_n}\right)} \right| \right] \cdot \left(r_n\right)^3$$

$$g(v,w) := \sum_{n=0}^{9} \left[\left| \frac{2}{3} \cdot A(v) \cdot e^{-2.405 \cdot \left(\frac{w}{r_n}\right)} - \frac{4}{3} \cdot C(v) \cdot e^{-1.841 \cdot \left(\frac{w}{r_n}\right)} \right| \right] \cdot \left(r_n\right)^3 \cdot e^{i \cdot \psi(v) \cdot n}$$

$$h(v,w) := 20 \cdot \log\left(\frac{|f(v,w)|}{|g(v,w)|} \right) \qquad C_0(v,w) := -20 \cdot \log\left(|f(v,w)| \right)$$

$v := 7.00 \cdot GHz, 7.01 \cdot GHz .. 14.00 \cdot GHz$



แบบไบโนเมี่ยล มีจำนวน 20 รูป

โปรแกรมออกแบบไดเรกชันแนลคัปเปลอร์ในช่วงความถี่ 8-12GHz ด้วยวิธี Binomial

$f_{lower} := 8 \cdot GHz$ $f_{upper} := 12 \cdot GHz$ ช่วงความถี่ที่สนใจ

$D_m := 40$ $C_o := 20$ ค่า Directivity ต่ำสุด และค่า Coupling ที่ต้องการ

นำข้อมูลมาคำนวณหาขนาดของเวกเตอร์การแพร่ในท่อนำคลื่นขนาดมาตรฐาน

$c := 3 \cdot 10^{8} \frac{m}{sec}$ $\lambda_{lower} := \frac{c}{f_{lower}}$ $\lambda_{upper} := \frac{c}{f_{upper}}$

$k_{lower} := \frac{2 \cdot \pi}{\lambda_{lower}}$ $k_{lower} = 167.55160819 \cdot m^{-1}$

$k_{upper} := \frac{2 \cdot \pi}{\lambda_{upper}}$ $k_{upper} = 251.32741229 \cdot m^{-1}$

ขนาดของเวกเตอร์การแพร่ในสุญญากาศ

ขนาดของเวกเตอร์การแพร่ในท่อนำคลื่นที่เป็นฟังก์ชั่นของความกว้างของท่อนำคลื่น โดยที่ a คือความกว้างของท่อและ b คือความสูงของท่อ

$$\beta_{lower}(a) := \left[k_{lower}^{2} - \left(\frac{\pi}{a}\right)^{2} \right]^{\frac{1}{2}} \qquad \beta_{upper}(a) := \left[k_{upper}^{2} - \left(\frac{\pi}{a}\right)^{2} \right]^{\frac{1}{2}}$$

$$\beta_{o}(a) := \frac{\beta_{lower}(a) + \beta_{upper}(a)}{2}$$

ขนาดของเวกเตอร์การแพร่กลางที่เราต้องการนำมาออกแบบที่ความถี่ของความถี่กลางนี้

$a := 22.90 \cdot mm$ $b := 10.2 \cdot mm$ ความกว้าง a และความสูง b

$f_c := \frac{c}{2 \cdot a}$ $f_c = 6.55 \cdot GHz$ ความถี่ cutoff ของ TE_{10} ในท่อมาตรฐาน

จากขนาดของท่อนำคลื่นดังกล่าวจะได้ขนาดของเวกเตอร์การแพร่ดังต่อไปนี้

$\beta_o(a) = 153.388 \cdot m^{-1}$ $\beta_{lower}(a) = 96.193 \cdot m^{-1}$ $\beta_{upper}(a) = 210.583 \cdot m^{-1}$

$d := \frac{\pi}{2 \cdot \beta_o(a)}$ $d = 10.24067 \cdot mm$ ระยะห่างระหว่างรู

$H := 20$ จำนวนรู

$N := H - 1$ $N = 19$

$$k_o := \left[\beta_o(a)^2 + \left(\frac{\pi}{a} \right)^2 \right]^{\frac{1}{2}}$$

$\lambda_o := \frac{2 \cdot \pi}{k_o}$ $\lambda_o = 3.053 \cdot cm$ $\frac{c}{\lambda_o} = 9.8256 \cdot GHz$

$x_o := \left(\frac{a}{\pi} \right) \cdot asin\left(\frac{\lambda_o}{\sqrt{6} \cdot a} \right)$ $x_o = 4.19552 \cdot mm$ ระยะห่างของรูจากผนังท่อ

สัมประสิทธิ์ความสัมพันธ์ระหว่าง d_n และรัศมีของรู

$$T_f := \frac{-2i \cdot k_o^2}{3 \cdot \beta_o(a) \cdot a \cdot b} \cdot \sin\left(\frac{\pi \cdot x_o}{a} \right)^2 + \frac{4i}{3 \cdot a \cdot b} \cdot \left(\beta_o(a) \cdot \sin\left(\frac{\pi \cdot x_o}{a} \right)^2 + \frac{\pi^2}{\beta_o(a) \cdot a^2} \cdot \cos\left(\frac{\pi \cdot x_o}{a} \right)^2 \right)$$

$$|T_f| = 5.188 \cdot 10^{5} \cdot m^{-3}$$

$$f_{19} := \frac{10^{-\frac{C_0}{20}}}{|T_f| \cdot 2^N} \qquad f_{19} = 3.67624 \cdot 10^{-13} \cdot m^3$$

$$f(w) := f_{19} \cdot \left[\prod_{n=1}^{N} (w+1) \right] \qquad f(w) := f_{19} \cdot (w+1)^N$$

$$3.67624 \cdot 10^{-13} \cdot m^3 \cdot (w+1)^{19}$$

$$3.67624 \cdot 10^{-13} \cdot m^3 \cdot w^{19} + 6.984856 \cdot 10^{-12} \cdot m^3 \cdot w^{18} + 6.2863704 \cdot 10^{-11} \cdot m^3 \cdot w^{17} + \blacksquare$$

$$3.56227656 \cdot 10^{-10} \cdot m^3 \cdot w^{16} + 1.424910624 \cdot 10^{-9} \cdot m^3 \cdot w^{15} + 4.274731872 \cdot 10^{-9} \cdot m^3 \cdot w^{14} + \blacksquare$$

$$9.974374368 \cdot 10^{-9} \cdot m^3 \cdot w^{13} + 1.8523838112 \cdot 10^{-8} \cdot m^3 \cdot w^{12} + 2.7785757168 \cdot 10^{-8} \cdot m^3 \cdot w^{11}$$

$$3.3960369872 \cdot 10^{-8} \cdot m^3 \cdot w^{10} + 3.3960369872 \cdot 10^{-8} \cdot m^3 \cdot w^{9} + 2.7785757168 \cdot 10^{-8} \cdot m^3 \cdot w^{8}$$

$$\blacksquare + 1.8523838112 \cdot 10^{-8} \cdot m^3 \cdot w^{7} + 9.974374368 \cdot 10^{-9} \cdot m^3 \cdot w^{6} + 4.274731872 \cdot 10^{-9} \cdot m^3 \cdot w^{5}$$

$$\blacksquare + 1.424910624 \cdot 10^{-9} \cdot m^3 \cdot w^{4} + 3.56227656 \cdot 10^{-10} \cdot m^3 \cdot w^{3} + 6.2863704 \cdot 10^{-11} \cdot m^3 \cdot w^{2}$$

$$\blacksquare + 6.984856 \cdot 10^{-12} \cdot m^3 \cdot w + 3.67624 \cdot 10^{-13} \cdot m^3$$

จะได้รัศมีของแต่ละรูดังต่อไปนี้

$$r_{20} := \left(3.67624 \cdot 10^{-13} \cdot m^3\right)^{\frac{1}{3}} \qquad r_{20} = 0.07164 \cdot mm$$

$$r_{19} := \left(6.984856 \cdot 10^{-12} \cdot m^3\right)^{\frac{1}{3}} \qquad r_{19} = 0.19116 \cdot mm$$

$$r_{18} := \left(6.2863704 \cdot 10^{-11} \cdot m^3\right)^{\frac{1}{3}} \qquad r_{18} = 0.39762 \cdot mm$$

$$r_{17} := \left(3.56227656 \cdot 10^{-10} \cdot m^3\right)^{\frac{1}{3}} \qquad r_{17} = 0.70889 \cdot mm$$

$$r_{16} := \left(1.424910624 \cdot 10^{-9} \cdot m^3\right)^{\frac{1}{3}} \qquad r_{16} = 1.12529 \cdot mm$$

$$r_{15} := \left(4.274731872 \cdot 10^{-9} \cdot m^3\right)^{\frac{1}{3}} \qquad r_{15} = 1.62294 \cdot mm$$

$$r_{14} := \left(9.974374368 \cdot 10^{-9} \cdot m^3\right)^{\frac{1}{3}} \qquad r_{14} = 2.15259 \cdot mm$$

$$r_{13} := \left(1.8523838112 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_{13} = 2.64592 \cdot mm$$

$$r_{12} := \left(2.7785757168 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_{12} = 3.02882 \cdot mm$$

$$r_{11} := \left(3.3960369872 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_{11} = 3.23835 \cdot mm$$

$$r_{10} := \left(3.3960369872 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_{10} = 3.23835 \cdot mm$$

$$r_9 := \left(2.7785757168 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_9 = 3.02882 \cdot mm$$

$$r_8 := \left(1.8523838112 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_8 = 2.64592 \cdot mm$$

$$r_7 := \left(9.974374368 \cdot 10^{-9} \cdot m^3\right)^{\frac{1}{3}} \qquad r_7 = 2.15259 \cdot mm$$

$$r_6 := \left(4.274731872 \cdot 10^{-9} \cdot m^3\right)^{\frac{1}{3}} \qquad r_6 = 1.62294 \cdot mm$$

$$r_5 := \left(1.424910624 \cdot 10^{-9} \cdot m^3\right)^{\frac{1}{3}} \qquad r_5 = 1.12529 \cdot mm$$

$$r_4 := \left(3.56227656 \cdot 10^{-10} \cdot m^3\right)^{\frac{1}{3}} \qquad r_4 = 0.70889 \cdot mm$$

$$r_3 := \left(6.2863704 \cdot 10^{-11} \cdot m^3\right)^{\frac{1}{3}} \qquad r_3 = 0.39762 \cdot mm$$

$$r_2 := \left(6.984856 \cdot 10^{-12} \cdot m^3\right)^{\frac{1}{3}} \qquad r_2 = 0.19116 \cdot mm$$

$$r_1 := \left(3.67624 \cdot 10^{-13} \cdot m^3\right)^{\frac{1}{3}} \qquad r_1 = 0.07164 \cdot mm$$

$$v := 7.0\cdot GHz, 7.01\cdot GHz .. 14\cdot GHz$$

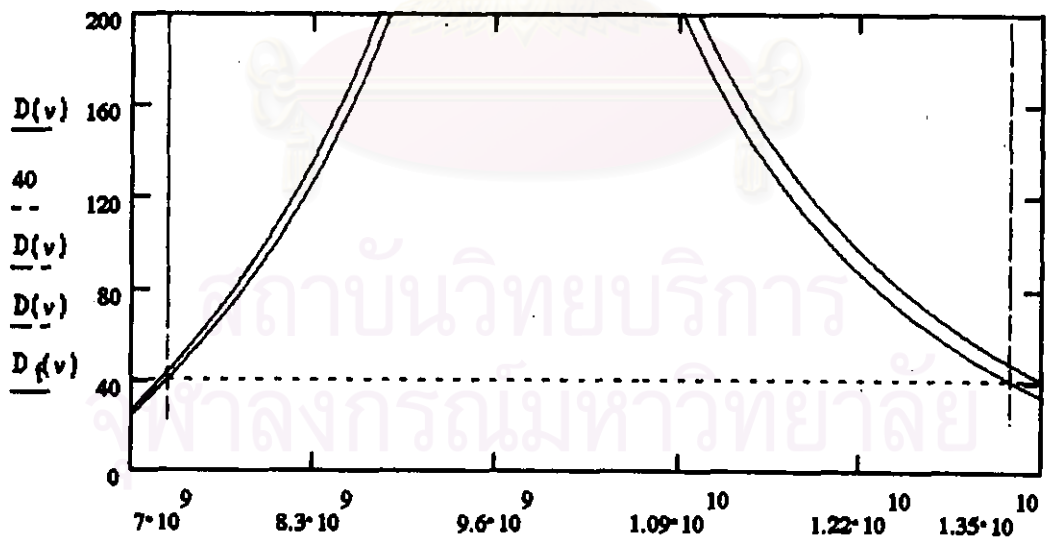
$$\beta(v) := \left[\left(\frac{2\cdot\pi\cdot v}{c}\right)^2 - \left(\frac{\pi}{a}\right)^2\right]^{\frac{1}{2}}$$

$$T_f(v) := \frac{-2\cdot k_o^{\,2}}{3\cdot\beta(v)\cdot a\cdot b}\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{4}{3\cdot a\cdot b}\cdot\left(\beta(v)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{\pi^2}{\beta(v)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right)$$

$$T_b(v) := \frac{-2\cdot k_o^{\,2}}{3\cdot\beta(v)\cdot a\cdot b}\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 - \frac{4}{3\cdot a\cdot b}\cdot\left(\beta(v)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 - \frac{\pi^2}{\beta(v)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right)$$

$$\psi(v) := -2\cdot\beta(v)\cdot d \qquad w(v) := e^{i\cdot\psi(v)}$$

$$D(v) := 20\cdot\log\left(\frac{|f(1)|}{|f(w(v))|}\right) \qquad D_f(v) := 20\cdot\log\left(\frac{|T_f(v)|}{|T_b(v)|}\right) + D(v)$$



