Lecture 11: Loop Antennas

11.1 Introduction to the Loop Antenna

- Loop Antenna:

- A wire or a printed strip in a closed loop form

- Applications:

Wireless comm.: NVIS

Amateur radio communication: 3-30MHz

Short-wave radio Rx

Radio direction finding

NFC / RFID

Magentic field measurements,

- Useful frequency range: 3kHz – 30GHz

Figure: HF loop antenna for amateur radio (qrznow.com, J. Hallas, W1ZR)

11.1 Introduction to the Loop Antenna

- Loop Antenna Types:

- Small loop

- Large loop

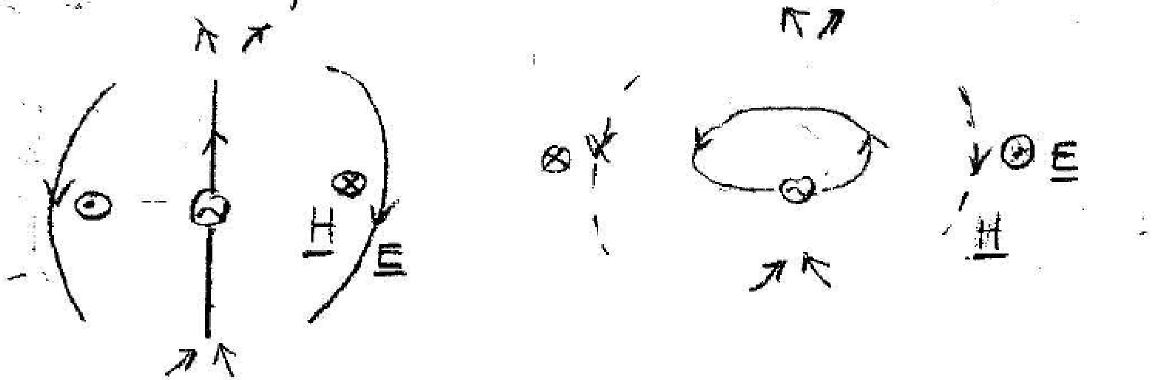
- Horizontal/vertical loop

- Multi-turn loop

- Loop array

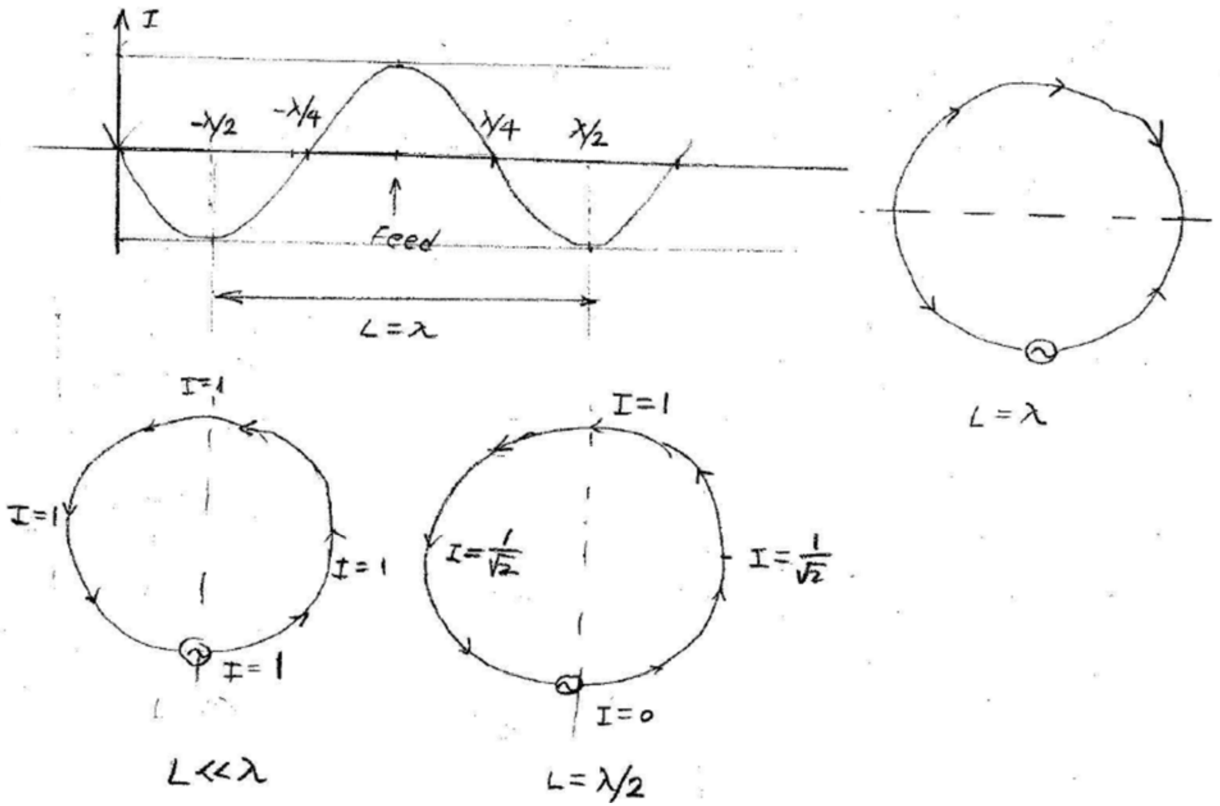
- Active loop

- Duality Principle:

