DESIGN AND MODELING OF A VHF BOW-TIE CROSS-DIPOLE ANTENNA ONBOARD A GENERIC FUSELAGE

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Abstract

A Bow-Tie Cross-Dipole (BT-CD) design is considered as a potentially broadband horizontally polarized (H-Pol) antenna. Even though it is possible to use the BT-CD in both the VHF and UHF bands, the analysis in this effort is solely focused on the 174-230 MHz frequency range in the VHF-band. The BT-CD antenna is designed and optimized in the presence of a generic fuselage using WIPL-D, a Method of Moments (MoM) program. The design and optimization are carried out to obtain 1.6:1 VSWR (i.e., = -12.74 dB return loss) or better, and -5 dBi matched gain or better. A lumped two-element, parallel LC circuit in parallel with the antenna feed, matching circuit is used to compensate for the imaginary component of the input admittance, to obtain acceptable VSWR .

1. General Description. The main objective of the antenna system design in this effort is to achieve the following:

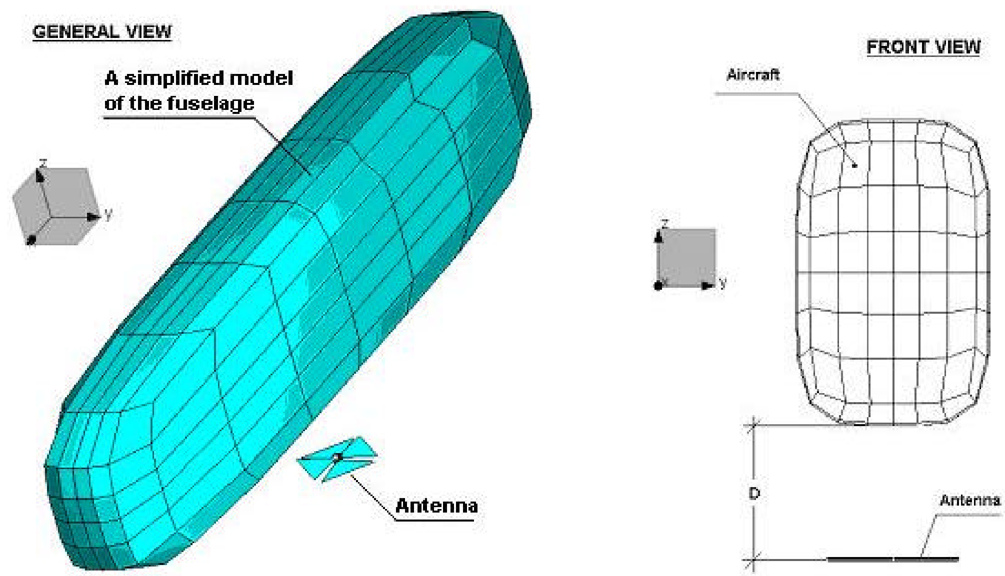
1. A uniform H-Pol radiation pattern (RP) in the azimuth plane.
2. A well matched antenna closely resembling a "Traveling Wave" condition (1.6:1 or better VSWR, required), within the 174-230 MHz frequency band.

One of the solutions to satisfy the first objective is the use of a pair of cross-dipole (CD) antennas, with 90^0 out of phase excitation. In order to satisfy the second objective, a wideband bow-tie (BT) antenna is chosen, the one to most likely satisfy Rumsay's condition [1]. Fig.1 below shows a WIPL-D model of a BT-CD antenna onboard a generic fuselage, as well as, the antenna's parametric dimensional information.

If the frequency band is in the [f_{min}, f_{max}] range, then the distance D is chosen based on the median frequency $f_0 = (f_{max} + f_{min})/2$, such that

$$D \approx l_0 / 2 \quad , \qquad (1)$$

where, $l_0 = c / f_0$ is the wavelength for the central frequency, f_0. The choice in (1) is based on the fact that the downward vertical propagated wave, generated by the antenna, must be suppressed by the wave reflected from the fuselage's underbelly. Consequently, most of the radiation becomes directed towards the horizon. This results in a horizontal "toroid-shaped" RP. The three dimensional (3-D) RPs for three different frequencies are presented in Fig.2. It must be noted that the shape of an RP is frequency sensitive, since the design based on (1) satisfies only a single frequency in the 174-230 MHz range.