กราฟความสัมพันธ์ระหว่าง Directivity และความถี่

$$\beta(f) := \left[\left(\frac{2\cdot\pi\cdot f}{c}\right)^2 - \left(\frac{\pi}{a}\right)^2\right]^{\frac{1}{2}} \qquad -20\cdot\log\left[\left(|\cos(x\cdot d)|\right)^{19}\right] = D_m$$

$$x_1 := \frac{\operatorname{acos}\left[10^{-\left(\frac{D_m}{20\cdot 19}\right)}\right]}{d} \qquad \left[\left(\frac{2\cdot\pi\cdot f}{c}\right)^2 - \left(\frac{\pi}{a}\right)^2\right]^{\frac{1}{2}} = x_1$$

$$\begin{bmatrix} \frac{1}{(2\cdot\pi)}\cdot c\cdot\frac{\sqrt{x^2 + x_1^{2\cdot 2}\cdot a^2}}{a} \\ \frac{-1}{(2\cdot\pi)}\cdot c\cdot\frac{\sqrt{x^2 + x_1^{2\cdot 2}\cdot a^2}}{a} \end{bmatrix}$$

$$f_{lower} := \frac{1}{(2\cdot\pi)}\cdot c\cdot\frac{\sqrt{x^2 + x_1^{2\cdot 2}\cdot a^2}}{a} \qquad f_{lower} = 7.254\cdot GHz$$

$$x_2 := \frac{\pi - \operatorname{acos}\left[10^{-\left(\frac{40}{20\cdot 19}\right)}\right]}{d} \qquad \left[\left(\frac{2\cdot\pi\cdot f}{c}\right)^2 - \left(\frac{\pi}{a}\right)^2\right]^{\frac{1}{2}} = x_2$$

$$\begin{bmatrix} \frac{1}{(2\cdot\pi)}\cdot c\cdot\frac{\sqrt{x^2 + x_2^{2\cdot 2}\cdot a^2}}{a} \\ \frac{-1}{(2\cdot\pi)}\cdot c\cdot\frac{\sqrt{x^2 + x_2^{2\cdot 2}\cdot a^2}}{a} \end{bmatrix}$$

$$f_{upper} := \frac{1}{(2\cdot\pi)}\cdot c\cdot\frac{\sqrt{x^2 + x_2^{2\cdot 2}\cdot a^2}}{a} \qquad f_{upper} = 13.261\cdot GHz$$

$$A := \frac{k_o^{\,2}}{\beta_o(a)\cdot a\cdot b}\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 \qquad A = 3.502\cdot 10^{5}\ \cdot m^{-3}$$

$$B := \frac{1}{a\cdot b}\cdot\left(\beta_o(a)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{\pi^2}{\beta_o(a)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right) \qquad B = 5.642\cdot 10^{5}\ \cdot m^{-3}$$

$$T_f := \frac{-2i\cdot k_o^{\,2}}{3\cdot\beta_o(a)\cdot a\cdot b}\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{4i}{3\cdot a\cdot b}\cdot\left(\beta_o(a)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{\pi^2}{\beta_o(a)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right)$$

$$r_{14} = 2.153\ \cdot mm \qquad c_n := |T_f|\cdot r_{15}^{\,3}$$

$r := 1\cdot mm$

given

$$\left[\frac{2}{3}\cdot A\cdot e^{-2.405\cdot\left(\frac{1\cdot mm}{r}\right)} + \frac{4}{3}\cdot B\cdot e^{-1.841\cdot\left(\frac{1\cdot mm}{r}\right)}\right]\cdot r^3 = c_n \qquad \text{find}(r) = 2.10157\ \cdot mm$$

$$r_{20} = 0.07164\ \cdot mm \qquad c_n := |T_f|\cdot r_{14}^{\,3}$$

$r := 1\cdot mm$

given

$$\left[-(0.55)\cdot A\cdot e^{-2.405\cdot\left(\frac{1\cdot mm}{r}\right)} + (1.12)\cdot B\cdot e^{-1.841\cdot\left(\frac{1\cdot mm}{r}\right)}\right]\cdot r^3 = c_n \qquad \text{find}(r) = 2.76752\ \cdot mm$$

$n := 0..19$

$r_n :=$

0.35877·mm
0.54327·mm
0.79981·mm
1.14709·mm
1.58792·mm
2.10157·mm
2.64147·mm
3.14118·mm
3.52779·mm
3.73902·mm
3.73902·mm
3.52779·mm
3.14118·mm
2.64147·mm
2.10157·mm
1.58792·mm
1.14709·mm
0.79981·mm
0.54327·mm
0.35877·mm

$d_n :=$

0.07164·mm
0.19116·mm
0.39762·mm
0.70889·mm
1.12529·mm
1.62294·mm
2.15259·mm
2.64592·mm
3.02882·mm
3.23835·mm
3.23835·mm
3.02882·mm
2.64592·mm
2.15259·mm
1.62294·mm
1.12529·mm
0.70889·mm
0.39762·mm
0.19116·mm
0.07164·mm

$$\beta(v) := \left[\left(\frac{2\cdot\pi\cdot v}{c}\right)^2 - \left(\frac{\pi}{a}\right)^2\right]^{\frac{1}{2}}$$

$$A(v) := \frac{k_o^{\,2}}{\beta(v)\cdot a\cdot b}\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 \qquad B(v) := \frac{1}{a\cdot b}\cdot\left(\beta(v)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{\pi^2}{\beta(v)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right)$$

$$C(v) := \frac{1}{a\cdot b}\cdot\left(\beta(v)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 - \frac{\pi^2}{\beta(v)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right)$$

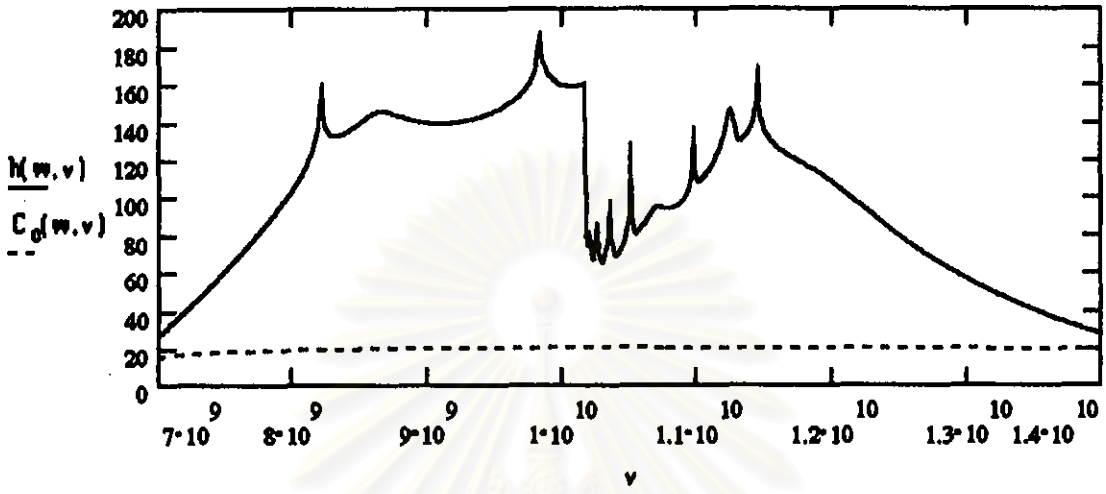
$w := 1\cdot mm$

$$f(w,v) := \sum_{n=0}^{19}\left[\left|\frac{2}{3}\cdot A(v)\cdot e^{-2.405\cdot\left(\frac{w}{r_n}\right)} + \frac{4}{3}\cdot B(v)\cdot e^{-1.841\cdot\left(\frac{w}{r_n}\right)}\right|\cdot(r_n)^3\right]$$

$$g(w,v) := \sum_{n=0}^{19}\left[\left|\frac{2}{3}\cdot A(v)\cdot e^{-2.405\cdot\left(\frac{w}{r_n}\right)} - \frac{4}{3}\cdot C(v)\cdot e^{-1.841\cdot\left(\frac{w}{r_n}\right)}\right|\cdot(r_n)^3\cdot e^{i\cdot\psi(v)\cdot n}\right]$$

$$h(w,v) := 20\cdot\log\left(\frac{|f(w,v)|}{|g(w,v)|}\right) \qquad C_o(w,v) := -20\cdot\log(f(w,v))$$

$v := 7.00 \cdot GHz, 7.01 \cdot GHz .. 14.00 \cdot GHz$



ภาคผนวก ข

โปรแกรมการออกแบบไดเรกชันเนอคัปเปลอร์แบบเชบีเชฟที่อดริปเปิ้ล

แบบเซปิเชฟ มีจำนวน 7 รู ที่ 40 เดซิเบล

```
M(n,δ) := | for row ∈ 0..n-1
          |   column ← 0
          |   while column < 2^n
          |     for i ∈ 1..2^(n-row-1)
          |       M_(row,column) ← δ
          |       column ← column + 1
          |     for j ∈ 1..2^(n-row-1)
          |       M_(row,column) ← -δ
          |       column ← column + 1
          | M
```

$$\text{count}(n,\text{last\_digit}) := \begin{cases} \text{if } \operatorname{mod}(\text{last\_digit},2)=0 \\ \quad \begin{cases} jj \leftarrow n \text{ if } n \le \dfrac{\text{last\_digit}}{2} \\ jj \leftarrow \left\lfloor \dfrac{\text{last\_digit}}{2} - \left\lfloor (n-1) - \dfrac{\text{last\_digit}}{2} \right\rfloor \right\rfloor \text{ otherwise} \end{cases} \\ \text{otherwise} \\ \quad \begin{cases} jj \leftarrow n \text{ if } n \le \dfrac{\text{last\_digit}+1}{2} \\ jj \leftarrow \left\lfloor \left(\dfrac{\text{last\_digit}+1}{2}\right) - \left\lfloor n - \left(\dfrac{\text{last\_digit}+1}{2}\right) \right\rfloor \right\rfloor \text{ otherwise} \end{cases} \\ jj - 1 \end{cases}$$

$n := 1..N$ $\quad C_0 := 20$ $\quad D_m := 40$ $\quad N = 6$

$$\frac{-C_0}{20} \qquad \frac{-C_0 - D_m}{20}$$

$$g_{wl} := \frac{10}{|T_f|} \qquad g_{max} := \frac{10}{|T_f|}$$

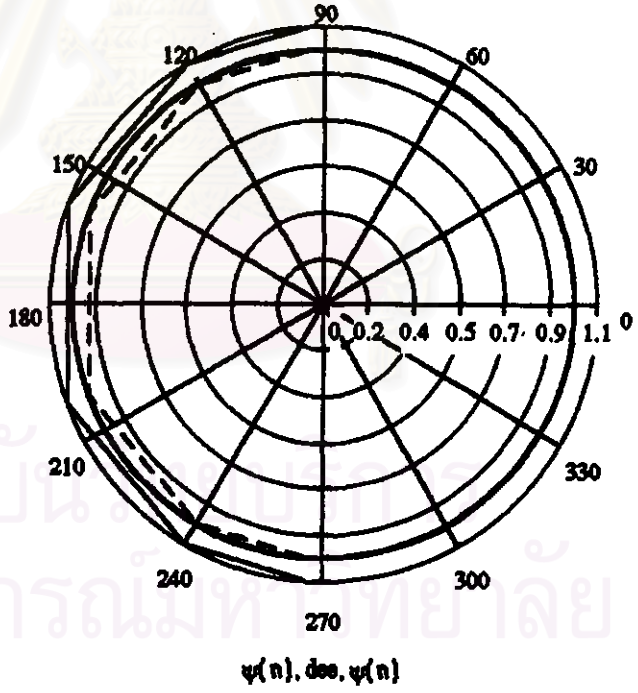
$$\theta_m := \operatorname{acos}\left[\frac{1}{\cos\left(\frac{\operatorname{acos}\left(\frac{g_{wl}}{g_{max}}\right)}{N}\right)}\right] \qquad \theta_m = 0.786582$$

$$\psi(n) := -2\cdot\operatorname{acos}\left[\cos\left(\theta_m\right)\cdot\cos\left[\frac{\left(2\cdot n - 1\right)\cdot\pi}{2\cdot N}\right]\right]$$

$dec := 0, 0.1..360$ $\quad aa := \text{FRAME}$

$$\frac{1 + \left(M\left(3, 0.09\right)^T\right)_{aa,\,count(n,N)}}{\frac{1}{--}}$$

$$\frac{1}{--}$$



$\psi(n), dec, \psi(n)$

$$d_n(w) := \left[\prod_{n=1}^{N} \left(w - e^{i \cdot \psi(n)} \right) \right] \qquad f_N := \frac{g_{w1}}{d_n(1)} \qquad f_N = 7.765 \cdot 10^{-9} \cdot m^3$$

$$g(w) := f_N \cdot d_n(w) \qquad g(1) = 1.927 \cdot 10^{-7} \cdot m^3$$

$$d_{n\_modi}(w) := \left[\prod_{n=1}^{N} \left[w - \left[\left[1 + \left(M\left(3, \frac{9}{100}\right)^{T} \right)_{2,\, count(n,N)} \right] \cdot e^{i \cdot \psi(n)} \right] \right] \right]$$

$$f_N := \frac{g_{w1}}{d_{n\_modi}(1)} \qquad \beta_o(a) := \frac{\beta_{lower}(a) + \beta_{upper}(a)}{2}$$

$$g_{modi}(w) := f_N \cdot d_{n\_modi}(w) \qquad f_N = 7.12199 \cdot 10^{-9} \cdot m^3$$

$$v := 7.0 \cdot GHz, 7.01 \cdot GHz .. 14 \cdot GHz \qquad a := 22.90 \cdot mm \qquad b := 10.2 \cdot mm$$

$$\beta(v) := \left[\left(2 \cdot \pi \cdot \frac{v}{c} \right)^2 - \left(\frac{\pi}{a} \right)^2 \right]^{\frac{1}{2}} \qquad d := \frac{\pi}{2 \cdot \beta_o(a)}$$

