Two Multiple-Antenna-Port and Multiple-User-Port Antenna Tuners

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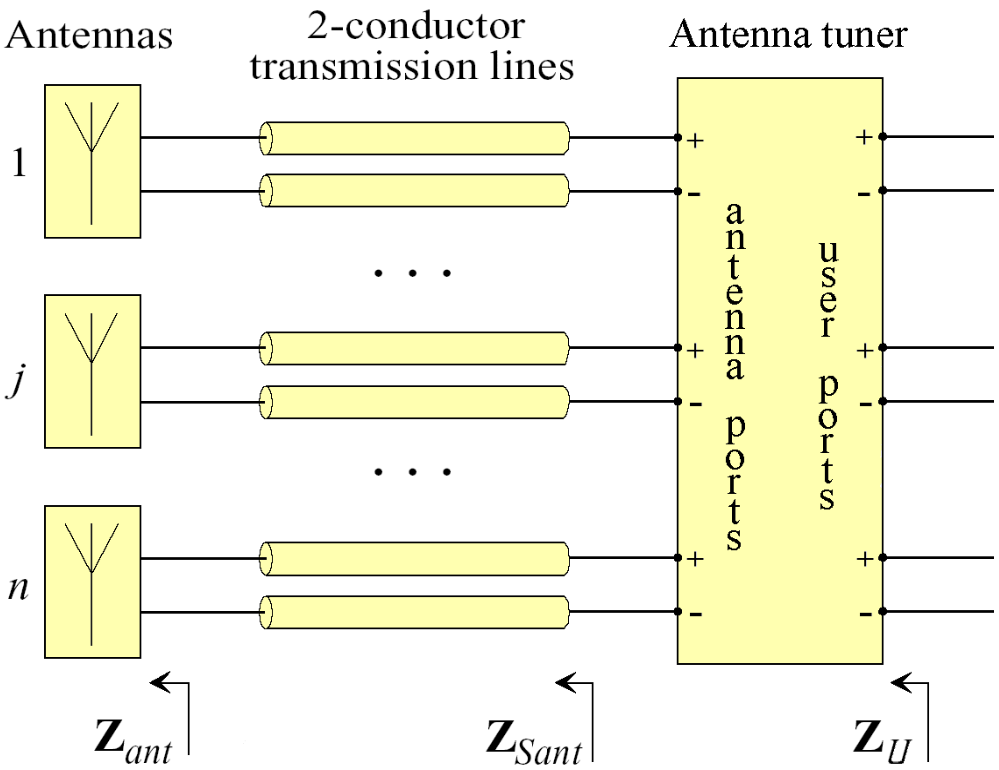
1. Introduction

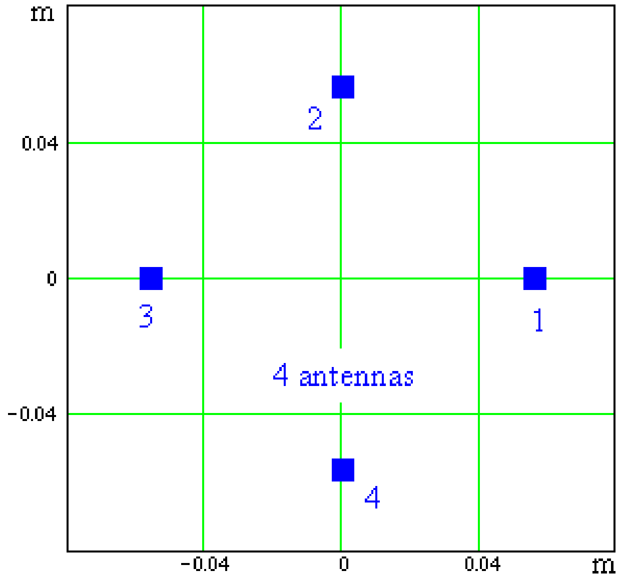
❒ A radio device uses several antennas simultaneously in the same frequency band.

❒ A MAPMUP antenna tuner is intended to be inserted between the antennas and the radio device.



❒ The MAPMUP antenna tuner allows an adjustment of $\mathbf{Z}_U$, using a selection of the reactance values of its p adjustable impedance devices. Thus, it is possible to compensate a variation in $\mathbf{Z}_{Sant}$.

