Parasitic effects of the metallic towers on the characteristics of the broadcast antennas

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Abstract
In this article, we use a tool NEC (Numerical Electromagnetic Code) to model antenna on top of a tower structure. Simulation results for the parasitic effect of the tower on characteristics of broadcast DVB-T (Digital Video Broadcasting Terrestrial) antenna such as input impedance, return loss, gain, front-to-back ratio and radiation patterns are reported. In addition, the effect of a nearby tower on antenna characteristics is studied. A 3D tower and broadband antenna in the UHF (470-862) MHz band are constructed. The antenna works for both digital and analog TV with return loss (RL) ≥ 10 dB, fractional bandwidth of 87% and gain of 12.3 dBi at center frequency. The effective radiated power is calculated by mounting the antenna at each face of the tower to give a satisfactory coverage to a region around the antenna.

KEYWORDS
Broadcast, DVB-T, ERP, NEC, parasitic tower, UHF

1 | INTRODUCTION
Digital Video Broadcasting-Terrestrial (DVB-T) opened new doors of research in many fields. Versatile antennas are being developed with wider bandwidth, higher gain and front-to-back ratio, large return loss and half power beamwidth to give optimal coverage to a particular region. Recently, many antennas have been reported in the literature1–7 for DVB-T applications. When DVB-T or any broadcast antenna is mounted on top of a tower, it is important to see whether properties of the antenna, such as patterns, impedance, return loss, gain and front-to-back ratio, are affected by the tower itself. It is also useful to analyze the effect of nearby towers on the characteristics of transmitting antennas. Unfortunately, in the literature, there are limited studies providing detailed analysis of parasitic effects of nearby towers on the antenna characteristics. For instance, in Ref. [8], an effort is made to install UHF antennas on an existing tower containing VHF antennas, and mutual interference is studied, but it is unclear whether the tower has an effect on the characteristics of the antennas. Furthermore, the effect of tower on the radiation pattern depends on the frequency, azimuth, and elevation angle in the near field.9 The authors in Ref. [10] have reported no effect from metal frames of solar panel on the radiation patterns of the HF antennas. Indeed, a detailed study analysis is required to see the circumstances under which a nearby tower can affect the radiation characteristics of broadcast antennas including input impedance, return loss, bandwidth, gain, front-to-back ratio, and radiation patterns.

Why detailed analysis for the parasitic effect of the tower on the characteristics of the broadcast antenna is important? The answer to this question is simple. We think that there are practical cases where one needs to see that how will the actual antenna behave in the vicinity of other objects. For instance, the radiation patterns of the antenna in free space can be different than the case when it is mounted on top of a tower near buildings, trees, or other metallic structures.11 Therefore, the antennas will not perform efficiently under such scenario. Such analysis can also be useful to ease the job of a field engineer installing antenna on top of a tower.

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prior study of the effects of tower can save his time from doing many trials while installing antenna. In another aspect, such analysis can be useful to study electromagnetic compatibility of metallic objects near antenna arrays radiating high power.\textsuperscript{10}

In the past, various numerical codes employing method of moments (MoM) have been used to simulate induced current caused by lightening.\textsuperscript{12–16} The similarity and discrepancies of these codes are discussed in Refs. \textsuperscript{12} and \textsuperscript{17}. 4nec2 (open source software) and Feko\textsuperscript{®} are the two software based on MoM can be used to study the effect of metallic towers on the characteristics of broadcast antennas.\textsuperscript{15,16}

To model the surfaces of antennas with wire grids, then surface area rule or equal area rule must be satisfied for accuracy.\textsuperscript{18–20} However, in some cases, equal area rule can result in less accurate results when complex meshing is used.\textsuperscript{20}

In this article, we investigate the parasitic effects of a tower structure on the characteristics of broadcast antennas in the UHF band. We used an open source software 4nec2 (numerical electromagnetic code) to design and analyze a horizontally polarized, broadband and high gain dipole array together with the supporting tower structure. For the validation of the results, we used Feko\textsuperscript{®}. The antenna was simulated on top of the tower and the parasitic effects of the latter on the antenna properties are reported. Moreover, the effect of a nearby tower on the characteristics of the transmitting antenna is also presented. With the same software 4nec2, the Effective Radiated Power (ERP) required to give coverage to a determined area is also studied and presented.