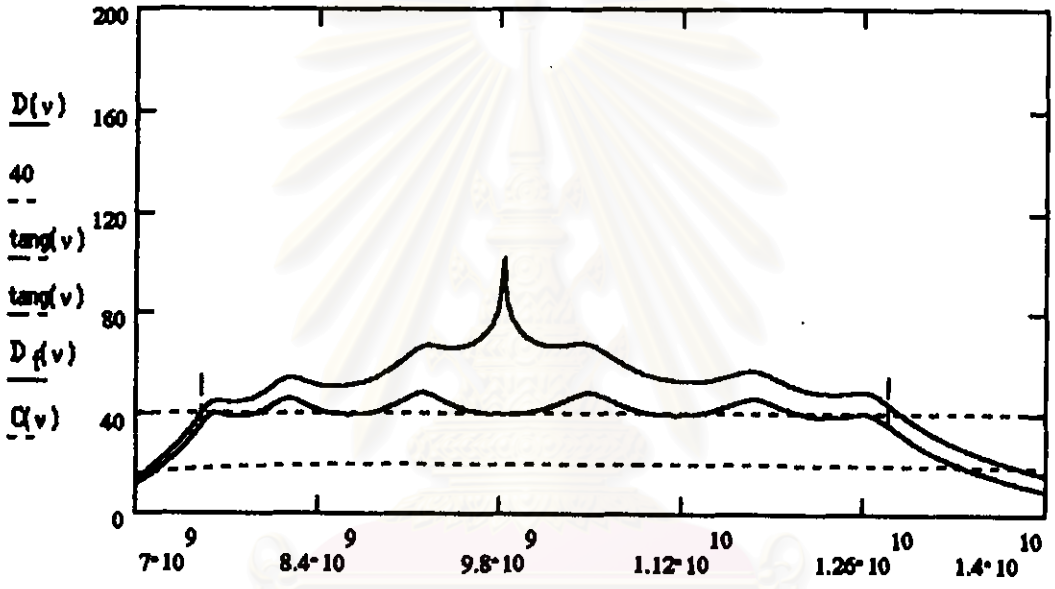
$$T_f(v) := \frac{-2 \cdot k_o^{\,2}}{3 \cdot \beta(v) \cdot a \cdot b} \cdot \sin\left(\frac{\pi \cdot x_o}{a} \right)^2 + \frac{4}{3 \cdot a \cdot b} \cdot \left(\beta(v) \cdot \sin\left(\frac{\pi \cdot x_o}{a} \right)^2 + \frac{\pi^2}{\beta(v) \cdot a^2} \cdot \cos\left(\frac{\pi \cdot x_o}{a} \right)^2 \right)$$

$$T_b(v) := \frac{-2 \cdot k_o^{\,2}}{3 \cdot \beta(v) \cdot a \cdot b} \cdot \sin\left(\frac{\pi \cdot x_o}{a} \right)^2 - \frac{4}{3 \cdot a \cdot b} \cdot \left(\beta(v) \cdot \sin\left(\frac{\pi \cdot x_o}{a} \right)^2 - \frac{\pi^2}{\beta(v) \cdot a^2} \cdot \cos\left(\frac{\pi \cdot x_o}{a} \right)^2 \right)$$

$$\psi(v) := -2\cdot\beta(v)\cdot d \qquad w(v) := e^{i\cdot\psi(v)}$$

$$D(v) := 20\cdot\log\left(\frac{\left|g_{modi}(1)\right|}{\left|g_{modi}(w(v))\right|}\right) \qquad D_f(v) := 20\cdot\log\left(\frac{\left|T_f(v)\right|}{\left|T_b(v)\right|}\right) + D(v)$$

$$C(v) := -20\cdot\log\left(\left|T_f(v)\right|\cdot\left|g_{modi}(1)\right|\right) \qquad tang(v) := 70\cdot\left|\sin\left(2\cdot\pi\cdot\frac{v - 1\cdot GHz}{v}\right)\right|$$



$$f_N = 7.12199\cdot10^{-9}\cdot m^3$$

$$7.12199\cdot10^{-9}\cdot m^3\cdot\left[\left[w - \left(-0.069 - 0.998i\right)\cdot1.09\right]\cdot\left[w - \left(-0.501 - 0.865i\right)\cdot0.91\right]\cdot\left[w - \left(-0.933 - 0.359i\right)\cdot1.09\right]\cdot\left[\left[\right.\right.\right.$$

$$r_7 := \left(7.12199 \cdot 10^{-9} \cdot m^3\right)^{\frac{1}{3}} \qquad r_7 = 1.92398 \cdot mm$$

$$r_6 := \left(2.20509629982 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_6 = 2.8042 \cdot mm$$

$$r_5 := \left(3.9181683779381859 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_5 = 3.39647 \cdot mm$$

$$r_4 := \left(4.8787216535392304309 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_4 = 3.654 \cdot mm$$

$$r_3 := \left(4.2726545544363508597 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_3 = 3.49596 \cdot mm$$

$$r_2 := \left(2.4472377364096893857 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_2 = 2.9033 \cdot mm$$

$$r_1 := \left(8.3197883523240257 86 \cdot 10^{-9} \cdot m^3\right)^{\frac{1}{3}} \qquad r_1 = 2.0263 \cdot mm$$

$$A := \frac{k_o^{\,2}}{\beta_o(a)\cdot a\cdot b}\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 \qquad A = 3.502\cdot 10^{5}\ \cdot m^{-3}$$

$$B := \frac{1}{a\cdot b}\cdot\left(\beta_o(a)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{x^2}{\beta_o(a)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right) \qquad B = 5.642\cdot 10^{5}\ \cdot m^{-3}$$

$$T_f := \frac{-2i\cdot k_o^{\,2}}{3\cdot\beta_o(a)\cdot a\cdot b}\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{4i}{3\cdot a\cdot b}\cdot\left(\beta_o(a)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{x^2}{\beta_o(a)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right)$$

$$r_7 = 1.924\ \cdot mm \qquad c_n := \left|T_f\right|\cdot r_1^{\,3}$$

$r := 1\cdot mm$

given

$$\left[\frac{2}{3}\cdot A\cdot e^{-2.405\cdot\left(\frac{1\cdot mm}{r}\right)} + \frac{4}{3}\cdot B\cdot e^{-1.841\cdot\left(\frac{1\cdot mm}{r}\right)}\right]\cdot r^3 = c_n \qquad \text{find}(r) = 2.51313\ \cdot mm$$

$n := 0..6$ $\quad r_n :=$ $\quad dd_n :=$

r_n	dd_n
$2.409\cdot mm$	$1.92398\cdot mm$
$3.3011\cdot mm$	$2.8042\cdot mm$
$3.8983\cdot mm$	$3.39647\cdot mm$
$4.15753\cdot mm$	$3.654\cdot mm$
$3.99847\cdot mm$	$3.49596\cdot mm$
$3.40114\cdot mm$	$2.9033\cdot mm$
$2.51313\cdot mm$	$202263\cdot mm$

$$\beta(v) := \left[\left(\frac{2\cdot\pi\cdot v}{c}\right)^2 - \left(\frac{\pi}{a}\right)^2\right]^{\frac{1}{2}}$$

$$A(v) := \frac{k_o^{\,2}}{\beta(v)\cdot a\cdot b}\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 \qquad B(v) := \frac{1}{a\cdot b}\cdot\left(\beta(v)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{\pi^2}{\beta(v)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right)$$

$$C(v) := \frac{1}{a\cdot b}\cdot\left(\beta(v)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 - \frac{\pi^2}{\beta(v)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right)$$

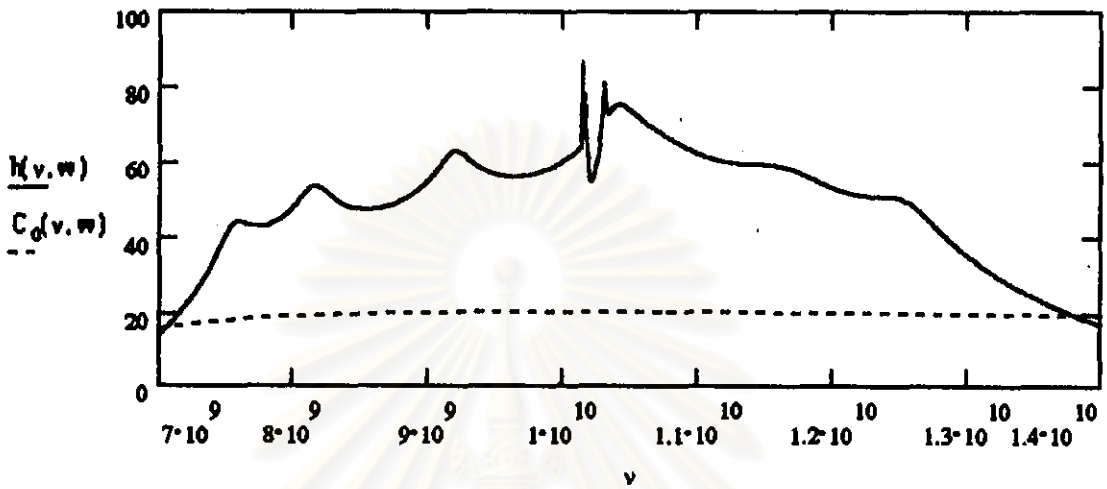
$w := 1\cdot mm$

$$f(v,w) := \left[\sum_{n=0}^{6}\left[\left|-\frac{2}{3}\cdot A(v)\cdot e^{-2.405\cdot\left(\frac{w}{r_n}\right)} + \frac{4}{3}\cdot B(v)\cdot e^{-1.841\cdot\left(\frac{w}{r_n}\right)}\right|\cdot\left(r_n\right)^3\right]\right]$$

$$g(v,w) := \left[\sum_{n=0}^{6}\left[\left|-\frac{2}{3}\cdot A(v)\cdot e^{-2.405\cdot\left(\frac{w}{r_n}\right)} - \frac{4}{3}\cdot C(v)\cdot e^{-1.841\cdot\left(\frac{w}{r_n}\right)}\right|\cdot\left(r_n\right)^3\cdot e^{i\cdot\psi(v)\cdot n}\right]\right]$$

$$h(v,w) := 20\cdot\log\left(\frac{|f(v,w)|}{|g(v,w)|}\right) \qquad C_o(v,w) := -20\cdot\log\left(|f(v,w)|\right)$$

$\nu := 7.00 \cdot GHz, 7.01 \cdot GHz .. 14.00 \cdot GHz$



แบบเชบิเชฟ มีจำนวน 10 รู ที่ 40 เดซิเบล

```
M(n,δ) := | for row ∈ 0..n-1
          |   column ← 0
          |   while column < 2^n
          |     for i ∈ 1..2^(n-row-1)
          |       M[row,column] ← δ
          |       column ← column + 1
          |     for j ∈ 1..2^(n-row-1)
          |       M[row,column] ← -δ
          |       column ← column + 1
          | M
```

$$\text{count}(n,\text{last\_digit}) := \left|\begin{array}{l} \text{if } \text{mod}(\text{last\_digit},2)=0 \\ \quad \left|\begin{array}{l} jj \leftarrow n \text{ if } n \le \frac{\text{last\_digit}}{2} \\ jj \leftarrow \left\lfloor \frac{\text{last\_digit}}{2} - \left\lfloor \left(n-1\right) - \frac{\text{last\_digit}}{2} \right\rfloor \right\rfloor \text{ otherwise} \end{array}\right. \\ \text{otherwise} \\ \quad \left|\begin{array}{l} jj \leftarrow n \text{ if } n \le \frac{\text{last\_digit}+1}{2} \\ jj \leftarrow \left\lfloor \left(\frac{\text{last\_digit}+1}{2}\right) - \left\lfloor n - \left(\frac{\text{last\_digit}+1}{2}\right) \right\rfloor \right\rfloor \text{ otherwise} \end{array}\right. \\ jj - 1 \end{array}\right.$$

$n := 1..N$ $\quad C_o := 20$ $\quad D_m := 40$ $\quad N = 9$

$$\frac{-C_o}{20} \qquad \frac{-C_o - D_m}{20}$$

$$g_{w1} := \frac{10}{|T_f|} \qquad g_{max} := \frac{10}{|T_f|}$$

$$\theta_m := \operatorname{acos}\left[\frac{1}{\cos\left(\frac{\operatorname{acos}\left(\frac{g_{w1}}{g_{max}}\right)}{N}\right)}\right] \qquad \theta_m = 0.5573739$$