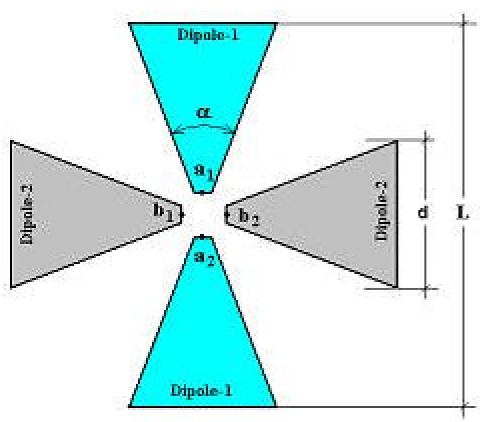
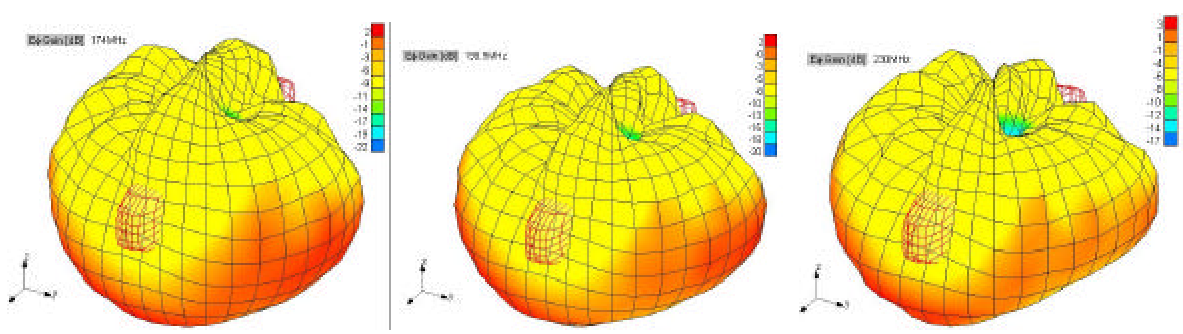


Fig.1. BT-CD antenna's WIPL-D model onboard a generic fuselage.

L – length of BT dipole
d – width ' – ' – ' – '
D – distance between BT dipole and aircraft
α – the angular dimension of the BT-dipole



f = 174 MHz f = 198.9 MHz f = 230 MHz

Fig.2. Low, mid, and high frequency 3-D RPs of a BT-CD antenna onboard a generic fuselage.

In order to obtain a low VSWR within the designated frequency band, a special matching approach has been employed. This approach is based on the behavior of the antenna's input admittance in the frequency band under consideration. Typical input admittance plots are shown

in Fig.3. Points A and B, in Fig. 3, are adjusted to the extremes of the frequency band, $f_{\max}$ and $f_{\min}$ by choosing the proper relationship between the dimensions L and q. Then the decreasing susceptance, B(f), within the [A, B] interval may be compensated for by using a single parallel LC circuit with increasing susceptance (purely imaginary admittance). This LC circuit is then connected in parallel to the feed-line of the antenna at the excitation port * (see Fig.4).
The following expressions are used to define the appropriate values of L and C for the matching network:

$$L = \frac{w_1^{\ 2} - w_2^{\ 2}}{w_1 w_2 (w_1 B_2 - w_2 B_1)} \qquad (2)$$

$$C = \frac{1}{w_1}\left[\frac{1}{w_1 L} - B_1\right], \qquad (3)$$

where $w_1 = 2p\, f_{\min}$, $w_2 = 2p\, f_{\max}$.

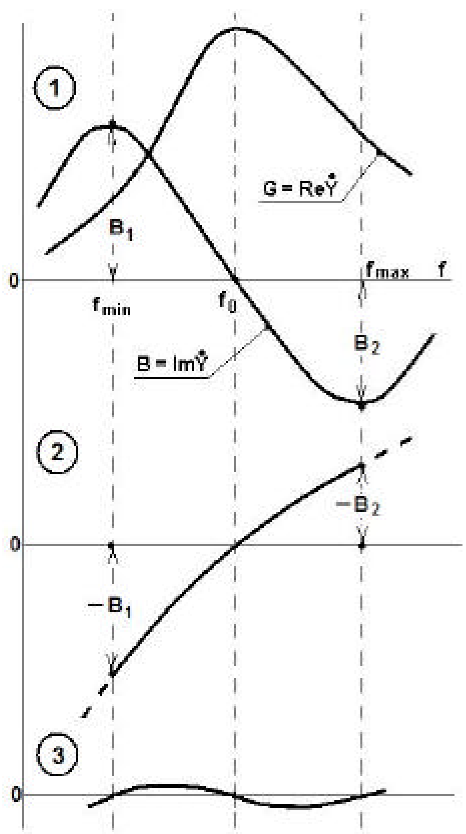


Fig.3. Compensation of the input susceptance of the BT-CD antenna by using a parallel LC circuit.
1. Unmatched input conductance and susceptance of the BT-CD antenna,
2. Reactive admittance of the single matching parallel LC-circuit,
3. Matched input susceptance.

