Over-the-Horizon Radiation Characteristics of a Side-mounted Circularly Polarized Collinear Array

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Abstract – Collinear array (CA) is an antenna system that finds applications in FM broadcast stations where identical elements are stacked to increase the gain. However, stacking generates minor lobes that produce downward radiation, pattern nulls and the corresponding adverse effects. Adjusting the inter-bay distance lowers the magnitude of the minor lobes but doing it comes with disadvantages. This paper presents the radiation characteristics over the horizon of a commonly used collinear dipole array mounted to a metallic tower used in FM broadcasting. The discussion includes the general location of pattern nulls and the gain of the downward radiation from the minor lobes. Emphasis is also given to the minimization of the minor lobes and its effects on the array major lobe gain. Using an advance antenna simulation software, results show that the metallic tower makes the azimuth radiation pattern directional making the gains of the major and minor lobes increase in some directions. The minor lobes produce downward radiations resulting to blanketing near the tower base. The magnitude of these lobes is reduced with lower inter-bay distances but has the effect of decreasing the gain of the array. By presenting the radiation patterns of the array with varied values of inter-bay distance, one can determine the location of pattern nulls, minor lobes and whether excessive radiation is produced. In this way, one can choose the best configuration that suits a particular application.

Keywords - Sidelobe, Uniform Linear Array, Omnidirectional Pattern, Blanketing, Slanted Dipole.

I. INTRODUCTION

The collinear array (CA) is a form of uniform linear antenna array where all elements are identical, stacked vertically and are electrically connected in parallel. These identical elements are called bays and are stacked primarily to increase the gain. Base stations of two-way communications systems usually utilize CA antenna systems using vertical half-wave dipole as bays. Television and FM broadcast stations utilize either horizontally polarized or circularly polarized elements as the basic elements. The bays are spaced one wavelength apart and are fed in-phase to appear to be connected in parallel [1] using suitable lengths of transmission lines. Practically, the number of bays is limited by the available tower height and ordinarily amounts to four bays.

Theoretically, stacking of bays creates minor lobes and the number of these lobes increases with the number of bays being stacked. The minor lobes produce downward radiation below the horizon in the elevation pattern of the antenna system [1, 2, 3]. Excessive radiation around the vicinity of the antenna system can be decreased by reducing or eliminating the sidelobes that produce it. Depending on the transmitter power and the gain of the sidelobes that are projected downward, excessive radiations can be produced to overload the front-end of receivers and can pose health hazard to human beings and animals around the antenna system. In the foregoing, there is a need to consider measures to limit the downward radiation of collinear antenna systems commonly used in FM broadcast stations.

Aside from the generation of sidelobes, stacking of bays also produces pattern nulls along the horizon. These pattern nulls are usually located between the lobes of the antenna radiation pattern. In pattern null locations, weak to zero signal levels are present making the reception of signals difficult.

The amplitude of the sidelobes in the radiation pattern of collinear antenna arrays are usually reduced by adjusting the inter-bay distance to less than one wavelength. Specific distances are effective in reducing the sidelobe to a nil magnitude, thereby, eliminating the pattern nulls. However, in the process, the over-all gain of the antenna system is reduced. With the use of an advance antenna simulation software, this paper presents and discusses the effects of varying the inter-bay distance between bays in a CA composed of shunt-fed, slanted dipoles. Particularly, the effects on the gain, downward radiation (due to the minor lobes) and the location of the pattern nulls are presented. In this way, any antenna design practitioner may determine the optimum inter-bay distance for a particular application and situation.

II. DIPOLE CHARACTERISTICS

The shunt-fed, slanted dipole shown in Figure 1 is the most commonly utilized circularly polarized element in CA antenna systems as far as FM broadcasting is concerned. It has a good circularity on the horizontal plane both for the vertically and horizontally polarized (V-pol and H-pol) components. As shown in the figure, the element is composed of two half-wave dipoles bent 90^0. The plane of each bent dipole is slanted by 22.5^0 from the horizontal plane; the two dipoles have 45^0 slant difference [3]. The metallic boom supporting the dipoles has a length of ¼ wavelength. The slant angle determines the axial ratio between the horizontal and vertical wave components. RF power is fed in-phase to the two dipoles through two opposite arms of the dipoles. The desired dipole impedance is achieved using Delta match and is done by adjusting the location of the feedpoint along the length of the opposite dipole arms. Detailed description of this antenna is presented in various papers, particularly [4, 5].