	Dipole	Loop
E- and H- field		
E at far field	$\sin\theta$	$\sin\theta$
Small antenna	$1-j500\,\Omega$	$1+j500\,\Omega$
Resonant antenna	$72\,\Omega$	$150\,\Omega$
Resonant length	0.45λ	1.05λ

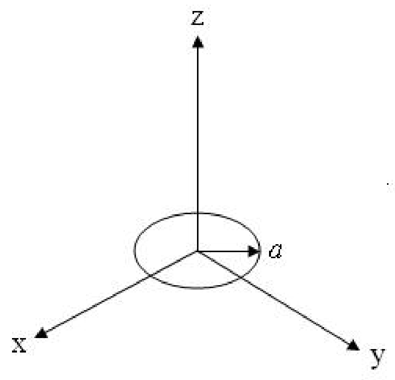
- Loop Current:

\- cos(*kl*), sin(*kl*) variation along the loop



- Electrically Small Loop:

- $C = 2\pi a < \lambda / 3$, $2a < 0.1\lambda$
- Current: constant along the loop, $I = I_0$



- Far-field:

$$H_\theta = -k^2 (I_0 S) \frac{e^{-jkr}}{4\pi r} \sin\theta; \; E_\phi = \eta H_\theta$$

$$k = \omega\sqrt{\mu\varepsilon} = \lambda / (2\pi); \; S = \pi a^2; \eta = \sqrt{\mu / \varepsilon}$$

11.4 Small Loop Antenna

- Radiation resistance:

$$R_r = \frac{2P_r}{I_0^2} = \frac{8}{3}\eta\pi^3\left(\frac{S}{\lambda^2}\right)^2 = 20\pi^2(\beta a)^4$$

- Directivity:

$$D_0 = 1.5 = 1.8 \text{ dB}$$

$$D(\theta,\phi) = D_0 \sin^2\theta$$

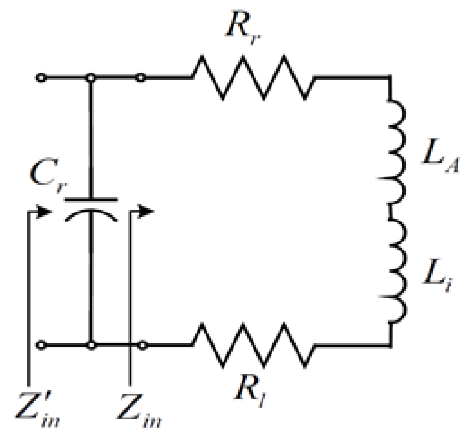
Thin wire (b<<a)

$$B = \frac{\mu_0 I}{2\pi r}$$

$$L_A = \mu_0 a\left[\ln\frac{8a}{b} - 2\right]$$

$$L_i = \begin{cases} \frac{\mu_0}{8\pi}2\pi a = \frac{\mu_0 a}{4}, & \text{DC} \\ 0, & \text{At high frequency} \end{cases}$$

- Equivalent circuit with a tuning capacitor



R_r : radiation resistance

R_l : conductor loss resistance

L_A : loop external inductance

L_i : loop internal inductance, due to H inside the conductor

$$R_l = \frac{2\pi a}{2\pi b}R_s,\ R_s = \sqrt{\frac{\pi f \mu_0}{\sigma}}$$

Thick wire: formulas by R. Dengler, Advanced Electromagnetics, 5(1), Jan. 2016

$$L_A = \mu_0 a\left[\left(1 + \frac{3}{4}\frac{a^2}{b^2}\right)\ln\frac{8a}{b} - 2 - \frac{3}{2}\frac{a^2}{b^2}\right]$$

$$L_i = \mu_0 a\left[\frac{1}{4} + \frac{a^2}{b^2}\left(\frac{5}{6} - \frac{3}{8}\ln\frac{8a}{b}\right)\right]$$