The article is organized as follow. In Section 2, the design of the antenna and the tower to accommodate the former is discussed. Then, in Section 3, the effects of the tower structure on the antenna characteristics are analyzed, while in Section 4, are reported the effects due to a nearby tower. Finally, in Section 5, the ERP of a broadcast antenna is reported, bringing in to the conclusions reported in Section 6.

## 2 | BROADBAND ANTENNA AND TOWER DESIGN

For the DVB-T transmission, the broadband antenna in the UHF band have to be designed assuring a return loss (RL) greater than 10 dB, which implies a Voltage-Wave-Standing-Ratio VSWR < 2 in the whole band.\textsuperscript{1} Moreover, the gain and half power beam-width of the antenna should be such that it can give coverage to a particular area. To meet the requirements of broadcasting, we choose to design a horizontally polarized broadband directional antenna array at 665MHz ($\lambda/4 \approx 45$ cm) that works for both analogue and digital TV.\textsuperscript{7} The geometry of the antenna is shown in Figure 1.

The antenna array is made up of four cylindrical dipoles with approximately radius and length of 1.75 cm and 30 cm, respectively. The cylindrical tube to make a dipole antenna is approximated by using hexagonal tube with radius of 1.75 cm and total number of hexagonal sections are 10 for each dipole. While approximating the cylindrical tube with hexagonal tube made of thin wires, it is important to satisfy the surface area rule.\textsuperscript{18–20} The surface area rule is satisfied by using the built-in feature of the 4nec2, when the radius for the thin wires making the hexagonal tube is 1.805 mm.\textsuperscript{15} The reason for using hexagonal tube with 10 number of sections is the simulation time and available maximum number of segments that can be used in 4nec2. One can use other approximations for cylindrical tube with more than 10 sections, but it will increase simulation time and the results are subjected to surface area rule. The wires making dipole antenna are not straight but are bent towards the back plane. Each $\lambda/4$ section is bent by 17$^\circ$ to increase beamwidth in the azimuthal plane as shown in Figure 1B.

All elements of the array are excited by a single source (with an internal impedance of 75 $\Omega$) connected through transmission lines (TLs). Since a TL with a length that is an odd multiple of $\lambda/4$ can act as an impedance transformer, its characteristic impedance could be properly select to provide the best matching conditions. In particular, since the distance from the middle of the antenna to the outer dipole is roughly...
such a way to satisfy the design rules of the software, as reported in Table 1. However, there are many factors that must be taken into consideration while designing towers, as for instance the environmental factors, including wind resistance and ice loading. Also, height, volume, structure type (rectangular or triangular), present and future loading must be properly considered.

3 | EFFECT OF THE TOWER ON ANTENNA CHARACTERISTICS

The designed broadband dipole array is assumed to be mounted on top of a tower at the height of \( h = 27 \) m, as shown in Figure 2. This configuration has been set in 4nec2 and Feko to highlight the effects of the tower structure on the antenna properties, such as the input impedance, return loss, gain, front-to-back ratio, and far-field patterns, with respect to the standalone antenna (i.e., without the tower).

3.1 | Input impedance and return loss

Parasitic effect of the tower on the input impedance of the antenna array is studied by monitoring magnitude and phase of the input impedance after mounting antenna on top of a tower. Such effects are illustrated by Figure 3.

As can be noted, the magnitude and phase behavior of the antenna input impedance are not affected by the tower structure, being the curves overlapping in the analyzed frequency sweep. The same effects can be also shown on the antenna return loss (RL), as shown in Figure 4. It can be noted that the antenna, designed to match a 75 \( \Omega \) line, with or without tower is resonating at 640 MHz, resulting in a RL > 10 dB, with a fractional bandwidth of 87% in the frequency band (470–1030 MHz).

On the other hand, we can see that the two softwares are giving slightly different results. The main reason behind these differences is that the two softwares are using different mechanism for approximating the segment current, treatment of segment junctions, and modeling of excitation source.

