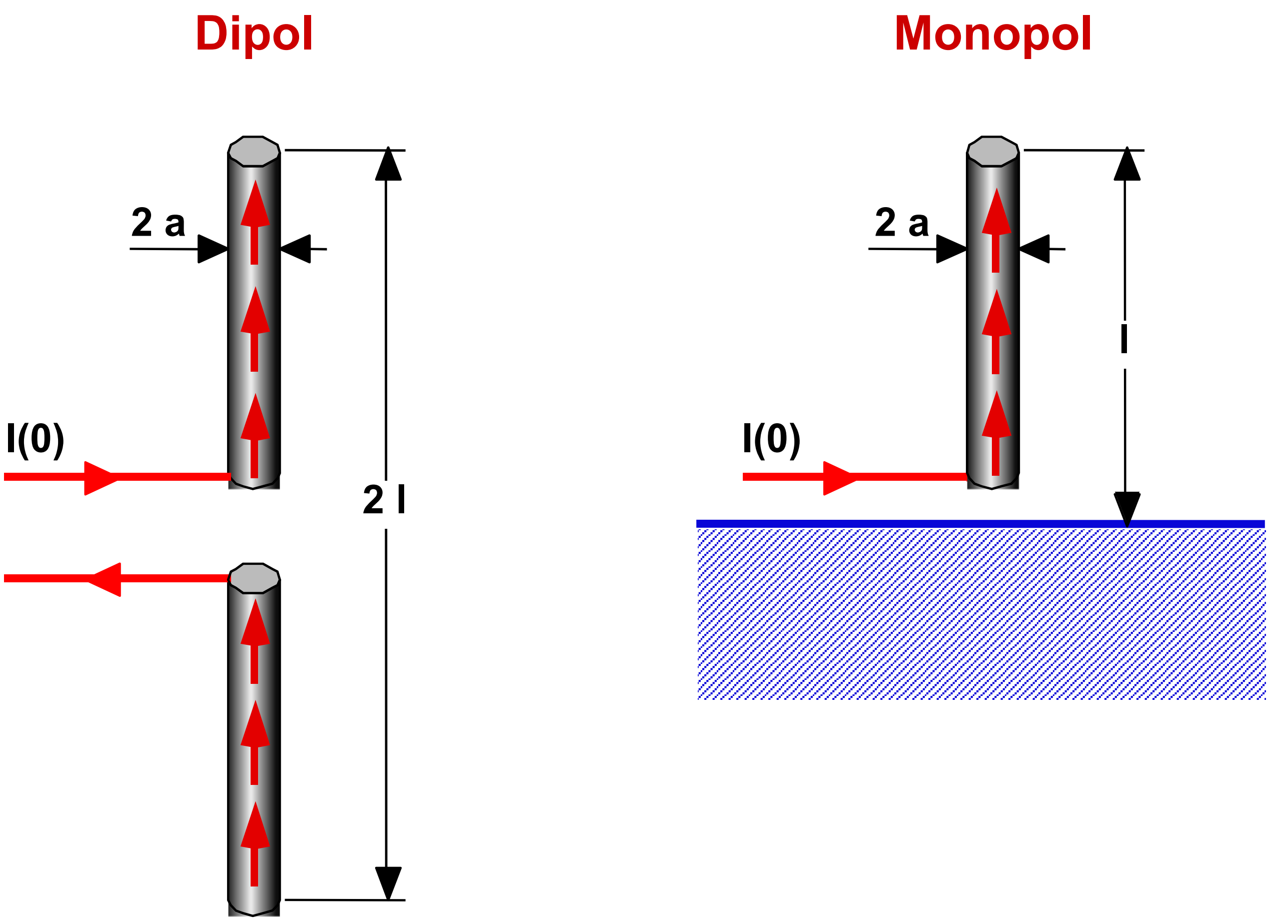
Stabstrahler

by Thomas Zwick

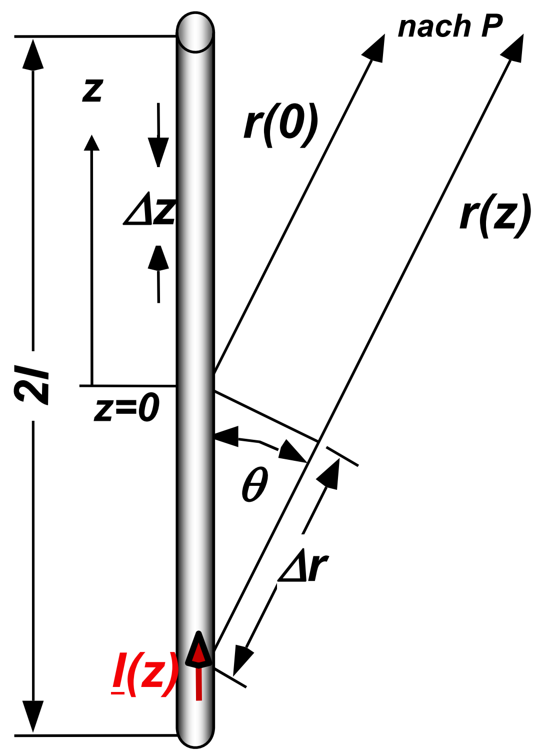
INSTITUT FÜR HOCHFREQUENZTECHNIK UND ELEKTRONIK

Lineare Antennen



Fernfeld von linearen Antennen

Geometrie



$$r(z) = r(0) + \Delta r$$
$$\Delta r = -z\cos(\theta)$$

Elektrisches Fernfeld des Hertz 'schen Dipols:

$$\underline{E}_{\theta HD} = I(z)dz\frac{\mu}{4\pi}\frac{e^{-j\beta r(z)}}{r(z)}j\omega\sin\theta$$

Elektrisches Fernfeld der linearen Antenne:

$$E_\theta = \iiint_V E_{\theta,HD}(\vec{r})\,dV \qquad E_\theta = \int_{-\ell}^{\ell} E_{\theta,HD}(z)\,dz$$

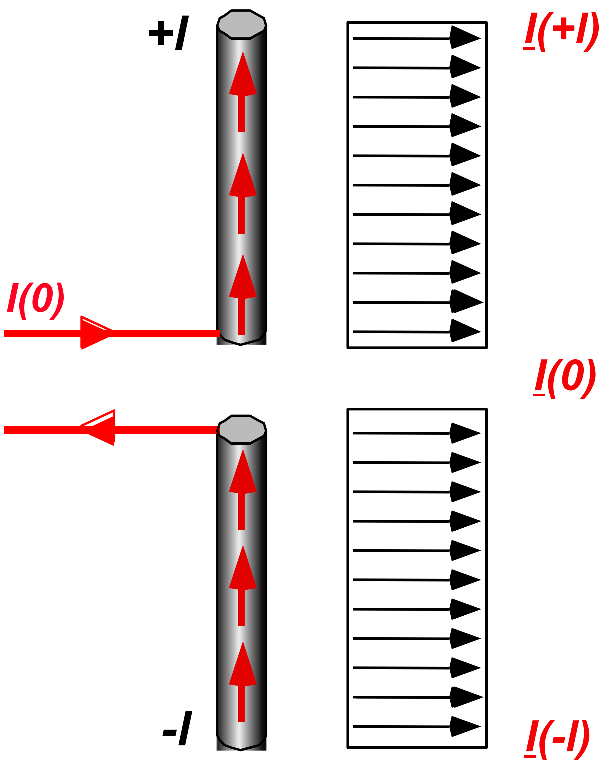
$$\underline{E}_\theta = \underbrace{j\omega\frac{\mu}{4\pi r}e^{-j\beta r(0)}}_{\text{Abstandsfaktor A(r)}}\underbrace{\sin\theta\int_{-\ell}^{\ell}\underline{I}(z)\cdot e^{j\beta z\cos\theta}dz}_{\text{und Richtungsfaktor F}(\theta)\text{ der Feldstärke}}$$

Magnetisches Fernfeld der linearen Antenne:

$$\underline{H}_\psi = \frac{\underline{E}_\theta}{Z_{F0}}$$

Lineare Antennen mit homogener Belegung

Stromverteilung



Konstante Stromverteilung:

$$\underline{I}(z) = \underline{I}(0)$$

Elektrisches Fernfeld der linearen Antenne:

$$\underline{E}_\theta = \underline{A}(r) \cdot \underline{F}(r)$$

Abstandsfaktor:

$$\underline{A}(r) = j\omega \frac{\mu}{4\pi r} e^{-j\beta r(0)}$$

Richtungsfaktor:

$$\underline{F}(r) = \sin\theta \int_{-\ell}^{\ell} \underline{I}(z) \cdot e^{j\beta z\cos\theta} dz$$

Institut für Hochfrequenztechnik und Elektronik

Linearer Stabstrahler mit homogener Stromverteilung

$$E_\theta = A(r)\sin\theta\int_{-\ell}^{\ell} I(0)\cdot e^{j\beta z\cos\theta}\,dz = A(r)\,I(0)\sin\theta\left[\frac{e^{j\beta z\cos\theta}}{j\beta\cos\theta}\right]_{-\ell}^{\ell} =$$

$$A(r)\,I(0)\sin\theta\frac{2j\sin(\beta\ell\cos\theta)}{j\beta\cos\theta} = A(r)\,I(0)\,2\ell\sin\theta\frac{\sin\xi}{\xi} \quad \text{mit } \xi = \beta\ell\cos\theta$$

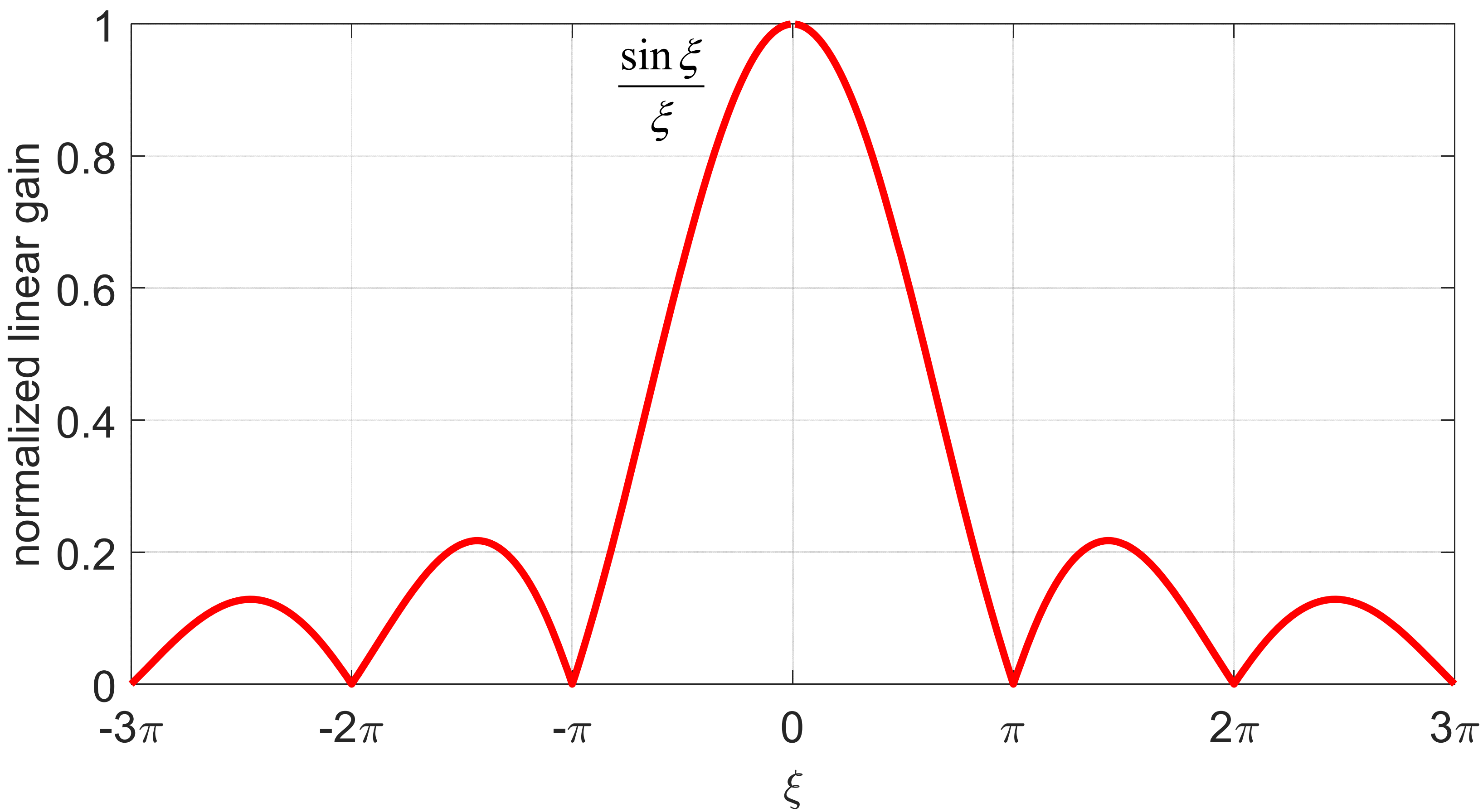
$$C(\theta) = \sin\theta\frac{\sin\xi}{\xi} \quad \text{Hauptstrahlrichtung: } \theta = \frac{\pi}{2}$$