2. A MAPMUP antenna tuner specification

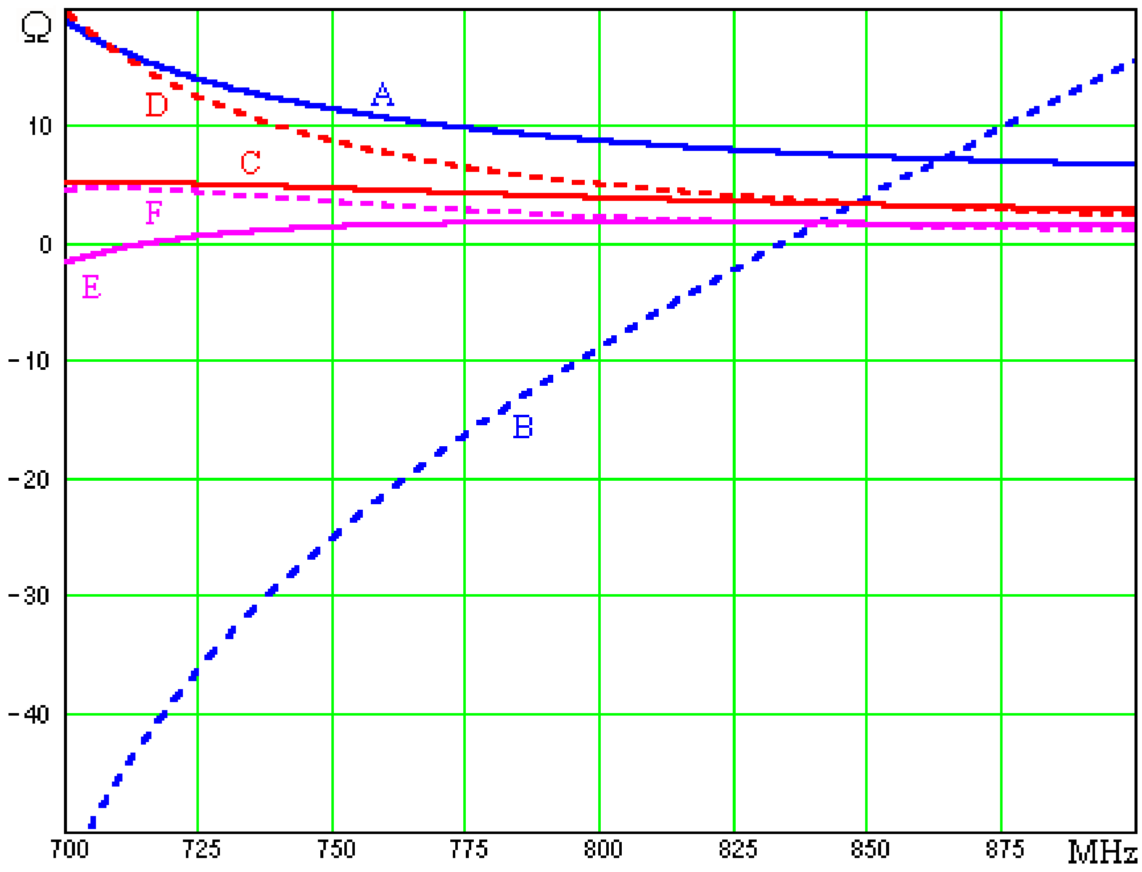


❒ A circular antenna array made up of $n = 4$ parallel dipole antennas is intended to operate in the frequency band 700 MHz to 900 MHz.

❒ At the center frequency f_c = 800 MHz, $\mathbf{Z}_{Sant}$ is approximately given by:

$$\mathbf{Z}_{Sant} \approx \begin{pmatrix} 8.6-8.9j & 3.8+4.9j & 1.7+2.2j & 3.8+4.9j \\ 3.8+4.9j & 8.6-8.9j & 3.8+4.9j & 1.7+2.2j \\ 1.7+2.2j & 3.8+4.9j & 8.6-8.9j & 3.8+4.9j \\ 3.8+4.9j & 1.7+2.2j & 3.8+4.9j & 8.6-8.9j \end{pmatrix} \Omega$$

❒ At any frequency, $\mathbf{Z}_{Sant}$ is symmetric and circulant.



Entries of $\mathbf{Z}_{Sant}$ versus frequency:
Re($\mathbf{Z}_{Sant\,11}$) is curve A;
Im($\mathbf{Z}_{Sant\,11}$) is curve B;
Re($\mathbf{Z}_{Sant\,12}$) is curve C;
Im($\mathbf{Z}_{Sant\,12}$) is curve D;
Re($\mathbf{Z}_{Sant\,13}$) is curve E;
Im($\mathbf{Z}_{Sant\,13}$) is curve F.

❒ The problem to be solved is the design of a lossless antenna tuner such that $\mathbf{Z}_U$ can approximate $\mathbf{Z}_{UW} = r_0\, \mathbf{1}_n$ at any frequency in the 700 MHz - 900 MHz band.

❒ Let $\mathbf{Z}$ be an impedance matrix of size $q \times q$. As a measure of the proximity of $\mathbf{Z}$ and $r_0\,\mathbf{1}_q$, we can use a scalar figure of merit such as the return figure $F_{dB}(\mathbf{Z})$ given by

$$F_{dB}(\mathbf{Z}) = 20\log\left(|||\mathbf{S}(\mathbf{Z})|||_2\right)$$

where $|||\cdot|||_2$ denotes the spectral norm and $\mathbf{S}(\mathbf{Z})$ is a scattering matrix defined by

$$\mathbf{S}(\mathbf{Z}) = \left(\mathbf{Z} + r_0\,\mathbf{I}_q\right)^{-1}\left(\mathbf{Z} - r_0\,\mathbf{I}_q\right) = \left(\mathbf{Z} - r_0\,\mathbf{I}_q\right)\left(\mathbf{Z} + r_0\,\mathbf{I}_q\right)^{-1}$$

❒ We show that, for a passive device, $|||\mathbf{S}(\mathbf{Z})|||_2 \leq 1$. Thus, $F_{dB}(\mathbf{Z}_U) \leq 0\text{dB}$ and $F_{dB}(\mathbf{Z}_{Sant}) \leq 0\text{dB}$.

❒ An ideal match $\mathbf{Z}_U = r_0\,\mathbf{1}_n$ corresponds to $F_{dB}(\mathbf{Z}_U) = -\infty$ dB.

❒ A possible design target is $F_{dB}(\mathbf{Z}_U) < -10$ dB.

