A Comparison Of the Coupling Between Collocated VHF Antenna on a Common Mast in Various Configurations

Elya B. Joffe, P.E., N.C.E.
K.T.M. Project Engineering, Ltd.
P.O. Box 264
Kfar-Sava 44102, ISRAEL

Abstract: Tactical antenna installations contain a multitude of collocated antennae, installed on a common mast. It is not uncommon to have installations containing dozens of VHF and UHF antenna operating simultaneously, with the need for minimal coupling and the consequent interference between them.

The objective of this paper is to address the issue of the preferred configuration for the installation of collocated Tactical VHF (30 to 88 MHz) dipole antenna installed on a common mast.

Method of Moments analysis is used for determining the decoupling between antennae in the different configurations, and practical recommendations for tactical antennae installations are thus derived.

BACKGROUND

Tactical antenna installations contain a multitude of collocated antennae, installed on a common mast. It is not uncommon to have installations containing dozens of VHF and UHF antenna operating simultaneously, with the need for minimal coupling and the consequent interference between them [4,5].

Where tactical systems are concerned, the antenna masts are relatively small, with limited space for antenna installations, implying a high density of antennae on such masts. One of the most common questions asked regarding the installation of such antennae is: "What is the preferred configuration for collocated antenna - a horizontal or a vertical installation?"

INVESTIGATED CONFIGURATIONS

Two principal, commonly used antennae configurations are considered for the analysis:

Horizontal (Parallel) Configuration

In this configuration,. the antennae are installed in parallel on the same level, separated horizontally, where the separation between the antennae is determined by the relative locations of the antennae on the arms of the antennae support. This is depicted in **Figure 1** (note the relative locations of the VHF antennae. Additional antenna were also installed on the mast).

Vertical (Collinear) Configuration

In this configuration,. the antennae are installed in a collinear manner in different elevations on the mast. The separation between two collinear antennae (bottom to top) is typically much less than the length of the antenna itself.. This is depicted in **Figure 2** (note the relative locations of the VHF antennae. Additional antenna were also installed on the mast).

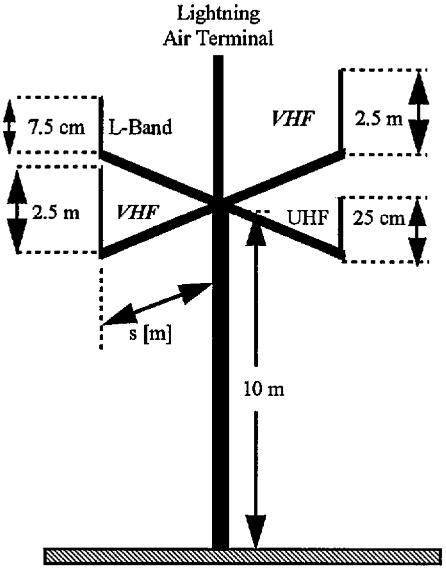

Figure 1: Horizontal (Parallel) Configuration

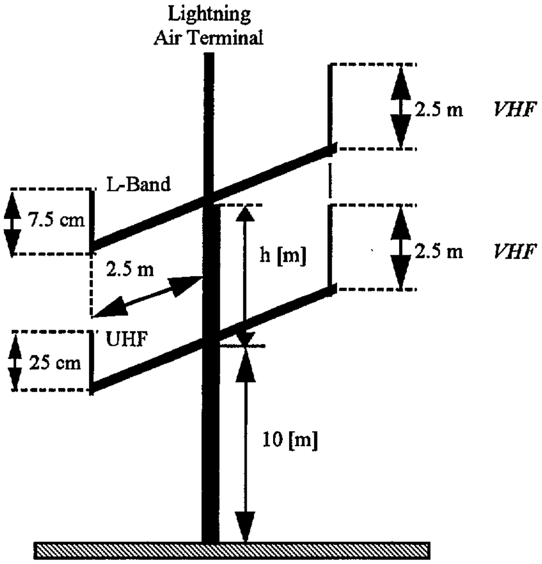

Figure 2: Vertical (Collinear) Configuration

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Each of these configuration was further examined, taking into consideration the relative separations of the antennae, in order to determine the optimal layout dimentions. The following configurations were examined:

Parallel Configuration:

- d=2×s=2×2.5 m=5.0 m
- d=2×s=2×3.5 m=7.0 m
- d=2×s=2×4.5 m=9.0 m
- d=2×s=2×5.5 m= 11.0 m

with d=5.0 m and d=11 m, a 3 m long lightning air terminal was also considered.

Collinear Configuration:

- s=3.0 m (Tip to base separation - h of 0.5 m)
- s=4.0 m (Tip to base separation - h of 1.5 m)
- s=5.0 m (Tip to base separation - h of 2.5 m)

OBJECTIVES OF THE ANALYSIS

The objective of this paper is to address the issue of the preferred configuration for the installation of collocated Tactical VHF (30 to 88 MHz) dipole antenna installed on a common mast. This is not a trivial question: The antennae are clearly in the "near field", and the separation between the antenna is often smaller than the actual dimensions of the antennae themselves.

The initial investigation was intended to determine the best configuration: The parallel or the collinear.

Following this phase, when the parallel configuration was selected, an additional study was performed in order to determine the optimal length of the antenna support arms.

Along the analysis it appeared that the mast is metallic, and that a lightning rod (air terminal) will be installed on the mast, between the antenna. It was suspected that the presence of the metallic structures of the mast and the lightning rod in the "near field" of the antenna may cause them to act as "directors" and "reflectors", especially since the spacing between the mast and air terminal to the antenna (and in parallel to them) was in the order of a half a wavelength at f=60 MHz.

This effect is briefly presented in this Paper, but will be further elaborated in another report.

METHODOLOGY OF THE ANALYSIS

Since the frequency band of interest (30 to 88 MHz) is relatively low, considering the dimensions of the setup with respect to wavelength, the antennae are within the "near field" of each other. Therefore, simple analytical models based on free space propagation and decoupling, are non valid, and could not be used for this problem.

Therefore, numerical simulation tools were to be applied, and the investigation was performed using the Method of Moments, as implemented in MiniNec [2], where the antenna mast and antennastructures were modeled using this wire models. The structures were divided into sufficiently small segments in order to consider them as "thin wires" (a<L/10, where a=diameter of segment and L=length of segment). A perfect ground was assumed.

As the VHF antenna are in practice dipole antennae, a center-fed configuration was used for the model. A 50Ω load was used between the antenna terminals.

Since the VHF band (30 to 88 MHz) extends for more than a octave, the analysis was performed at several frequencies, from 30 MHz to 88 MHz, at steps of 5 MHz, and at 88 MHz.

ANALYTICAL DERIVATION

In order to validate the MoM an analytical approach was also applied. The derivation was based on the two-port approach presented in [1, 2, 3], with the use of Z-parameters rather than the Y-parameters used in [2,3], as depicted in **Figure 3**.

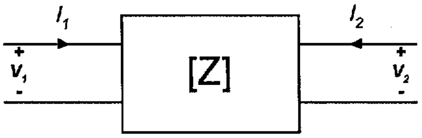

Figure 3: Two-Port Network Representation

$$\left.\begin{aligned} V_1 &= Z_{11}I_1 + Z_{12}I_2 \\ V_2 &= Z_{21}I_1 + Z_{22}I_2 \end{aligned}\right\} \tag{1}$$

where:

$$\begin{aligned} Z_{11} &= \frac{V_1}{I_1}\Big|_{I_2=0} \\ Z_{12} &= \frac{V_1}{I_2}\Big|_{I_1=0} \\ Z_{21} &= \frac{V_2}{I_1}\Big|_{I_2=0} \\ Z_{22} &= \frac{V_2}{I_2}\Big|_{I_1=0} \end{aligned} \tag{2}$$

For a reciprocal system, $Z_{12}=Z_{21}$.