Such results can be ascribed to the weak electromagnetic coupling between the two objects (i.e., the antenna and the tower) due to the back plane of the antenna. Thus, we can

| TABLE 1 | NEC design rules |
|----------|------------------|
| Segment length | \( l < \lambda/10 \) |
| Segment radius | \( R < \lambda/100 \) |
| Segment connections | \( l_1 > l_2 \) \( l_1 > 5 \ l_2 \) \( r_1 > r_2 \) \( r_1 > 5\ r_2 \) |
infer the first conclusion that for a broadband dipole antenna array with a back plane, the tower structure where it has to be mounted has almost no effect (or negligible) on its input impedance and bandwidth.

3.2 Gain and front-to-back ratio

The effects of the tower on gain and front-to-back ratio of the antenna, are reported in Figure 5. As can be noted in Figure 5A, the gain of the antenna is slightly modified due to the reflection of the back-lobe from the faces of tower, at some frequencies. In fact, the reflected back-lobe may be added constructively or destructively to the gain, resulting in a fluctuation of the gain of the antenna when mounted on the tower, with respect to the same parameter without tower.

The influence of the tower structure becomes more evident on the front-to-back ratio of the antenna, as shown in Figure 5B, resulting in larger variation for some frequencies. This remarkable variation is due to the fact that the back-lobes are not totally zero, due to the diffraction from the edges and finite area of the back plane. Moreover, the structure of the back plane itself is composed of wire grids containing vertical and horizontal sections, which affects the front-to-back ratio. As a result, the back lobes generated by the antenna are partially reflected at some frequencies from the tower, resulting in a reduction of back-lobe for those frequencies, which in turns implies an increase in the front-to-back ratio of the antenna at some frequencies.

Even though surface area rule is satisfied in the two softwares, Feko is predicting more gain and front-to-back ratio than NEC. The reason for these differences is the more complex meshing technique used by the Feko. However,
in general, the effect of tower on gain and front-to-back ratio of the antenna is almost similar in the two softwares.

3.3 | Gain and front-to-back ratio

Finally, the effects of the tower structure on the elevation and azimuthal patterns at frequency $f = 640$ MHz are reported in Figure 6.

The results show that the back lobe of the antenna in elevation pattern is affected almost at all angles than the azimuthal ones. The reason can be ascribed as the elevation plane of the antenna is totally lying in the same plane as that of tower at $\varphi = 0^\circ$. However, the azimuthal plane at $\theta = 90^\circ$ is coinciding with tower at some angles only and as a result the back lobe in azimuthal plane is affected at some angles only. Moreover, the main beam is not affected in both patterns. The results from both softwares are consistent. Overall effect of the tower on azimuthal pattern of the antenna is minimum. Our finding suggests that horizontally polarized antenna is best suitable to be mounted on top of a tower.

3.4 | Separation between backplane of antenna and tower

The effect of separation between the backplane of the antenna and tower, on the characteristics of broadcast antenna are simulated in 4nec2 and Feko, at separation distance of 20, 40, and 60 cm. Figure 7 shows the return loss is not affected by varying the separation distance between the antenna and tower. Since, the backplane of the antenna is properly isolating the two objects, therefore, bringing the
antenna closer or farther to the tower face will not affect its return loss.

Figure 8 shows effect on gain, and front-to-back ratio of the antenna. The effect on gain of the antenna is small in comparison to the front-to-back ratio. At each separation distance, the maximum gain variation is less than 0.5 dB in the whole band, whereas the front-to-back ratio variation is less than 2 dB. As a matter of fact, the design engineer can determine the best separation distance in simulation, to have the desire gain and front-to-back ratio before installing the actual antenna on top of a real tower.

Figure 9 shows the effect of separation distance on elevation and azimuthal patterns of the antenna at $f = 640$ MHz. Bringing the antenna closer to the tower is affecting the back lobe of the radiation patterns in both plane. In general, elevation pattern is affected more than azimuthal pattern. However, a horizontally polarized antenna can be affected by the tower, if the separation distance between them is not selected properly as can be seen in Figure 9B at separation distance of 20 and 40 cm.

4 | THE NEARBY TOWER EFFECT

For broadcasting services, typically many antenna towers are placed in the neighborhood of a transmitting location. In some practical cases, it is important to see that how will the actual antenna behave in the vicinity of other towers or objects. For instance, the radiation patterns of the antenna can be affected by trees, buildings, or other metallic structures. For this reason, the analysis of the effects of nearby tower on the broadcast antenna is clearly of interest and has to be properly taken into account.