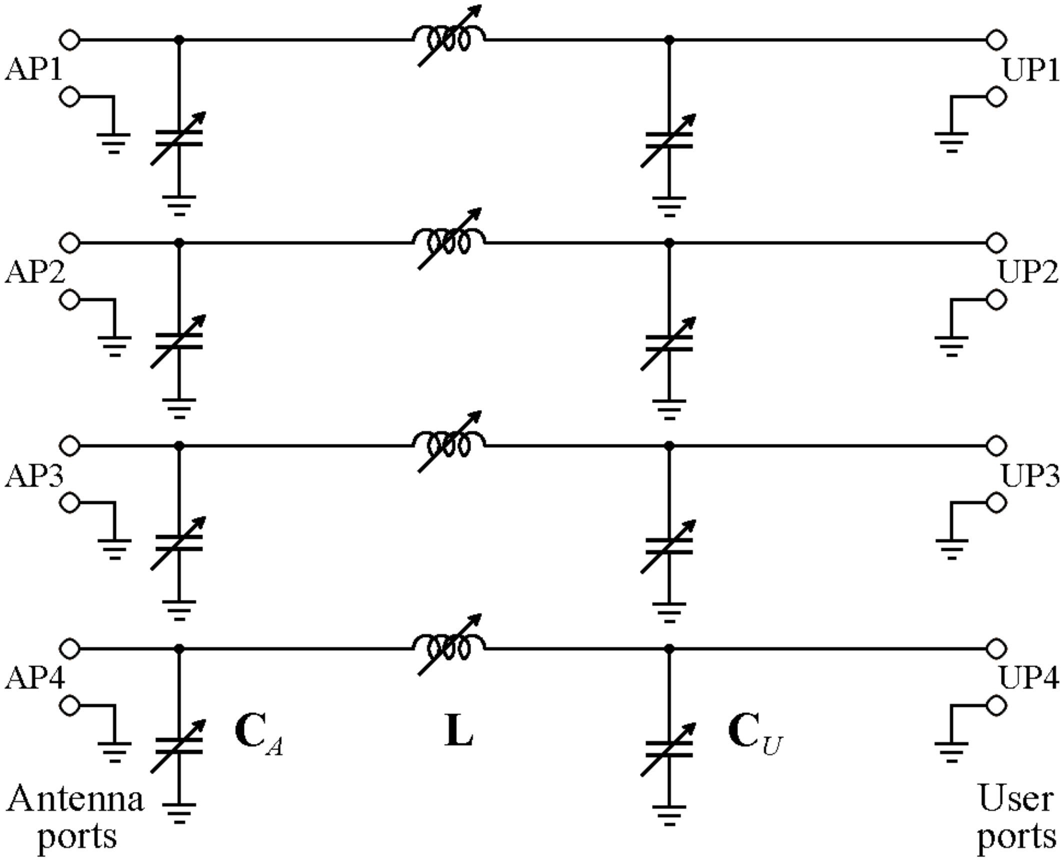
3. Case of a MAPMUP antenna tuner made of multiple SAPSUP antenna tuners

❒ The MAPMUP antenna tuner has $p = 3n$ adjustable impedance devices, or less.

❒ For $n \geq 3$, we have

$$p < n(n+1)$$

❒ Thus, there is no possibility of independently controlling the $n(n+1)$ real parameters which define $\mathbf{Z}_U$, to obtain $\mathbf{Z}_U = \mathbf{Z}_{UW}$.



❒ For the problem defined in § 2, $r_0 = 50\ \Omega$, and at $f_c = 800$ MHz, a numerical analysis leads us to conclude that:

- it is not possible to obtain $\mathbf{Z}_U = r_0\, \mathbf{1}_n$;
- the lowest possible value of $F_{dB}(\mathbf{Z}_U)$ is −4.65 dB ;
- the corresponding $\mathbf{Z}_U$ is

$$\mathbf{Z}_U \approx \begin{pmatrix} 72.7-3.0j & -42.4-10.1j & 25.2+20.5j & -42.4-10.1j \\ -42.4-10.1j & 72.7-3.0j & -42.4-10.1j & 25.2+20.5j \\ 25.2+20.5j & -42.4-10.1j & 72.7-3.0j & -42.4-10.1j \\ -42.4-10.1j & 25.2+20.5j & -42.4-10.1j & 72.7-3.0j \end{pmatrix} \Omega$$

whereas

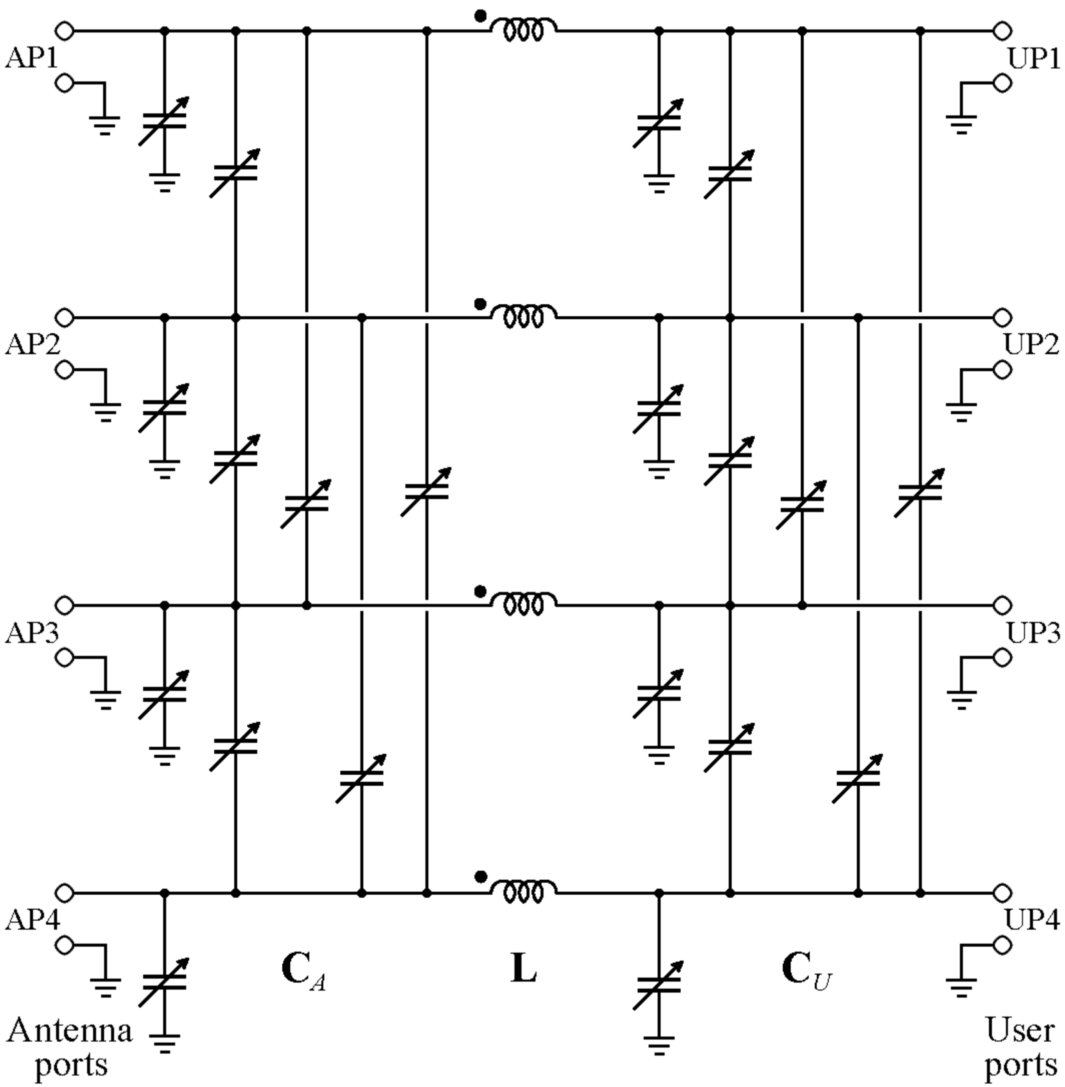
$$\mathbf{Z}_{UW} \approx \begin{pmatrix} 50 & 0 & 0 & 0 \\ 0 & 50 & 0 & 0 \\ 0 & 0 & 50 & 0 \\ 0 & 0 & 0 & 50 \end{pmatrix} \Omega$$