The driving point impedances are derived from (1) as follows:

$$\left.\begin{aligned} Z_{1d} &= \frac{V_1}{I_1} = Z_{11} + Z_{12}\frac{I_2}{I_1} \\ Z_{2d} &= \frac{V_2}{I_2} = Z_{22} + Z_{21}\frac{I_1}{I_2} \end{aligned}\right\} \tag{3}$$

The input power into antenna #1 - P_I and the output power from antenna #2 - P_O are computed using:

$$\left.\begin{aligned} P_O &= |I_2|^2 \operatorname{Re}\{Z_L\} \\ P_I &= |I_1|^2 \operatorname{Re}\{Z_{1in}\} \end{aligned}\right\} \tag{4}$$

Using the notation fron (3), (4) may be rewritten as:

$$\left.\begin{aligned} P_O &= |I_2|^2 \operatorname{Re}\{Z_L\} \\ P_I &= |I_1|^2 \operatorname{Re}\{Z_{1d}\} \end{aligned}\right\} \tag{5}$$

and the decoupling between the two ports of the antennae - C, may be thus computed as:

$$C = \frac{P_0}{P_1} = \frac{|I_2|^2 \operatorname{Re}\{Z_L\}}{|I_1|^2 \operatorname{Re}\{Z_{1d}\}} = \frac{|I_2|^2}{|I_1|^2} \cdot \frac{\operatorname{Re}\{Z_L\}}{\operatorname{Re}\{Z_{1d}\}} = \left|\frac{I_2}{I_1}\right|^2 \cdot \frac{\operatorname{Re}\{Z_L\}}{\operatorname{Re}\{Z_{1d}\}} \qquad (6)$$

Remembering that:

$$\left.\begin{aligned} Z_{in} &= \frac{V_1}{I_1} \\ Z_L &= -\frac{V_2}{I_2} \end{aligned}\right\} \qquad (7)$$

Substituting, from (3), we derive:

$$C = \frac{\operatorname{Re}\{Z_L\}}{\operatorname{Re}\{Z_{1d}\}} \cdot \frac{|Z_{21}|^2}{|Z_L + Z_{22}|^2} \qquad (8)$$

and in dB notation:

$$C\{dB\} = 10\operatorname{Log}\left\{\frac{\operatorname{Re}\{Z_L\}}{\operatorname{Re}\{Z_{1d}\}} \cdot \frac{|Z_{21}|^2}{|Z_L + Z_{22}|^2}\right\} \qquad (9)$$

where C[dB] is real and negative (in Figures 4÷6 and 8÷9, |CdB| is presented).

As, in practical cases, it is difficult to analytically derive the values of the Z-parameters, the analytical approach was performed for identical resonant dipoles only. Since the dipoles were 2.5 meters long, which correspond to a quater wavelength frequency of 60 MHz, the analysis was performed for F=60 MHz only, using the analytical derivation. Thus, from (3):

$$Z_{1d} = \frac{V_1}{I_1} = Z_{11} + Z_{12}\frac{I_2}{I_1} \qquad (10)$$

and since the two dipoles are identical: $I_1 = I_2$, thus:

$$Z_{1d} = Z_{11} + Z_{12} \qquad (11)$$

For a tuned $\lambda/2$ dipole:

$$Z_{11} = Z_{22} = 73 + j42.5 \qquad (12)$$

and Z_{12} can be obtained from graphs [1,7,8 and 9], thus, Z_{1d} can be derived and the decoupling can be computed for identical, tuned $\lambda/2$ dipoles. These parameters can be replaced in (9) in order to obtain the decoupling in dB between the antennae.

ANALYSIS RESULTS

The main results of the analysis are displayed graphically in Figures 4÷6 herein.