If the remaining variations of B(f) (see Fig.3.3) are neglected, then the resultant VSWR will be totally dependent on the behavior of G(f) in the corresponding frequency range. Rough estimates of the VSWR can be performed, based on the nearly real quantity $Z'_{in}(f) = 1/G(f)$, using

* Lumped element matching is being considered as a most preferable for the considering frequency range.

$$\dot{S} = \frac{Z'_{in} - W}{Z'_{in} + W} \; ; \qquad VSWR = \frac{1 + |\dot{S}|}{1 - |\dot{S}|} \; , \tag{4}$$

where $\dot{S}$ is the complex voltage reflection coefficient, and *W = 50 W* is the characteristic impedance of the feed coaxial cable.

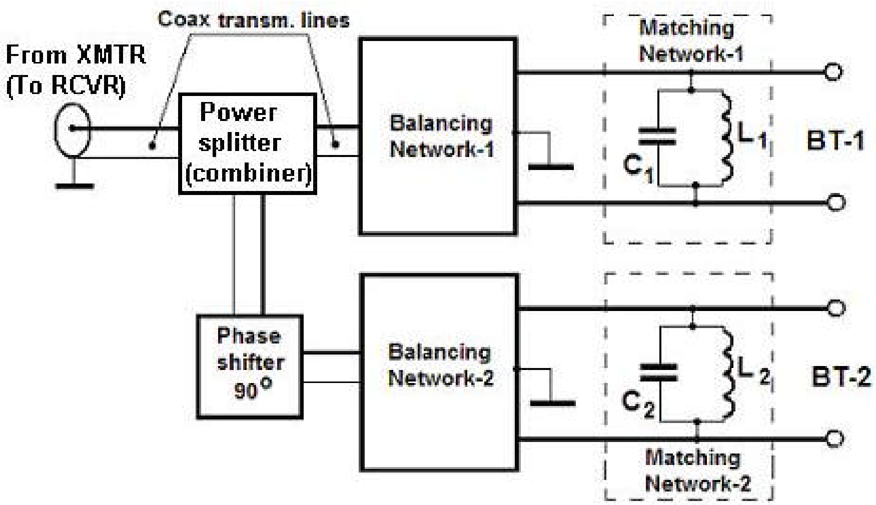


Fig.4. System connectivity block diagram.
(Note: For the receiving antenna the power splitter is replaced by combiner)

To further improve the VSWR, an additional feature of the balancing network in Fig. 4 may be used. This feature is impedance transformation, where the antenna input conductance, G(f), is matched to the transmission line. Then, the transformation factor of this network must be taken into account in (1) and (2) during the L and C lumped elements calculations.

If the VSWR requirement is top-limited (i.e., $VSWR \le VSWR_0$) then the range of variations of G(f) may be easily found using (4), as shown in Fig.5.

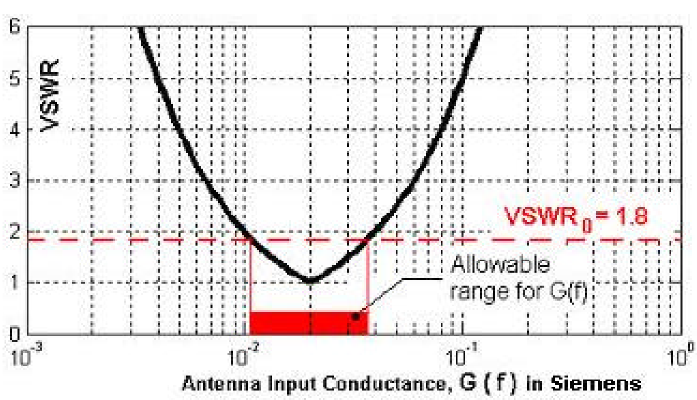
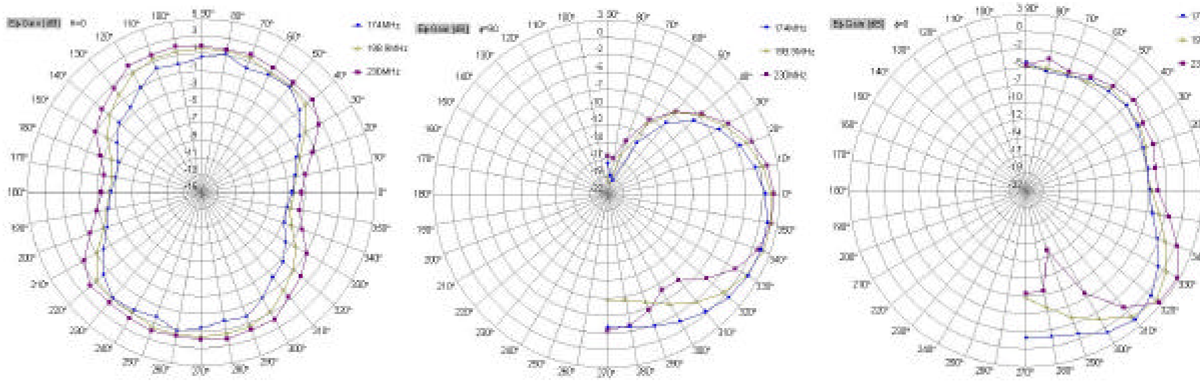


Fig.5. VSWR dependence on variations of the antenna's input conductance.