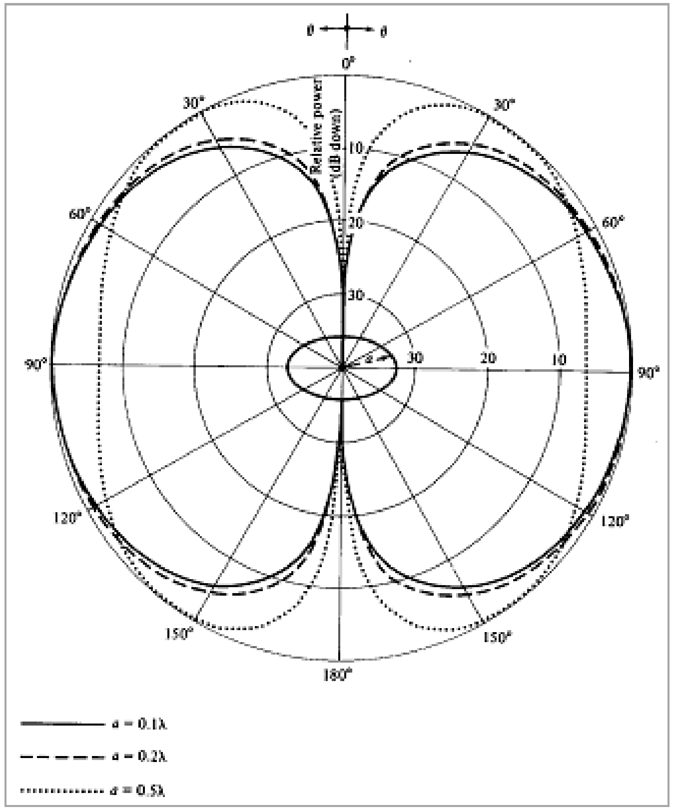
$$Q = \frac{\omega(L_A + L_i)}{R_A + R_s}$$: quality factor

11.5 Large Loop Antenna

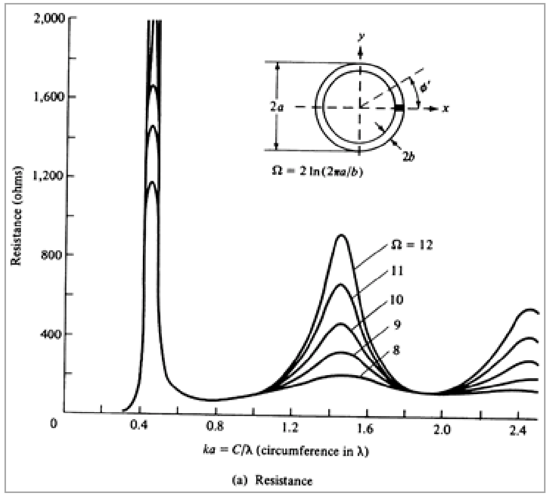
- Resonant loop: $2\pi a = \lambda$, $2a = 0.3\,\lambda$

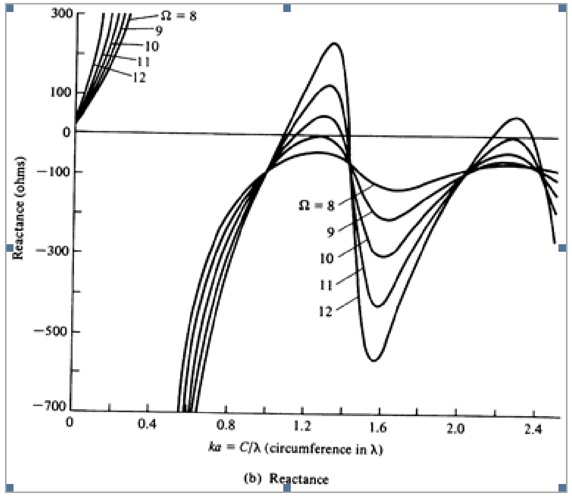
$C = 2\pi a \geq \lambda$

Radiation pattern



Input impedance





Large impedance (anti-resonance) when $C = 0.5\lambda$

Resonance at $C = 1.0, 1.5, 2.0, 2.5\ \lambda$

11.6 Small Loop Antenna, Impedance Matching

- Boswell *et al.*, https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1487778

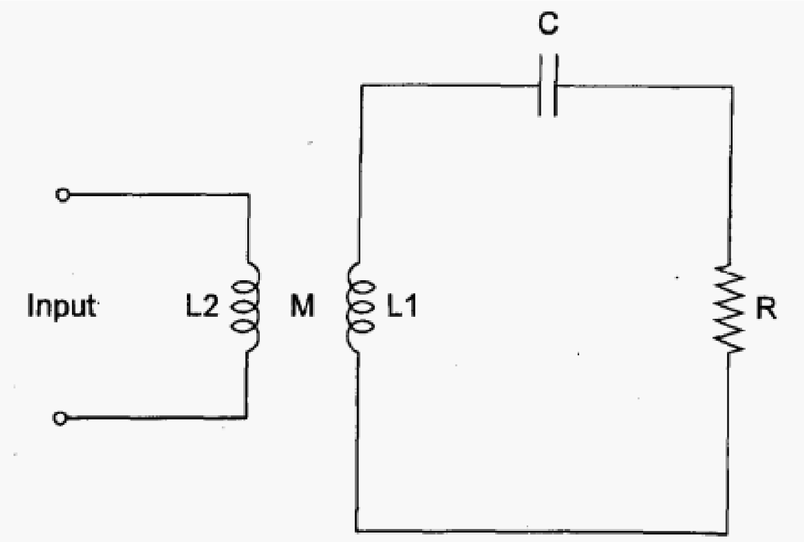


Figure 1. The equivalent circuit of the loop. L_1 **: main loop;** L_2 **: coupling loop;** M **: mutual inductance;** C **: resonating capacitance;** R **: total resistance.**