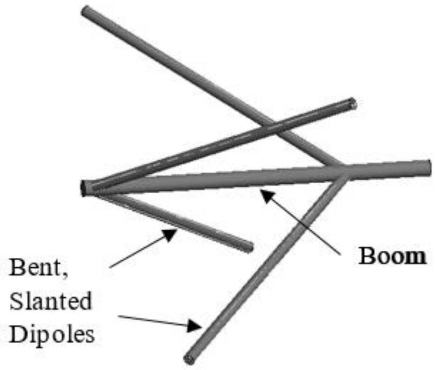


Fig. 1. The circularly polarized shunt-fed, slanted dipole

III. SYSTEM MODEL

The FCC (Federal Communications Commission) of the USA, the NTC (National Telecommunications Commission) of the Philippines and other regulatory bodies accept three sources of antenna characterization as proof-of-performance of antenna systems submitted for approval. One of these is the antenna characterization results from an antenna simulation software. In this paper, the more advance, multi-model Feko simulation software is used. The software has an optimization toolbox that allows the determination of the optimum antenna characteristics, e.g., gain, by varying a variable or a set of variables, e.g., inter-bay distance. The collinear array set-up shown in Figure 2 is simulated with varied values of the inter-bay distance (D) in an attempt to demonstrate the effect of D in limiting the downward radiation of the CA. The tower-to-bay center distance (d) is fixed at 0.625λ, being the most common and practical value. Practically, these distance values vary depending on the antenna installer and are not seriously being considered. The inter-bay distance is primarily the variable that is considered for simplicity in the implementation. The desired optimum antenna characteristics are minor lobe reduction and a reasonable antenna gain.

IV. PREVIOUS WORK

The CA in this paper is a form of uniform linear array where the elements are stacked vertically and with maximum radiation occurring perpendicular to the axis of the elements. It is generally called collinear broadside array described in antenna books [6] that generally refers to uniform linear array with maximum radiations in all directions normal to the array axis. A conference paper [1] presented in detail a CA composed of ideal elements and located in free-space.

Since the CA is a uniform linear array, its system radiation pattern is governed by the principle of array multiplication [6]. The principle states that the total electric field pattern of a CA is equal to the product of the electric field pattern of the bay and the array factor. [1] discussed this principle in detail and showed that the total pattern of a CA really contains minor lobes. If the bays in a CA are vertical half-wave dipoles and following the array multiplication principle, the total electric field pattern is vertically polarized and omnidirectional on the horizontal plane. This is true since each dipole has a vertically polarized electric field pattern that is omnidirectional on the horizontal plane. The total field pattern has a greater gain and with minor lobes compared to the field pattern of the bay.

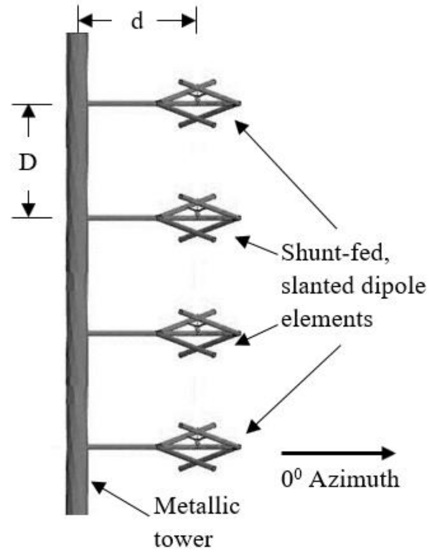


Fig. 2. The four-bay collinear array mounted to a 4-inch diameter metallic tower

Shunt-fed, slanted dipoles are intensively being characterized and described in various published papers [2, 3, 4, 5]. These dipoles are circularly polarized and designed to exhibit omnidirectional patterns on the horizontal plane, both for the vertically and horizontally polarized components. Unlike in [1] and [2], this paper particularly deals with the over-the-horizon radiation characteristics of the CA considering the effect of the metallic tower. Due to the effects of the tower, there is a recognized increase in the total gain in the main lobe as well as in the sidelobes on the horizontal plane in some directions. This will be shown in the discussion of results.