- **Figure 4** presents the decoupling obtained between parallel dipoles vs. frequency [MHz] for horizontal separation - d.
- **Figure 5** presents the decoupling obtained between collinear dipoles vs. frequency [MHz] for vertical separation - s.
- **Figure 6** presents the comparison between decoupling results obtained with parallel and collinear dipoles vs. frequency [MHz]

The definition of the horizontal and vertical separation - s, is as depicted in **Figure 7** (a and b, respectively).

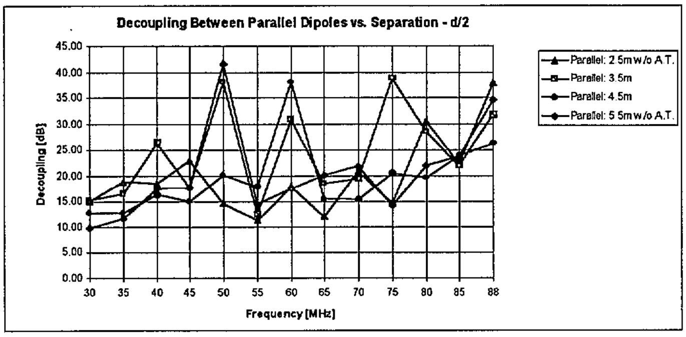

Figure Decoupling between Parallel Dipoles vs. frequency [MHz] for Horizontal Separation between the Antenna

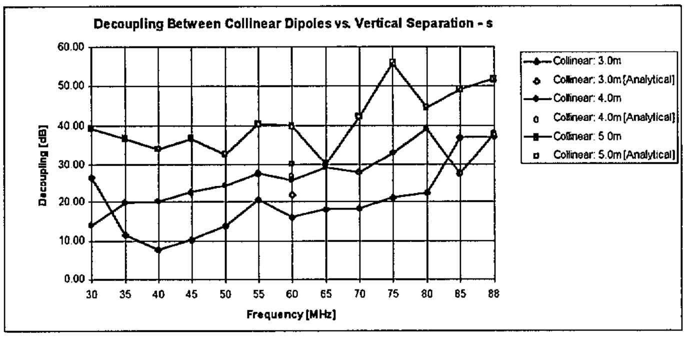

Figure 5: Decoupling between Collinear Dipoles vs. Frequency for Vertical Separation - s between the Antenna

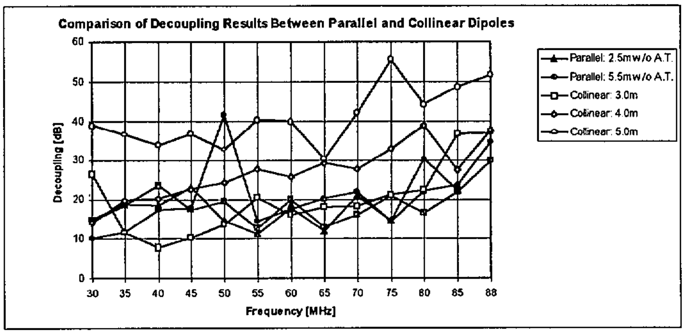

Figure 6: Comparison of Decoupling Results between Parallel and Collinear Dipoles vs. Frequency

In addition to the above analyses results, preliminary results of computation were obtained when a lightning air terminal was incorportaed in the model, as depicted in Figure 1 and 2. This analysis was performed for the parallel configuration only, and for antenna separations of d=2×2.5 m=5.0 m and d=5×2.5 m=11.0 m only. This will be further analyzed in another report.