Therefore, in this section, the effect of nearby tower is reported. In particular, to see the effect of a nearby tower, we constructed another tower and antenna identical to the previous one used in Section 2. The nearby tower is placed at a certain distance $d$ in the main beam direction of the broadcast antenna.

We have analyzed the following two cases to see the effect of a nearby tower on the characteristics of the designed broadcast antenna:

Case I. Nearby tower without an antenna.
Case II. Nearby tower with an antenna

Figure 10 shows the structures of the two towers for the second case. We have the same configuration for the first case without having antenna on the nearby tower. In the second case, the antenna on the nearby tower is not excited. The separation between the two towers is varied and characteristics of antenna closer or farther to the tower face will not affect its return loss.

FIGURE 9  Effect of the separation between, A, backplane of antenna and tower on the elevation and B, azimuthal patterns of the antenna at $f = 640$ MHz

FIGURE 10  Structure of the two towers, when there is an antenna on top of the nearby tower
the broadcast antenna are monitored continuously for the two cases.

4.1 Separation between backplane of antenna and tower

Figure 11 are reported the effects on the reflection coefficient (e.g., return loss) of the broadcast antenna, in the two cases, for different distances $d$, and compared to the same parameter achieved in absence of the nearby tower.

As can be noted, the input impedance (and return loss) of the broadcast antenna are slightly or negligibly affected by the nearby tower, if the antenna of the latter is not present (Figure 11A). Conversely, when the antenna is present on the nearby tower, the effects becomes more evident due to the strong coupling between the two antennas, which obviously decreases increasing the distance $d$. In particular, for example, at a distance $d = 5$ m ($\approx 11\lambda$), the return loss is extremely modified, thus deeply changing the characteristics of the broadcast antenna. However, when the distance $d$ becomes larger than 9 m ($\approx 20\lambda$), the effects become negligible. Thus, it can be concluded as a generic rule, that it is required to assure a minimum distance between two towers with similar antenna of at least $20\lambda$, to avoid appraising changes in the return loss and antenna impedance bandwidth.

4.2 Gain and front-to-back ratio

The effects of the nearby tower on the gain are reported in Figure 12, for the two cases.

In particular, for case I (a nearby tower without an antenna), it can be noted that the gain of the broadcast antenna is deeply affected when the distance $d$ is comparable with the height position of the antenna, that is, for $d \approx h$. In this case, a gain penalty of roughly 1 dB is resulting, and such a gain reduction in comparison to the broadcast antenna without the nearby tower is clearly increasing in frequency. The same effects have been observed also in case II, that is, when the antenna is present on the nearby tower.

From the analysis, it can be observed that the broadcast antenna induces a current on the antenna of the nearby tower,
which radiates a weak electromagnetic field. Such a weak EM field interferes constructively or destructively with the EM field of the broadcast antenna, and as a result the gain of the latter fluctuates with frequency. The effect of the nearby tower with antenna becomes minimum when the separation is at least 54 m (i.e., two times the height $h$ position at which antenna is mounted on the tower). Contrasting the two cases I and II of nearby tower, we observed that nearby tower with antenna (case II) has more effect on the gain of the broadcast antenna.

Analogously, the effects on the front-to-back ratio ($F/B$) of the broadcast antenna were analyzed and reported in Figure 13 for the two cases.

The $F/B$ ratio fluctuates with frequency in both cases and at some of the frequencies the effect of the closer tower is high. In case of the nearby tower without an antenna, the effect on the $F/B$ ratio reduces when the towers are separated by a distance of at least 54 m, that is, $2h$. It can also be noted that the nearby tower with an antenna affects the $F/B$ ratio of the broadcast antenna more deeply, in comparison to case when the nearby tower is without an antenna. Such effect, however, becomes weak or negligible if the separation was 63 m or more (i.e., for $d \gg 2h$).

**FIGURE 13** Effect of the nearby tower on the front-to-back ratio for A, case I and B, case II

**FIGURE 14** Effect of the nearby tower on the elevation pattern at different distances for $f = 640$ MHz
A broadcast engineer should consider these results if in the main beam of the broadcast antenna there exists an unused tower, and it is not at a certain distance for the minimum distortion of the gain and front-to-back ratio.