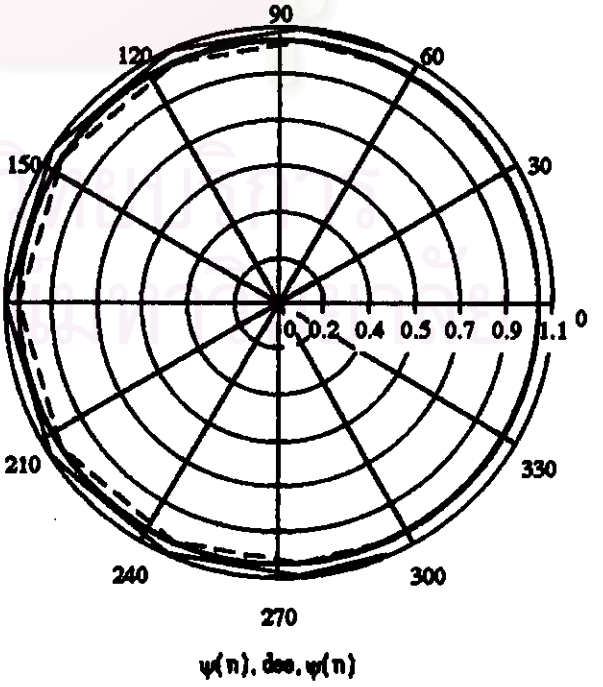
$$\psi(n) := -2\cdot\operatorname{acos}\left[\cos(\theta_m)\cdot\cos\left[\frac{(2\cdot n - 1)\cdot\pi}{2\cdot N}\right]\right]$$

$dee := 0, 0.1..360$ $\quad aa := FRAME$

$$1 + \left(M(5, 0.05)^T\right)_{FRAME,\, count(n, M)}$$

$$\frac{1}{--}$$

$$\frac{1}{--}$$



$\psi(n), dee, \psi(n)$

$$d_n(w) := \left[\prod_{n=1}^{N} \left(w - e^{i \cdot \psi(n)} \right) \right]$$

$$f_N := \frac{g_{w1}}{d_n(1)} \qquad f_N = 4.221 \cdot 10^{-9} \cdot m^3$$

$$g(w) := f_N \cdot d_n(w) \qquad g(1) = 1.927 \cdot 10^{-7} \cdot m^3$$

$$d_{n\_modi}(w) := \left[\prod_{n=1}^{N} \left[w - \left[\left[1 + \left(M\left(5, \frac{FRAME}{100}\right)^T \right)_{2,\, count(n,N)} \right] \cdot e^{i \cdot \psi(n)} \right] \right] \right]$$

$$f_N := \frac{g_{w1}}{d_{n\_modi}(1)} \qquad \beta_o(a) := \frac{\beta_{lower}(a) + \beta_{upper}(a)}{2}$$

$$g_{modi}(w) := f_N \cdot d_{n\_modi}(w)$$

$$v := 7.0 \cdot GHz, 7.01 \cdot GHz .. 14 \cdot GHz \qquad a := 22.90 \cdot mm \qquad b := 10.2 \cdot mm$$

$$\beta(v) := \left[\left(2 \cdot \pi \cdot \frac{v}{c} \right)^2 - \left(\frac{\pi}{a} \right)^2 \right]^{\frac{1}{2}} \qquad d := \frac{\pi}{2 \cdot \beta_o(a)}$$

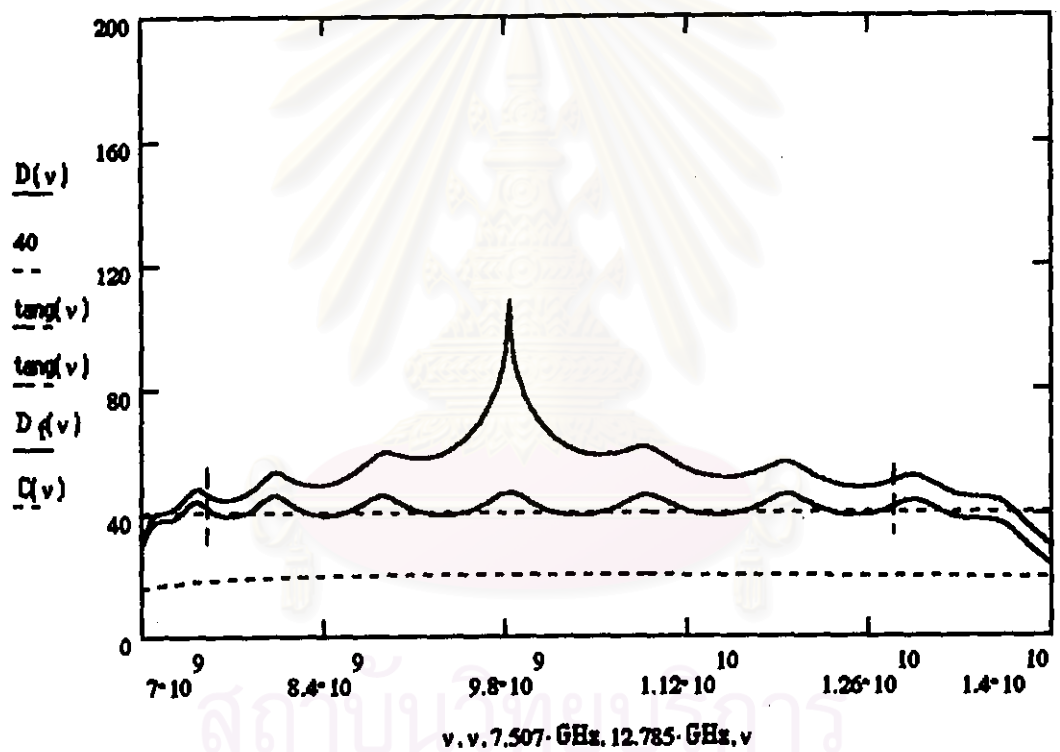
$$T_f(v) := \frac{-2 \cdot k_o^{\,2}}{3 \cdot \beta(v) \cdot a \cdot b} \cdot \sin\left(\frac{\pi \cdot x_o}{a} \right)^2 + \frac{4}{3 \cdot a \cdot b} \cdot \left(\beta(v) \cdot \sin\left(\frac{\pi \cdot x_o}{a} \right)^2 + \frac{\pi^2}{\beta(v) \cdot a^2} \cdot \cos\left(\frac{\pi \cdot x_o}{a} \right)^2 \right)$$

$$T_b(v) := \frac{-2 \cdot k_o^{\,2}}{3 \cdot \beta(v) \cdot a \cdot b} \cdot \sin\left(\frac{\pi \cdot x_o}{a} \right)^2 - \frac{4}{3 \cdot a \cdot b} \cdot \left(\beta(v) \cdot \sin\left(\frac{\pi \cdot x_o}{a} \right)^2 - \frac{\pi^2}{\beta(v) \cdot a^2} \cdot \cos\left(\frac{\pi \cdot x_o}{a} \right)^2 \right)$$

$$\psi(v) := -2\cdot\beta(v)\cdot d \qquad w(v) := e^{i\cdot\psi(v)}$$

$$D(v) := 20\cdot\log\left(\frac{\left|g_{modi}(1)\right|}{\left|g_{modi}(w(v))\right|}\right) \qquad D_f(v) := 20\cdot\log\left(\frac{\left|T_f(v)\right|}{\left|T_b(v)\right|}\right) + D(v)$$

$$C(v) := -20\cdot\log\left(\left|T_f(v)\right|\cdot\left|g_{modi}(1)\right|\right) \qquad tang(v) := 70\cdot\left|\sin\left(2\cdot\pi\cdot\frac{v - 1\cdot GHz}{v}\right)\right|$$



$$\left(3.37553\cdot10^{-9}\right)\cdot m^3\cdot\left[\left[w - \left(0.397 - 0.918i\right)\cdot1.09\right]\cdot\left[w - \left(0.08 - 0.997i\right)\cdot1.09\right]\cdot\left[w - \left(-0.405 - 0.914i\right)\cdot1.09\right]\cdot\left[v\right.\right.$$

$$-1.012659\cdot10^{-28}\cdot i\cdot m^3 + 1.3368046011919492364\cdot10^{-8}\cdot m^3\cdot w + 6.75106\cdot10^{-28}\cdot i\cdot m^3\cdot w^3 - 6.75106\cdot10^{-28}\cdot i\cdot m^3$$

$$r_{10} := \left(3.37553 \cdot 10^{-9} \cdot m^3\right)^{\frac{1}{3}} \qquad r_{10} = 1.50008 \cdot mm$$

$$r_9 := \left(8.2608670584 \cdot 10^{-9} \cdot m^3\right)^{\frac{1}{3}} \qquad r_9 = 2.02151 \cdot mm$$

$$r_8 := \left(1.6433173022774327 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_8 = 2.54238 \cdot mm$$

$$r_7 := \left(2.5521946541767465313 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_7 = 2.94423 \cdot mm$$

$$r_6 := \left(3.2055361193049593514 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_6 = 3.17663 \cdot mm$$

$$r_5 := \left(3.5006063223943263258 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_5 = 3.27126 \cdot mm$$

$$r_4 := \left(3.0813361540937796199 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_4 = 3.13506 \cdot mm$$

$$r_3 := \left(2.3039779075004090506 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_3 = 2.84551 \cdot mm$$

$$r_2 := \left(1.3368046011919492364 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_2 = 2.37332 \cdot mm$$

$$r_1 := \left(5.1176565698848901322 \cdot 10^{-9} \cdot m^3\right)^{\frac{1}{3}} \qquad r_1 = 1.72328 \cdot mm$$

$$A := \frac{k_o^2}{\beta_o(a) \cdot a \cdot b} \cdot \sin\left(\frac{\pi \cdot x_o}{a}\right)^2 \qquad A = 3.502 \cdot 10^5 \cdot m^{-3}$$

$$B := \frac{1}{a \cdot b} \cdot \left(\beta_o(a) \cdot \sin\left(\frac{\pi \cdot x_o}{a}\right)^2 + \frac{\pi^2}{\beta_o(a) \cdot a^2} \cdot \cos\left(\frac{\pi \cdot x_o}{a}\right)^2\right) \qquad B = 5.642 \cdot 10^5 \cdot m^{-3}$$

$$T_f := \frac{-2i \cdot k_o^2}{3 \cdot \beta_o(a) \cdot a \cdot b} \cdot \sin\left(\frac{\pi \cdot x_o}{a}\right)^2 + \frac{4i}{3 \cdot a \cdot b} \cdot \left(\beta_o(a) \cdot \sin\left(\frac{\pi \cdot x_o}{a}\right)^2 + \frac{\pi^2}{\beta_o(a) \cdot a^2} \cdot \cos\left(\frac{\pi \cdot x_o}{a}\right)^2\right)$$

$r_{10} := 1.5 \cdot mm$ $\qquad c_n := |T_f| \cdot r_1^{\,3}$

$r := 1 \cdot mm$

given

$$\left[\frac{2}{3} \cdot A \cdot e^{-2.405 \cdot \left(\frac{1 \cdot mm}{r}\right)} + \frac{4}{3} \cdot B \cdot e^{-1.841 \cdot \left(\frac{1 \cdot mm}{r}\right)}\right] \cdot r^3 = c_n \qquad \text{find}(r) = 2.20424 \cdot mm$$

$v := 7.00 \cdot GHz, 7.01 \cdot GHz .. 14.00 \cdot GHz$

$n := 0..9$

$r_n :=$

$1.97553 \cdot mm$
$2.50826 \cdot mm$
$3.03647 \cdot mm$
$3.44244 \cdot mm$
$3.67682 \cdot mm$
$3.77217 \cdot mm$
$3.63492 \cdot mm$
$3.3428 \cdot mm$
$2.86533 \cdot mm$
$2.20424 \cdot mm$

$dd_n :=$

$1.61609 \cdot mm$
$2.17785 \cdot mm$
$2.739 \cdot mm$
$3.17193 \cdot mm$
$3.42231 \cdot mm$
$3.52425 \cdot mm$
$3.37753 \cdot mm$
$3.0655 \cdot mm$
$2.55687 \cdot mm$
$1.85656 \cdot mm$

$$\beta(v) := \left[\left(\frac{2 \cdot \pi \cdot v}{c}\right)^2 - \left(\frac{\pi}{a}\right)^2\right]^{\frac{1}{2}}$$

$$A(v) := \frac{k_o^{\,2}}{\beta(v) \cdot a \cdot b} \cdot \sin\left(\frac{\pi \cdot x_o}{a}\right)^2 \qquad B(v) := \frac{1}{a \cdot b} \cdot \left(\beta(v) \cdot \sin\left(\frac{\pi \cdot x_o}{a}\right)^2 + \frac{\pi^2}{\beta(v) \cdot a^2} \cdot \cos\left(\frac{\pi \cdot x_o}{a}\right)^2\right)$$