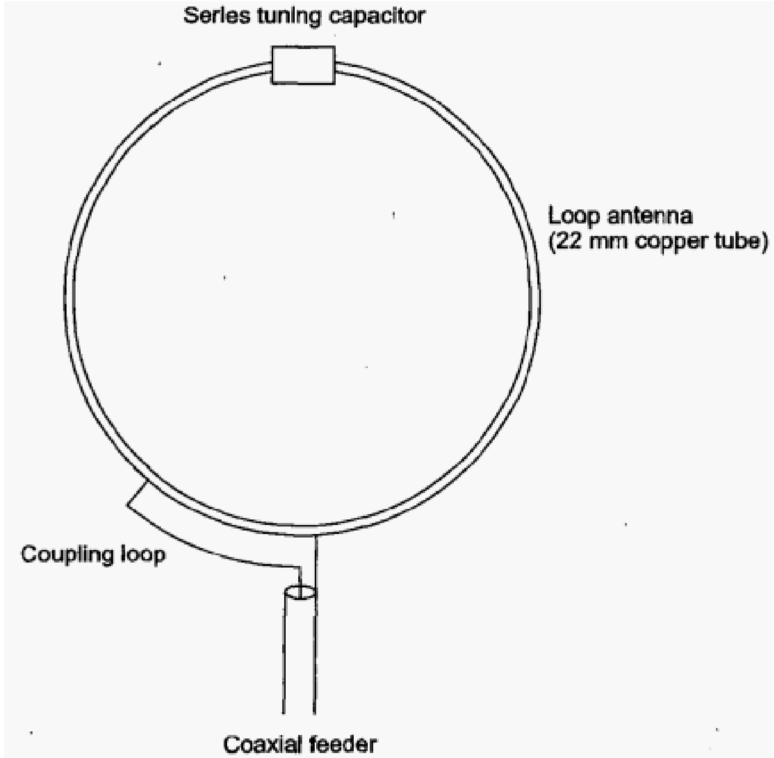
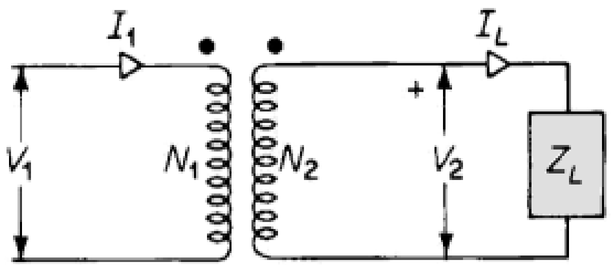
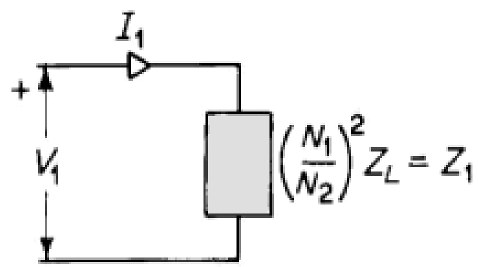


Figure 2. The arrangement of the loop antenna.





11.6 Small Loop Antenna, Impedance Matching

- Solbach *et al.*, https://www.uni-due.de/imperia/md/content/hft/papers/mla_paper_english.pdf