The main results of this analysis are displayed graphically in Figures

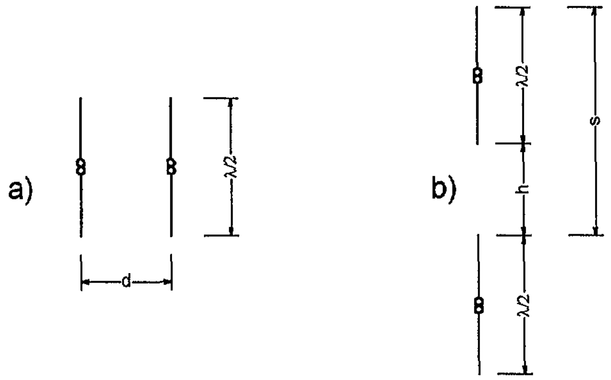

Figure 7: Definition of Horizontal (s) and Vertical (h) Separation

8÷9 herein:

- **Figure 8** presents the decoupling obtained between parallel dipoles vs. frequency [MHz] for d=2×2.5 m=5.0 m, with and without a 3 m long lightning air terminal.
- **Figure 9** presents the decoupling obtained between parallel dipoles vs. frequency [MHz] for d=5×2.5 m=11.0 m, with and without a 3 m long lightning air terminal.

In Figures 8 and 9, in addition to the MoM analysis results, the decoupling at 60 MHz, obtained analytically using (9) where Z_{21}, Z_{22} and Z_{1d} are as defined in (10)÷(12), and $Z_L=50\Omega$ is presented in Figures 8, 9.

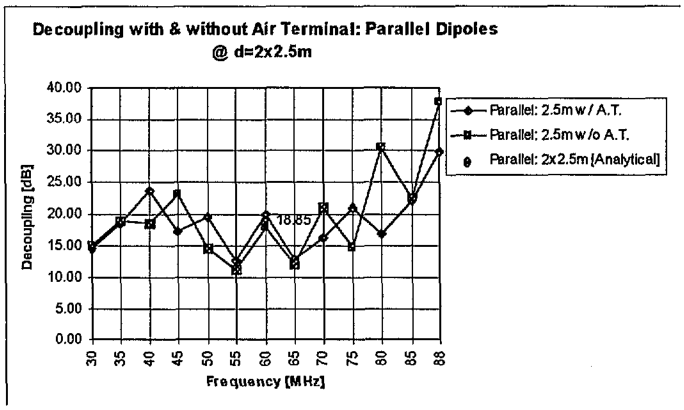

Figure 8: Decoupling between Parallel Dipoles vs. Frequency for d=2×2.5 m=5.0 m, with and without a Lightning Air Terminal

INTERPRETATION OF RESULTS

The following paragraphs present an interpretation of the analysis results.

Horizontal (Parallel) Configuration

The analysis results for the Parallel Configuration are depicted in Figure 4. All results depicted in Figure 4 are obtained with the lightning air terminal excluded from the model.

From observation it is evident that in general, no clear rule for the best separation can be derived. In fact, at different frequencies, one configuration may be preferred over the other. This is of no surprize, since for frequencies of up to 88 MHz, the antenna configuration (considering the metallic mast as a passive element between them) is evidently in the near field (for the highest frequency, f=88 MHz, λ≈3.4m, which is in the order of the antenna separation).

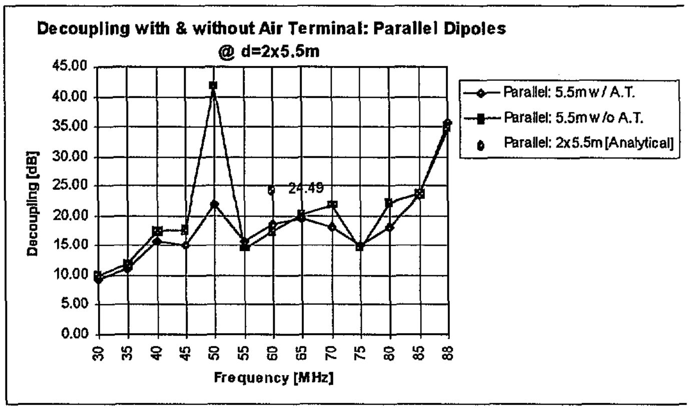

Figure 9: Decoupling between Parallel Dipoles vs. Frequency for d=2×5.5 m=11.0 m, with and without a Lightning Air Terminal

In fact, the configuration with the largest separation (s=11.0 m), is advantageous only around 50 MHz, where the separation between the two antennae is approximately 2×λ (for f=50 MHz, λ≈6m). Similarly, for a separation of s=9.0 m, the antenna configuration is advantageous around f=60 MHz (for f=60 MHz, λ≈5m), etc..

