Magnetic Loop Antenna calculation

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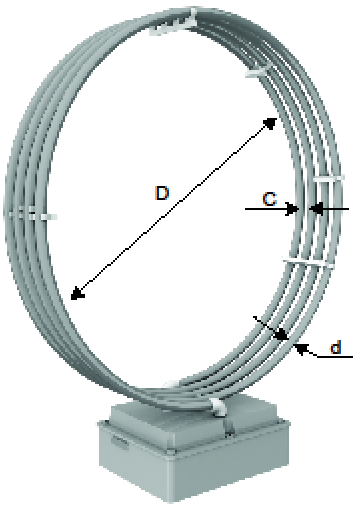


Frequency [Hz] $fo := 14100000$

Freq. range: $f := 1000000, 1001000 .. 4000000$

Conductor diamettter [m] $d := 0.022$

Diameter of the loop [m] $D := 0.8$

Number of turns $N := 3$

Transmitting power [W] $P := 100$

Spacing between turns [m] (measured to the center conductor) $C := 0.045$

Material conductivity [S/m] $\sigma := 58.108 \cdot 10^{6}$

$c := 299.792 \cdot 10 \quad \mu := 4\pi \cdot 10^{-7}$

GEOMETRY

Wavelenght [m]	$\lambda(f) := \frac{c}{f}$	$\lambda(fo) = 21.262$
Lenght (circumference) of one turn [m]	$U := \pi \cdot D$	$U = 2.513$
Lenght of N-turn loop [m]	$Uall := U \cdot N$	$Uall = 7.54$
Diameter to wavelenght ratio [%]	$k(f) := \frac{U \cdot 100}{\lambda(f)}$	$k(fo) = 11.821$
Diameter of coupling loop [m]	$dv := \frac{D}{5}$	$dv = 160 \times 10^{-3}$
Lenght of coupling loop [m]	$u := dv \cdot \pi$	$u = 502.655 \times 10^{-3}$
Surface of mail loop [m^2]	$A := \pi \cdot \frac{D^2}{4}$	$A = 502.655 \times 10^{-3}$

GEOMETRY

Rezistances

Radiation rezistance [Ω] $Rr(f) := \frac{8\cdot(120\pi)\cdot\pi^3}{3}\cdot\frac{N^2\cdot A^2}{\lambda(f)^4}$ $Rr(fo) = 346.839\times10^{-3}$

Skin-depth [m] $\delta(f) := \sqrt{\frac{2}{2\pi\cdot f\cdot\mu\cdot\sigma}}$ $\delta(fo) = 17.583\times10^{-6}$

another eq: $\delta 2(f) := 10^{-3}\cdot 50.3\cdot\sqrt{\frac{1.673}{f}}$ $\delta 2(fo) = 17.326\times10^{-6}$

Surface of orthogonal conductor cut (respecting skin-depth): $Sc := \pi\cdot\delta(fo)\cdot(d-\delta(fo))\cdot10^6$ $Sc = 1.\,mm^2$

Omit Skin-effect if d/δ>1 $\frac{d}{\delta(fo)} = 1.251\times10^3$

Loss resistance[Ω]

Conductor surface resistance [Ω] $Rs(f) := \sqrt{\frac{\pi\cdot f\cdot\mu}{\sigma}}$ $Rs(fo) = 978.749\times10^{-6}$

HF resistance for one turn loop [Ω] $Rl(f) := \frac{Uall\cdot Rs(f)}{\pi\cdot d}$ $Rl(fo) = 106.773\times10^{-3}$

(For N-1 use Rl)

Overall R [Ω] $Rin(f) := \begin{cases}(Rl(f)+Rr(f)) & \text{if } N = 1\\ (RL(f)+Rr(f)) & \text{if } N > 1\end{cases}$ $Rin(fo) = 474.432\times10^{-3}$

Rezistances

Main loop inductance [H] $Lmain := \mu\cdot\frac{D}{2}\cdot\left(\ln\left(\frac{8\cdot D}{d}\right)-2\right)\cdot N^2$ $Lmain = 16.616\times10^{-6}$