$$\text{Nullstellen: } \sin\theta = 0 \Rightarrow \theta = 0, \pi \quad \frac{\sin\xi}{\xi} = 0 \Rightarrow \frac{2\pi\ell}{\lambda}\cos\theta = n\pi$$

$$\text{Halbwertswinkel: } \frac{1}{\sqrt{2}} = \sin\theta\frac{\sin\xi}{\xi}$$

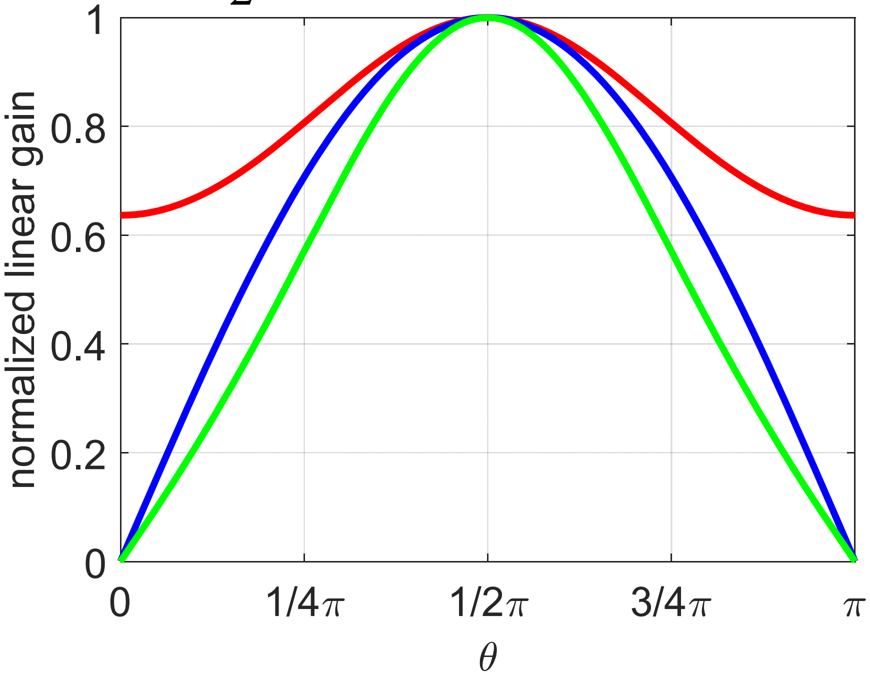
Institut für Hochfrequenztechnik und Elektronik

Richtdiagramm des Stabstrahlers mit homogener Belegung

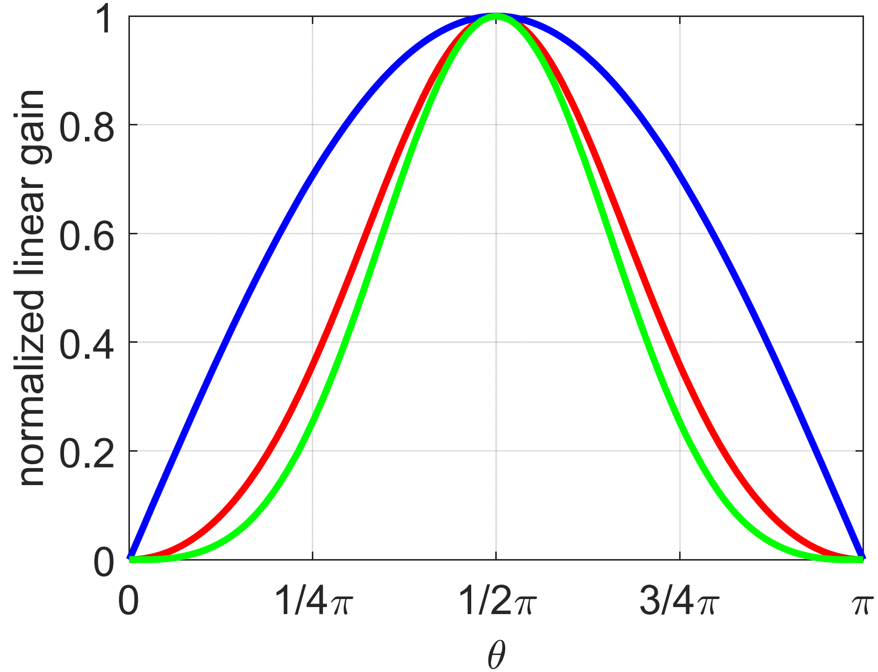


Richtdiagramm des Stabstrahlers mit homogener Belegung

$2\ell = \frac{\lambda}{2}$



$2\ell = \lambda$



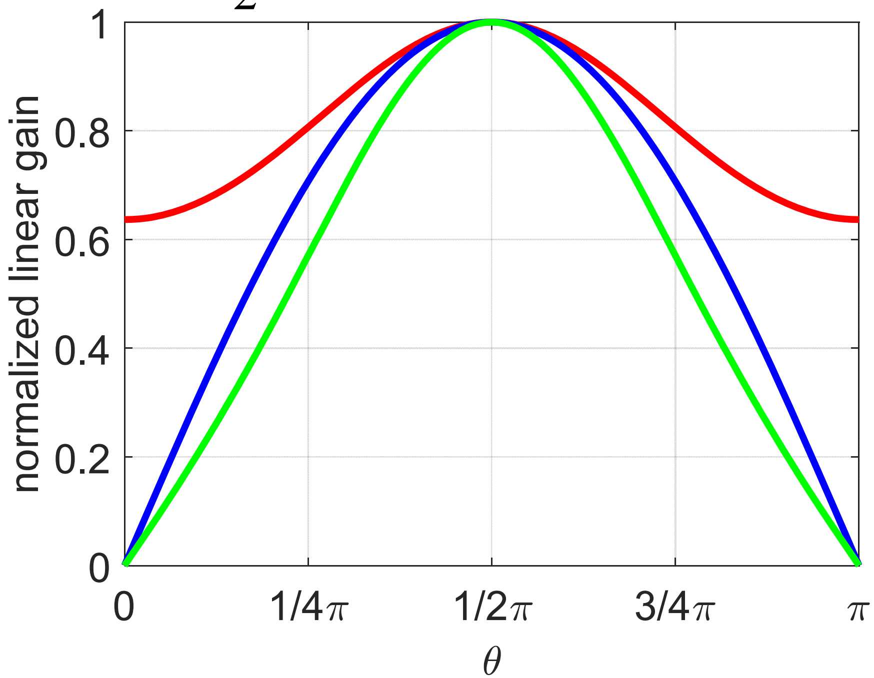
$$\boxed{\frac{\sin\xi}{\xi} \text{ mit } \xi = \frac{2\pi\ell}{\lambda}\cos\theta}$$

$$\boxed{\sin\theta}$$

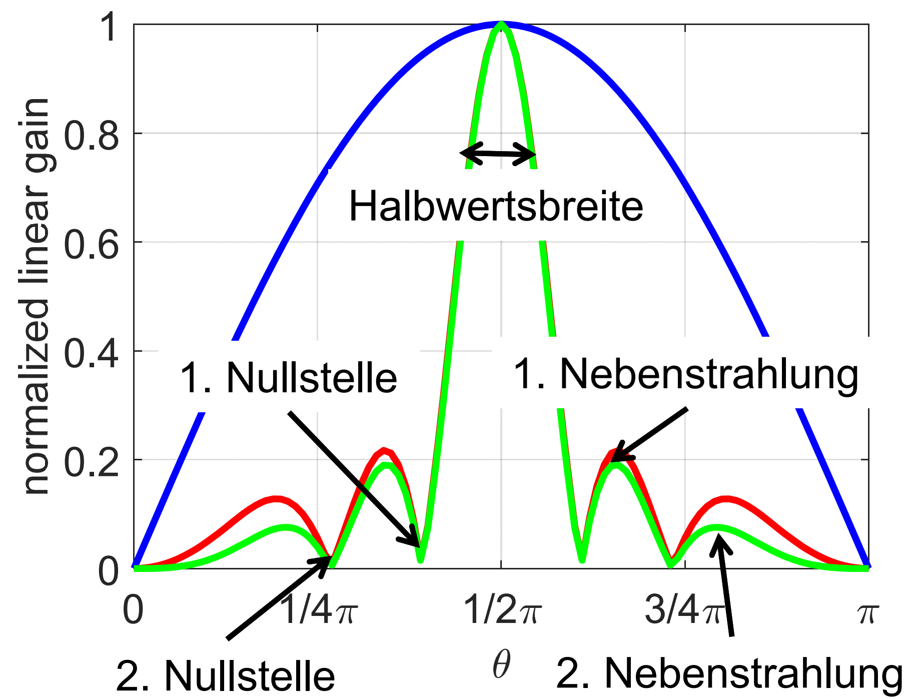
$$\boxed{\sin\theta\frac{\sin\xi}{\xi} = \sin\theta\frac{\sin\left(\beta\ell\cos\theta\right)}{\beta\ell\cos\theta}}$$

Richtdiagramm des Stabstrahlers mit homogener Belegung

$2\ell = \frac{\lambda}{2}$



$2\ell = 3\lambda$



$$\boxed{\frac{\sin\xi}{\xi} \text{ mit } \xi = \frac{2\pi\ell}{\lambda}\cos\theta}$$

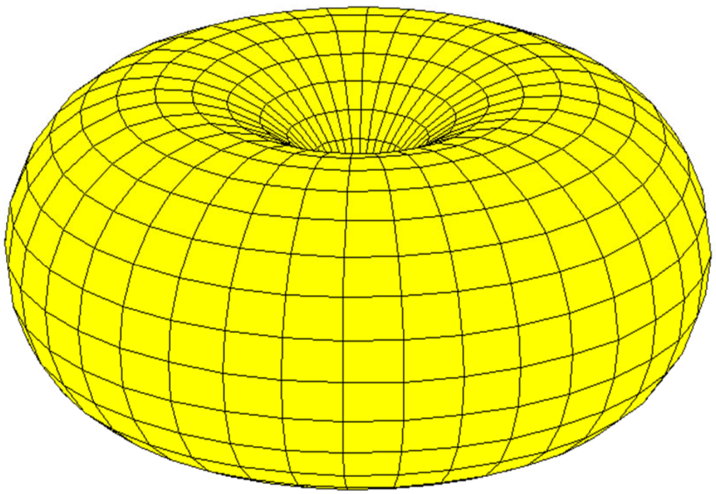
$$\boxed{\sin\theta}$$

$$\boxed{\sin\theta\frac{\sin\xi}{\xi} = \sin\theta\frac{\sin(\beta\ell\cos\theta)}{\beta\ell\cos\theta}}$$