The increase in the main lobe increases the coverage area of the CA but the increase in the gain in the minor lobes responsible in producing downward radiation is a good point to discuss, especially on the undesirable effects. With excessive amount of radiation, there exists the adverse effect of blanketing of radio receivers and exceeding the limits on RF field Maximum Permissible Exposure (MPE) to humans. Discussed in [7], MPE is limited to $1mW/cm^2$ in the FM band, while blanketing in most receivers occurs when the electric field intensity at the front-end of the receiver is 115 dBu [8].

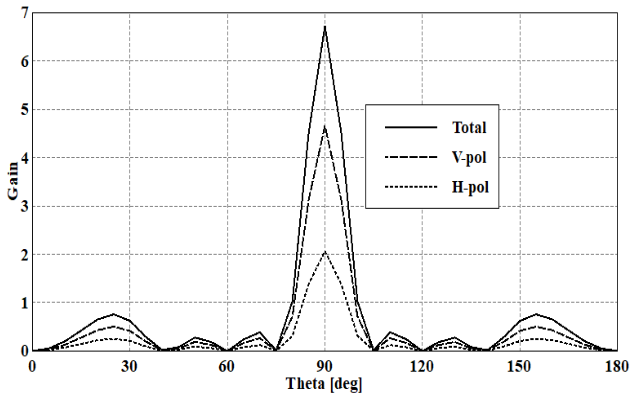
V. PROPOSED METHODOLOGY

This paper presents and discusses the radiation pattern on the vertical plane of a four-element circularly polarized CA system used in FM broadcasting. The set-up is shown in Figure 2 with the dipoles mounted to a metallic tower. In this study, the values of D are 1, 0.75, 0.7, 0.65 and 0.6 wavelength (λ), while the value of d is 0.625λ. The presence of a 4-inch metallic tower in the CA somewhat affects the circularity of the azimuth radiation pattern of the array as discussed in [2]. The value of d = 0.625λ is used in this paper as a balance between practicality and effect on circularity. Though not realistic, a no tower scenario is also included for reference purposes. For each of the values of D and d, a set of radiation patterns on the vertical plane are created using Feko. Radiation patterns on the vertical plane are used to show the radiation pattern over the horizon. The radiation patterns are simulated with a frequency of 97.4885 MHz, which is the algebraic mean of the 88-108 MHz FM band. For the sake of illustrations, zero azimuth refers to the direction directly infront of the array as indicated in Figure 2. The locations of pattern nulls and the gain of the major and minor lobes are determined. For further guidance, a sample situation is discussed to illustrate the practical significance of the paper