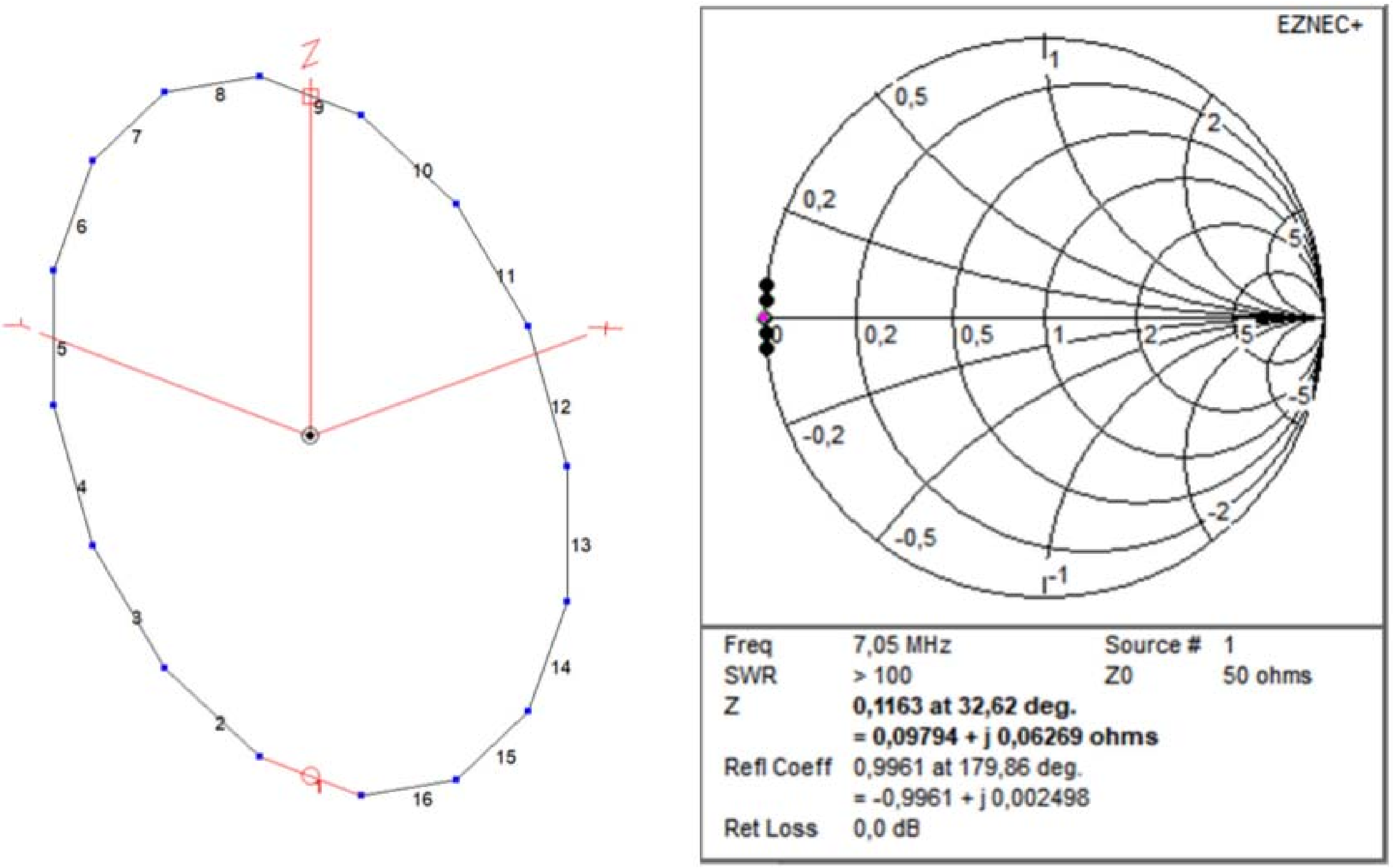


Figure 3 The conductors of the MLA with the source in wire 1 below and the capacitor in wire 9 above and the reflection factor in the Smith Chart as a simulation result. Note: Model with only 1 seg/wire.

11.6 Small Loop Antenna, Impedance Matching

- Solbach *et al.*, https://www.uni-due.de/imperia/md/content/hft/papers/mla_paper_english.pdf

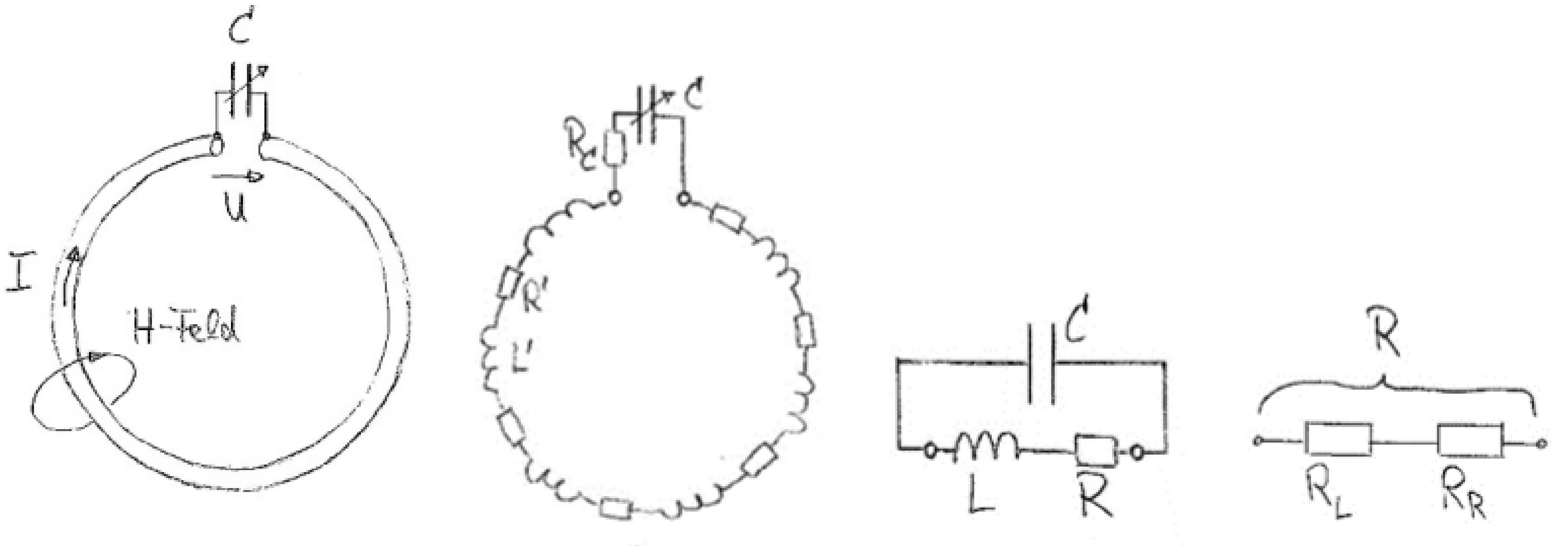


Figure 2 The MLA conductor loop in free space with capacitor tuning and corresponding equivalent circuit diagrams