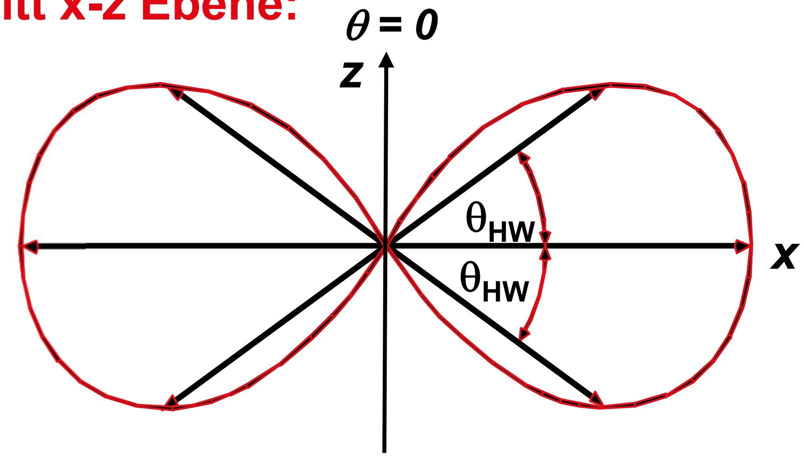
Institut für Hochfrequenztechnik und Elektronik

Vertikale Halbwertsbreite eines Stabstrahlers

3D:



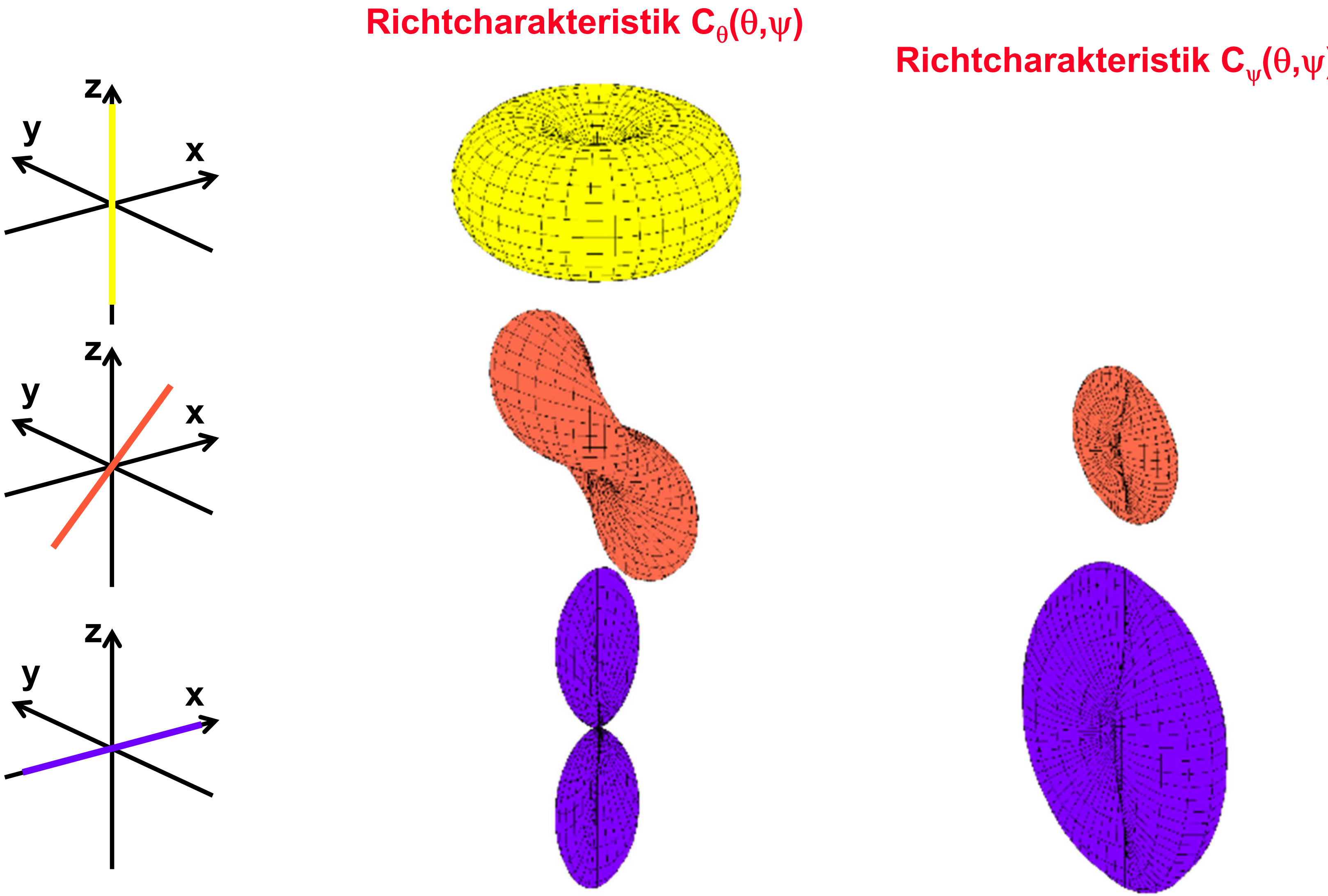
Schnitt x-z Ebene:



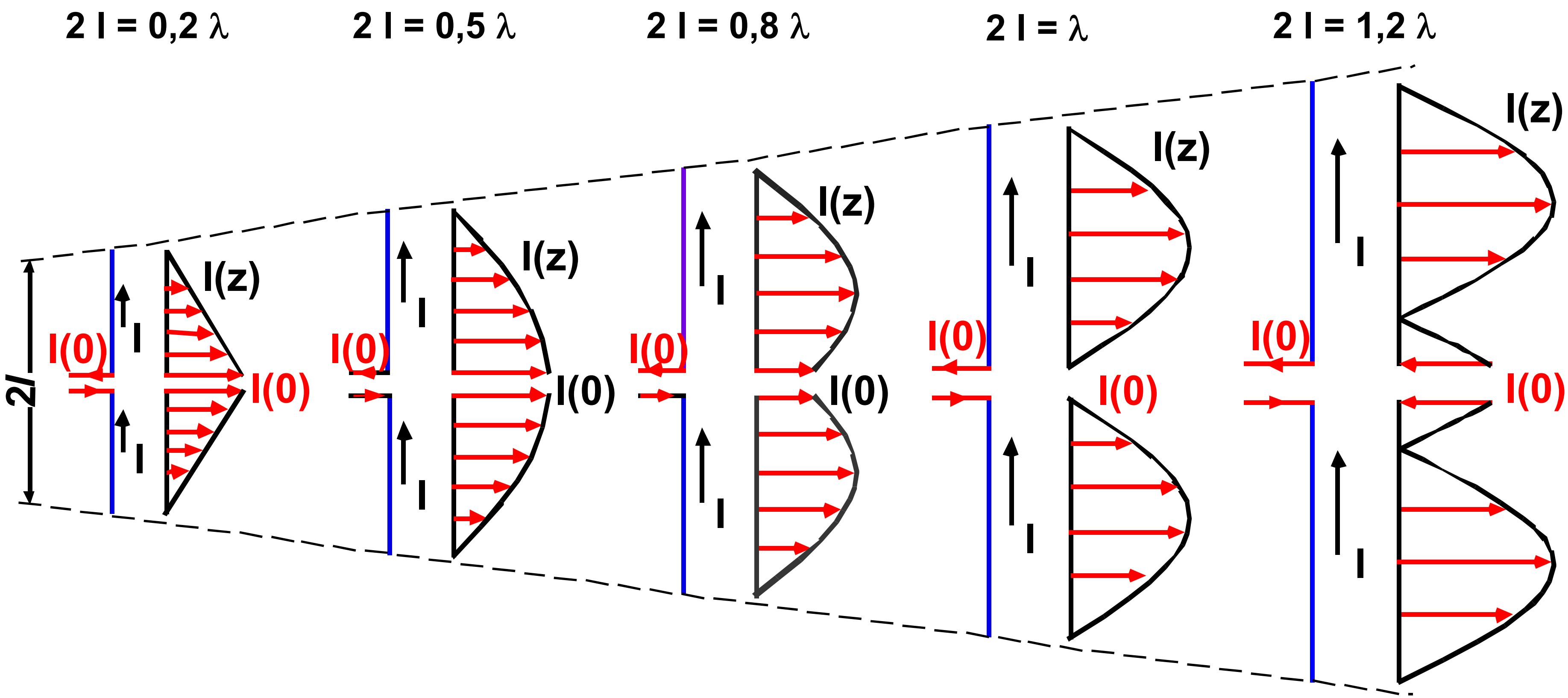
Halbwertswinkel θ_{HW} bei homogener Belegung:

$$\frac{1}{\sqrt{2}} = \sin\theta_{HW} \cdot \frac{\sin\left(\frac{2\pi\ell}{\lambda_0}\cos\theta_{HW}\right)}{\frac{2\pi\ell}{\lambda_0}\cos\theta_{HW}}$$

Einfluss des Koordinatensystems auf $C_\theta(\theta,\psi)$, $C_\psi(\theta,\psi)$



Reale Stromverteilung auf Stabstrahlern



Institut für Hochfrequenztechnik und Elektronik

Formeln Linearer Stabstrahler

$$E_\theta = j\omega \frac{\mu}{4\pi r} e^{-j\beta r(0)} \frac{I(0)}{\sin(\beta\ell)} \sin\theta \int_{-\ell}^{\ell} \sin\left(\beta\left(\ell - |z|\right)\right) \cdot e^{j\beta z\cos\theta}\, dz$$

$$\int_{-\ell}^{\ell} \sin\left(\beta\left(\ell - |z|\right)\right) \cdot e^{j\beta z\cos\theta}\, dz = \int_{-\ell}^{0} \sin\left(\beta\left(\ell + z\right)\right) \cdot e^{j\beta z\cos\theta}\, dz + \int_{0}^{\ell} \sin\left(\beta\left(\ell - z\right)\right) \cdot e^{j\beta z\cos\theta}\, dz =$$

$$\left[\frac{e^{j\beta z\cos\theta}}{-\beta^2\cos^2\theta + \beta^2}\left\{j\beta\cos\theta\sin(\beta\ell + \beta z) - \beta\cos(\beta\ell + \beta z)\right\}\right]_{-\ell}^{0} +$$

$$\left[\frac{e^{j\beta z\cos\theta}}{-\beta^2\cos^2\theta + \beta^2}\left\{j\beta\cos\theta\sin(\beta\ell - \beta z) + \beta\cos(\beta\ell - \beta z)\right\}\right]_{0}^{\ell} =$$

Formelsammlung:

$$\int e^{\alpha x}\sin(\beta x + \gamma)\, dx = \frac{e^{\alpha x}}{\alpha^2 + \beta^2}\left[\alpha\sin(\beta x + \gamma) - \beta\cos(\beta x + \gamma)\right]$$