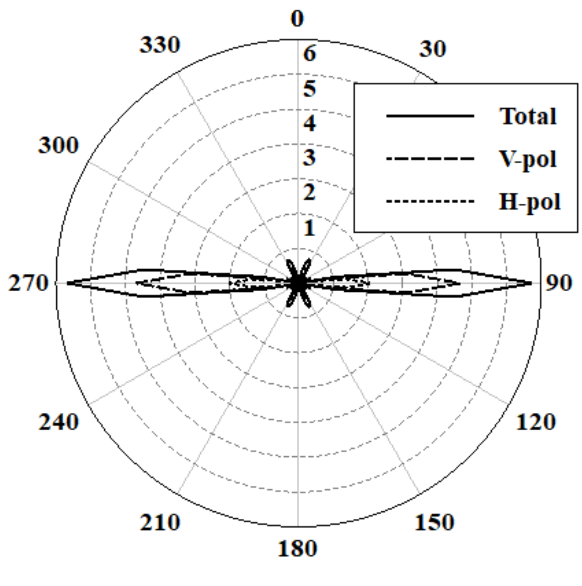
VI. SIMULATION RESULTS

The first set of results is the radiation patterns of a 4-element CA without a metallic tower. The patterns are simply the radiation patterns of the array of identical elements without the effects of surrounding objects. Since the array cannot be suspended without any support, the patterns are therefore theoretical. Figure 3 (a)-(b) show the over the horizon radiation pattern of the towerless CA described above with inter-element distance equal to one wavelength both in cartesian and polar plots. It also shows the total radiation pattern and its V-pol and H-pol components. In cartesian plots as in Figure 3(a), theta is perceived to be the angle of incidence and is varied from 0^0 to 180^0 as shown in the figures. In polar plots such as Figure 3(b), varying the value of theta (from 0^0 to 180^0) shows the radiation pattern of the array on the vertical plane. The main beam or lobe of the array pattern occurs at 90^0; downward radiation or the so-called below-the-horizon radiation occurs in all values of theta above 90^0. Therefore, all theta values from 0^0 to 90^0 refer to the radiation pattern components that contribute to upward radiations and therefore produce insignificant radiations within the target area. In broadcasting, only the radiations over and below the horizon matter.

As shown in Figure 3 (a)-(b), maximum values of these minor lobes that contribute to downward radiations occur at 0^0 azimuth and in three distinct values of theta: 110^0, 130^0 and 155^0. The total gains of these minor lobes are 0.3886 (-4.1050dBi), 0.2777 (-5.5752dBi) and 0.7593 (-1.1959dBi), respectively. At 105^0, 120^0, 140^0, 175^0, and 180^0 values of theta, weak to no radiation occur. This is also true for the V-pol and H-pol components of the radiated signal. The same observation is made with the CA with metallic tower. Therefore, the presence of the tower has the same effect for V-pol and H-pol components as far as the location of the pattern null and minor lobe locations are concerned. For this reason, in the discussions and presentations that follow, only the total radiation patterns are presented. Also, in all presentations, note that just below the antenna array, theta is equal to 180^0. As shown in Figure 3(c), the radiation pattern on the horizontal plane of a CA is a near perfect circularity. It will be shown later that this circularity will be altered if surrounding objects will be considered.



(a)



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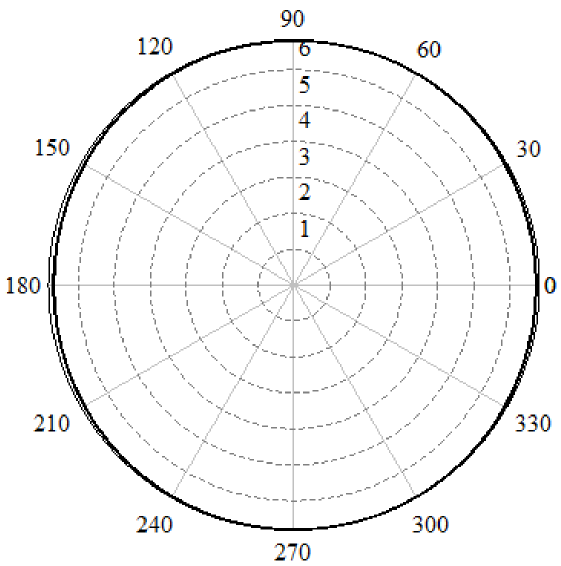
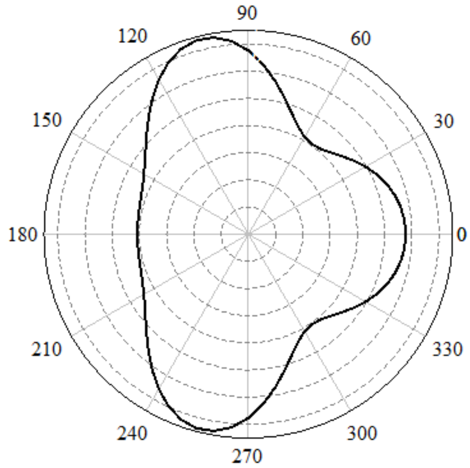


(c)

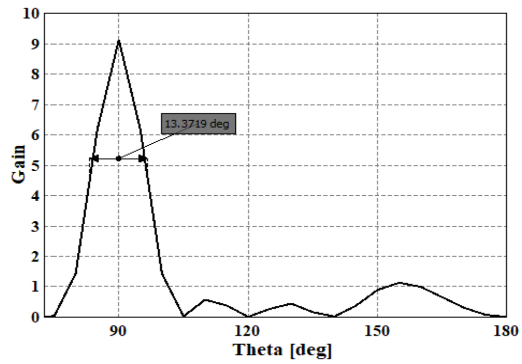
Fig. 3. Far-field pattern over the horizon of a 4-element CA without tower in (a) Cartesian, and (b) Polar plots; (c) azimuth radiation pattern