4. Results obtained with a new MAPMUP antenna tuner

❒ The MAPMUP antenna tuner has $p = n\ (n + 1)$ adjustable impedance devices.

❒ Thus, there is a possibility of independently controlling the $n\ (n + 1)$ real parameters which define $\mathbf{Z}_U$, to obtain $\mathbf{Z}_U = \mathbf{Z}_{UW}$.

❒ For the problem defined in § 2 and for $r_0 = 50\ \Omega$, we can find $\mathbf{L}$ such that it is possible to obtain $\mathbf{Z}_U = r_0\ \mathbf{1}_n$ at any frequency in the 700 MHz - 900 MHz band.



❒ The design of the lossless antenna tuner may be based on 3 formulas:

◆ To compute a possible $\mathbf{C}_U$ for a given $\mathbf{C}_\mathrm{A}$

$$\omega \mathbf{C}_U = \left[g_0 \mathbf{G}_{Sant} + g_0 (\mathbf{B}_{Sant} + \omega \mathbf{C}_A) \mathbf{G}_{Sant}^{-1} (\mathbf{B}_{Sant} + \omega \mathbf{C}_A) - g_0^2 \mathbf{1}_n \right]^{1/2}$$

where $\mathbf{Z}_{UW} = (1/g_0)\ \mathbf{1}_n = r_0\ \mathbf{1}_n$ and $\mathbf{Z}_{Sant}^{-1} = \mathbf{G}_{Sant} + j\mathbf{B}_{Sant}$

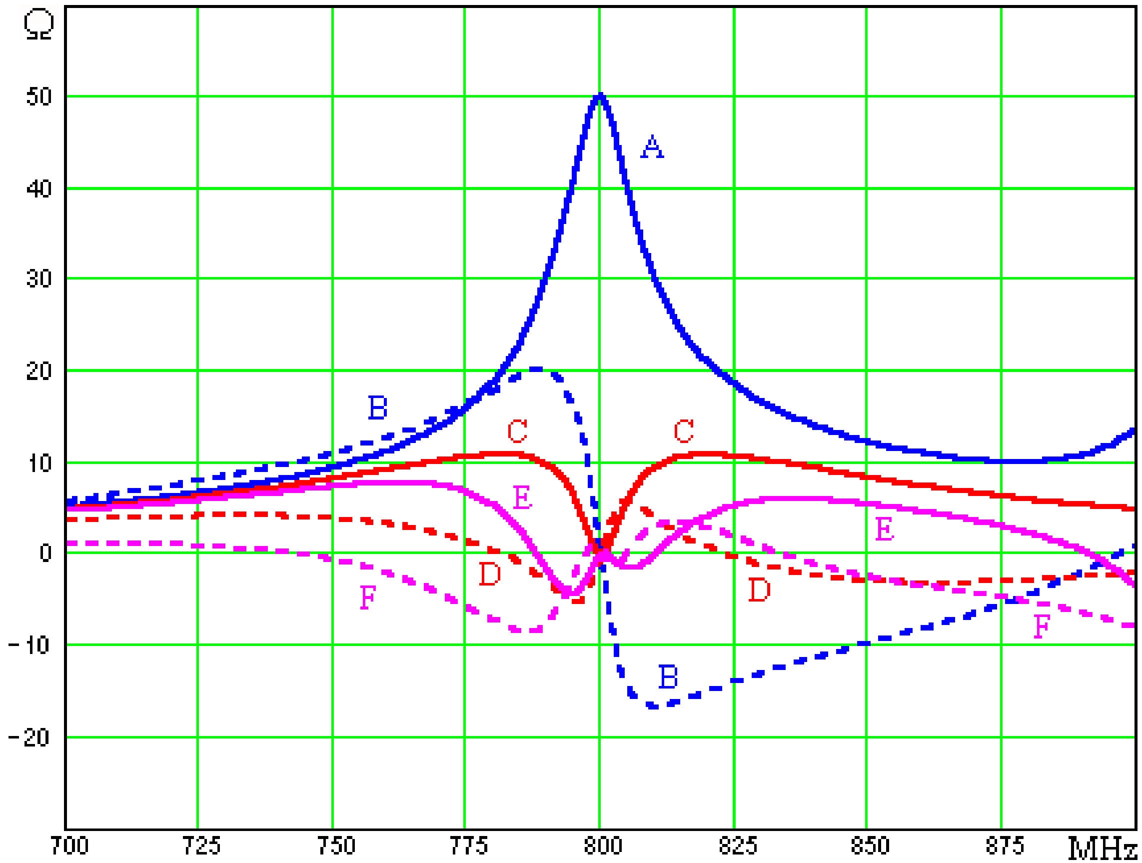
◆ To compute $\mathbf{L}$ for a given $\mathbf{C}_A$ and a given $\mathbf{C}_U$