Internal inductance [H] $Li(f) := \frac{Uall}{2\cdot\pi\cdot fo\cdot\pi\cdot d}\cdot Rs(f)$ $Li(fo) = 1.205\times10^{-9}$

Total inductance [H] $Lall(f) := Lmain + Li(f)$ $Lall(fo) = 16.618\times10^{-6}$

Resonant capacitance [F] $Xin(f) := 2\pi\cdot f\cdot Lall(f)$ $Xin(fo) = 1.472\times10^3$

Tuning capacitor [F] $Cr(f) := \frac{1}{2\pi\cdot f}\cdot\frac{Xin(f)}{Rin(f)^2+Xin(f)^2}$ $Cr(fo) = 7.667\times10^{-12}$

Ohmic skin-efect resistance for N-loop [Ω]

$$R0(f) := \frac{N \cdot Rs(f)}{\pi \cdot d} \qquad R0(fo) = 42.483 \times 10^{-3}$$

Proximity effect [Ω]

$$Rp(f) := R0(f) \cdot z \qquad Rp(fo) = 8.284 \times 10^{-3}$$

Loss resistance N-turn (skin+proximity) [Ω]

(For N-turn loop use RL)

$$RL(f) := \frac{N \cdot D}{d} \cdot Rs(f) \cdot \left(\frac{Rp(f)}{R0(f)} + 1 \right)$$

$$RL(fo) = 127.593 \times 10^{-3}$$

$\frac{C}{d} = 2.05$

according C/d and N find in the table z and put it here: $z := 0.195$

Table 1-1. Normalized Additional Ohmic Resistance Per Unit Length Due to the Proximity Effect R_p/R_o.

Spacing c/a	Number of Conductors						
	2	3	4	5	6	7	8
1.00	0.333						
1.05	0.316	0.748	1.231				
1.10	0.299	0.643	0.996	1.347	1.689	2.020	2.340
1.15	0.284	0.580	0.868	1.142	1.400	1.693	1.872
1.20	0.268	0.531	0.777	1.002	1.210	1.401	1.577
1.25	0.254	0.491	0.704	0.896	1.068	1.224	1.365
1.30	0.240	0.455	0.644	0.809	0.956	1.086	1.203
1.40	0.214	0.395	0.546	0.674	0.784	0.880	0.965
1.50	0.191	0.346	0.470	0.572	0.658	0.732	0.796
1.60	0.173	0.305	0.408	0.492	0.561	0.620	0.670
1.70	0.155	0.270	0.353	0.428	0.485	0.532	0.573
1.80	0.141	0.241	0.316	0.375	0.423	0.462	0.495
1.90	0.128	0.216	0.281	0.332	0.372	0.405	0.433
2.00	0.116	0.195	0.252	0.295	0.330	0.358	0.392
2.20	0.098	0.161	0.205	0.239	0.265	0.286	0.304
2.40	0.032	0.135	0.170	0.197	0.217	0.234	0.247
2.50	0.077	0.124	0.156	0.180	0.198	0.213	0.225
2.60	0.071	0.114	0.144	0.165	0.182	0.195	0.206
2.80	0.061	0.098	0.123	0.141	0.154	0.165	0.174
3.00	0.054	0.085	0.106	0.121	0.133	0.142	0.150
3.50	0.040	0.062	0.077	0.087	0.095	0.101	0.106
4.00	0.031	0.048	0.058	0.066	0.072	0.076	0.080

Quality of LC circuit $Q(f) := \frac{Xin(f)}{Rin(f)}$ $Q(fo) = 3.103 \times 10^{3}$

Capacitor voltage [V] $Uc(f) := \sqrt{P \cdot 2\pi \cdot fo \cdot Lall(f) \cdot Q(f)}$ $Uc(fo) = 21.374 \times 10^{3}$