Figure 4 (a) illustrates the general radiation pattern of the CA showing that the tower affects the circularity of the azimuth radiation pattern. The difference is obvious when compared to Figure 3(c). Basically, with the presence of the metallic tower with a distance of 0.625λ from the bay center, the value of the circularity of the radiation pattern on the horizontal plane is within ±1.3 dB for all inter-bay spacing of λ, 0.75λ, 0.7λ, 0.65λ and 0.6λ. Because of the pattern deformation, there is a perceived increase in the major and minor lobe gains at certain azimuth directions (phi). The tower makes the pattern directional in three distinct directions. High lobe gains occur at phi = 0^0, 100^0 and 260^0, for D = λ and at phi = 0^0, 105^0 and 255^0 for all other values of D. Due attention is given to these maximum gain values for they produce the greatest downward radiation and the corresponding adverse effects. When the inter-element distance is one wavelength, as shown in Figure 4(a), the maximum gain of the array is 9.1453 (9.612 dBi) as compared to 6.7276 (8.279 dBi) in a towerless set-up. The maximum downward radiation is also increased from 0.759 (-1.196 dBi) to 1.132 (0.540 dBi) occurring at theta = 155^0. The beamwidth is also lower than the beamwidth of the array patterns in the other values of D.

The effect of this downward radiation can be illustrated using a common scenario in a provincial station in the Philippines. If an FM station has a transmitter power of 10kW and an antenna height of 100 feet (30 meters), the downward radiation caused by the largest sidelobe will be 0.0822 mW/cm^2 and 144.914 dBu at 13.989 meters from the tower base. In this location, the signal level of 144.914 dBu is way above the limit of 115 dBu and definitely blanketing will occur. Though the produced power density is below the limit of 1 mW/cm^2, care must be observed when the aggregate radiation from other sources in the same area exceeds the limit.



(a)



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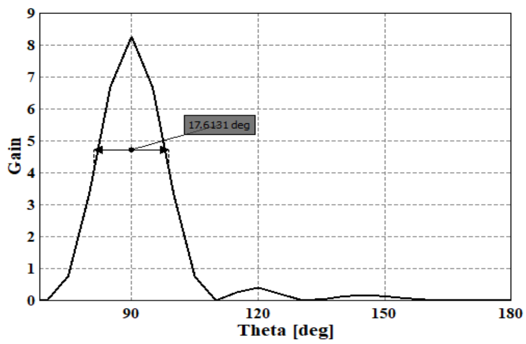

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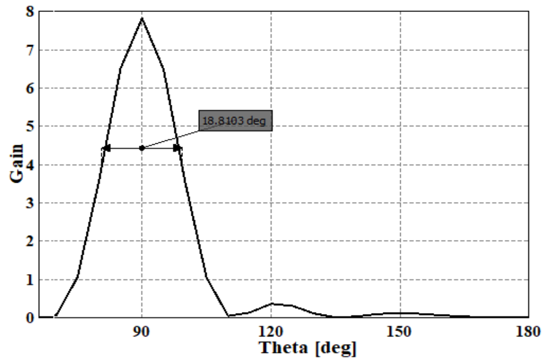
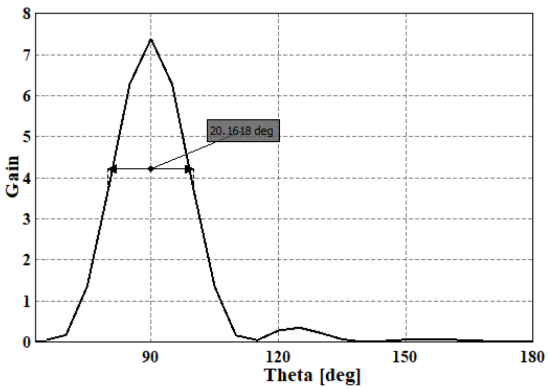
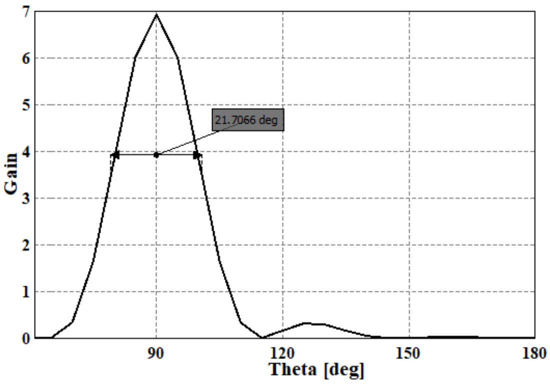


