Optimization of Damping Distribution along a Broadband Monopole Antenna

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Abstract — Distributed damping is a desired feature for broadband naval HF fan wire antennas. Lumped resistors currently in use cause hazards due to the mechanical load and their infrared signature. Optimization of the distributed damping by using 3D field solvers is extremely time consuming for this application. Therefore, the impact of distributed damping on the antenna matching and the efficiency of a long thin broadband monopole antenna is calculated as a simplified model by using an improved Fourier series analysis. This method allows efficiently the calculation of many different damping scenarios for a given antenna geometry. Thus, the fundamental characteristics of the impact of distributed damping on antenna performance are investigated systematically.

I. INTRODUCTION

On naval vessels a single broadband transmitting antenna – typically a fan wire antenna – is used for multiple services in the enhanced HF band. Impedance matching is an important issue in this case as matching networks alone are not sufficient to compensate the frequency response. Therefore ohmic damping is essential and common [1]. The goal of this paper is to study the impact of the spatial profile of the damping distribution along the antenna wires on antenna efficiency and matching. A very efficient semi analytical approach for the calculation of the current distribution based on Fourier series analysis is used [2]. Knowing the current distribution the input impedance Z_A and the efficiency η_A of the monopol antenna can be calculated.

Ohmic damping of the antenna decreases the standing wave ratio *SWR* at the input of the matching network, however, it also decreases the antenna efficiency drastically. In order to maximize the radiated power, the overall efficiency η_{eff} with

$$\eta_{eff} = \eta_A \, (1- |\Gamma|^2) \qquad (1)$$

is the figure of merit where Γ is the reflection coefficient at the input of the matching network. This matching network has to be optimized for each individual damping distribution in order to provide the lowest possible maximum of standing wave ratio SWR^{max} in the frequency range considered. The goal is to achieve the maximum possible value for the minimum of $\eta_{eff}(f)$, in the following called η_{eff}^{min}, for a given value of SWR^{max} – in our case $SWR^{max} < 3$ in the frequency range of f = 2-30MHz.

II. OPTIMIZATION VIA A COMBINATORIAL APPROACH

The monopole of length L is divided equally into 10 sections of length $l=L/10$. Each of these sections (x = 1…10) can be either undamped ($R_x'=0$) or damped with all damped sections having the same resistance load per unit length ($R_x' = R_d' \neq 0$). This results in 2^{10} different combinations of spatial damping profiles for any given R_d' value. At first, the total series resistance of all sections is keept constant at R_{tot}=240Ω. The computational method for the calculation of the input impedance and efficiency of a damped monopole antenna introduced in [2] has to be modified. The coefficients of the unknown current distribution along the antenna, summarized in the vector **A**, are linked to the coefficients of the feeding voltage (vector **U**) by a resistor matrix. This resistor matrix is the sum of the matrix **Z**, which represents the impact of the geometrical dimensions of the antenna, and the matrix **R**, which represents the impact of the damping:

$$\mathbf{U} = (\mathbf{Z}+\mathbf{R})\ \mathbf{A}\ . \qquad (2)$$

The equation for the calculation of the elements r_{ms} of the matrix **R** (see [2]) has to be modified as follows

$$\begin{aligned} r_{ms} &= R_1'\int_0^{l_1}\cos\left(s\frac{\pi z}{2l}\right)\cos\left(m\frac{\pi z}{2l}\right)dz + \\ &\quad R_2'\int_{l_1}^{l_2}\cos\left(s\frac{\pi z}{2l}\right)\cos\left(m\frac{\pi z}{2l}\right)dz + \ldots \\ &\quad R_{10}'\int_{l_9}^{L}\cos\left(s\frac{\pi z}{2l}\right)\cos\left(m\frac{\pi z}{2l}\right)dz = \\ &= R_1' r_{ms}^{(1)} + R_2' r_{ms}^{(2)} + \ldots + R_{10}' r_{ms}^{(10)} \end{aligned} \qquad (3)$$

and, hence, there is a matrix $\mathbf{R}^{(x)}$ for each section. The resistance per unit length of each section R_x' is a constant factor and can be put in front of the corresponding matrix

$$\mathbf{U} = \left[\mathbf{Z} + \sum_{x=1}^{10} R_x' \mathbf{R}^{(x)}\right]\mathbf{A}\ . \qquad (4)$$

The matrices $\mathbf{R}^{(x)}$ have not to be recalculated when varying the values of R_x'. Only the weighted sum of all matrices has to be computed again. This provides an easy and time-efficient calculation for all 1024 combinations.