$$\omega \mathbf{L} = \left[g_0^2 \mathbf{1}_n + (\omega \mathbf{C}_U)^2 \right]^{-1} \omega \mathbf{C}_U + \left[\mathbf{B}_{Sant} + \omega \mathbf{C}_A + \mathbf{G}_{Sant} (\mathbf{B}_{Sant} + \omega \mathbf{C}_A)^{-1} \mathbf{G}_{Sant} \right]^{-1}$$

◆ To compute a possible $\mathbf{C}_A$ for a given $\mathbf{L}$

$$\omega \mathbf{C}_A = (\omega \mathbf{L})^{-1} - \mathbf{B}_{Sant} + \mathbf{G}_{Sant} \left[(g_0 \mathbf{G}_{Sant})^{-1} (\omega \mathbf{L})^{-2} - \mathbf{1}_n \right]^{1/2}$$

❒ For one of the possible designs, we obtain:



Entries of $\mathbf{Z}_U$, for a tuning at 800 MHz :

Re($\mathbf{Z}_{U\,11}$) is curve A;

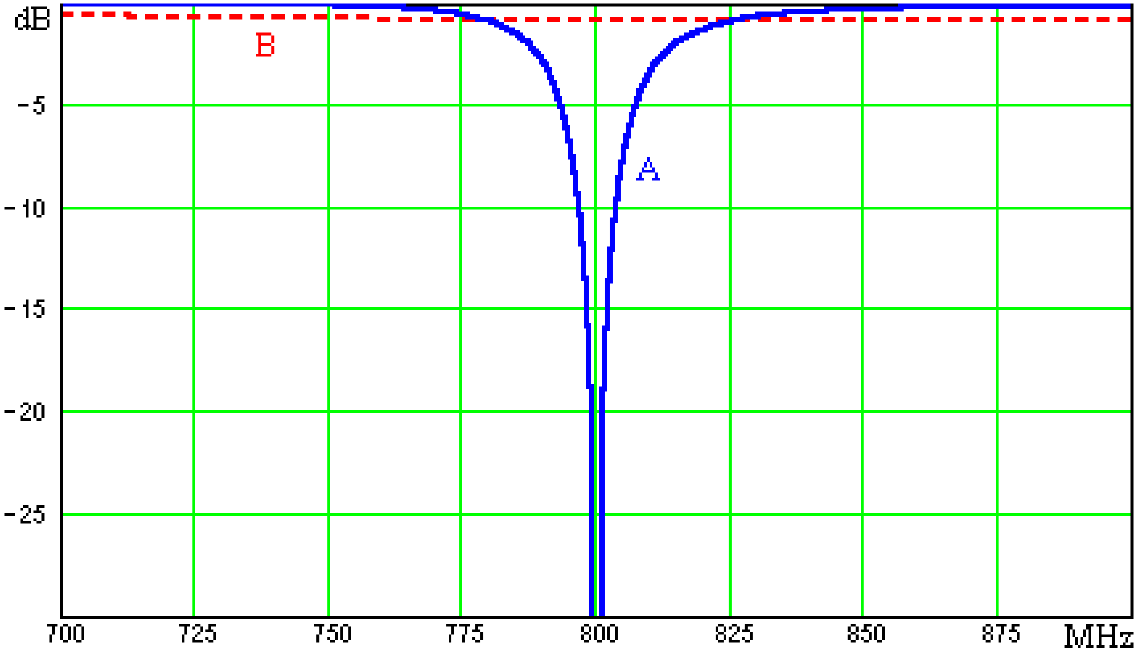
Im($\mathbf{Z}_{U\,11}$) is curve B;

Re($\mathbf{Z}_{U\,12}$) is curve C;