- Solbach *et al.*, https://www.uni-due.de/imperia/md/content/hft/papers/mla_paper_english.pdf

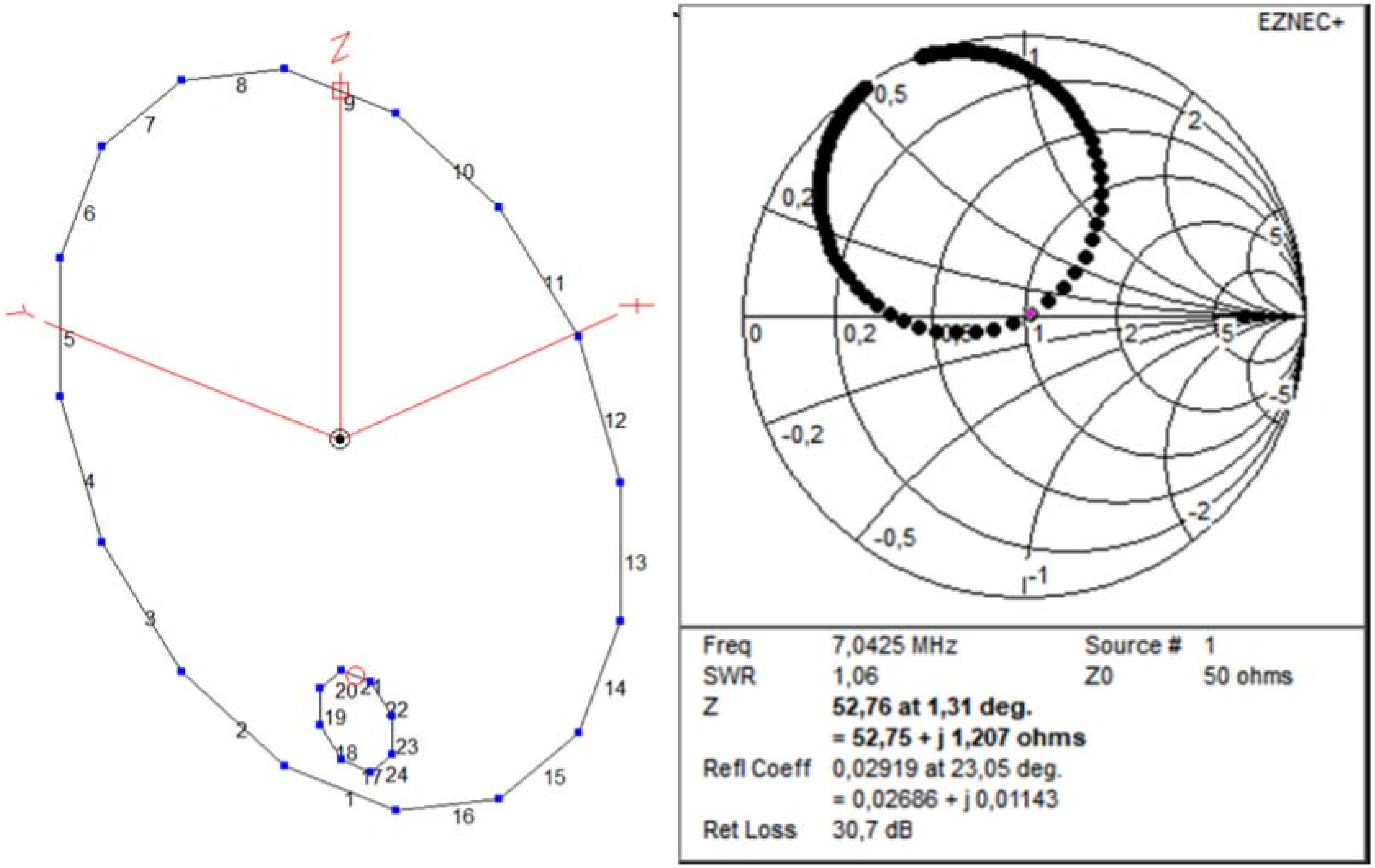


Figure 4 Conductor configuration of the MLA with feed in the lower conductor segment of a coupling loop with a diameter of 23.3 cm and a Smith Chart showing the calculated antenna impedance over the frequency range from 7.01 to 7.07 MHz.

