Design of Novel Dual-Band Monopole Using Genetic Algorithms[1]

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ABSTRACT

The design of dual-band monopole antenna for GSM and DCS1800 uplink and downlink bands is introduced. The antenna current distribution is calculated using the method of moments (MM) applied for the surface currents and the optimisation is performed using a heuristic optimisation method: the genetic algorithm. The monopole antenna was manufactured and measured.
Topics: numerical methods for electromagnetic field calculations, integral equations, electromagnetic theory, antenna theory, heuristic optimisation, genetic algorithm, method of moments.

INTRODUCTION

The GSM extension operates in the 1800 MHz band in order to reach higher capacity in dense areas. The dual band operation makes necessary the usage of dual band antennas also as base station antennas. In these applications a low input reflection is needed. In the article the design of a dual band indoor base station antenna with omnidirectional radiation pattern is presented. The voltage standing wave ratio (VSWR) was chosen as a cost function for optimisation.
The monopole is divided into two parts and the compensation is placed inside of the antenna at the midsection in the form of coaxial resonator which represents nearly short at 900 MHz and open at 1800 MHz bands.

THE CURRENT DISTRIBUTION ON THE ANTENNA

A cylindrical coordinate system is used to analyse the problem shown in fig. 1. and the length of the envelope line is expressed by the variable t. The current that flows on the surface is decomposed into the component J^{t} parallel to the tangent of the envelope and to J^{φ} in the φ direction.

$$\mathbf{J}(t,\varphi) = \mathbf{e_t}\mathbf{J}^{\mathbf{t}}(t,\varphi) + \mathbf{e}_{\varphi}\mathbf{J}^{\varphi}(t,\varphi) \tag{1}$$

where $\mathbf{e_t}$ and $\mathbf{e}_{\varphi}$ are the unit vectors in the tangential direction of t and φ direction.
By using the boundary condition on the conductor surface the integral equation on the antenna current is obtained. The tangential component of the electric field generated by the current that flows on the conductor surface is $\mathrm{E}^{\mathrm{s}}_{\tan}$ while the incident field generated by the exciting aperture is $\mathrm{E}^{\mathrm{i}}_{\tan}$. Then the boundary condition is

$$\mathrm{E}^{\mathrm{i}}_{\tan} + \mathrm{E}^{\mathrm{s}}_{\tan} = 0 \tag{2}$$

on the conductor surface. The $\mathbf{E}^{\mathrm{s}}$ field can be derived from the **A** magnetic vector potential due to the current $\mathbf{J}(\mathrm{t},\varphi)$.

$$\mathbf{E}^{\mathrm{s}}(\mathrm{t},\varphi) = \frac{1}{\mathrm{j}\omega\varepsilon_{\mathrm{o}}}(\mathrm{grad\,div} + \beta^2)\,\mathbf{A} \tag{3}$$

where

$$\mathbf{A}\left(\mathbf{t},\varphi = \frac{\mu_0}{4\pi}\right)\iint_{S'} \mathbf{J}(\mathbf{t}',\varphi)\frac{\exp(-j\beta R)}{R}\,d\mathbf{t}'\,d\varphi'$$

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$$R=\sqrt{\rho^2(t)+\rho^2(t')-2\rho(t)\rho(t')\cos(\varphi-\varphi')+[z(t)-z(t')]^2}$$