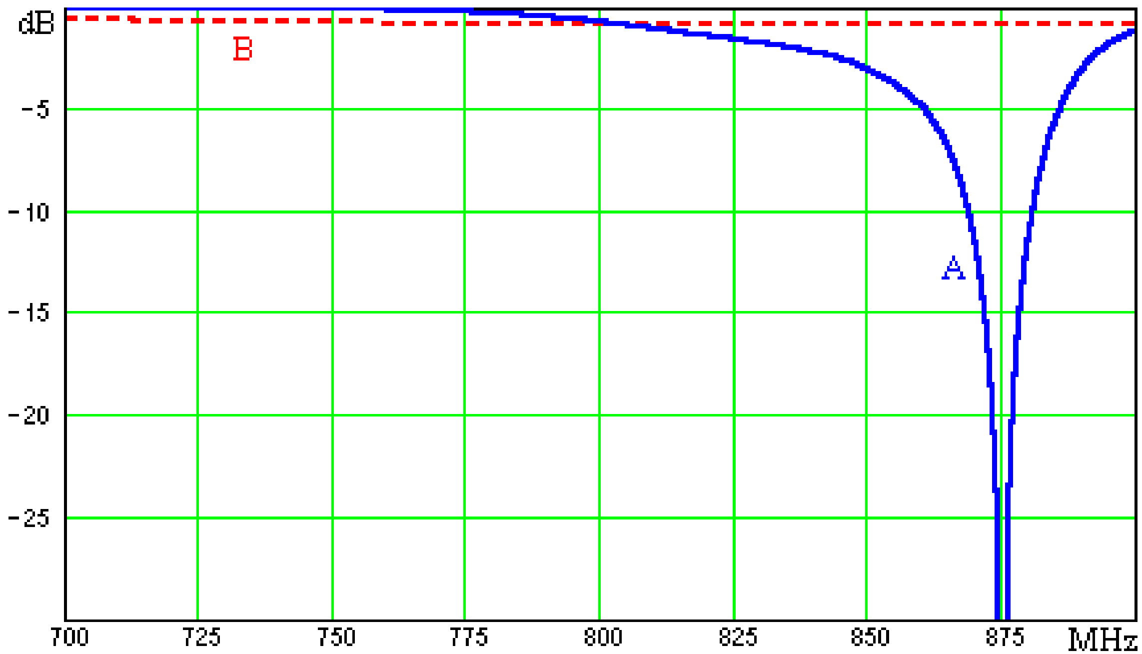
Im($\mathbf{Z}_{U\,12}$) is curve D;

Re($\mathbf{Z}_{U\,13}$) is curve E;

Im($\mathbf{Z}_{U\,13}$) is curve F.



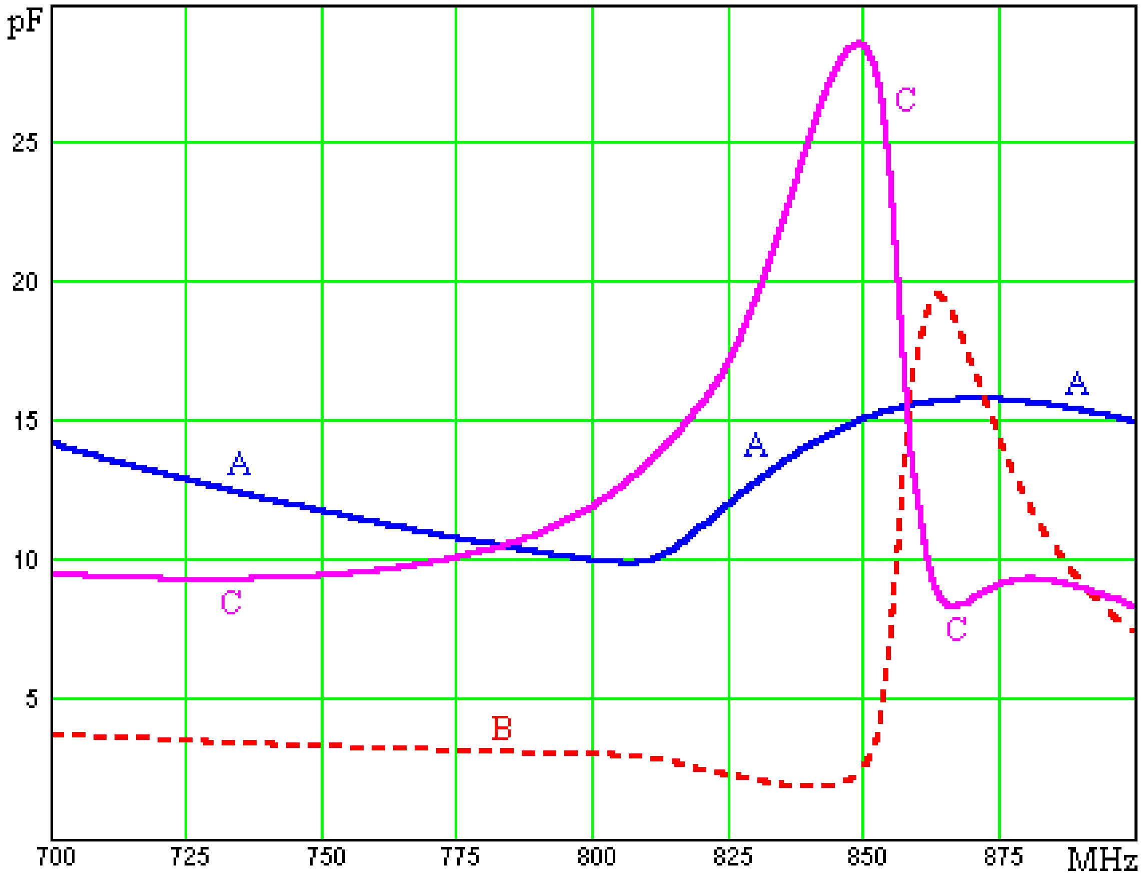
The return figure versus frequency, for the tuning at 800 MHz:
F_{dB} ($\mathbf{Z}_U$) is curve A;
F_{dB} ($\mathbf{Z}_{Sant}$) is curve B.



The return figure versus frequency, for a tuning at 875 MHz:

F_{dB} ($\mathbf{Z}_U$) is curve A;

F_{dB} ($\mathbf{Z}_{Sant}$) is curve B.