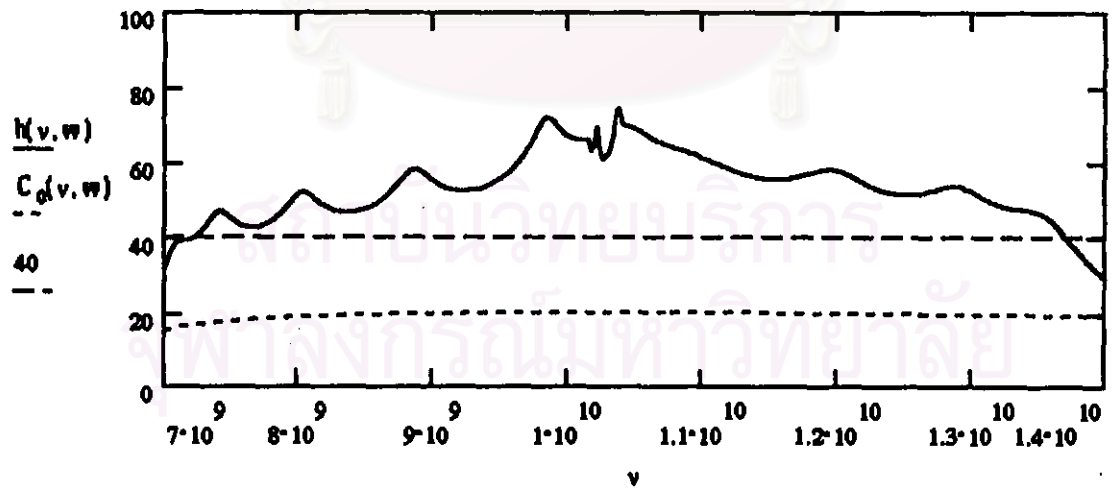
$$C(v) := \frac{1}{a \cdot b} \cdot \left(\beta(v) \cdot \sin\left(\frac{\pi \cdot x_0}{a}\right)^2 - \frac{\pi^2}{\beta(v) \cdot a^2} \cdot \cos\left(\frac{\pi \cdot x_0}{a}\right)^2 \right)$$

$w := 1 \cdot mm$

$$f(v,w) := \left[\sum_{n=0}^{9} \left[\left| \frac{2}{3} \cdot A(v) \cdot e^{-2.405 \cdot \left(\frac{w}{r_n}\right)} + \frac{4}{3} \cdot B(v) \cdot e^{-1.841 \cdot \left(\frac{w}{r_n}\right)} \right| \cdot (r_n)^3 \right] \right]$$

$$g(v,w) := \left[\sum_{n=0}^{9} \left[\left| \frac{2}{3} \cdot A(v) \cdot e^{-2.405 \cdot \left(\frac{w}{r_n}\right)} - \frac{4}{3} \cdot C(v) \cdot e^{-1.841 \cdot \left(\frac{w}{r_n}\right)} \right| \cdot (r_n)^3 \cdot e^{i \cdot \psi(v) \cdot n} \right] \right]$$

$$h(v,w) := 20 \cdot \log\left(\frac{|f(v,w)|}{|g(v,w)|}\right) \qquad C_0(v,w) := -20 \cdot \log(|f(v,w)|)$$



แบบเชบีเชฟ มีจำนวน 7 รู ที่ 60 เดซิเบล

```
M(n,δ) := | for row ∈ 0..n-1
          |   column ← 0
          |   while column < 2^n
          |     for i ∈ 1..2^(n-row-1)
          |       M[row,column] ← δ
          |       column ← column + 1
          |     for j ∈ 1..2^(n-row-1)
          |       M[row,column] ← -δ
          |       column ← column + 1
          | M
```

$$\text{count}(n, \text{last\_digit}) := \begin{cases} \text{if } \text{mod}(\text{last\_digit}, 2) = 0 \\ \quad \begin{cases} jj \leftarrow n \text{ if } n \le \frac{\text{last\_digit}}{2} \\ jj \leftarrow \left\lfloor \frac{\text{last\_digit}}{2} - \left\lfloor \left(n-1\right) - \frac{\text{last\_digit}}{2} \right\rfloor \right\rfloor \text{ otherwise} \end{cases} \\ \text{otherwise} \\ \quad \begin{cases} jj \leftarrow n \text{ if } n \le \frac{\text{last\_digit}+1}{2} \\ jj \leftarrow \left\lfloor \left\langle \frac{\text{last\_digit}+1}{2} \right\rangle - \left\lfloor n - \left\langle \frac{\text{last\_digit}+1}{2} \right\rangle \right\rfloor \right\rfloor \text{ otherwise} \end{cases} \\ jj - 1 \end{cases}$$

$n := 1..N$ $\quad C_o := 20$ $\quad D_m := 60$ $\quad N = 6$

$$-\frac{C_o}{20} \qquad \frac{-C_o - D_m}{20}$$

$$g_{w1} := \frac{10}{|T_f|} \qquad g_{max} := \frac{10}{|T_f|}$$

$$\theta_m := \operatorname{acos}\left[\frac{1}{\cos\left(\frac{\operatorname{acos}\left(\frac{g_{w1}}{g_{max}}\right)}{N}\right)}\right] \qquad \theta_m = 1.0215776$$

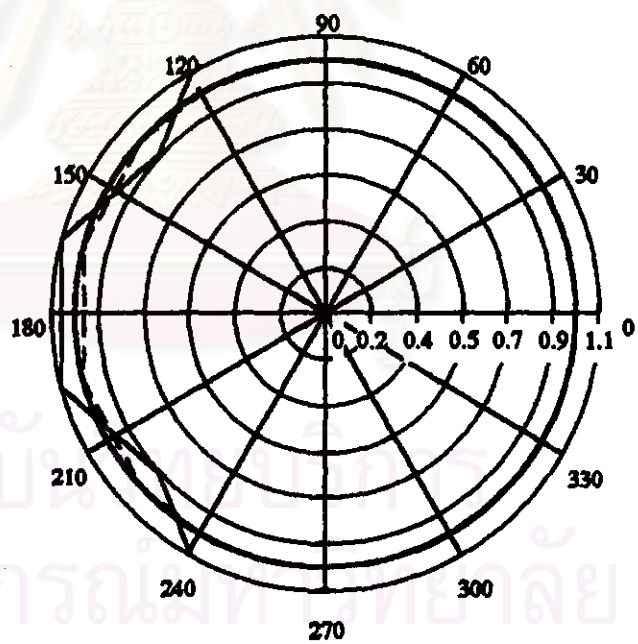
$$\psi(n) := -2\cdot\operatorname{acos}\left[\cos(\theta_m)\cdot\cos\left[\frac{(2\cdot n - 1)\cdot\pi}{2\cdot N}\right]\right]$$

$dee := 0, 0.1..360$ $\quad aa := FRAME$

$$1 + \left(M(3, 0.09)^T\right)_{02,\,count(n,N)}$$

$$\frac{1}{--}$$

$$\frac{1}{--}$$



$\psi(n), dee, \psi(n)$

$$d_n(w) := \left[\prod_{n=1}^{N} \left(w - e^{i \cdot \psi(n)} \right) \right] \qquad f_N := \frac{g_{w1}}{d_n(1)} \qquad f_N = 5.984 \cdot 10^{-9} \cdot m^3$$

$$g(w) := f_N \cdot d_n(w) \qquad g(1) = 2.422 \cdot 10^{-7} \cdot m^3$$

$$d_{n\_modi}(w) := \left[\prod_{n=1}^{N} \left[w - \left[\left[1 + \left(M\left(3, \frac{9}{100}\right)^T \right)_{2, count(n,N)} \right] \cdot e^{i \cdot \psi(n)} \right] \right] \right]$$

$$f_N := \frac{g_{w1}}{d_{n\_modi}(1)} \qquad \beta_o(a) := \frac{\beta_{lower}(a) + \beta_{upper}(a)}{2}$$

$$g_{modi}(w) := f_N \cdot d_{n\_modi}(w) \qquad f_N = 5.49653 \cdot 10^{-9} \cdot m^3$$

$$v := 7.0 \cdot GHz, 7.01 \cdot GHz .. 14 \cdot GHz \qquad a := 22.90 \cdot mm \qquad b := 10.2 \cdot mm$$

$$\beta(v) := \left[\left(2 \cdot \pi \cdot \frac{v}{c} \right)^2 - \left(\frac{\pi}{a} \right)^2 \right]^{\frac{1}{2}} \qquad d := \frac{\pi}{2 \cdot \beta_o(a)}$$

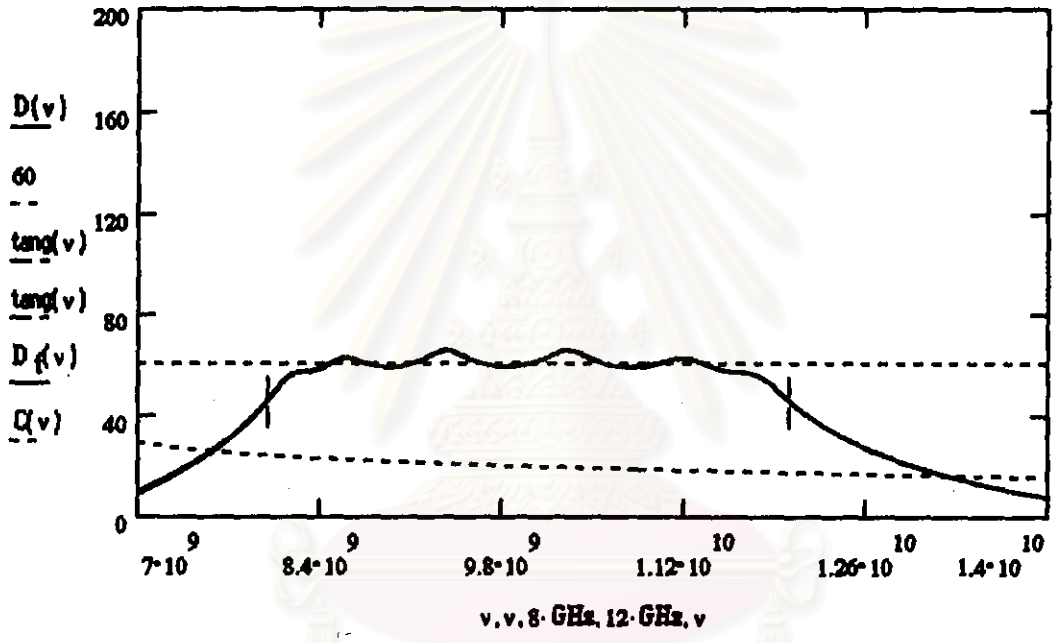
$$T_f(v) := \frac{-2 \cdot k_o^{\,2}}{3 \cdot \beta(v) \cdot a \cdot b} \cdot \sin\left(\frac{\pi \cdot x_o}{a} \right)^2 + \frac{4}{3 \cdot a \cdot b} \cdot \left(\beta(v) \cdot \sin\left(\frac{\pi \cdot x_o}{a} \right)^2 + \frac{\pi^2}{\beta(v) \cdot a^2} \cdot \cos\left(\frac{\pi \cdot x_o}{a} \right)^2 \right)$$

$$T_b(v) := \frac{-2 \cdot k_o^{\,2}}{3 \cdot \beta(v) \cdot a \cdot b} \cdot \sin\left(\frac{\pi \cdot x_o}{a} \right)^2 - \frac{4}{3 \cdot a \cdot b} \cdot \left(\beta(v) \cdot \sin\left(\frac{\pi \cdot x_o}{a} \right)^2 - \frac{\pi^2}{\beta(v) \cdot a^2} \cdot \cos\left(\frac{\pi \cdot x_o}{a} \right)^2 \right)$$

$$\psi(v) := -2\cdot\beta(v)\cdot d \qquad w(v) := e^{i\cdot\psi(v)}$$

$$D(v) := 20\cdot\log\left(\frac{\left|g_{modi}(1)\right|}{\left|g_{modi}(w(v))\right|}\right) \qquad D_f(v) := 20\cdot\log\left(\frac{\left|T_f(v)\right|}{\left|T_b(v)\right|}\right) + D(v)$$

$$C(v) := -20\cdot\log\left(\left|T_f(v)\right|\cdot\left|g_{modi}(1)\right|\right) \qquad tang(v) := 70\cdot\left|\sin\left(2\cdot\pi\cdot\frac{v - 1\cdot GHz}{v}\right)\right|$$



$$f_N = 5.49653\cdot10^{-9}\cdot m^3$$

$$5.49653\cdot10^{-9}\cdot m^3\cdot\left[\left[w - \left(-0.491 - 0.871i\right)\cdot1.09\right]\cdot\left[w - \left(-0.727 - 0.686i\right)\cdot0.91\right]\cdot\left[w - \left(-0.963 - 0.268i\right)\cdot1.09\right]\right.$$

$$2.737338428947473084\cdot10^{-8}\cdot m^3\cdot w + 5.300502410365682\cdot10^{-8}\cdot m^3\cdot w^4 + 6.871942855520616953\cdot10^{-8}\cdot m^3\cdot w^3 + 5.$$

$$r_7 := \left(5.49653 \cdot 10^{-9} \cdot m^3\right)^{\frac{1}{3}} \qquad r_7 = 1.7648 \cdot mm$$

$$r_6 := \left(2.46951397758 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_6 = 2.91208 \cdot mm$$

$$r_5 := \left(5.300502410365682 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_5 = 3.7564 \cdot mm$$

$$r_4 := \left(6.871942855520616953 8 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_4 = 4.096 \cdot mm$$

$$r_3 := \left(5.614583245776664213 9 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_3 = 3.82918 \cdot mm$$

$$r_2 := \left(2.737338428947473084 5 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_2 = 3.01377 \cdot mm$$

$$r_1 := \left(6.412477249006920022 \cdot 10^{-9} \cdot m^3\right)^{\frac{1}{3}} \qquad r_1 = 1.85784 \cdot mm$$

$$A := \frac{k_o^2}{\beta_o(a)\cdot a\cdot b}\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 \qquad A = 5.545\cdot 10^5\ \cdot m^{-3}$$

$$B := \frac{1}{a\cdot b}\cdot\left(\beta_o(a)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{x^2}{\beta_o(a)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right) \qquad B = 5.869\cdot 10^5\ \cdot m^{-3}$$

$$T_f := \frac{-2i\cdot k_o^2}{3\cdot\beta_o(a)\cdot a\cdot b}\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{4i}{3\cdot a\cdot b}\cdot\left(\beta_o(a)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{x^2}{\beta_o(a)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right)$$