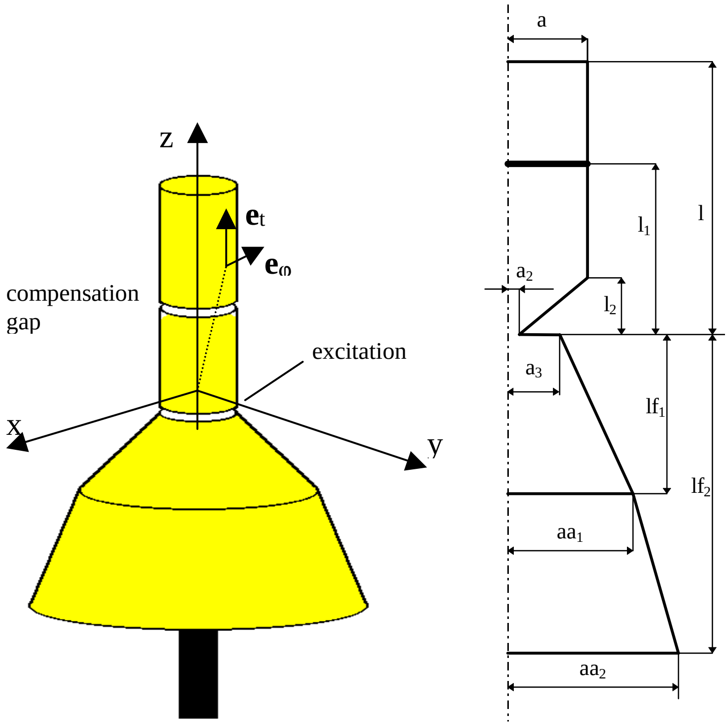

Fig. 1. Antenna geometry

Substituting (1) into (3) and using $\partial/\partial\varphi=0$ because of the rotational symmetry, one obtains after some rearrangement

$$\mathbf{E}^s=-\frac{j\omega\mu_0}{4\pi}\int_{S'}\mathbf{J}\frac{\exp(-j\beta R)}{R}dA'+\frac{1}{4\pi j\omega\varepsilon_0}\int_{S'}div\mathbf{J}\cdot grad\frac{\exp(-j\beta R)}{R}dA \tag{4}$$

Using the exciting field as in [3] and the field generated by the surface current (4) after substituting into (2) the integral equation on the antenna current can be obtained:

$$\mathbf{E}^i(t)\mathbf{e_t}=-\mathbf{E}^s(t)\mathbf{e_t}=\frac{j\omega\mu_0}{4\pi}\int_T\int_0^{2\pi}\mathbf{e_{t'}}\mathbf{e_t}J^t(t')G(t,t',\varphi)d\varphi'dt'-\frac{1}{4\pi\omega\varepsilon_0}\int_T\int_0^{2\pi}\frac{\partial J^t(t')}{\partial t'}\frac{\partial G(t,t',\varphi')}{\partial t}d\varphi'dt' \tag{5}$$

SOLUTION OF THE INTEGRAL EQUATION USING THE MM

Applying the moment method first we start by expanding the current in terms of sinusoidal expansion functions and using the Galerkin method to solve the integral equation (5) the sinusoidal functions are chosen as weight function as well.

To decrease the condition number the following sinusoidal expansion and weighting functions were chosen:

$$f_i=\begin{cases}\dfrac{\sin[\beta(t-t_{i-1})]}{\sin[\beta(t_i-t_{i-1})]}, & t_{i-1}<t<t_i\\[2ex] \dfrac{\sin[\beta(t_{i+1}-t)]}{\sin[\beta(t_{i+1}-t_i)]}, & t_i<t<t_{i+1}\end{cases} \tag{6}$$

The MM linear equation system is the following:

$$\underline{\underline{\mathbf{Z}}}\,\underline{\mathbf{I}} = \underline{\mathbf{V}} \tag{7}$$

where

$$\left[\underline{\underline{\mathbf{Z}}}\right]_{ij} = \int_T \int_{T'} \left[\frac{j\omega\mu_0}{2\pi} \mathbf{e}_{t'} \mathbf{e}_t f_i(t') w(t) + \frac{1}{2\pi j\omega\varepsilon_0} \frac{\partial f(t')}{\partial t'} \frac{\partial w(t)}{\partial t} \right] \frac{\exp(-j\beta R)}{R} d\varphi' \, dt' \, dt$$

and f and w are the expansion and weight functions.

The singular integrals in (7) are accomplished by using weighted Gauss quadrature to enforce the convergence. The compensation has been achieved using two serial coaxial lines placed inside the monopole body.