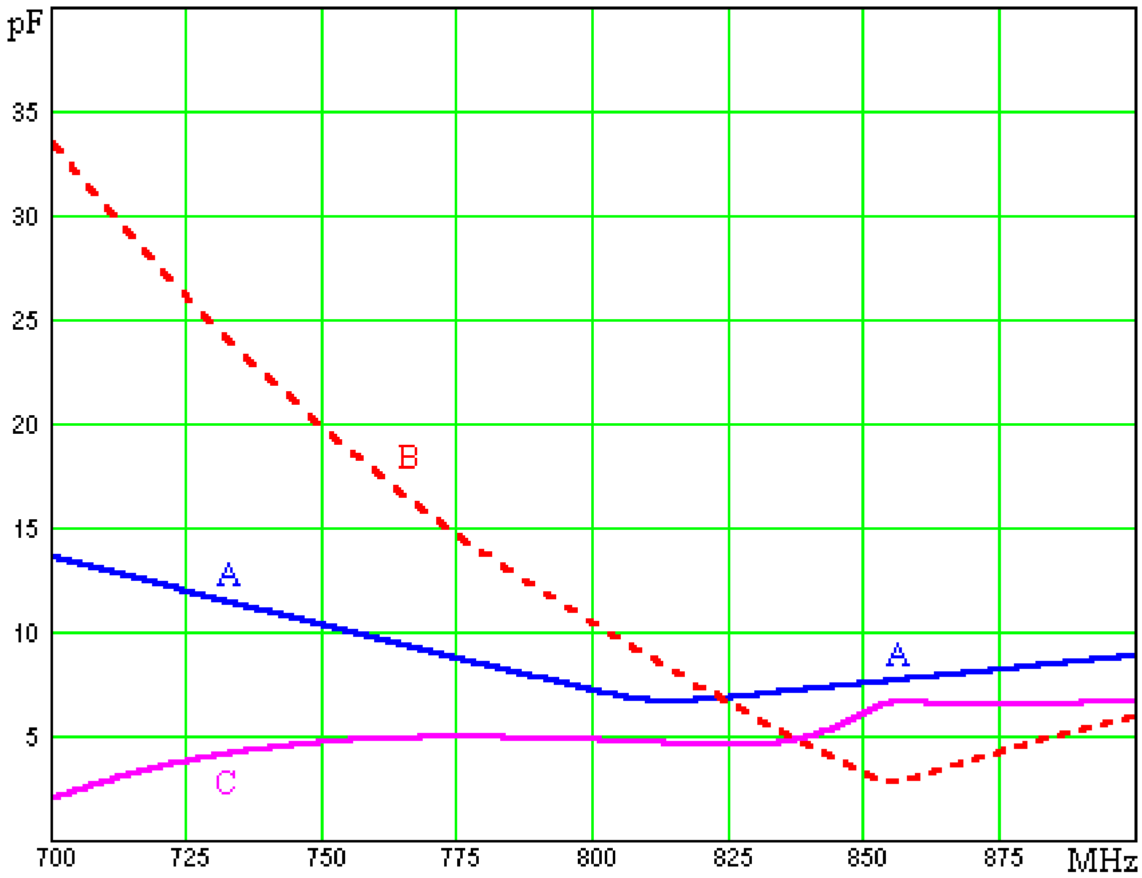


Capacitances of the adjustable impedance devices which realize $\mathbf{C}_A$, versus the tuning frequency:

C_{AG} is curve A;

C_{AN} is curve B;

C_{AF} is curve C.