Formeln Linearer Stabstrahler

$$\int_{-\ell}^{\ell} \sin\left(\beta\left(\ell-|z|\right)\right)\cdot e^{j\beta z\cos\theta}\,dz = \int_{-\ell}^{0} \sin\left(\beta\left(\ell+z\right)\right)\cdot e^{j\beta z\cos\theta}\,dz + \int_{0}^{\ell} \sin\left(\beta\left(\ell-z\right)\right)\cdot e^{j\beta z\cos\theta}\,dz =$$

$$\left[\frac{e^{j\beta z\cos\theta}}{-\beta^2\cos^2\theta+\beta^2}\left\{j\beta\cos\theta\sin\left(\beta\ell+\beta z\right)-\beta\cos\left(\beta\ell+\beta z\right)\right\}\right]_{-\ell}^{0} +$$

$$\left[\frac{e^{j\beta z\cos\theta}}{-\beta^2\cos^2\theta+\beta^2}\left\{j\beta\cos\theta\sin\left(\beta\ell-\beta z\right)+\beta\cos\left(\beta\ell-\beta z\right)\right\}\right]_{0}^{\ell} =$$

$$\frac{1}{\beta^2\sin^2\theta}\left\{j\beta\cos\theta\sin\left(\beta\ell\right)-\beta\cos\left(\beta\ell\right)\right\}-\frac{e^{-j\beta\ell\cos\theta}}{\beta^2\sin^2\theta}\left\{-\beta\right\}+$$

$$\frac{e^{j\beta\ell\cos\theta}}{\beta^2\sin^2\theta}\left\{\beta\right\}-\frac{1}{\beta^2\sin^2\theta}\left\{j\beta\cos\theta\sin\left(\beta\ell\right)+\beta\cos\left(\beta\ell\right)\right\} =$$

$$\frac{e^{-j\beta\ell\cos\theta}+e^{j\beta\ell\cos\theta}-2\cos(\beta l)}{\beta\sin^2\theta} = \frac{2}{\beta}\,\frac{\cos\left(\beta\ell\cos\theta\right)-\cos(\beta l)}{\sin^2\theta}$$

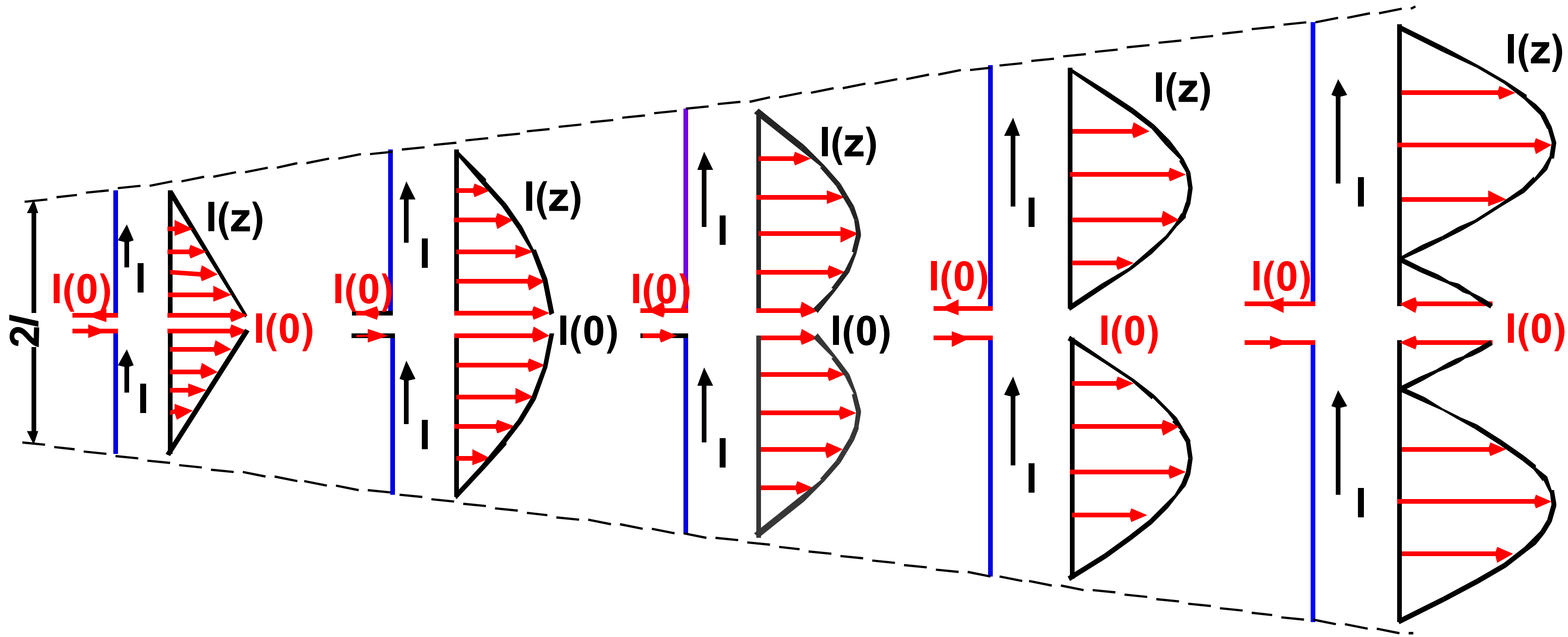
Formeln Linearer Stabstrahler

$$\int_{-\ell}^{\ell} \sin\left(\beta\left(\ell-|z|\right)\right)\cdot e^{j\beta z\cos\theta}\,dz = \frac{2}{\beta}\,\frac{\cos\left(\beta\ell\cos\theta\right)-\cos(\beta l)}{\sin^2\theta}$$

$$I(z) = \frac{I(0)}{\sin(\beta\ell)}\sin\left(\beta\left(\ell-|z|\right)\right) \qquad E_\theta = A(r)\frac{I(0)}{\sin(\beta\ell)}\sin\theta\int_{-\ell}^{\ell}\sin\left(\beta\left(\ell-|z|\right)\right)\cdot e^{j\beta z\cos\theta}\,dz$$

$$A(r) = j\omega\frac{\mu}{4\pi r}e^{-j\beta r(0)} \qquad F(\theta) = \frac{I(0)}{\sin(\beta\ell)}\cdot\frac{2}{\beta}\cdot\frac{\cos\left(\beta\ell\cos\theta\right)-\cos\left(\beta\ell\right)}{\sin\theta}$$

Stromverteilung auf Stabstrahlern



$$I(z) = \frac{I(0)}{\sin(\beta\ell)} \sin\left(\beta\left(\ell - |z|\right)\right) \qquad E_\theta = A(r)\frac{I(0)}{\sin(\beta\ell)} \sin\theta \int_{-\ell}^{\ell} \sin\left(\beta\left(\ell - |z|\right)\right) \cdot e^{j\beta z\cos\theta} dz$$

$$A(r) = j\omega \frac{\mu}{4\pi r} e^{-j\beta r(0)} \qquad F(\theta) = \frac{I(0)}{\sin(\beta\ell)} \cdot \frac{2}{\beta} \cdot \frac{\cos(\beta\ell\cos\theta) - \cos(\beta\ell)}{\sin\theta}$$

λ/2 und λ-Dipol

λ/2-Dipol:

$$2\ell = \frac{\lambda}{2} \Rightarrow \beta\ell = \frac{\pi}{2} \quad F(\theta) = \frac{2I(0)}{\beta} \cdot \frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta} \quad F_{\max} = \frac{2I(0)}{\beta} \text{ bei } \theta = \frac{\pi}{2} \Rightarrow C(\theta) = \frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta}$$

$$G_i = \frac{4\pi}{\int\limits_{\psi=0}^{2\pi}\int\limits_{\theta=0}^{\pi} C^2(\theta,\psi)\sin\theta\, d\theta\, d\psi} \approx 1.64\,(2.15\,dBi)$$

$$R_S = \frac{2P_T}{|I(0)|^2} \quad P_T = 4\pi r^2 \frac{|S|_{\max}}{G_i} \quad |S|_{\max} = \frac{|E_\theta|_{\max}^2}{2Z_{F0}} \quad |E_\theta|_{\max} = \frac{\omega\mu}{2\pi\beta r}|I(0)| = \frac{Z_{F0}}{2\pi r}|I(0)|$$

$$R_S = \frac{4\pi r^2 |E_\theta|_{\max}^2}{|I(0)|^2 G_i Z_{F0}} = \frac{Z_{F0}}{\pi G_i} = 73.2\Omega$$

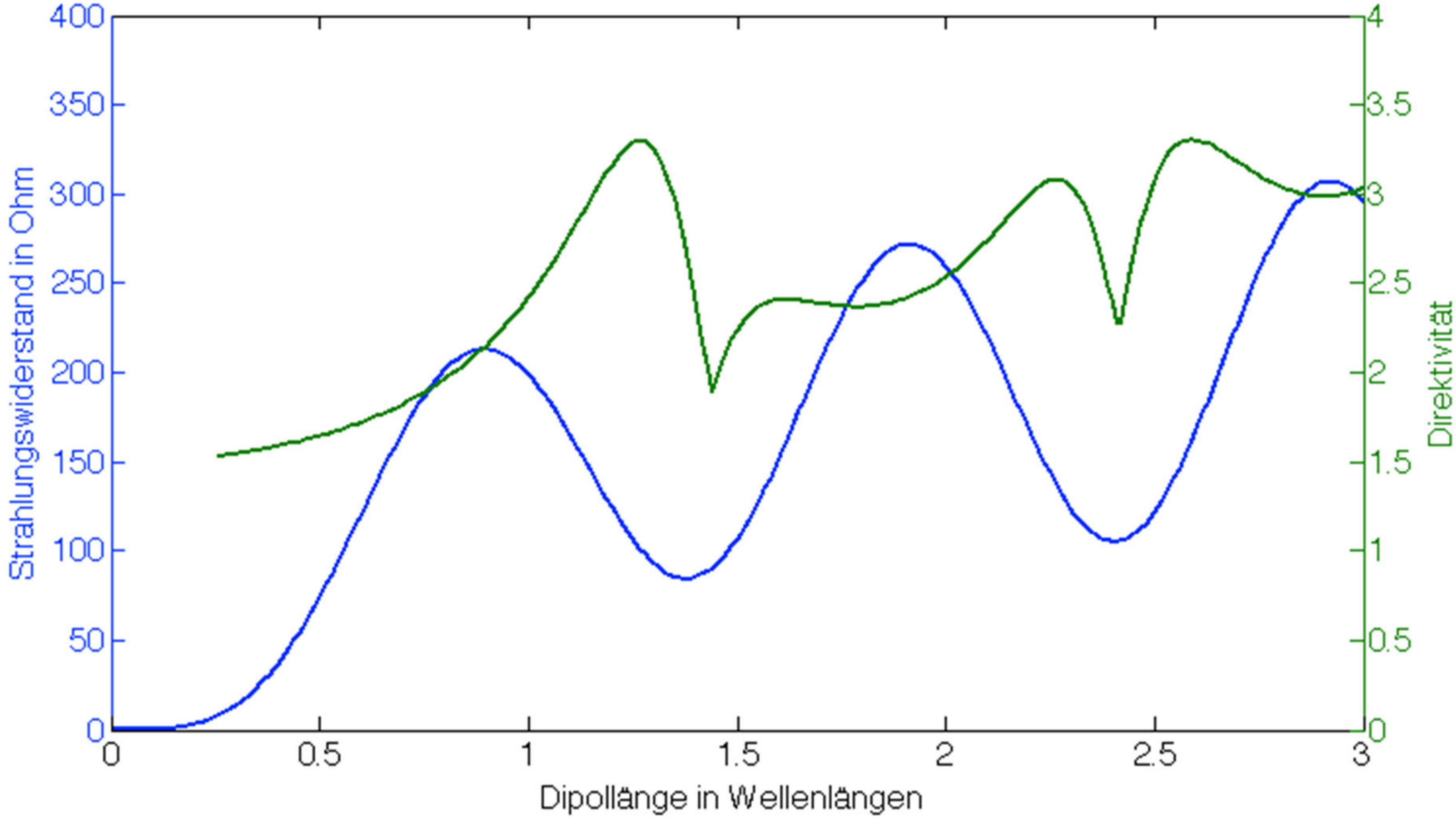
Passt gut zu Coax-Wellenwiderstand 75Ω

λ-Dipol:

$$2\ell = \lambda \Rightarrow \beta\ell = \pi \quad F_{\max} = \frac{I(0)}{\sin(\beta\ell)} \cdot \frac{2}{\beta} \cdot 2 \quad C(\theta) = \frac{F(\theta)}{F_{\max}} = \frac{\cos(\pi\cos\theta) + 1}{2\sin\theta}$$

numerische Auswertung: $G_i \approx 2.41\,(3.82\,dBi)$

Strahlungswiderstand und Direktivität



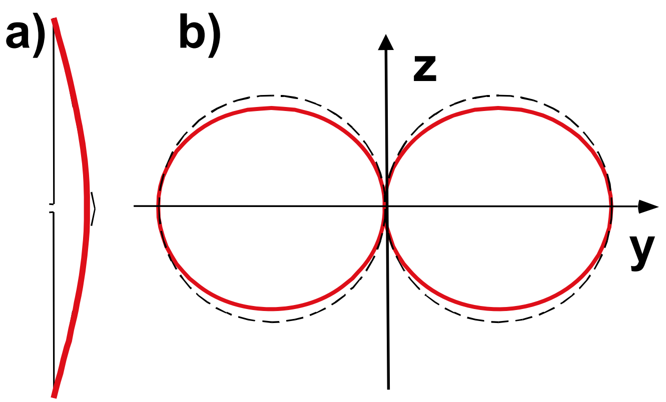
Dipol-Antennen

$\lambda/2$ - Dipol   ($2l = \lambda/2$)

$$C(\theta,\psi) = \left| \frac{\cos\left(\frac{\pi}{2}\cos\theta\right)}{\sin\theta} \right|$$