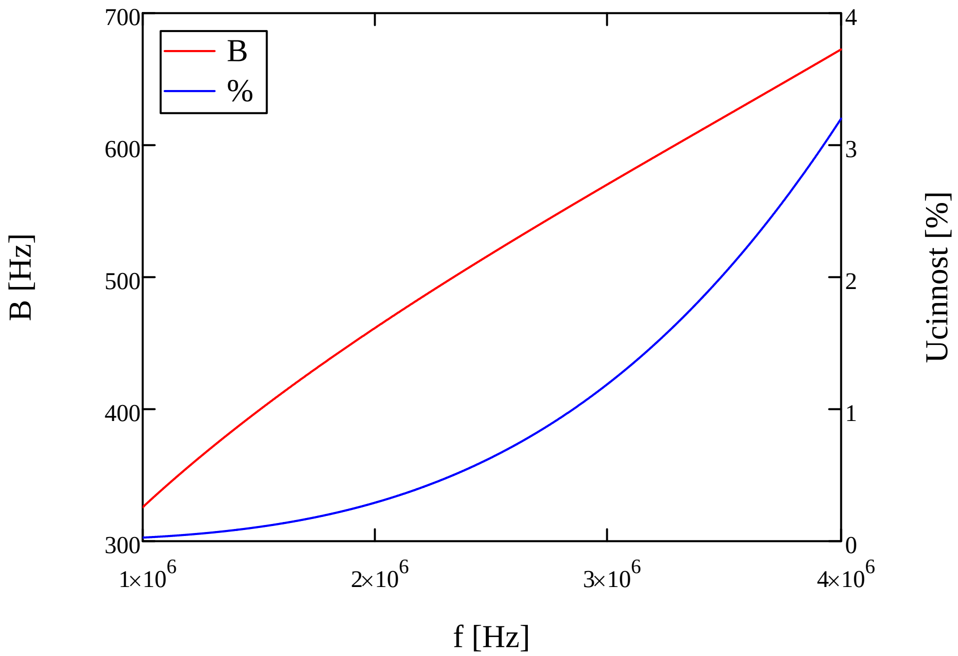
Efficiency [%] $\eta(f) := \frac{Rr(f) \cdot 100}{Rin(f)}$ $\eta(fo) = 73.106 \times 10^{0}$

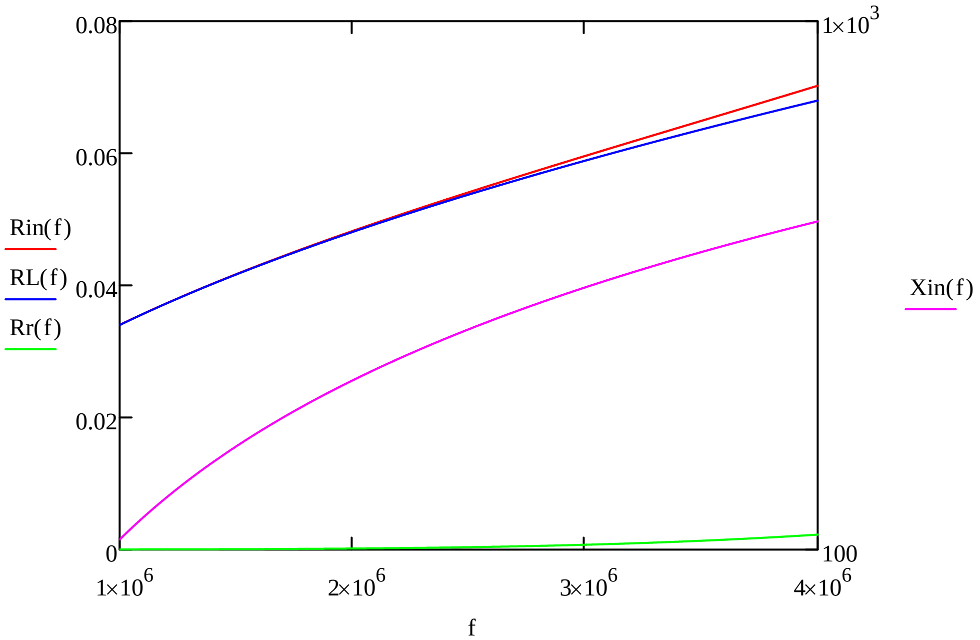
Resonant circular current [A] $I(f) := \frac{Uc(f)}{Xin(f)}$ $I(fo) = 14.518 \times 10^{0}$