(d)



(e)



(f)

Fig. 4. Far-field pattern of the 4-element CA with tower with d = 0.625λ (a) on the horizontal plane and on the vertical plane with D equal to: (b) λ, (c) 0.75λ, (d) 0.7λ, (e) 0.65λ, (g) 0.6λ

When the inter-bay distance is decreased from one wavelength, the gain of the main beam decreased. Also, the gain of the minor lobes is decreased and located much away from the tower base. The decrease in the minor lobe gains and at the same time directed to a point farther away from the tower base are effective in limiting the adverse effects of the downward radiations. Generally based on the results, when the inter-bay distance is decreased from one wavelength starting from 0.75λ, (a) the gain of the main beam and minor lobes is decreased, (b) the azimuth radiation pattern becomes directional and maximum gain occurs at phi = 255^0, (c) the location of the most significant minor lobe is moved farther away from the base of the tower. For D equal to 0.75λ and 0.70λ, the maximum downward radiation is directed to 30^0 below the horizon (theta = 120^0). This is located about 51.96 meters from the tower base. For 0.65λ and 0.60λ values of D, the maximum downward radiation will be directed to a point 42.84 meters away from the tower base. The said radiation is directed 35^0 below the horizon (theta = 125^0) Table-1 summarizes these results including the decrease in the major lobe gain as D is reduced. As the table shows, for all values of D, the downward radiation is still large enough to produce blanketing near the antenna array with the conditions specified, while the maximum power density produced is much lower than the MPE limit.

Table-1: Sidelobe Locations, Power Density and Electric Field Intensity for 10kW Transmitter, 30m Tower

D	Significant Minor Lobe		Power Density, mW/cm^2	Field Intensity, dBu	Major Lobe Max Gain
	Gain	Location,m			
0.75λ	0.399	51.96 (120^0)	0.0088	135.22	8.282
0.70λ	0.359	51.96 (120^0)	0.0079	134.76	7.828
0.65λ	0.347	42.84 (125^0)	0.0101	135.80	7.391
0.60λ	0.319	42.84 (125^0)	0.0093	135.44	6.944

VII. CONCLUSION

This paper has shown that downward radiations happen in side-mounted CA antenna systems in the radio horizon within the coverage area. Though the magnitude of these radiations could be reduced, there still exists the possibility of blanketing and even exceeding the MPE limits to RF exposure. Generally, blanketing is likely to occur at phi = 255^0 and 105^0, theta = 120^0 and 125^0 due to the relatively higher gains at these points. If these points are located in a highly populated area and blanketing is a problem, one solution is to increase the antenna height. This will reduce the downward radiation and relocates it away from the tower base. The antenna height can also be reduced to relocate the downward radiation nearer to the tower base. However, care must be observed in doing this for it increases the radiation exposure to people, especially the ones manning the transmitter. With the results presented, lower than a wavelength values of inter-element spacing is recommended starting from 0.75λ. However, values lower than 0.60λ are discouraged due to the effect of mutual impedance between elements. Lastly, as the inter-element distance is reduced from 0.75λ, the beamwidth is increased. This increase in beamwidth increases the coverage area of the array below the horizon with the absence of any pattern null.

VIII. FUTURE SCOPES

In previous papers, it was shown that there are limitations of the basic element used in the array, especially in the compliance of some broadcast standards. Also, there is a need to properly determine the optimal value of the tower distance to the array to optimize the array gain and circularity. For future directive, the topic needs to be revisited with the elements and array being optimized. It would be interesting to note the locations of maximum downward radiation along the horizon in these optimum conditions.

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