However, the optimal separation appears to be of s=3.5 m, where the best overall performance is obtained in the frequency band of interest.

The effect of the smaller, collocated antennae on the mast (UHF and L-Band) is not expected to be of significant contribution due to their small electrical dimensions.

It is interesting to observe, from Figure 8, that the decoupling between the antennae when separated by s=5.0 m, obtained analytically, using (3) and (10)÷(12) is in good agreement with the MoM computation results for f=60 MHz. Hoever, when the separation is increased to s=11.0 m, from Figure 9 it is clear that the analytical result exceeds the MoM result by 7 dB, approximately, for f=60 MHz. This indicates The importance of the numerical analysis in these frequencies, especially when the generic cases do not preveil (as when the separation is λ/2, as when s=5.0 m).

It is most reasonable to expect, in the near field, an interaction between the antennae and the mast, and between the antennae to the horizontal arms of the antenna support, all being in the very near field. This may be further examined in a later phase.

Vertical (Collinear) Configuration

The analysis results for the Collinear Configuration are depicted in Figure 5. All results depicted in Figure 5 are obtained with the lightning air terminal excluded from the model.

From the MoM analysis results a clear advantage is evident for the larger separation - h of 2.5 m (s=5.0 m, as it is a tip-to-tip separation, whereas h=true separation between the antennae; see Figure 7). Analytical results are also presented in Figure 5, where the same trend is maintained, although some variation is found between the analytical and numerical results (except fot the excellent agreement for s=4.0 / h=1.5 m).

This is of no surprize, as small coupling should be expected for collinear dipoles, when collocated with sufficient vertical separation. However, for the smaller separations, the antennae are still well within the near field, and thus, significant coupling does occur, although, in general - having a decreasing trend with frequency.

With the far field boundry approximately 3.4 m, it is evident that the increase of vertical separation - s to 5 m (h increased to 2.5 m), a significant improvement in isolation is obtained.

Comparison of Parallel to Collinear Configurations

Figure 6 presents a comparison between the decoupling results obtained in both configurations: Paralle and Collinear. It was clear that for a large vertical separation (s=5.0 m / h=2.5 m) the collinear configuration was much more advantageous, however, for smaller separation, no signifcant advantage was observed between the two general configurations.

Effect of Air Terminal in the Parallel Configuration

A prelimnary investigation of the effects of a metallic lightning air terminal installed on the mast, as depicted in Figures 1 and 2 was also investigated partially, and the results are presented in Figures 8 and 9, for s=5.0m and s=11.0 m, respectively.

From observation in those figures, it appears that across most of the frequency band of interest, the air terminal has a minimal effect on the decoupling between the antennae, however:

- For the s=5.0 m configuration (Figure 8), it is evident that except for the frequencies around f=60 MHz and f=30 MHz, where the separation between the antennae is equivalent to λ (5.0 m) and 2×λ (10.0 m) respecively, the decoupling results significantly deviate from each other with and without the air terminal. However, in different frequencies, a different configuration will dominate over the other. For instance, at the higher frequencies, the configuration without the air terminal generally displays a better performance.
- For the s=11.0 m configuration (Figure 9), it is evident that except for the frequencies around f=50 MHz, where the separation between the antennae is approximately to λ/2 (6.0 m compared to the 5.5 m present), the decoupling results are almost independent of the presence of the air terminal between the antennae.

At this time, these are only preliminary observations and they will be further investigated and the results presented in a lated report.

CONCLUSIONS

In this paper, the common question of antenna configurations on a mast, with respect to antenna-to-antenna coupling and RF compatibility are discussed. The question and problem are not new, however, in practical tactical installations, often the installation and location of the antenna are not considered sufficiently early in the design and thus the radio systems performance must be compromised.