$r_7 = 1.765\ \cdot mm$ $\qquad c_n := |T_f|\cdot r_2^3$

$r := 1\cdot mm$

given

$$\left[\frac{2}{3}\cdot A\cdot e^{-2.405\cdot\left(\frac{1\cdot mm}{r}\right)} + \frac{4}{3}\cdot B\cdot e^{-1.841\cdot\left(\frac{1\cdot mm}{r}\right)}\right]\cdot r^3 = c_n \qquad \text{find}(r) = 3.45142\ \cdot mm$$

$n := 0..6$ $\qquad r_n :=$ $\qquad dd_n :=$

r_n
$2.28874\cdot mm$
$3.45142\cdot mm$
$4.26897\cdot mm$
$4.53627\cdot mm$
$4.19604\cdot mm$
$3.34938\cdot mm$
$2.19475\cdot mm$

dd_n
r_1
r_2
r_3
r_4
r_5
r_6
r_7

$$\beta(v) := \left[\left(\frac{2\cdot\pi\cdot v}{c}\right)^2 - \left(\frac{\pi}{a}\right)^2\right]^{\frac{1}{2}}$$

$$A(v) := \frac{k_o^{\,2}}{\beta(v)\cdot a\cdot b}\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 \qquad B(v) := \frac{1}{a\cdot b}\cdot\left(\beta(v)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{\pi^2}{\beta(v)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right)$$

$$C(v) := \frac{1}{a\cdot b}\cdot\left(\beta(v)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 - \frac{\pi^2}{\beta(v)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right)$$

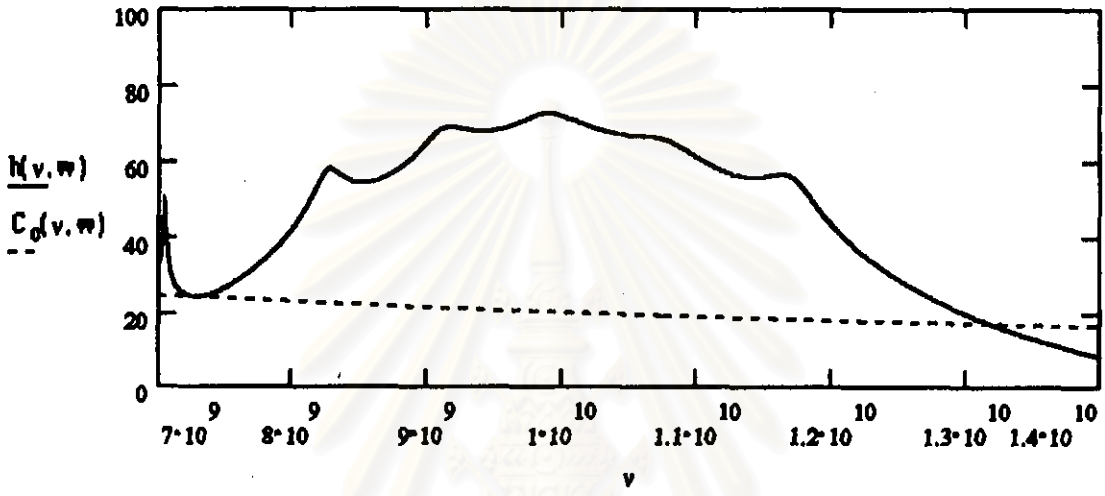
$w := 1\cdot mm$

$$f(v,w) := \left[\sum_{n=0}^{6}\left[\left|-\frac{2}{3}\cdot A(v)\cdot e^{-2.405\cdot\left(\frac{w}{r_n}\right)} + \frac{4}{3}\cdot B(v)\cdot e^{-1.841\cdot\left(\frac{w}{r_n}\right)}\right|\cdot\left(r_n\right)^3\right]\right]$$

$$g(v,w) := \left[\sum_{n=0}^{6}\left[\left|-\frac{2}{3}\cdot A(v)\cdot e^{-2.405\cdot\left(\frac{w}{r_n}\right)} - \frac{4}{3}\cdot C(v)\cdot e^{-1.841\cdot\left(\frac{w}{r_n}\right)}\right|\cdot\left(r_n\right)^3\cdot e^{i\cdot\psi(v)\cdot n}\right]\right]$$

$$h(v,w) := 20\cdot\log\left(\frac{|f(v,w)|}{|g(v,w)|}\right) \qquad C_o(v,w) := -20\cdot\log(|f(v,w)|)$$

$\nu := 7.00 \cdot GHz, 7.01 \cdot GHz .. 14.00 \cdot GHz$



แบบเซบีเชฟ มีจำนวน 10 รู ที่ 60 เดซิเบล

```
M(n,δ) := | for row ∈ 0..n-1
          |   column ← 0
          |   while column < 2^n
          |     for i ∈ 1..2^(n-row-1)
          |       M[row,column] ← δ
          |       column ← column + 1
          |     for j ∈ 1..2^(n-row-1)
          |       M[row,column] ← -δ
          |       column ← column + 1
          | M
```

$$\text{count}(n,\text{last\_digit}) := \begin{cases} \text{if } \operatorname{mod}(\text{last\_digit},2)=0 \\ \quad \begin{cases} jj \leftarrow n \text{ if } n \le \dfrac{\text{last\_digit}}{2} \\ jj \leftarrow \left\lfloor \dfrac{\text{last\_digit}}{2} - \left\lfloor (n-1) - \dfrac{\text{last\_digit}}{2} \right\rfloor \right\rfloor \text{ otherwise} \end{cases} \\ \text{otherwise} \\ \quad \begin{cases} jj \leftarrow n \text{ if } n \le \dfrac{\text{last\_digit}+1}{2} \\ jj \leftarrow \left\lfloor \left(\dfrac{\text{last\_digit}+1}{2} \right) - \left\lfloor n - \left(\dfrac{\text{last\_digit}+1}{2} \right) \right\rfloor \right\rfloor \text{ otherwise} \end{cases} \\ jj - 1 \end{cases}$$

$n := 1..N$ $\quad C_0 := 20$ $\quad D_m := 60$ $\quad N = 9$

$$\frac{-C_0}{20} \qquad \frac{-C_0 - D_m}{20}$$

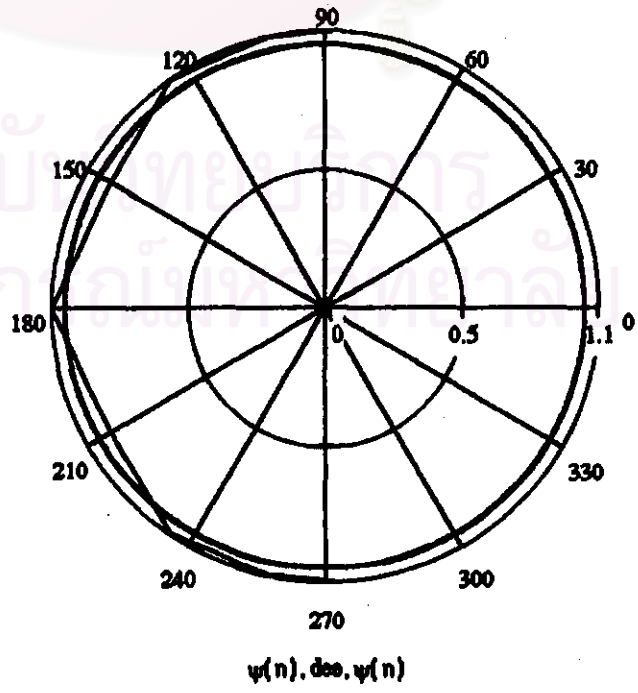
$$g_{w1} := \frac{10}{|T_f|} \qquad g_{max} := \frac{10}{|T_f|}$$

$$\theta_m := \operatorname{acos}\left[\frac{1}{\cos\left(\frac{\operatorname{acos}\left(\frac{g_{w1}}{g_{max}}\right)}{N}\right)}\right] \qquad \theta_m = 0.7590172$$

$$\psi(n) := -2\cdot\operatorname{acos}\left[\cos(\theta_m)\cdot\cos\left[\frac{(2\cdot n - 1)\cdot\pi}{2\cdot N}\right]\right]$$

$dec := 0, 0.1..360$ $\quad aa := FRAME$

$$\frac{1 + \left(M(5, 0.05)^T\right)_{2,\,count(n,N)}}{1}$$



$\psi(n), dec, \psi(n)$

$$d_n(w) := \left[\prod_{n=1}^{N} \left(w - e^{i \cdot \psi(n)}\right) \right]$$

$$f_N := \frac{g_{w1}}{d_n(1)} \qquad f_N = 2.174 \cdot 10^{-9} \cdot m^3$$

$$g(w) := f_N \cdot d_n(w) \qquad g(1) = 2.422 \cdot 10^{-7} \cdot m^3$$

$$d_{n\_modi}(w) := \left[\prod_{n=1}^{N} \left[w - \left[\left[1 + \left(M\left(5, \frac{5}{100}\right)^T \right)_{2,\,count(n,N)} \right] \cdot e^{i \cdot \psi(n)} \right] \right] \right]$$

$$f_N := \frac{g_{w1}}{d_{n\_modi}(1)} \qquad \beta_o(a) := \frac{\beta_{lower}(a) + \beta_{upper}(a)}{2}$$

$$g_{modi}(w) := f_N \cdot d_{n\_modi}(w)$$

$$v := 7.0 \cdot GHz, 7.01 \cdot GHz .. 14 \cdot GHz \qquad a := 22.90 \cdot mm \qquad b := 10.2 \cdot mm$$

$$\beta(v) := \left[\left(2 \cdot \pi \cdot \frac{v}{c}\right)^2 - \left(\frac{\pi}{a}\right)^2 \right]^{\frac{1}{2}} \qquad d := \frac{\pi}{2 \cdot \beta_o(a)}$$

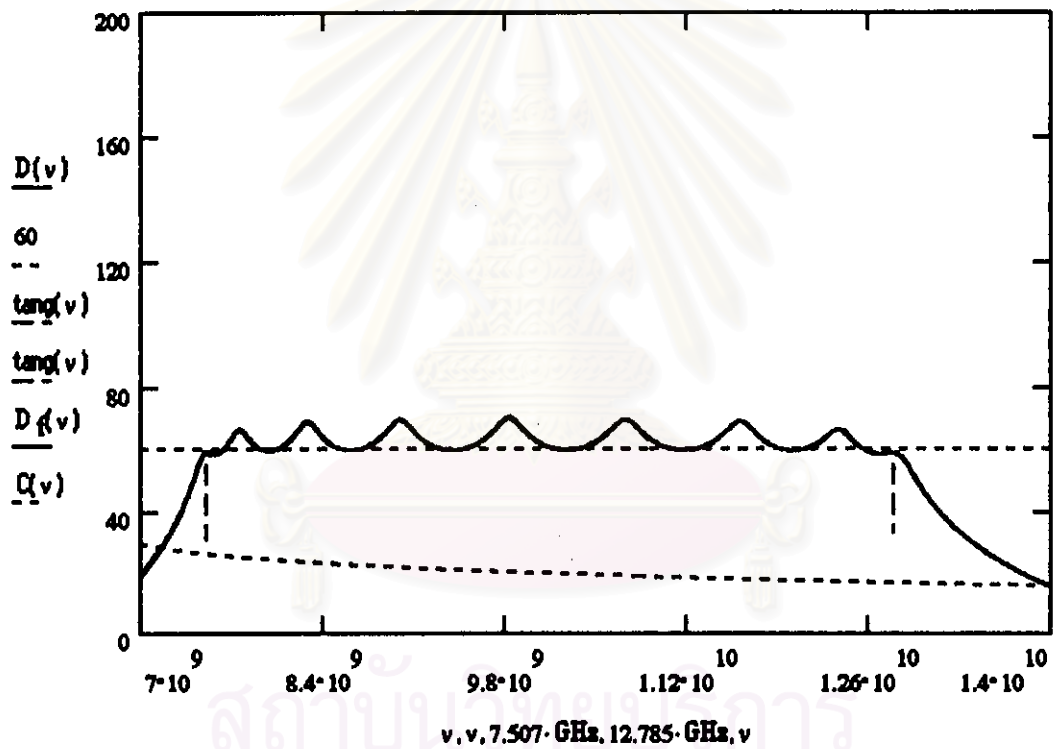
$$T_f(v) := \frac{-2 \cdot k_o^{\,2}}{3 \cdot \beta(v) \cdot a \cdot b} \cdot \sin\left(\frac{\pi \cdot x_o}{a}\right)^2 + \frac{4}{3 \cdot a \cdot b} \cdot \left(\beta(v) \cdot \sin\left(\frac{\pi \cdot x_o}{a}\right)^2 + \frac{\pi^2}{\beta(v) \cdot a^2} \cdot \cos\left(\frac{\pi \cdot x_o}{a}\right)^2 \right)$$