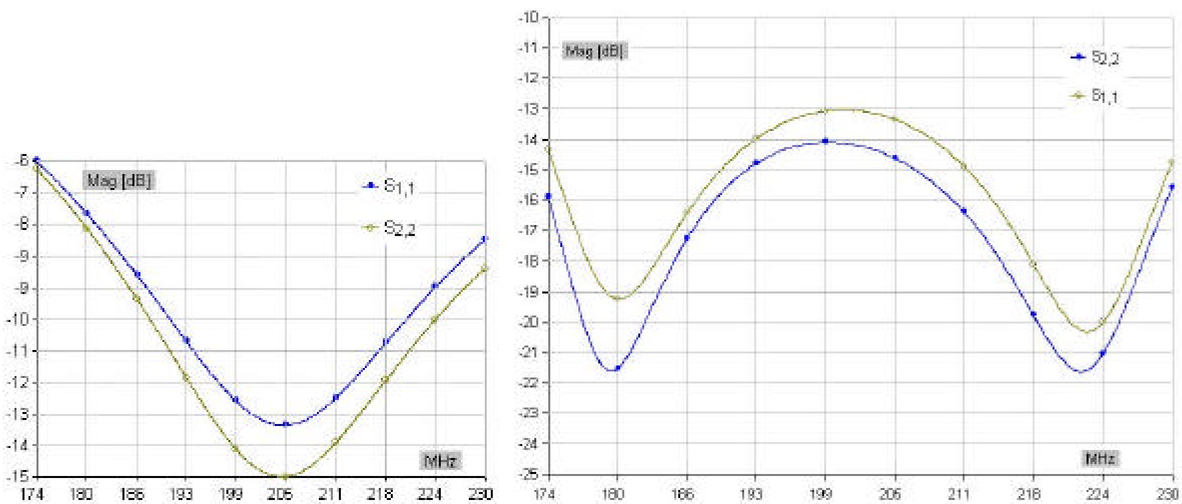
Example: If VSWR is limited to $VSWR_0 \le 1.8$, then the range of variation for G(f) is allowed from 10^{-2} to $2.8 \cdot 10^{-2}$ S (variations in R_{in} are allowed in the range of 35 to 100 W).

2. Results. The final results of the WIPL-D simulations are shown in Fig. 6 and Fig.7.



(a) (b) (c)

Fig.6. RPs for low, mid and high frequencies:
(a). Azimuth cut ($\theta = 0$), (b). Roll cut ($\varphi = 90^0$), (c). Pitch cut ($\varphi = 0^0$).



(a) (b)

Fig.7. WIPL-D return loss computations: (a) before matching, (b) after matching

The values of L_1 = 14.2 nH, C_1 = 42.2 pF (first port) and L_2 = 14.5 nH, C_2 = 40.9 pF (second port) are calculated using (2) and (3). These parameters are obtained using the following procedure: 1. Run the WIPL-D simulation without any matching being applied; 2. Collect the resulting unmatched ".ad1" data file and import it into an EXCEL spreadsheet; 3. Run previously prepared EXCEL macros to generate the required L and C values for both antenna elements, and meeting the VSWR requirement; 4. Finally, rerun the WIPL-D simulation with the addition of the concentrated parallel LC-loading in parallel with each element's excitation port.

3. Conclusions. The use of airborne BT-CD antennas is quite effective for the special VHF frequency range under study here. This is achieved by placing the antenna at a proper distance from the underbelly of the fuselage. This technique successfully generates a horizontal toroid-

shaped RP. A 90^0 out-of phase excitation is set to achieve a relatively omni-directional H-Pol component.
The effective matching of the antenna is achieved by using a simple parallel LC circuit in parallel with the antenna feed port. For the corresponding frequency range of 174-230 MHz, a return loss of better than -13 dB was achieved for each BT dipole.

4. References.

[1] John D. Kraus, Ronald J. Marhefka, "*Antennas,*" Third Edition, McGraw Hill, Inc., 2003.

[2] B.M. Kolundzija, J.S. Ognjanovic, and T.K. Sarkar, "WIPL-D: Electromagnetic Modeling of Composite Metallic and Dielectric Structures – Software and User's Manual," Artech House Publishers, 2000.