- Solbach *et al.*, https://www.uni-due.de/imperia/md/content/hft/papers/mla_paper_english.pdf

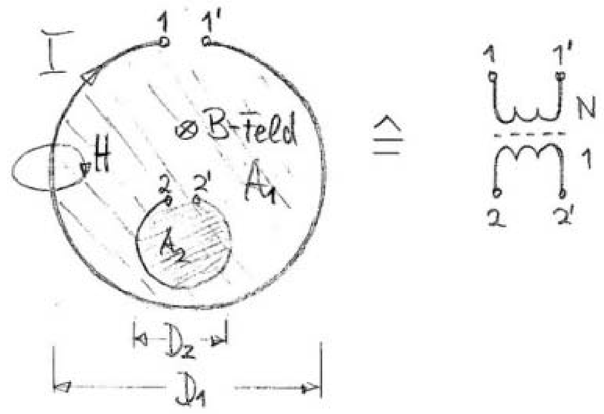


Figure 5 Equivalent circuit representation of the coupling of the large loop and the coupling loop

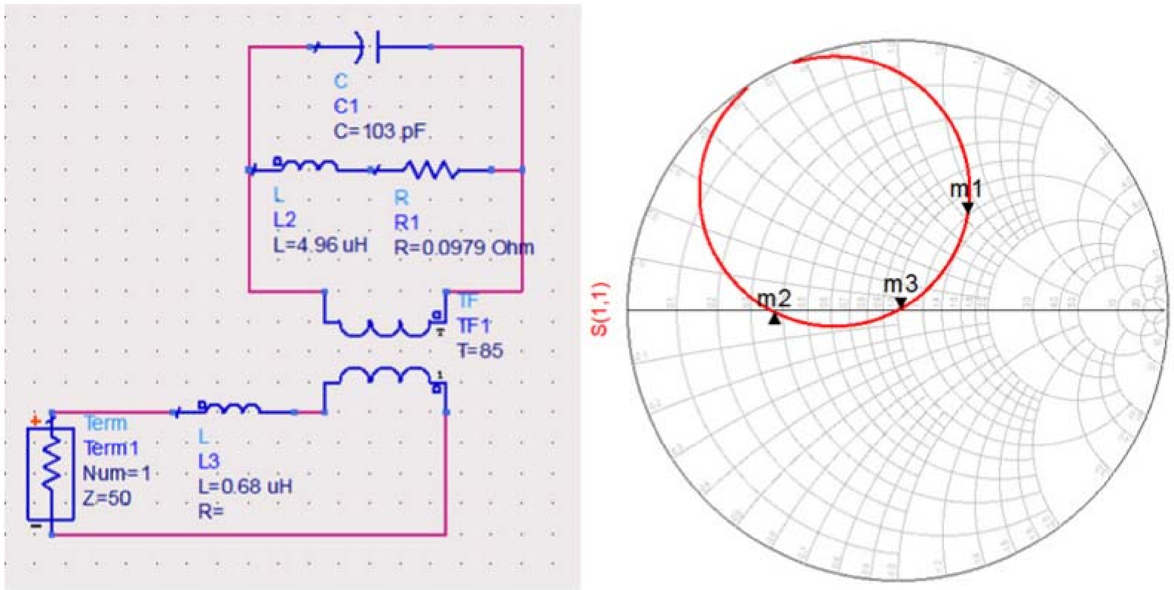


Figure 6 Equivalent circuit diagram of the MLA with coupling loop for matching to 50 Ω and Smith Chart as the result of the simulation in ADS.

11.7 Loop Antenna Application Examples

- FM antenna: 87.5-108 MHz, 21.5" dia., 75-ohm impedance, $50

- Amateur antenna: 6.6-29.8MHz, 0.6-1kW, ATU(automatic tuning unit), 40" dia., $2100

11.7 Loop Antenna Application Examples

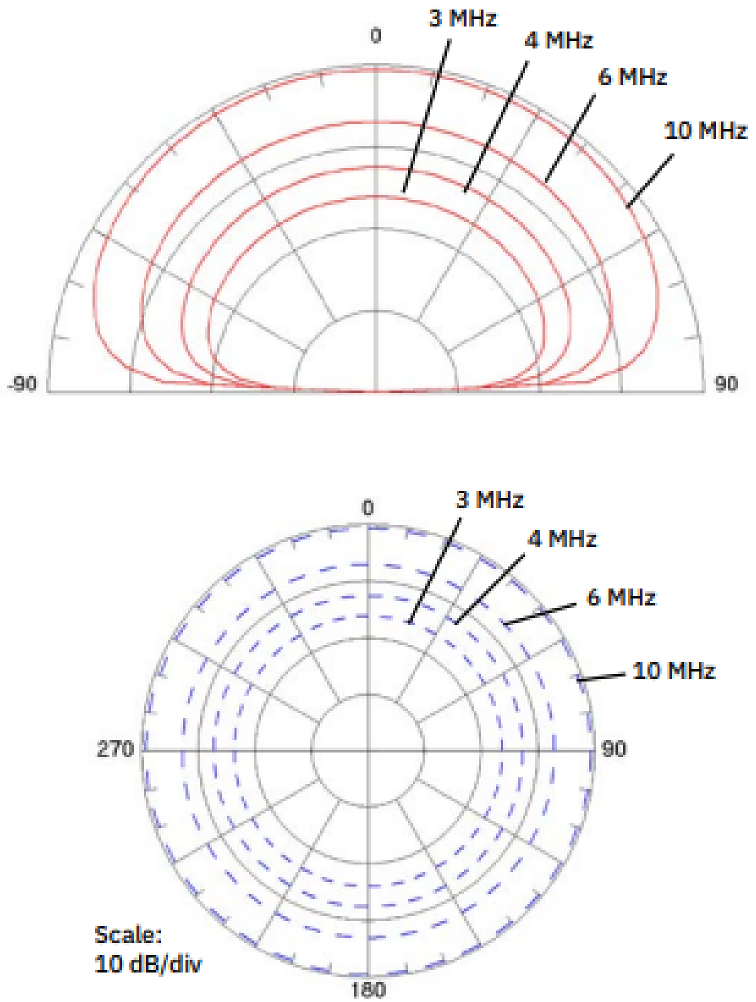
- AM radio receiving antenna: 0.52-1.71MHz, $66