$$T_b(v) := \frac{-2 \cdot k_o^{\,2}}{3 \cdot \beta(v) \cdot a \cdot b} \cdot \sin\left(\frac{\pi \cdot x_o}{a}\right)^2 - \frac{4}{3 \cdot a \cdot b} \cdot \left(\beta(v) \cdot \sin\left(\frac{\pi \cdot x_o}{a}\right)^2 - \frac{\pi^2}{\beta(v) \cdot a^2} \cdot \cos\left(\frac{\pi \cdot x_o}{a}\right)^2 \right)$$

$$\psi(v) := -2\cdot\beta(v)\cdot d \qquad w(v) := e^{i\cdot\psi(v)}$$

$$D(v) := 20\cdot\log\left(\frac{\left|g_{modi}(1)\right|}{\left|g_{modi}(w(v))\right|}\right) \qquad D_f(v) := 20\cdot\log\left(\frac{\left|T_f(v)\right|}{\left|T_b(v)\right|}\right) + D(v)$$

$$C(v) := -20\cdot\log\left(\left|T_f(v)\right|\cdot\left|g_{modi}(1)\right|\right) \qquad tang(v) := 70\cdot\left|\sin\left(2\cdot\pi\cdot\frac{v - 1\cdot GHz}{v}\right)\right|$$



$$r_{10} := \left(1.92185 \cdot 10^{-9} \cdot m^3\right)^{\frac{1}{3}} \qquad r_{10} = 1.24329 \cdot mm$$

$$r_9 := \left(8.321341441 \cdot 10^{-9} \cdot m^3\right)^{\frac{1}{3}} \qquad r_9 = 2.02643 \cdot mm$$

$$r_8 := \left(2.1208435278668505 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_8 = 2.76802 \cdot mm$$

$$r_7 := \left(3.8225872278316393184 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_7 = 3.36862 \cdot mm$$

$$r_6 := \left(5.2145388552401809372 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_6 = 3.73599 \cdot mm$$

$$r_5 := \left(5.5513879068649718118 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_5 = 3.81476 \cdot mm$$

$$r_4 := \left(4.5719585574625468776 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_4 = 3.57575 \cdot mm$$

$$r_3 := \left(2.8485073044371841077 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_3 = 3.05402 \cdot mm$$

$$r_2 := \left(1.2315529253812452964 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_2 = 2.30932 \cdot mm$$

$$r_1 := \left(2.9132677217505096979 \cdot 10^{-9} \cdot m^3\right)^{\frac{1}{3}} \qquad r_1 = 1.42821 \cdot mm$$

$$A := \frac{k_o^2}{\beta_o(a) \cdot a \cdot b} \cdot \sin\left(\frac{\pi \cdot x_o}{a}\right)^2 \qquad A = 5.545 \cdot 10^{5} \cdot m^{-3}$$

$$B := \frac{1}{a \cdot b} \cdot \left(\beta_o(a) \cdot \sin\left(\frac{\pi \cdot x_o}{a}\right)^2 + \frac{\pi^2}{\beta_o(a) \cdot a^2} \cdot \cos\left(\frac{\pi \cdot x_o}{a}\right)^2\right) \qquad B = 5.869 \cdot 10^{5} \cdot m^{-3}$$

$x_o = 5.5 \cdot mm$

$$T_f := \frac{-2i \cdot k_o^{\,2}}{3 \cdot \beta_o(a) \cdot a \cdot b} \cdot \sin\left(\frac{\pi \cdot x_o}{a}\right)^2 + \frac{4i}{3 \cdot a \cdot b} \cdot \left(\beta_o(a) \cdot \sin\left(\frac{\pi \cdot x_o}{a}\right)^2 + \frac{\pi^2}{\beta_o(a) \cdot a^2} \cdot \cos\left(\frac{\pi \cdot x_o}{a}\right)^2 \right)$$

$$c_n := |T_f| \cdot r_1^{\,3}$$

$r := 1 \cdot mm$

given

$$\left[\frac{2}{3} \cdot A \cdot e^{-2.405 \cdot \left(\frac{1 \cdot mm}{r}\right)} + \frac{4}{3} \cdot B \cdot e^{-1.841 \cdot \left(\frac{1 \cdot mm}{r}\right)} \right] \cdot r^3 = c_n$$

$find(r) = 1.85365 \cdot mm$

$v := 7.00 \cdot GHz, 7.01 \cdot GHz .. 14.00 \cdot GHz$

$n := 0..9$

$r_n :=$

$1.66525 \cdot mm$
$2.45883 \cdot mm$
$3.20475 \cdot mm$
$3.80735 \cdot mm$
$4.17558 \cdot mm$
$4.25452 \cdot mm$
$4.015 \cdot mm$
$3.49182 \cdot mm$
$2.74373 \cdot mm$
$1.85365 \cdot mm$

$dd_n :=$

r_1
r_2
r_3
r_4
r_5
r_6
r_7
r_8
r_9
r_{10}

$$\beta(v) := \left[\left(\frac{2\cdot\pi\cdot v}{c}\right)^2 - \left(\frac{\pi}{a}\right)^2\right]^{\frac{1}{2}}$$

$$A(v) := \frac{k_o^{\,2}}{\beta(v)\cdot a\cdot b}\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 \qquad B(v) := \frac{1}{a\cdot b}\cdot\left(\beta(v)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 + \frac{\pi^2}{\beta(v)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right)$$

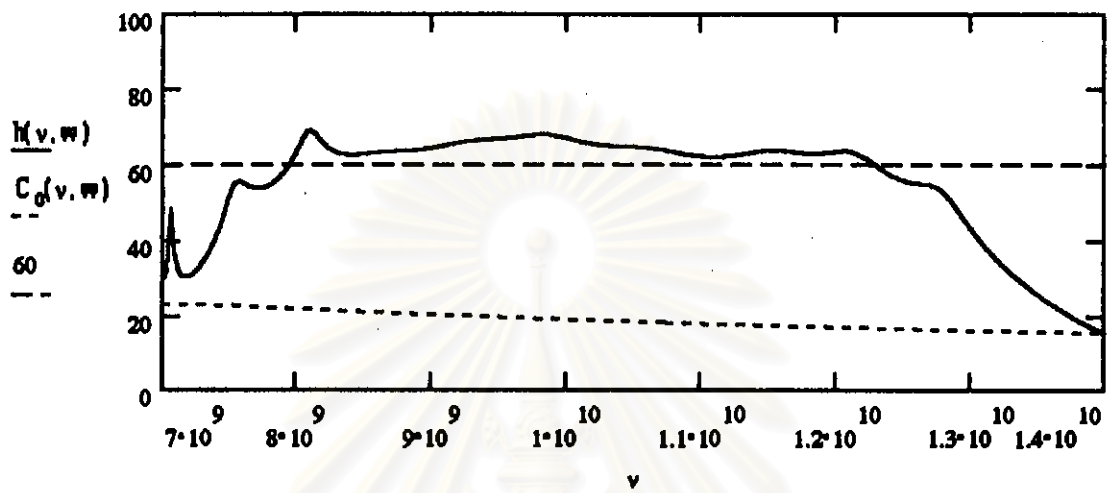
$$C(v) := \frac{1}{a\cdot b}\cdot\left(\beta(v)\cdot\sin\left(\frac{\pi\cdot x_o}{a}\right)^2 - \frac{\pi^2}{\beta(v)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_o}{a}\right)^2\right)$$

$w := 1\cdot mm$

$$f(v,w) := \left[\sum_{n=0}^{9}\left[\left|\frac{2}{3}\cdot A(v)\cdot e^{-2.405\cdot\left(\frac{w}{r_n}\right)} + \frac{4}{3}\cdot B(v)\cdot e^{-1.841\cdot\left(\frac{w}{r_n}\right)}\right|\cdot\left(r_n\right)^3\right]\right]$$

$$g(v,w) := \left[\sum_{n=0}^{9}\left[\left|\frac{2}{3}\cdot A(v)\cdot e^{-2.405\cdot\left(\frac{w}{r_n}\right)} - \frac{4}{3}\cdot C(v)\cdot e^{-1.841\cdot\left(\frac{w}{r_n}\right)}\right|\cdot\left(r_n\right)^3\cdot e^{i\cdot\psi(v)\cdot n}\right]\right]$$

$$h(v,w) := 20\cdot\log\left(\frac{|f(v,w)|}{|g(v,w)|}\right) \qquad C_o(v,w) := -20\cdot\log\left(|f(v,w)|\right)$$



แบบเซมีเชฟ มีจำนวน 15 รู ที่ 60 เดซิเบล

```
M(n,δ) := | for row ∈ 0..n-1
          |   column ← 0
          |   while column < 2^n
          |     for i ∈ 1..2^(n-row-1)
          |       M[row,column] ← δ
          |       column ← column + 1
          |     for j ∈ 1..2^(n-row-1)
          |       M[row,column] ← -δ
          |       column ← column + 1
          | M
```

$$\text{count}(n,\text{last\_digit}) := \begin{cases} \text{if } \text{mod}(\text{last\_digit},2)=0 \\ \quad jj \leftarrow n \text{ if } n \le \frac{\text{last\_digit}}{2} \\ \quad jj \leftarrow \left\lceil \frac{\text{last\_digit}}{2} - \left\lceil (n-1) - \frac{\text{last\_digit}}{2} \right\rceil \right\rceil \text{ otherwise} \\ \text{otherwise} \\ \quad jj \leftarrow n \text{ if } n \le \frac{\text{last\_digit}+1}{2} \\ \quad jj \leftarrow \left\lceil \left(\frac{\text{last\_digit}+1}{2} \right) - \left\lceil n - \left(\frac{\text{last\_digit}+1}{2} \right) \right\rceil \right\rceil \text{ otherwise} \\ jj - 1 \end{cases}$$

$n := 1..N$ $\quad C_0 := 20$ $\quad D_m := 60$ $\quad N = 14$

$$\frac{-C_0}{20} \qquad \frac{-C_0 - D_m}{20}$$

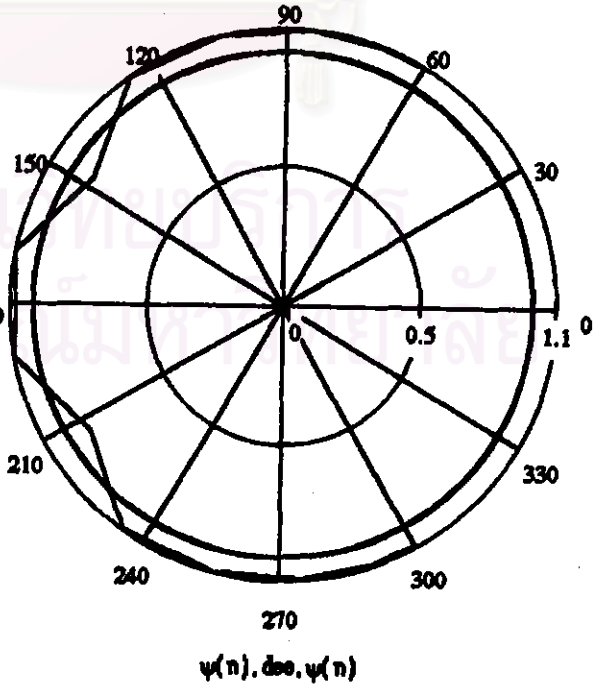
$$g_{wl} := \frac{10}{|T_f|} \qquad g_{max} := \frac{10}{|T_f|}$$

$$\theta_m := \operatorname{acos}\left[\frac{1}{\cos\left(\frac{\operatorname{acos}\left(\frac{g_{wl}}{g_{max}}\right)}{N}\right)}\right] \qquad \theta_m = 0.5180608$$

$$\psi(n) := -2\cdot\operatorname{acos}\left[\cos(\theta_m)\cdot\cos\left[\frac{(2\cdot n - 1)\cdot\pi}{2\cdot N}\right]\right]$$

$dec := 0, 0.1..360$ $\quad aa := FRAME$

$$\frac{1 + \left(M(7, 0.09)^T\right)_{2,\,count(n,N)}}{1}$$



$$d_n(w) := \left[\prod_{n=1}^{N} \left(w - e^{i \cdot \psi(n)} \right) \right]$$

$$f_N := \frac{g_{w1}}{d_n(1)} \qquad f_N = 8.677 \cdot 10^{-10} \cdot m^3$$

$$g(w) := f_N \cdot d_n(w) \qquad g(1) = 2.422 \cdot 10^{-7} \cdot m^3$$

$$d_{n\_modi}(w) := \left[\prod_{n=1}^{N} \left[w - \left[\left[1 + \left(M\left(7, \frac{9}{100}\right)^T \right)_{2,\,count(n,N)} \right] \cdot e^{i \cdot \psi(n)} \right] \right] \right]$$

$$f_N := \frac{g_{w1}}{d_{n\_modi}(1)} \qquad \beta_o(a) := \frac{\beta_{lower}(a) + \beta_{upper}(a)}{2}$$

$$g_{modi}(w) := f_N \cdot d_{n\_modi}(w) \qquad a := 22.90 \cdot mm \qquad b := 10.2 \cdot mm$$

$$v := 7.0 \cdot GHz, 7.01 \cdot GHz .. 14 \cdot GHz \qquad d := \frac{\pi}{2 \cdot \beta_o(a)}$$

$$\beta(v) := \left[\left(2 \cdot \pi \cdot \frac{v}{c} \right)^2 - \left(\frac{\pi}{a} \right)^2 \right]^{\frac{1}{2}}$$