4.3 | Far-field patterns

The effects on the radiation patterns, both elevation and azimuthal, are reported in Figures 14 and 15, respectively, at different distances between the two towers. In these figures, the two cases of the nearby tower are compare at $f = 640$ MHz with the case when there is no nearby tower.

The nearby tower has some effect on the far-field radiation patterns of the broadcast antenna. For instance, when the separation between the two towers is 50 m or 100 m, the elevation and azimuthal patterns of the broadcast antenna are affected more by the nearby tower for the two cases. However, in the case, when the nearby tower contains antenna, it affects the patterns of the broadcast antenna more than the nearby tower without an antenna.

The nearby tower introduced distortion in the radiation patterns of the antenna. On the other hand, when the separation between the two towers is at least 150 m then, both cases of the nearby towers have smaller effect on the radiation patterns of the broadcast antenna.

5 | EFFECTIVE RADIATED POWER

Finally, to evaluate the coverage area capability, the ERP (Effective radiated power) has been computed by putting the antenna arrays on each face of the tower.

Nevertheless, the use of the wideband array designed earlier, results in a total number of segments exceeding the limits of the adopted software 4nec2. Thus, for this purpose, a narrow band antenna array made up of thin wires rather than hexagonal tubes was properly designed at 665 MHz. The simulated gain and radiated power from such antenna are 13.5 dBi and 192.78 watts (22.84 dBW) when the input power of 192.78 watts is applied to the array. The resulting ERP is 36.35 dBW.

Table 2 shows gain, radiated power and ERP by mounting antenna array at single and multi faces. As can be noted,

| TABLE 2  | ERP with different configuration |
|----------|---------------------------------|
| Antenna at | Gain (dBi) | $P_{\text{rad}}$ (dBW) | ERP (dBW) |
|----------|------------|-----------------|-----------|
| Single face | 13.5 | 22.84 | 36.35 |
| Double face | 10.5 | 25.826 | 36.33 |
| Triple face | 9.71 | 27.625 | 37.33 |
| Quadruple face | 8.46 | 28.9 | 37.36 |
the ERP practically does not change whether to mount antenna array at each or single face of the tower. Conversely, the directivity and radiated power changes with the addition of antenna array at each face of the tower. In particular, with the addition of the antenna array on the other faces of the tower, a coverage of a wider area can be pursued since the radiated power increases, but at the expenses of a reduced directivity (i.e., reduced gain).

When four set of antenna arrays are mounted at all faces of the tower, we get almost omnidirectional like pattern with some gaps. As an example, the elevation and azimuthal patterns at 665 MHz are reported in Figure 16.

6 | CONCLUSIONS

In this work, a broadband antenna based on cylindrical dipoles has been designed and used to simulate the requirement of digital video broadcasting. The designed antenna gives a return loss $RL \geq 10$ dB for the frequency band 470—1030 MHz, with 87% of fractional impedance bandwidth. Since the antenna should be mounted on a tower, the parasitic effects of the latter on the broadcast antenna characteristics have been examined as a function of frequency and radiation angle. The input impedance (return loss) of the broadcast antenna is not affected by the tower. In addition, it has been shown that the effect of tower on the gain and main lobe is very small and it may be ignored. However, depending on the frequency, the front-to-back ratio of the antenna is maximum varying by 2 dB in the presence of tower. Varying the separation distance between the backplane of the antenna and tower can also significantly affect the back lobe of radiation patterns and front-to-back ratio. Horizontally polarized antenna to be mounted on tower face is less affected if the separation distance between tower and antenna is properly selected.

The effects of a nearby tower on the radiation characteristics of the broadcast antenna are also examined. In this case, the return loss of the broadcast antenna is affected more at a small separation ($11\lambda$) by the presence of another antenna on the nearby tower.

We also observed that the effect of a nearby tower on the input impedance and return loss of the broadcast antenna is minimal, if both towers are separated by distance of at least 14 meters ($31\lambda$). However, gain, front-to-back ratio and radiation patterns are deeply affected if antenna is present on the nearby tower. The effects are clearly dependent on the separation between the towers, the frequency and the angle (elevation or azimuth). If the separation between the two towers is greater than 140$\lambda$ (for UHF band), the effects of a nearby tower becomes negligible. If there is an unused tower around the broadcast tower, its effect should be considered if it is not far enough for the desired radiation characteristics of the transmitting antenna.

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