- HF active loop antenna: 0.5-55MHz, 14", HF multicoupler, 50 ohm, 0.8 dB noise figure, 25dB gain at 14MHz

11.7 Loop Antenna Application Examples

- L3Harris RF-3134-AT003/5, On-the-move vehicular loop antenna for NVIS HF comm.
  Gain = -24, -15, -8, -3 dBi @ 2, 3.5, 10, 30 MHz; 1.5m x 1.5m, 8 kg; VSWR < 2 with a coupler
https://www.l3harris.com/sites/default/files/2020-12/cs-tcom-rf-3134-at003-5-otm-vehicular-loop-antenna-datasheet.pdf

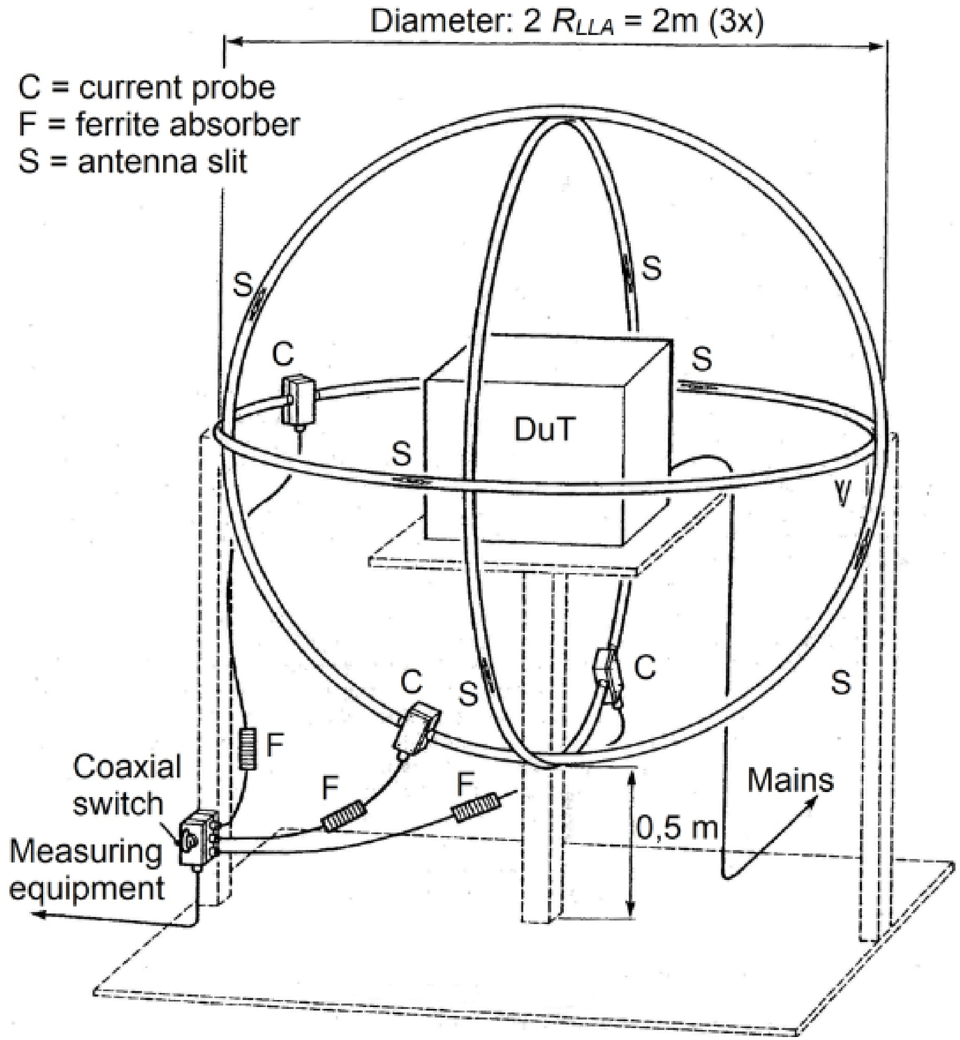
RF-3134C-AT003/5 Radiation Patterns



RF-3134-AT003/5 mounted on vehicle

11.7 Loop Antenna Application Examples

- Radiated emission measurement: Kundrata *et al*.
https://www.researchgate.net/figure/The-Large-Loop-Antenna-LLA-system-which-consists-of-three-orthogonal-loop-antennas_fig3_318613679



The Large Loop Antenna (LLA) system which consists of three orthogonal loop antennas, according to the standard CISPR 16 [5].

ICE-5108084 Antenna Design

Lecture 11: Loop Antennas

Fin

(End)