G = 1.64 oder 2.15 dBi

R_S = 73.2 Ω θ_{HB} = 78°



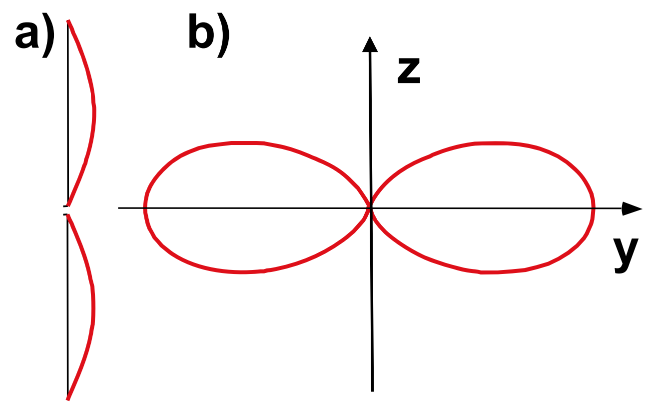
a) Stromverteilung
b) Richtch., Vergleich zum Hertzschen Dipole (- - - -)

λ - Dipol   ($2l = \lambda$)

$$C(\theta,\psi) = \left| \frac{1}{2} \cdot \frac{\cos(\pi\cos\theta)+1}{\sin\theta} \right|$$