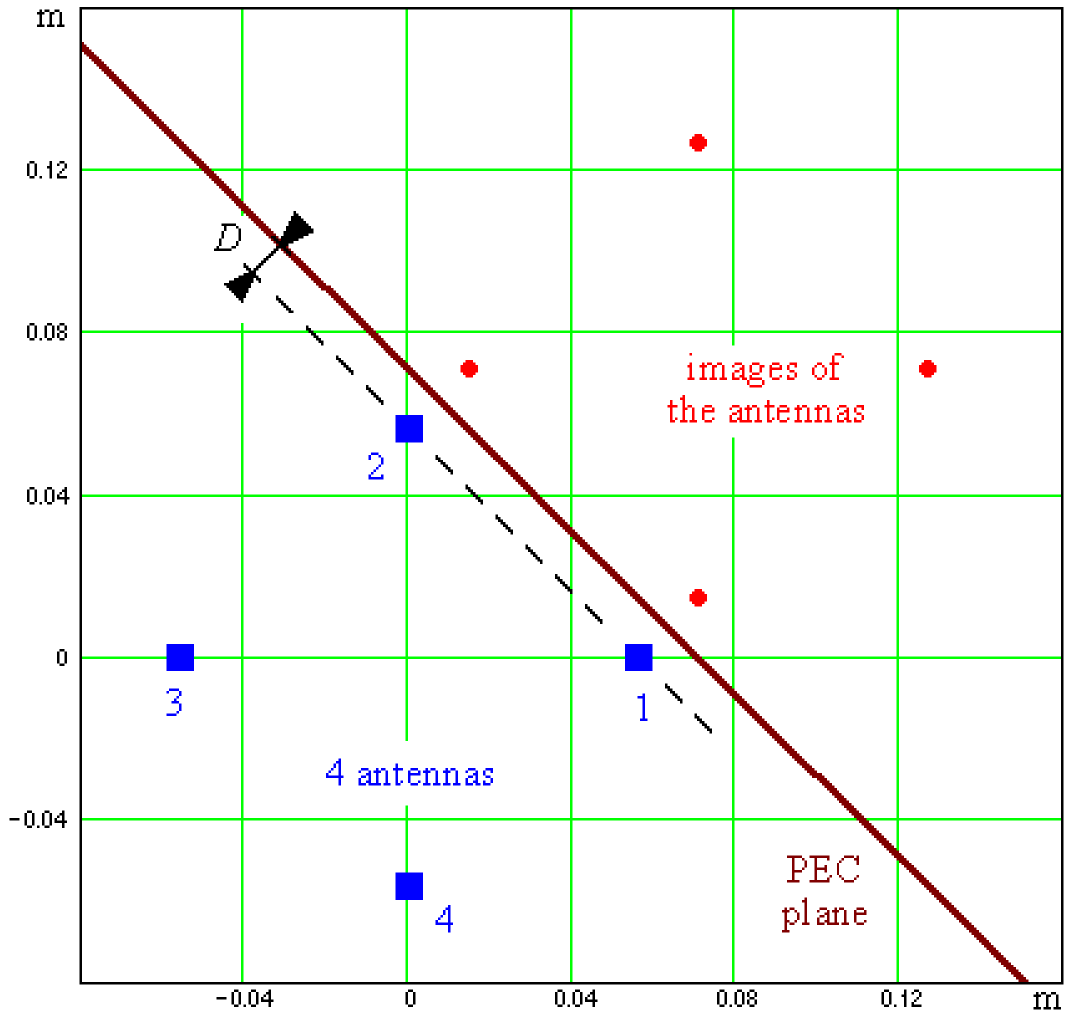


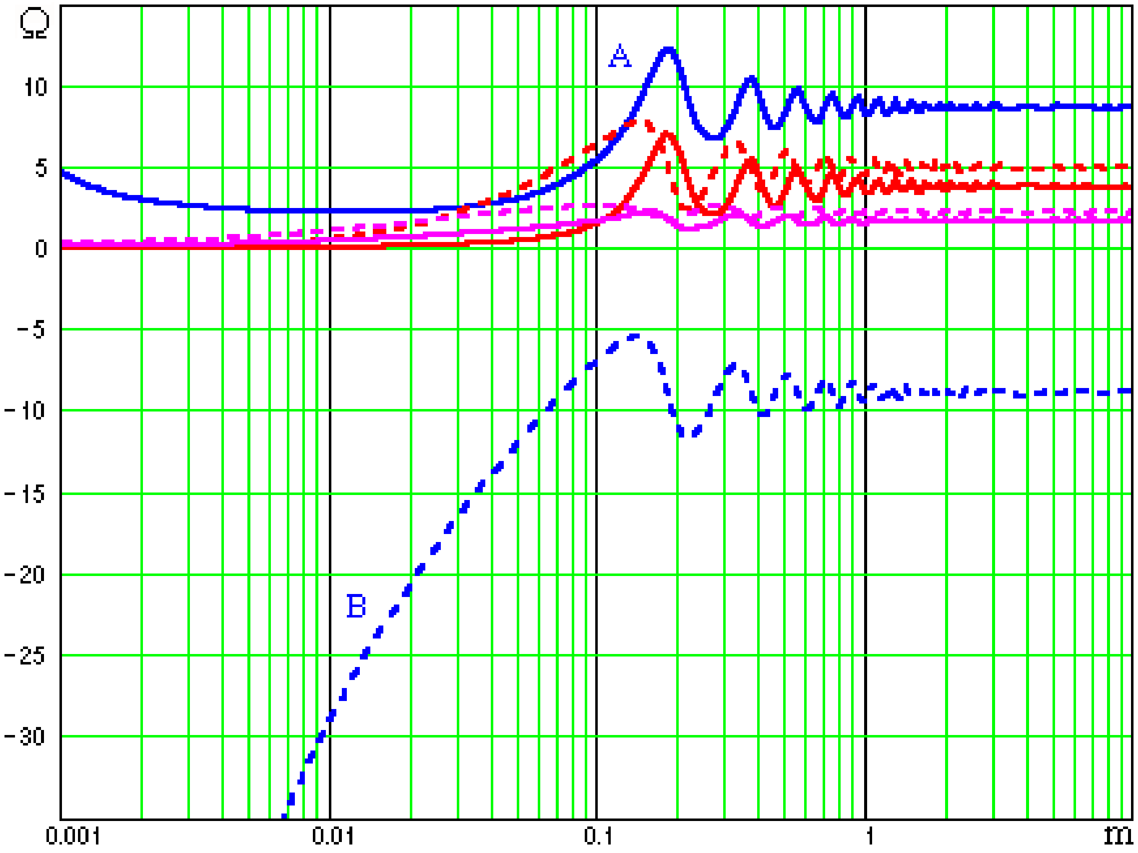
Capacitances of the adjustable impedance devices which realize $\mathbf{C}_U$, versus the tuning frequency:
C_{UG} is curve A;
C_{UN} is curve B;
C_{UF} is curve C.

5. Compensation of variations in the medium surrounding the antennas

❒ We consider strong variations in the electromagnetic characteristics of the volume surrounding the antennas, created by a vertical PEC plate.

❒ A new problem to be solved is the design of a lossless antenna tuner such that $\mathbf{Z}_U$ can approximate $\mathbf{Z}_{UW} = r_0\,\mathbf{1}_n$ at 800 MHz, in spite of the PEC plate.





Some entries of $\mathbf{Z}_{Sant}$, versus *D*, at 800 MHz:
Re($\mathbf{Z}_{Sant\ 11}$) is curve A;
Im($\mathbf{Z}_{Sant\ 11}$) is curve B;
and the four other curves are
Re($\mathbf{Z}_{Sant\ 12}$),
Im($\mathbf{Z}_{Sant\ 12}$),
Re($\mathbf{Z}_{Sant\ 13}$) and
Im($\mathbf{Z}_{Sant\ 13}$).

❒ It was shown that a design of the new MAPMUP antenna tuner can provide an exact match for any *D* greater than about 7 mm.

6. Conclusion

❒ A new antenna tuner having the structure of a multidimensional π-network is able to provide an ideal match (i.e., decoupling and matching).

❒ It comprises $n\ (n + 2)$ circuit elements, among which $n\ (n + 1)$ adjustable impedance devices.

❒ It cannot be separated into independent and uncoupled antenna tuners.

❒ It can provide an ideal match over a frequency band, and in the presence of variations in the medium surrounding the antennas.

❒ An iterative technique can be used to take losses into account in the design of the antenna tuner.