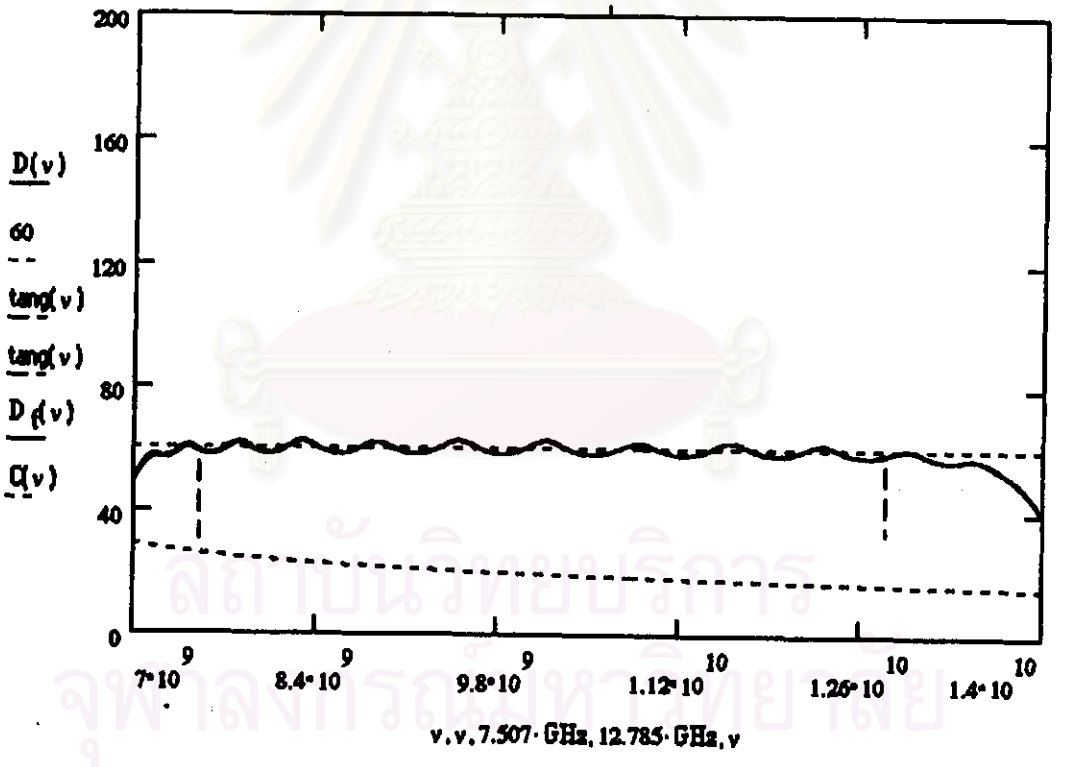
$$T_f(v) := \frac{-2 \cdot k_o^{\,2}}{3 \cdot \beta(v) \cdot a \cdot b} \cdot \sin\left(\frac{\pi \cdot x_o}{a} \right)^2 + \frac{4}{3 \cdot a \cdot b} \cdot \left(\beta(v) \cdot \sin\left(\frac{\pi \cdot x_o}{a} \right)^2 + \frac{\pi^2}{\beta(v) \cdot a^2} \cdot \cos\left(\frac{\pi \cdot x_o}{a} \right)^2 \right)$$

$$T_b(v) := \frac{-2 \cdot k_o^{\,2}}{3 \cdot \beta(v) \cdot a \cdot b} \cdot \sin\left(\frac{\pi \cdot x_o}{a} \right)^2 - \frac{4}{3 \cdot a \cdot b} \cdot \left(\beta(v) \cdot \sin\left(\frac{\pi \cdot x_o}{a} \right)^2 - \frac{\pi^2}{\beta(v) \cdot a^2} \cdot \cos\left(\frac{\pi \cdot x_o}{a} \right)^2 \right)$$

$$\psi(v) := -2\cdot\beta(v)\cdot d \qquad w(v) := e^{j\cdot\psi(v)}$$

$$D(v) := 20\cdot\log\left(\frac{\left|g_{modi}(1)\right|}{\left|g_{modi}(w(v))\right|}\right) \qquad D_f(v) := 20\cdot\log\left(\frac{\left|T_f(v)\right|}{\left|T_b(v)\right|}\right) + D(v)$$

$$C(v) := -20\cdot\log\left(\left|T_f(v)\right|\cdot\left|g_{modi}(1)\right|\right) \qquad tang(v) := 70\cdot\left|\sin\left(2\cdot\pi\cdot\frac{v - 1\cdot GHz}{v}\right)\right|$$



$$r_{15} := \left(5.53646 \cdot 10^{-10} \cdot m^3\right)^{\frac{1}{3}} \qquad r_{15} = 0.82113 \cdot mm$$

$$r_{14} := \left(1.9052832398064 \cdot 10^{-9} \cdot m^3\right)^{\frac{1}{3}} \qquad r_{14} = 1.23971 \cdot mm$$

$$r_{13} := \left(4.784774337093968 4711 \cdot 10^{-9} \cdot m^3\right)^{\frac{1}{3}} \qquad r_{13} = 1.68508 \cdot mm$$

$$r_{12} := \left(9.5200461830643306261 \cdot 10^{-9} \cdot m^3\right)^{\frac{1}{3}} \qquad r_{12} = 2.1194 \cdot mm$$

$$r_{11} := \left(1.5869147815632761 24 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_{11} = 2.51295 \cdot mm$$

$$r_{10} := \left(2.3151301956358883226 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_{10} = 2.85009 \cdot mm$$

$$r_9 := \left(2.9630858912662264425 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_9 = 3.09444 \cdot mm$$

$$r_8 := \left(3.3847967111131035596 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_8 = 3.23478 \cdot mm$$

$$r_7 := \left(3.4441966399400846236 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_7 = 3.25359 \cdot mm$$

$$r_6 := \left(3.1067203705051263316 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_6 = 3.14365 \cdot mm$$

$$r_5 := \left(2.4817985849318988023 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_5 = 2.9169 \cdot mm$$

$$r_4 := \left(1.7002983842134198362 \cdot 10^{-8} \cdot m^3\right)^{\frac{1}{3}} \qquad r_4 = 2.57143 \cdot mm$$

$$r_3 := \left(9.8556263946482277408 \cdot 10^{-9} \cdot m^3\right)^{\frac{1}{3}} \qquad r_3 = 2.14402 \cdot mm$$

$$r_2 := \left(4.4524815310321493879 \cdot 10^{-9} \cdot m^3\right)^{\frac{1}{3}} \qquad r_4 = 2.57143 \cdot mm$$

$$r_1 := \left(1.2895420422535966933 \cdot 10^{-9} \cdot m^3\right)^{\frac{1}{3}} \qquad r_1 = 1.08846 \cdot mm$$

$$A := \frac{k_o^2}{\beta_o(a) \cdot a \cdot b} \cdot \sin\left(\frac{\pi \cdot x_o}{a}\right)^2 \qquad A = 5.545 \cdot 10^5 \cdot m^{-3}$$

$$B := \frac{1}{a \cdot b} \cdot \left(\beta_o(a) \cdot \sin\left(\frac{\pi \cdot x_o}{a}\right)^2 + \frac{x^2}{\beta_o(a) \cdot a^2} \cdot \cos\left(\frac{\pi \cdot x_o}{a}\right)^2\right) \qquad B = 5.869 \cdot 10^5 \cdot m^{-3}$$

$$T_f := \frac{-2i \cdot k_o^2}{3 \cdot \beta_o(a) \cdot a \cdot b} \cdot \sin\left(\frac{\pi \cdot x_o}{a}\right)^2 + \frac{4i}{3 \cdot a \cdot b} \cdot \left(\beta_o(a) \cdot \sin\left(\frac{\pi \cdot x_o}{a}\right)^2 + \frac{x^2}{\beta_o(a) \cdot a^2} \cdot \cos\left(\frac{\pi \cdot x_o}{a}\right)^2\right)$$

$$c_n := |T_f| \cdot r_{15}^3$$

$r := 1 \cdot mm$

given

$$\left[\frac{2}{3} \cdot A \cdot e^{-2.405 \cdot \left(\frac{1 \cdot mm}{r}\right)} + \frac{4}{3} \cdot B \cdot e^{-1.841 \cdot \left(\frac{1 \cdot mm}{r}\right)}\right] \cdot r^3 = c_n \qquad \text{find}(r) = 1.22995 \cdot mm$$

$v := 7.00 \cdot GHz, 7.01 \cdot GHz .. 14.00 \cdot GHz$

$n := 0 .. 14$

$r_n :=$

1.50665·mm
2.07369·mm
2.57732·mm
3.00788·mm
3.35422·mm
3.58178·mm
3.692·mm
3.67313·mm
3.53236·mm
3.28715·mm
2.94851·mm
2.55253·mm
2.11412·mm
1.66159·mm
1.22995·mm

$dd_n :=$

r_1
r_2
r_3
r_4
r_5
r_6
r_7
r_8
r_9
r_{10}
r_{11}
r_{12}
r_{13}
r_{14}
r_{15}

$$\beta(v) := \left[\left(\frac{2\cdot\pi\cdot v}{c}\right)^2 - \left(\frac{\pi}{a}\right)^2\right]^{\frac{1}{2}}$$

$$A(v) := \frac{k_0^2}{\beta(v)\cdot a\cdot b}\cdot\sin\left(\frac{\pi\cdot x_0}{a}\right)^2 \qquad B(v) := \frac{1}{a\cdot b}\cdot\left(\beta(v)\cdot\sin\left(\frac{\pi\cdot x_0}{a}\right)^2 + \frac{\pi^2}{\beta(v)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_0}{a}\right)^2\right)$$

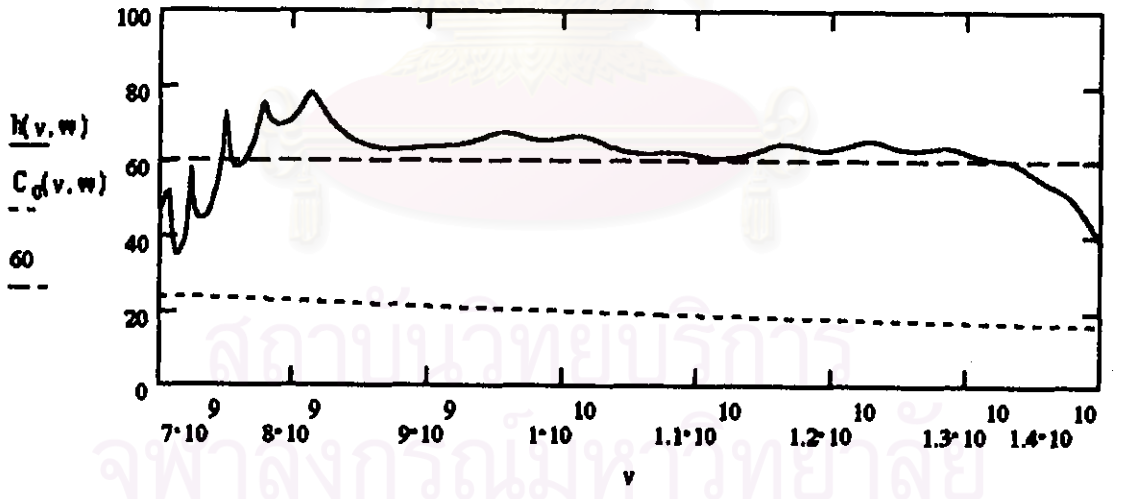
$$C(v) := \frac{1}{a\cdot b}\cdot\left(\beta(v)\cdot\sin\left(\frac{\pi\cdot x_0}{a}\right)^2 - \frac{\pi^2}{\beta(v)\cdot a^2}\cdot\cos\left(\frac{\pi\cdot x_0}{a}\right)^2\right)$$

$$w := 1 \cdot mm$$

$$f(v,w) := \left[\sum_{n=0}^{14} \left[\left| \frac{2}{3} \cdot A(v) \cdot e^{-2.405 \cdot \left(\frac{w}{r_\eta}\right)} + \frac{4}{3} \cdot B(v) \cdot e^{-1.841 \cdot \left(\frac{w}{r_\eta}\right)} \right| \cdot \left(r_\eta\right)^3 \right] \right]$$

$$g(v,w) := \left[\sum_{n=0}^{14} \left[\left| \frac{2}{3} \cdot A(v) \cdot e^{-2.405 \cdot \left(\frac{w}{r_\eta}\right)} - \frac{4}{3} \cdot C(v) \cdot e^{-1.841 \cdot \left(\frac{w}{r_\eta}\right)} \right| \cdot \left(r_\eta\right)^3 \cdot e^{i \cdot \psi(v) \cdot \eta} \right] \right]$$

$$h(v,w) := 20 \cdot \log\left(\frac{|f(v,w)|}{|g(v,w)|} \right) \qquad C_o(v,w) := -20 \cdot \log\left(|f(v,w)| \right)$$



ประวัติผู้เขียน

นายภูเบศร์ อุดมทรัพย์ เกิดวันที่ 22 สิงหาคม พ. ศ. 2515 ที่เขตปทุมวัน จังหวัดกรุงเทพฯ สำเร็จการศึกษาปริญญาตรีวิทยาศาสตรบัณฑิต ภาควิชาฟิสิกส์ประยุกต์ คณะวิทยาศาสตร์ พระจอมเกล้าเจ้าคุณทหารลาดกระบัง ในปีการศึกษา 2536 และเข้าศึกษาต่อในหลักสูตรวิทยาศาสตร์มหาบัณฑิต ที่จุฬาลงกรณ์มหาวิทยาลัย เมื่อ พ. ศ. 2537