Bandwith [Hz] $B(f) := \frac{f}{Q(f)}$ $B(fo) = 4.544 \times 10^{3}$

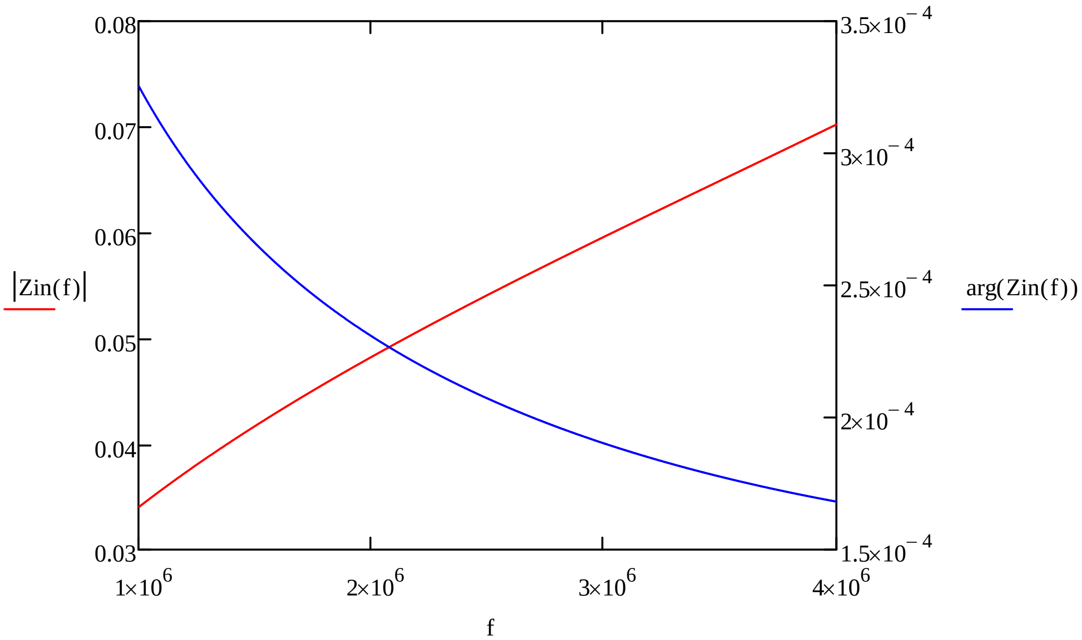
Current density [A/mm^2] $Jc := \frac{I(fo)}{Sc}$ $Jc = 11.956$

$Y(f) := \frac{1}{Rin(f)} + \frac{1}{i\,Xin(f)}$ $Zin(f) := \frac{1}{Y(f)}$




0.08
0.06
0.04
0.02
0
1×10^3
100
1×10^6
2×10^6
3×10^6
4×10^6
f
Rin(f)
RL(f)
Rr(f)
Xin(f)

f [Hz]



0.08
0.07
0.06
0.05
0.04
0.03
|Zin(f)|
3.5×10^−4
3×10^−4
2.5×10^−4
2×10^−4
1.5×10^−4
arg(Zin(f))
1×10^6
2×10^6
3×10^6
4×10^6
f

f [Hz]

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Sources:

[1]Balanis, Constantine. Antenna theory : analysis and design. Hoboken, NJ: John Wiley, 2005. Print. ISBN:9780471667827

[2]Smith, Glenn, S. "Radiation efficiency of electrically small multiturn loop antennas," in Antennas and Propagation, IEEE Transactions on , vol.20, no.5, pp.656-657, Sep 1972, doi: 10.1109/TAP.1972.1140293
URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1140293&isnumber=25508

[3]Smith, Glenn S., Proximity Effect in Systems of Parallel Conductors. Journal of Applied Physics, 43, 2196-2203 (1972), ISSN 0021-8979, DOI:http://dx.doi.org/10.1063/1.1661474