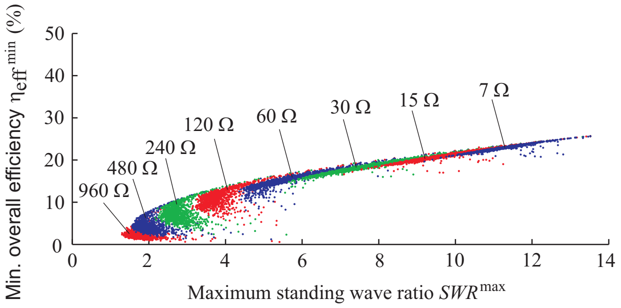

Fig. 1:. Minimum value of the overall efficiency η_{eff}^{min} versus the maximum value of the standing wave ratio SWR^{max} with parameter total resistance R_{tot} (7 Ω - 960 Ω) for each 1024 combinations of spatial damping profiles along a monople antenna (L= 21 m, r_A= 0,01 m, f = 2-30 MHz)

In a next step the impact of R_{tot} on the distribution of the 1024 tuple (η_{eff}^{min}, SWR^{max}) is taken into account. Fig. 1 shows a plot of the minimum value of the overall efficiency η_{eff}^{min} versus SWR^{max} for all 1024 combinations with parameter R_{tot} between 7Ω and 960Ω (antenna lenth L = 21m, antenna radius r_A = 0,01m, frequency f = 2-30MHz). All eight distributions of the corresponding 1024 tuple (η_{eff}^{min}, SWR^{max}) together show a sharply bounded line at their upper end which is quite linear for small values of the total resistance R_{tot} as is the sharply bounded line at the upper end of the individual distribution for each R_{tot} value. Furthermore, the distribution of each 1024 tuple (η_{eff}^{min}, SWR^{max}) shows an almost linear dependance $\eta_{eff}^{min}(SWR^{max})$ for low R_{tot} values. For distributions with R_{tot} between 7Ω and 60Ω the coefficient of correlation between η_{eff}^{min} and SWR^{max} is $r > 0.9$ (Tab. I). Increasing R_{tot} causes a better impedance matching and therefore a lower SWR^{max} whereas η_{eff}^{min} is lowered at the same time. This correlation coefficient declines with rising R_{tot}. This is seen in Fig. 1 in a broadening of the distributions for higher total resistances.

A confirmation of this effect is given by the comparison of the distributions for the 1024 tuple (η_{eff}^{min}, SWR^{max}) for the highest (960 Ω) and the lowest total resistance (7 Ω). The correlation between the η_{eff}^{min} values of both distributions shows an almost linear behavior with a coefficient of $r \approx 0{,}75$. However, in the case of the correlation between the SWR^{max} values of both distributions a correlation coefficient of $r < 0{,}1$ proves that there is only little correlation. But almost linear dependence of the standing wave ratio on R_{tot} is proven for small variations in R_{tot} by high correlation coefficients according to Pearson (Tab. II). In this table the correlation between SWR^{max} for adjacent values of R_{tot} is displayed. The correlation coefficients are all quite high ($r > 0{,}9$). Thus, it can be concluded that the position of a tuple (η_{eff}^{min}, SWR^{max}) inside a distribution of all 1024 combinations does not change significantly for small variations in R_{tot}. However, only small correlation ($r < 0{,}1$) occurs between SWR^{max} of the distributions for the smallest (7 Ω) and highest total resistance (960 Ω).

TABLE I
CORRELATION BETWEEN η_{eff}^{min} AND SWR^{max} FOR DIFFERENT R_{tot} ACCORDING TO PEARSON

R_{tot} [Ω]	7	15	30	60	120	240	480	960
r	0.92	0.95	0.97	0.90	0.74	0.54	0.52	0.55

TABLE II
CORRELATION BETWEEN SWR^{max} FOR ADJACENT VALUES OF R_{tot} ACCORDING TO PEARSON

R_{tot} [Ω]	7	15	30	60	120	240	480	960
r	0.97	0.98	0.96	0.92	0.91	0.94	0.95	

A desired low SWR^{max} value can be achieved with different R_{tot} values for different spatial damping profile combinations. A variation in R_{tot} causes a different combination to be the best one with quite similar values for SWR^{max} and η_{eff}^{min}.

III. CONCLUSION

A modified Fourier series approach for the calculation of the current distribution along a damped monopole antenna provides an efficient method for optimizing the spatial distribution of the losses along the antenna. In order to maximize the radiated power, the overall efficiency η_{eff} considering ohmic as well as return loss is the figure of merit. Optimization by a combinatorial approach shows a distinctive distribution in the graph of minimum overall efficiency η_{eff}^{min} versus maximum standing wave ratio SWR^{max} in the frequency band considered with a sharply bounded line at its upper end. Obviously, this upper line represents the maximum possible ratio η_{eff}^{min} / SWR^{max}. For a high total resistance R_{tot} a spatial damping profile with its (η_{eff}^{min}, SWR^{max}) tuple close to the upper sharply bounded line and, hence, with high η_{eff}^{min} / SWR^{max} ratio will still remain a 'good combination' even when reducing the total resistance significantly. Vice versa, this is not necessaryly the case when starting with a low total resistance R_{tot}. However, an antenna with a damping profile resulting in a high ratio η_{eff}^{min} / SWR^{max} can always be fine-tuned for a desired SWR^{max} value by a slight variation of R_{tot}. A unique optimum spatial damping distribution does not exist.

IV. REFERENCES

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