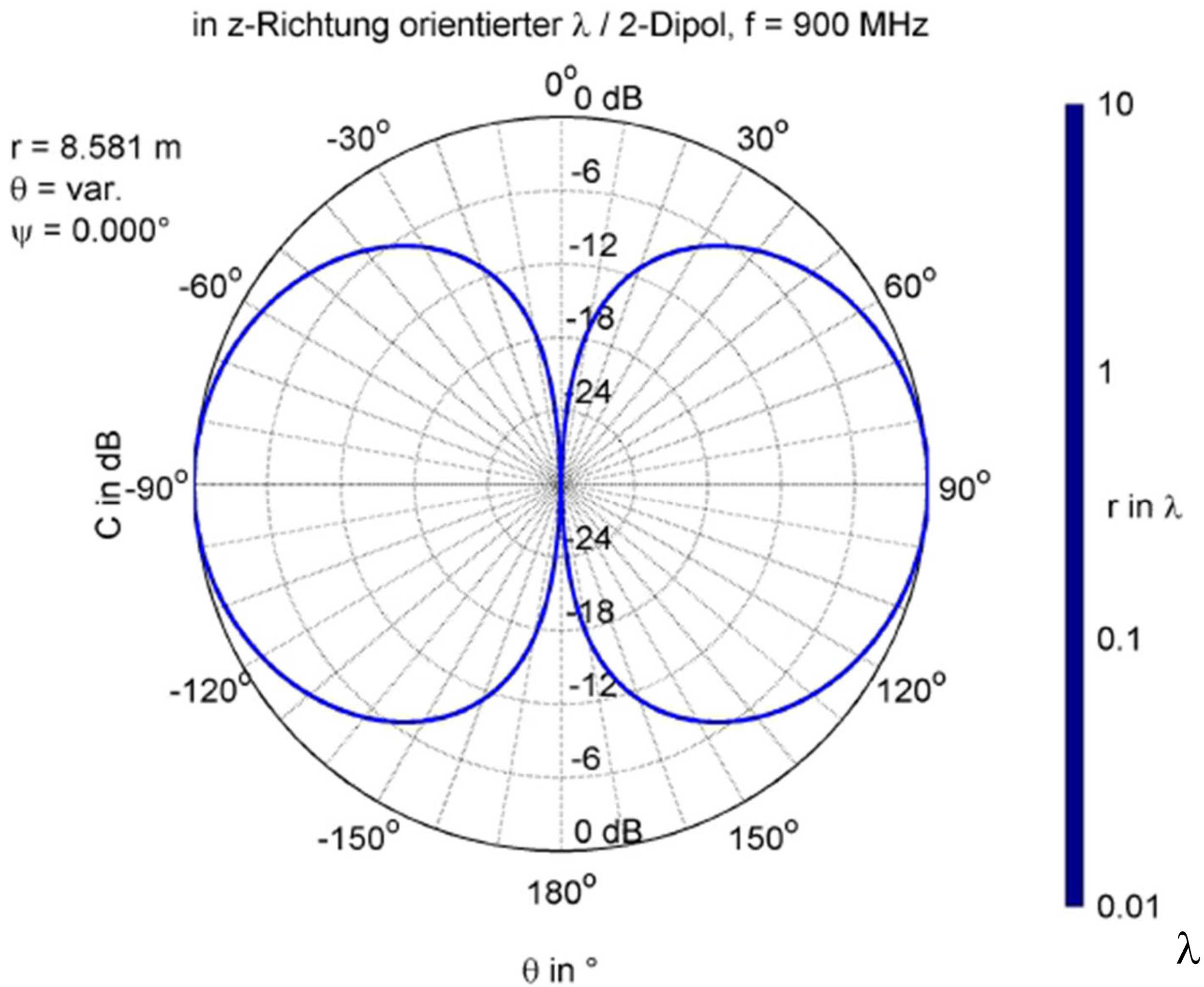
G = 2.41 oder 3.82 dBi

R_S = 200 Ω θ_{HB} = 47°



a) Stromverteilung
b) Richtcharakteristik

Elektr. Nahfeld Richtcharakteristik einer Dipolantenne

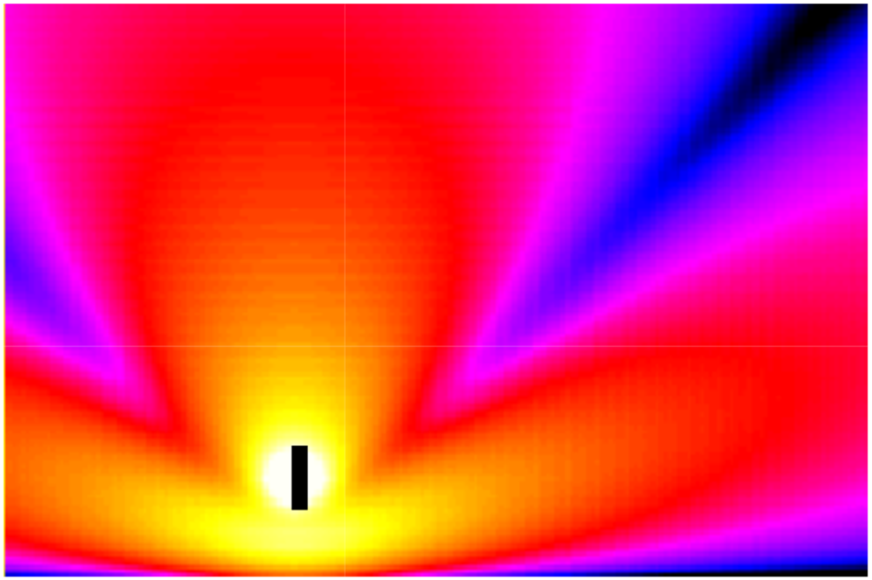


λ = 33,3cm

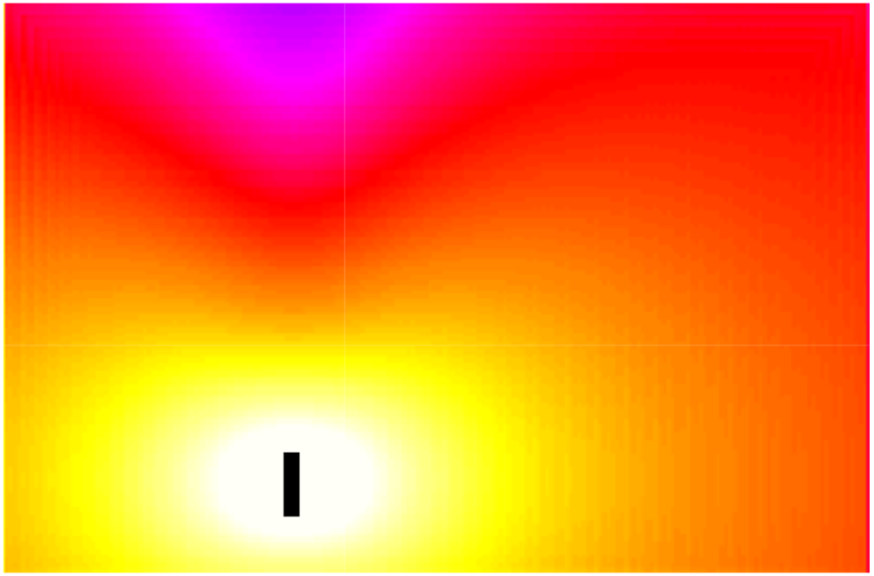
Feldstärken eines λ/2-Dipols

|E|norm
0 dB -20 dB

Dipol im Freiraum über metallischem Boden

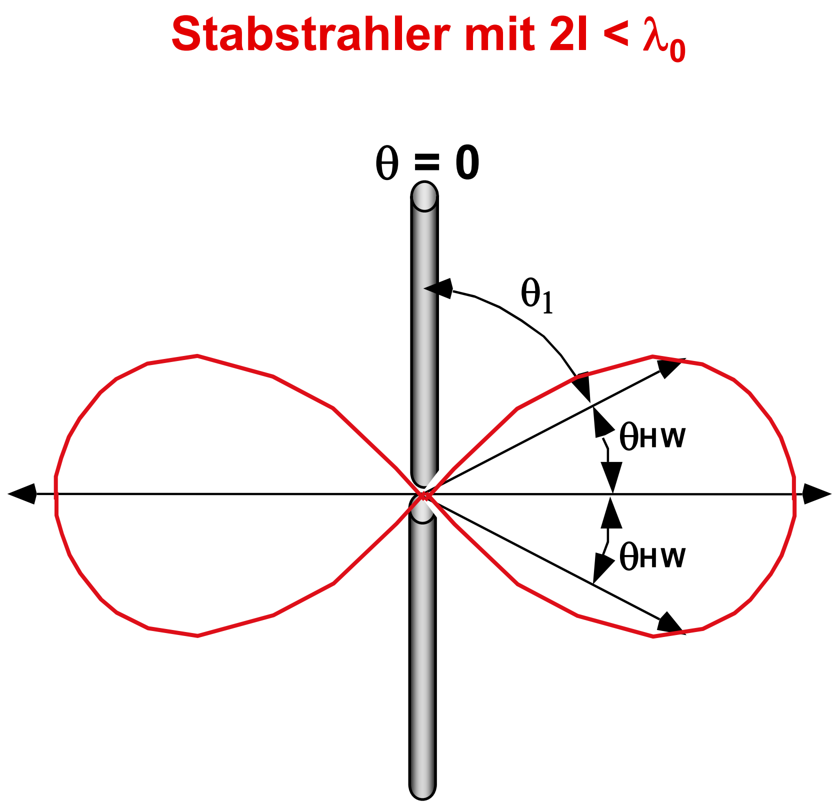


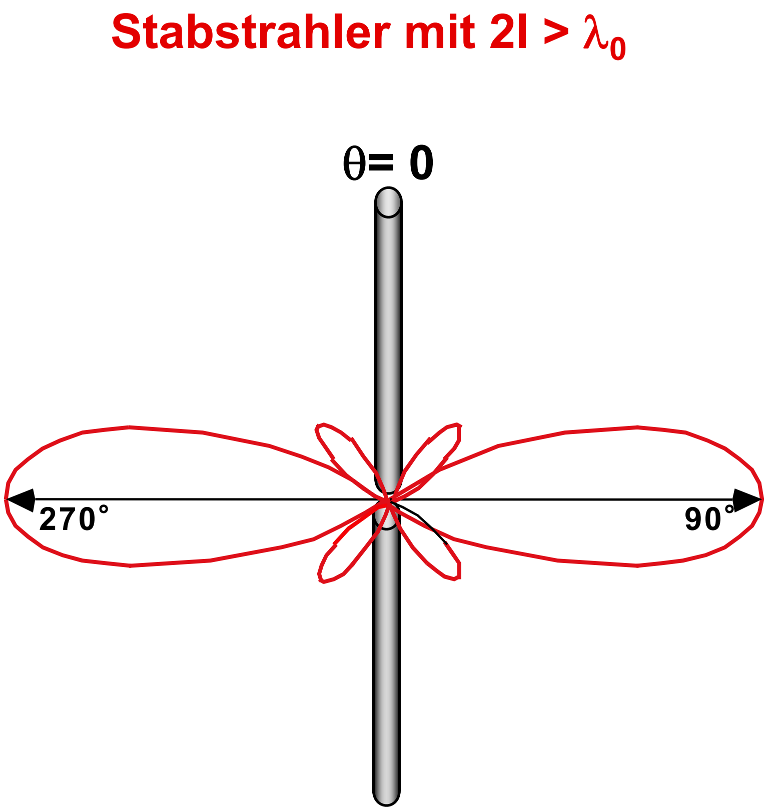
Dipol im Freiraum



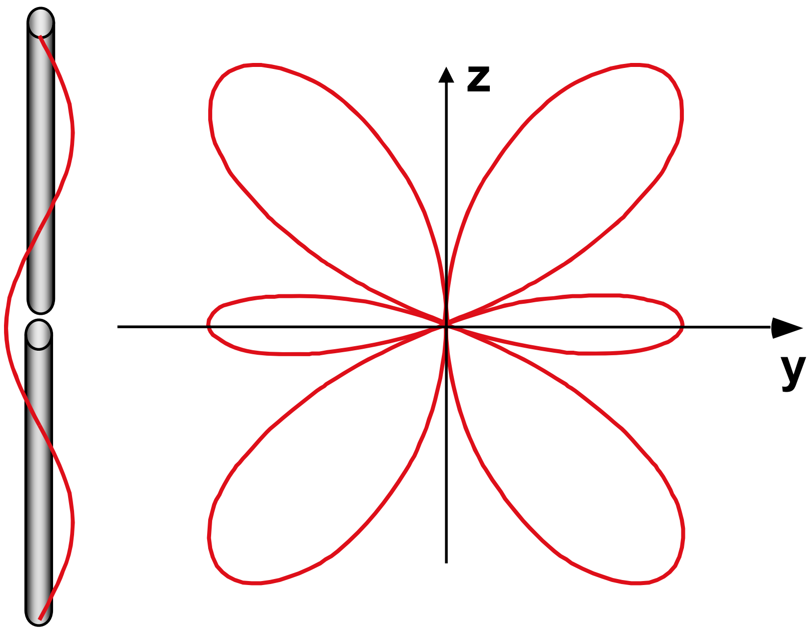
Frequenz 200 MHz, vertikale Polarisation, Dipolhöhe über Grund 2.5 m