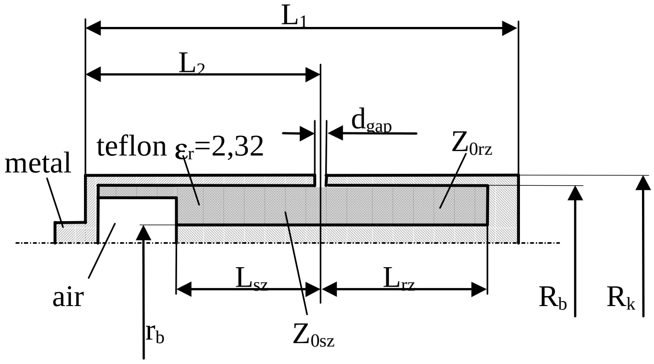

Fig. 2. The coaxial compensation

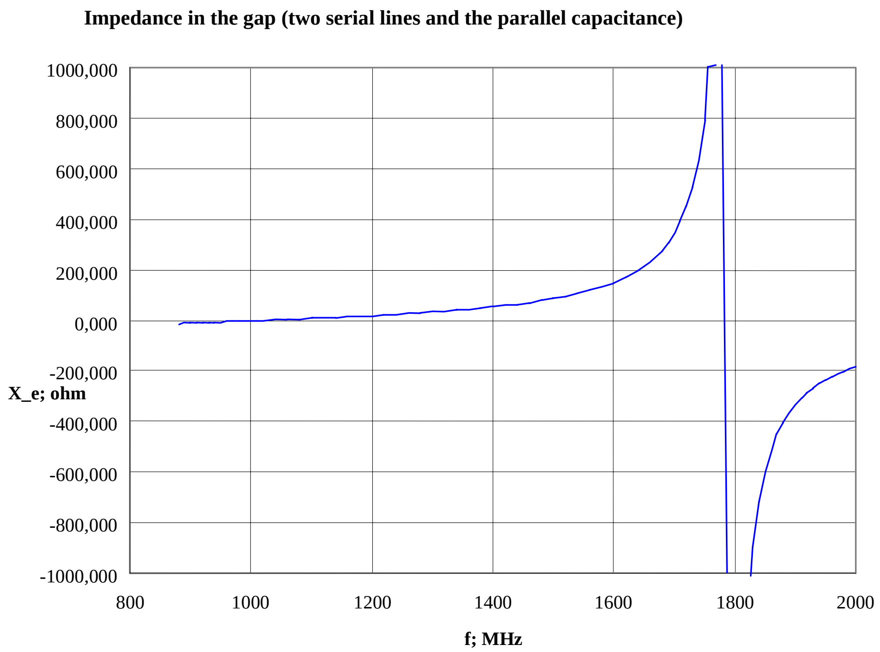

Fig. 3. Impedance value in the gap as a function of frequency

OPTIMISATION USING GENETIC ALGORITHM

The optimisation parameters can be seen in fig. 1. and these are a, l, l_1, lf_1, aa_1, lf_2 and aa_2. The optimisation for minimal VSWR in the two bands were performed using genetic algorithm which will presented in detail at the presentation.

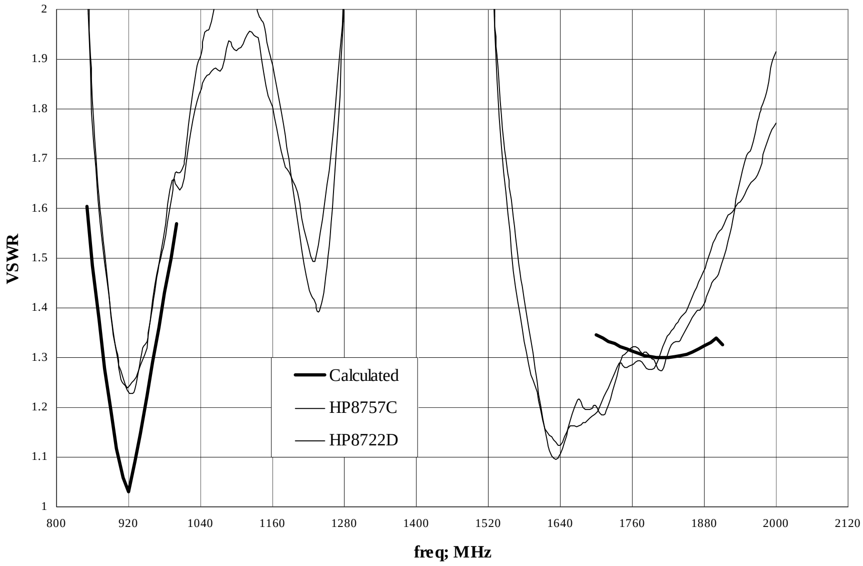

Fig. 4. Calculated and measured VSWR for the optimised antenna

The antenna finally was manufactured and measured with two analysers. The results can be seen in fig. 4. which shows that the optimised antenna has appropriate low (<1.5) VSWR in the two bands.

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