One of the most severe cases is encountered when multiple tactical VHF (30 to 88 MHz) are collocated on a single mast, and must operate simultaneously. In tactical installations, large spacings are not achievable, and thus they are clearly in the "near field" of each other. In this case, "notches" in the radiation patterns of monopoles and dipoles cannot be "counted on", and the relative configuration of the antennae is the only factor to consider.

A Method of Moments analysis was conducted in order to investigate a practical common mast installation of multiple VHF antennae, and several configurations were investigated.

The results of the analysis indicate that for practical tactical antenna masts (with a total height no greater than 15 meters) the Collinear Configurations offer little advantage over the Parallel Configuration.

Of course, for large vertical separations, the Collinear Configuration was much better (by 20 dB, at least) than any of the examined Parallel Configurations, however, this was impractical for field deployment.

It thus appears that the assumption that collinear antennae configurations are preferable in mast installations in order to obtain increased isolation, compared to horizontally spaced antennae, is based on the assumption that collinear antennae are placed in the "notch" in the antenna pattern of each other.

In the "near field", however, which prevails under the above described conditions, a classical radiation pattern, including only the E_Θ and H_Φ components are non valid and a radial component increases the decoupling since the expected "notch" in the pattern is not present, in effect. This is also the reason for the improvement in the isolation when the spacing between the levels of the arms was increased.

For practical reasons, therefore, the Parallel Configuration was preferred.

With respect to the Parallel Configuration, noting the fact that in general only a small advantage was evident for the larger separations between the parallel antennae, and only in very distinct bands, a separation of 2.5 m was selected for the field deployment of the antennae. This also offers a considerable simplification of the system design, with little disadvantage due to configuration.

The question of the impact of the metallic mast and lightning air terminal which are also installed on the mast, between the antennae was identified. It was suspected that the presence of the metallic structures of the mast and the lightning rod in the "near field" of the antennae may cause them to act as "directors" and "reflectors", distorting their radiation pattern. It was shown from preliminary observations, that the presence of a lightning air terminal on top of the metalic mast, and in fact - the presence of the mast itself, does in fact have, under certain conditions, a significant effect on the coupling between the antennae. This, and the effect of the metallic mast itself, will be the objectives of a future report.

REFERENCES:

[1] Balanis, C. A., *Antenna Theory Analysis and Design*, pp. 283÷318, Harper & Row, Publishers, New York, USA, 1982.

[2] Rockway, J. W., Logan, J. C., Tam, D. W., Li, S. T., *The MININEC System: Microcomputer Analysis of Wire Antennas*, Artech House, Norwood MA, USA, 1988.

[3] Li, S. T., Rockway, J. W., Logan, J. C., Tam, D. W., *Microcomputer Tools for Communications Engineering*, pp. 1÷4, Artech House, Dedham MA, USA, 1983

[4] Gavan J. J., Shulman, M. B., "Effects of Desensitization on Mobile Radio System Performance: Part I: Qualitative

[5] Analysis", *IEEE Transactions on Vehicular Technology*, Vol. VT-33, No. 4, November, 1984

[6] Gavan J. J., Shulman, M. B., "Effects of Desensitization on Mobile Radio System Performance: Part II: Quantitative Analysis", *IEEE Transactions on Vehicular Technology*, Vol. VT-33, No. 4, November, 1984

[7] Johnson, R. C., Jasik, H., *Antenna Engineers Handbook*, Section 4, McGraw-Hill Book Company, Second Edition.

[8] Jordan, E. C., Balmain, K. G., *Electromagnetic Waves and Radiating Systems*, pp. 535÷599, Prentice Hall, Inc., Englewood Cliffs, New Jersey, USA, 1968

[9] Weeks, W., L., *Antenna Engineering*, pp. 184÷198, Tata McGraw-Hill Publishing Company, New Delhi, India, 1978