Vertikale Halbwertsbreite eines Stabstrahlers



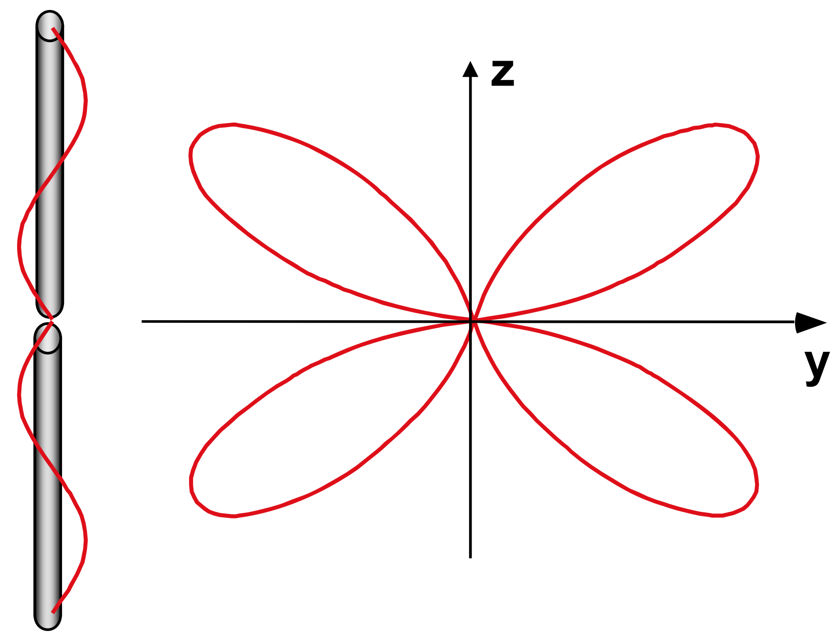


Dipol Antennen mit Länge *2l* > λ

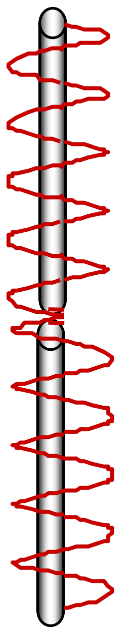


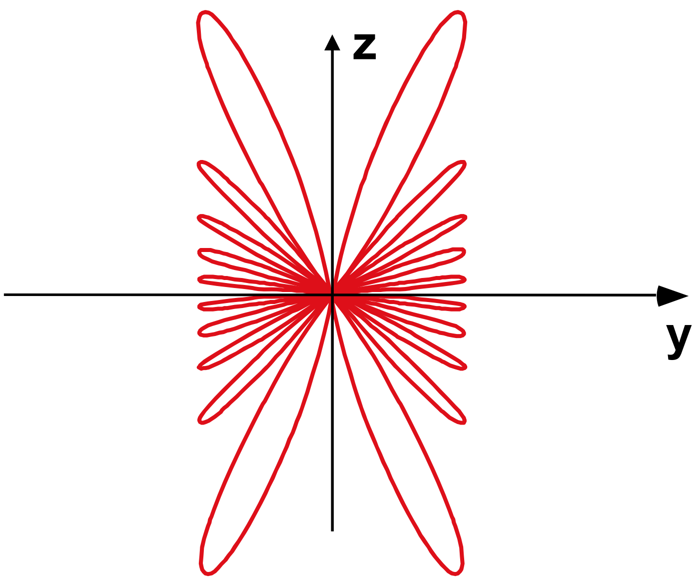
$2l = 3\lambda / 2$

$2l = 2\lambda$



Dipol Antennen mit Länge *2l* >> λ

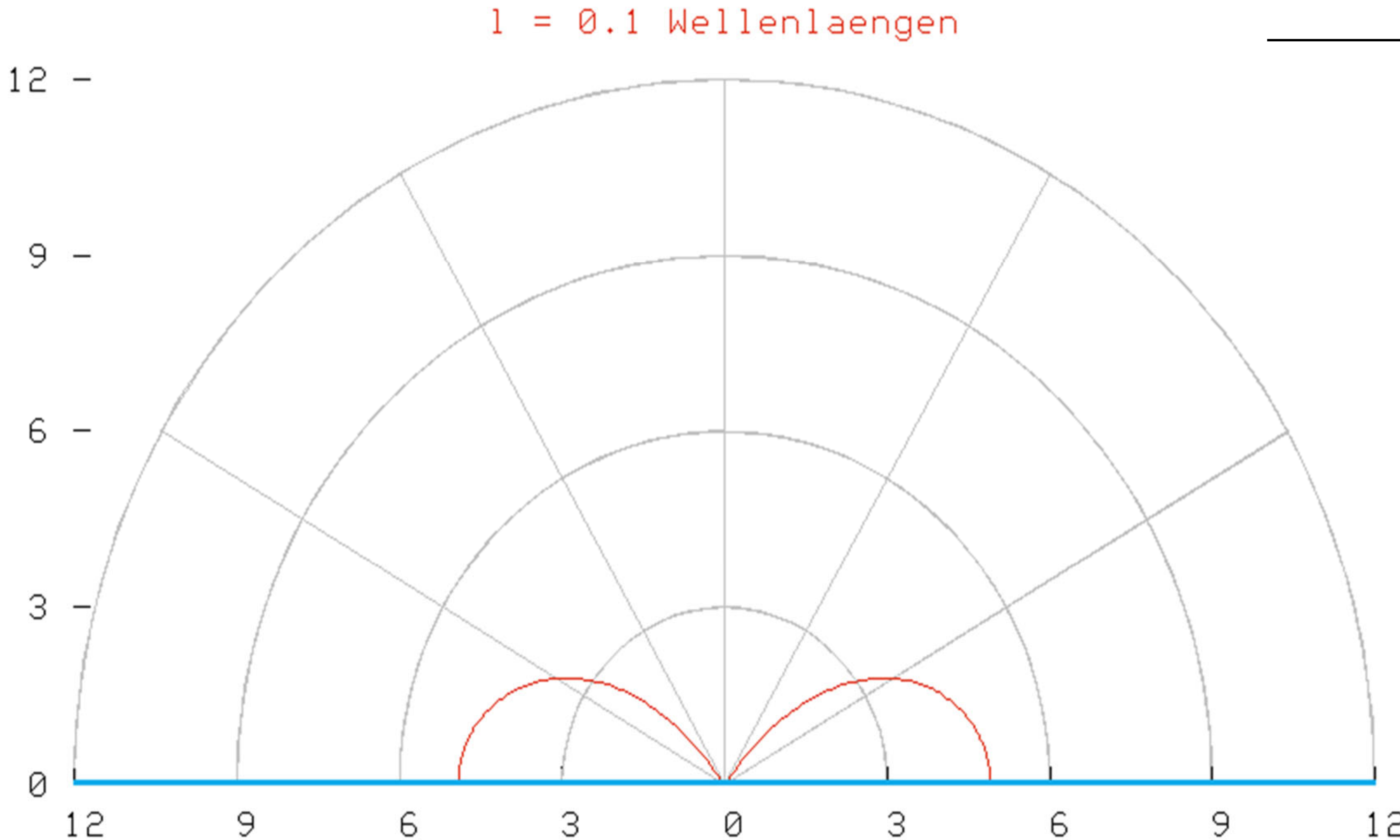


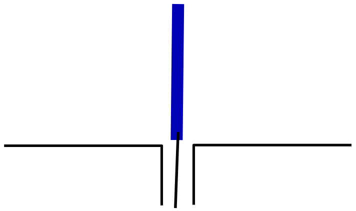


2l = 10λ

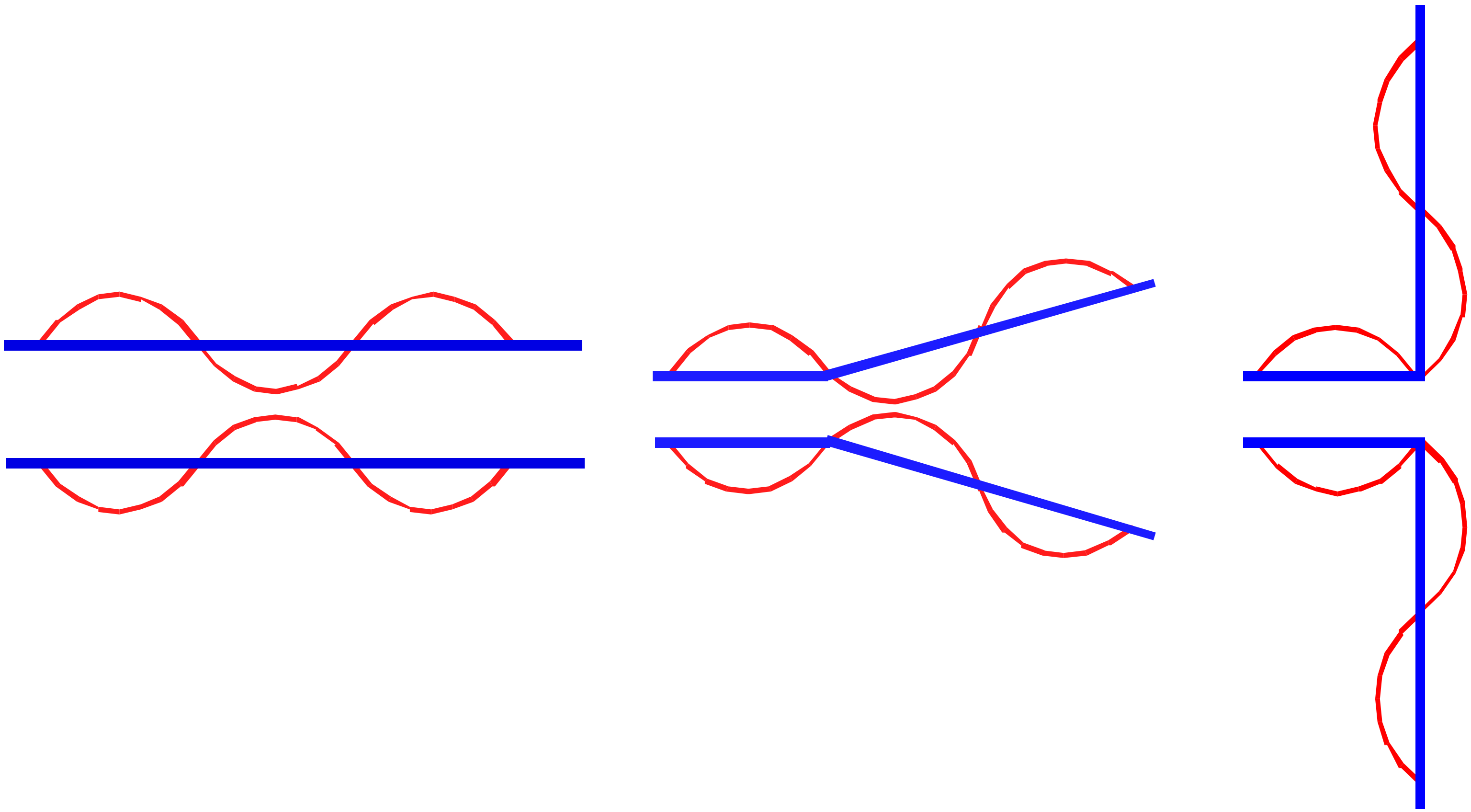
Vertikale Fernfeld-Richtcharakteristik eines Monopols

Gewinn in dBi **Länge: *0.1 λ < l <2.5 λ***

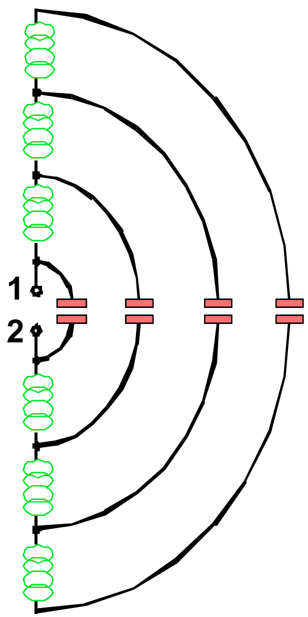


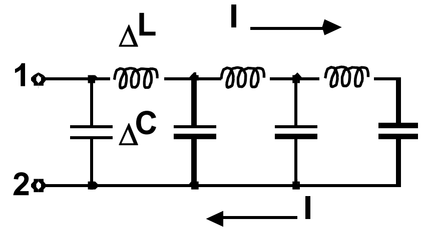


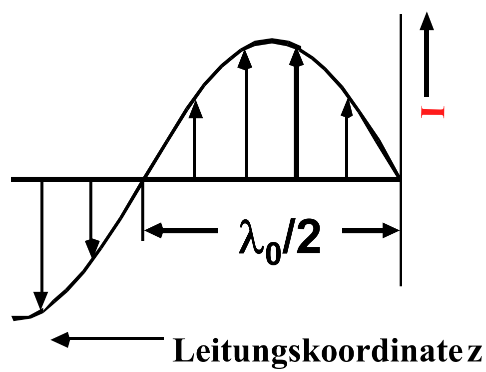
Stabantenne als Leitung

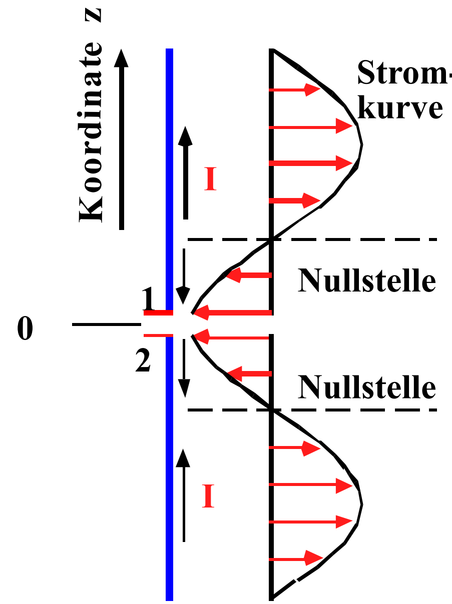


Leitungsersatzschaltbild einer Stabantenne









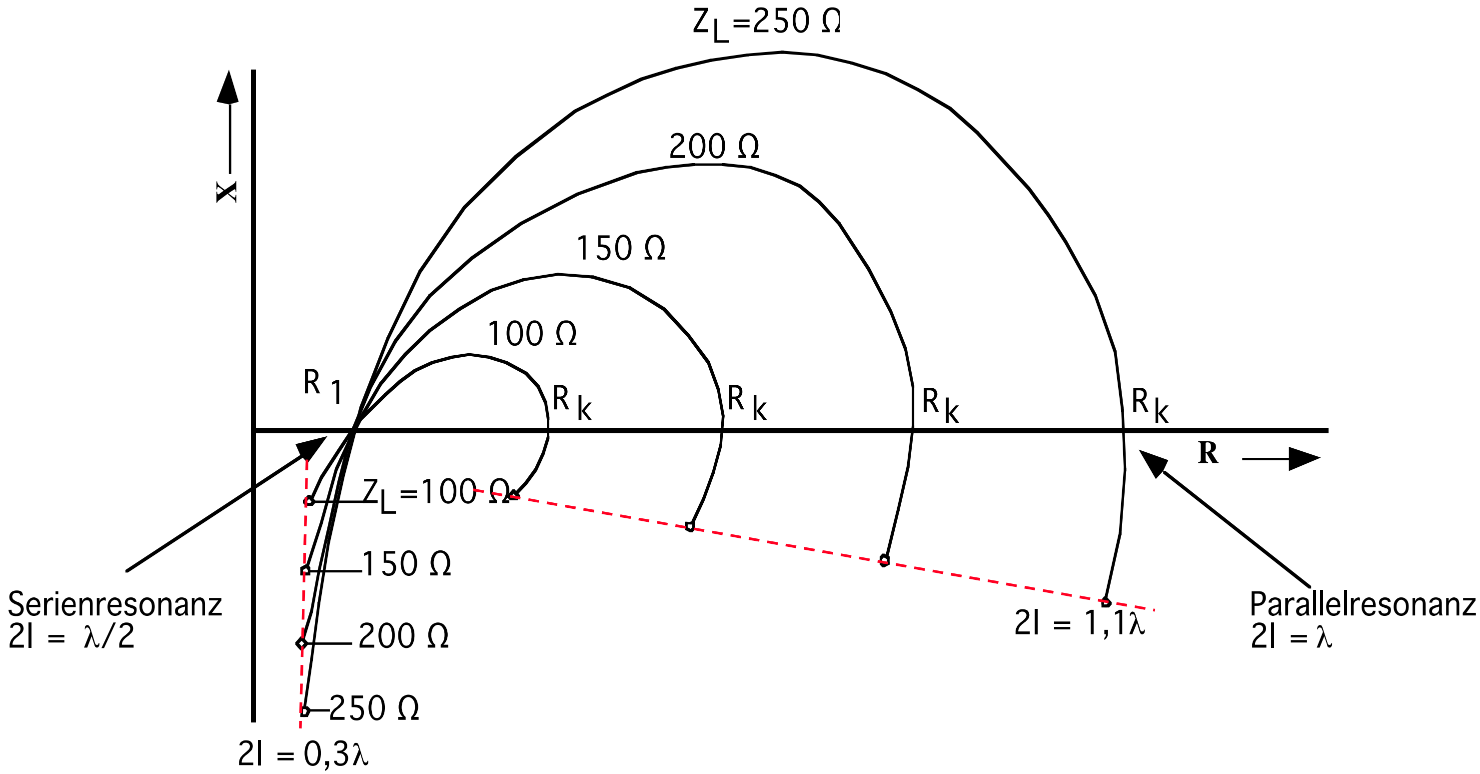
Näherungsformeln aus der Literatur:

$$Z_L = 120\Omega \ln\left[\left(\frac{2l}{a}\right) - 1\right] \approx 120\Omega \ln\left(1{,}47\,\frac{l}{2a}\right)$$

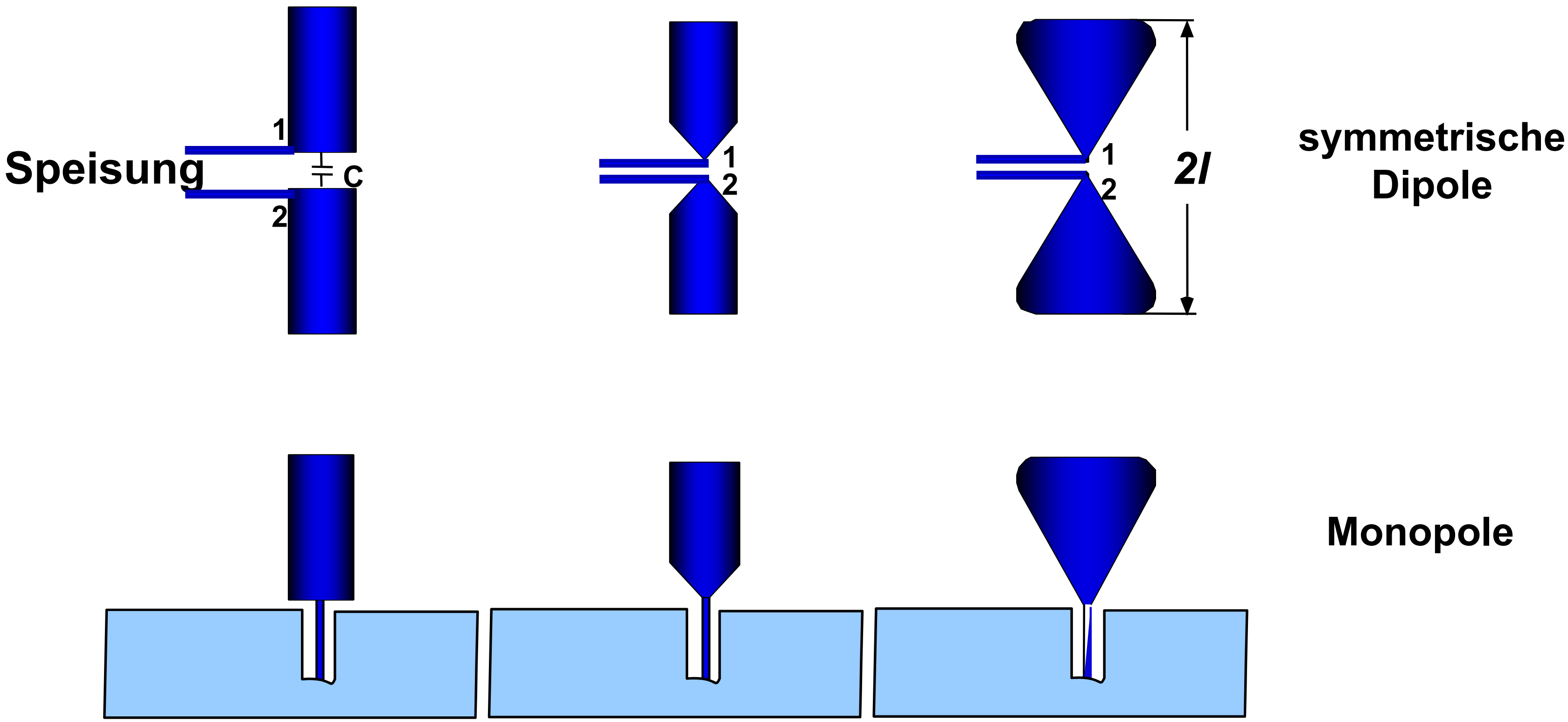
$$Z_L = 60\Omega \ln\left(\frac{l^2}{3a^2}\right) \approx 120\Omega \ln\left(1{,}15\,\frac{l}{2a}\right)$$

Eingangsimpedanz eines Stabstrahlers

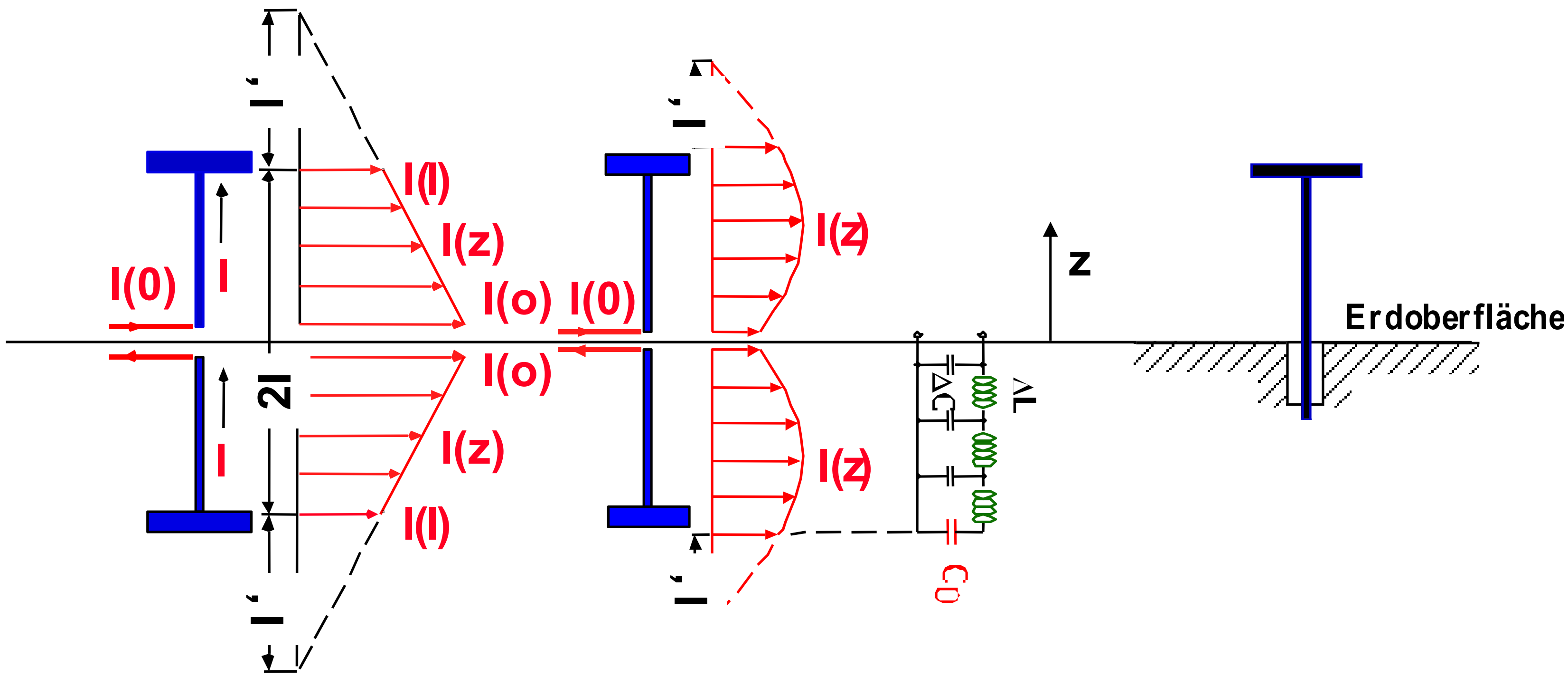
mittlere Wellenwiderstände Z_L



Breitband Monopole und Dipole



Kapazitiv belastete Stabstrahler (Mono- und Dipole)



Institut für Hochfrequenztechnik und Elektronik

U-Boot Kommunikation Sendeanlage WHV

Höhe: ca. 354 m

Frequenz: ca. 50 kHz

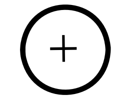
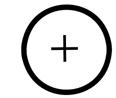
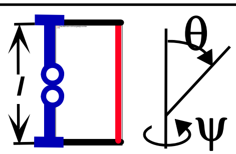
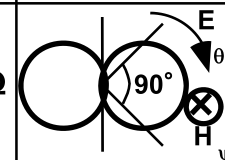
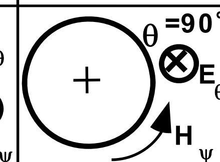
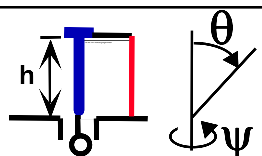
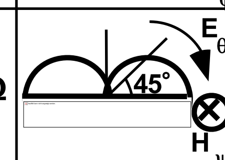
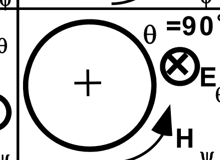
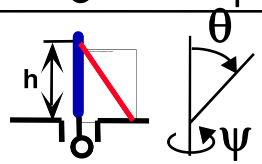
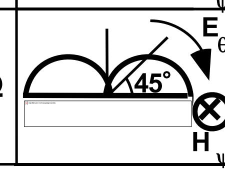
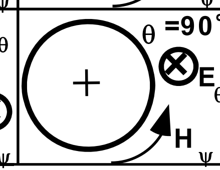
Mastdurchmesser : 2,50 m

Speisung:

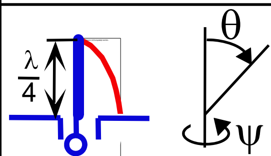
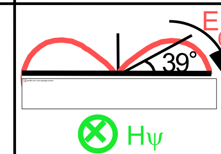
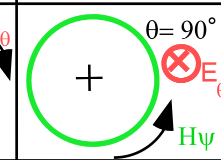
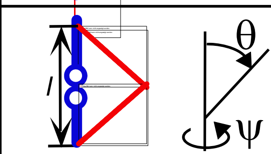
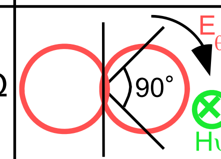
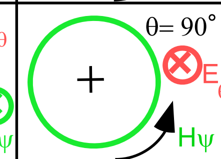
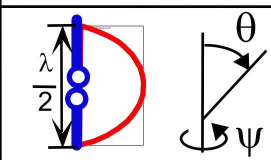
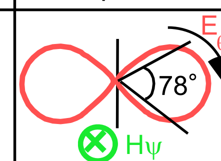
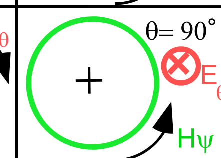
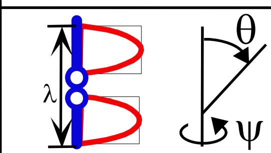
unsymm. 9 m über Grund

U-Boot Sendeanlage WHV (2 Masten und Zentrale)

Charakteristiken Einfacher Stabantennen I

Antennenart	Darstellung, Belegung	Richtfaktor, Gewinn linear (in dB)	wirksame Antennen-fläche	effektive Höhe	Strahlungs-Widerstand	vertikales Richt-diagramm 3dB-Bereich	horizontales Richt-diagramm
Isotrope Antenne	fiktiv	1 ; (0 dB)	$\frac{\lambda^2}{4\pi} = 0{,}08\lambda^2$	—	—		
Hertzscher Dipol, Dipol mit End-kapazität		1,5 ; (1,8 dB)	$\frac{3\lambda^2}{8\pi} = 0{,}12\lambda^2$	l	$80\left(\frac{\pi l}{\lambda}\right)^2\Omega$		
Kurze Antenne mit Dachkapa-zität auf leitender Ebene $h << \lambda$		3 ; (4,7 dB)	$\frac{3\lambda^2}{16\pi} = 0{,}06\lambda^2$	h	$160\left(\frac{\pi h}{\lambda}\right)^2\Omega$		
kurze Antenne auf leitender Ebene $h << \lambda$		3 ; (4,7 dB)	$\frac{3\lambda^2}{16\pi} = 0{,}06\lambda^2$	$\frac{h}{2}$	$40\left(\frac{\pi h}{\lambda}\right)^2\Omega$		

Charakteristiken Einfacher Stabantennen II

Antennenart	Darstellung, Belegung	Richtfaktor, Gewinn Linear (in dB)	Wirksname Antennen-fläche	Effektive Höhe	Strahlungs-Widerstand	Vertikales Richt-Diagramm (3dB Bereich)	Horizontales Richt-diagramm
$\lambda/4$ – Antenne auf leitender Ebene		3,28 ; (5,1 dBi)	$0{,}065\lambda^2$	$\frac{\lambda}{2\pi} = 0{,}16\lambda$	40 Ω		
Kurzer Dipol $l \ll \lambda$		1,5 ; (1,8 dBi)	$\frac{3\lambda^2}{8\pi} = 0{,}12\lambda^2$	$\frac{l}{2}$	$20\left(\frac{\pi l}{\lambda}\right)^2 \Omega$		
$\lambda/2$ - Dipol		1,64 ; (2,1 dBi)	$0{,}13\lambda^2$	$\frac{\lambda}{\pi} = 0{,}32\lambda$	73 Ω		
λ - Dipol		2,41 ; (3,8 dBi)	$0{,}19\lambda^2$	$\gg \lambda$	200 Ω