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Patterns of sidemount four-bay FM antenna system

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ABSTRACT

This paper presents the radiation characteristics of a 4-bay collinear FM antenna system, both in free-space and with the presence of a metallic tower where the bays are mounted, with the use of powerful computers and accurate antenna simulation software. The radiation characteristics of the array are presented and discussed, such as the total gain, polarization components, circularity, beamwidth and minor lobe of the array. This is to determine the conformity of the array performance with existing standards. The possible effects of the metallic tower and the downward radiation from the minor lobe are emphasized. Being aware with these radiation characteristics, broadcast practitioners can optimize the use of this popular array. Results of numerical analyses show that the array is basically a vertically polarized radiator, the beamwidth is quite small which makes it disadvantageous for high-elevated antenna systems, the metallic tower affects the circularity of the azimuth pattern, and the downward radiation from the minor lobes can cause adverse effects. Adjustments on the basic elements and bay placements are recommended.

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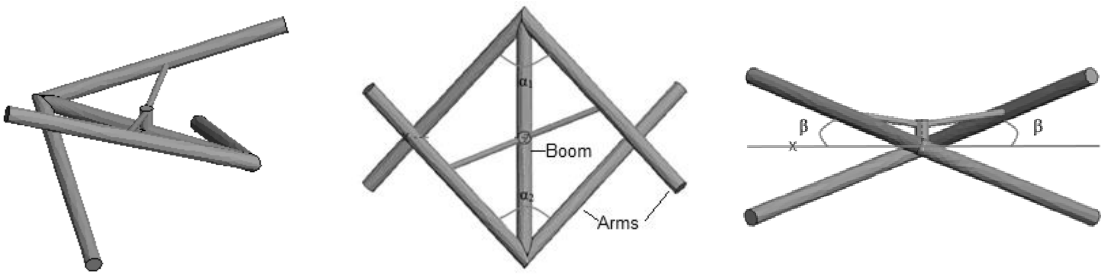
1. INTRODUCTION

Most FM antenna systems are composed of several identical bays that are stacked vertically forming a collinear array. This is done to attain higher gains. In the Philippines, the United States and other countries, these bays are required to exibit circular patterns on the azimuth and bidirectional on the vertical plane and the bandwidth must be at least 0.2 MHz. They must be basically horizontally polarized (H-pol) but circular polarization (C-pol) is also allowed so long as the vertically polarized (V-pol) component is not in anyway greater than the H-pol component. In the past years, several bays of this kind were developed, the patented circularly polarized antenna (CPA) being the more common and is illustrated in Figure 1. Its dimensions and other specifications are shown in Table 1. Figure 2 (a) shows the polar plot of the CPA total far-field gain on the horizontal and vertical planes in free-space. The pattern on the vertical plane is attained with the cutting plane on the y-z plane. The bay has a maximum power gain of 1.561 (1.934 dBi), and a pattern circularity on the azimuth is ±0.237 dB which is within the required circularity of ±2 dB. The bandwidth of the CPA is 6.4 MHz, which is much greater than the required minimum bandwidth [1]. However, the V-pol is greater than the H-pol on the azimuth, making the CPA basically a V-pol antenna.

Figure 2 (b) shows the azimuth far-field gain pattern of the same antenna illustrated in Figure 1 but with the presence of a 4-inch metallic tower, 0.375 wavelength away from the bay center. Due to the tower, the patterns were altered and deviated from the pattern in Figure 2 (a). The circularity of the gain pattern with the conditions described above and at 97.488 MHz (center of the FM band) is ±2.02 [2]. In the figure and with the tower at 270^0, maximum gains occur at 25^0 and 155^0. Note that all gains in this paper are referred to the gain of the isotropic antenna. Also, the V-pol component is more affected by the presence of the tower than the H-pol. Previous papers [1-4] dealing with the characterization of the CPA show that it has some limitations on conformance to some broadcast standards and requirements, but still remains to be a popular basic element in FM broadcasting.

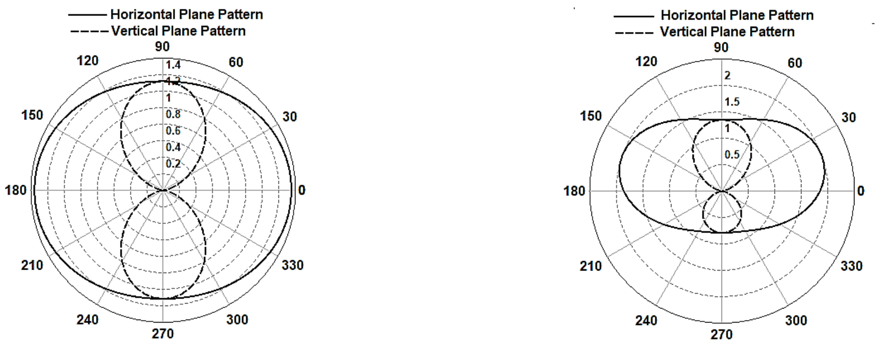


(a) (b) (c)

Figure 1. The circularly polarized antenna, (a) Isometric, (b) top, (c) front views

Table 1. CPA dimension and specifications

Dimension/Physical Specification	Value
Boom Length	¼ λ
Boom and Arm Diameter	2 inches
Arm Length	¼ λ
α_1 (Arm Offset Angle 1)	90^0
α_2 (Arm Offset Angle 2)	90^0
β (Skew angle)	22.5^0



(a) (b)

Figure 2. Radiation patterns on the vertical and horizontal planes of the CPA in (a) free-space, and (b) with tower

Engineers and technicians usually stack several bays forming a collinear array to attain higher gains in FM antenna systems [2, 3], without any knowledge and consideration of the overall radiation characteristics of the resulting array. Stacking identical bays this way produce minor lobes that create downward radiation at high depression angles [3]. Depending on the gain and location, minor lobes can produce undesirable effects. FM broadcast stations in the Philippines, especially in the provinces, four-bay collinear array is the most common antenna system. This paper presents and discusses the radiation patterns of a four sidemounted CPA element collinear array on a metallic tower. Specifically, the paper tackles on the total gain patterns, polarization components, circularity, beamwidth and the details of the minor lobe of the array. The conformance of the array to broadcast standards are determined through the first three items enumerated above. Determining the beamwidth of the main lobe of the elevation pattern is important for this determines the ability of the antenna system to radiate towards and below the horizon. Practically, the antenna system of an FM station is serving its listeners with that part of the elevation pattern from the horizon (0^0) to within an angle of depression (below the horizon) of 10^0 [4-6]. With a small beamwidth and a high antenna height, the station might miss serving the listeners in the vicinity of the antenna system. Since beamwidth decreases with increased gain, good balance between the two must be observed.

The downward radiation from the minor lobes can produce RF energy that leads to blanketing in FM receivers and expose the environment to excessive RF field around the vicinity of the tower [7-12]. Blanketing is a condition when there is excessive RF signal enough to overload the front-end of radio receivers making the demodulaton of the transmitted information difficult. The downward radiation can expose the environment, especially to animals and human beings, to excessive RF field. Every country adopts some sort of safety standards in working in RF fields [13].

A thorough understanding of the radiation characteristics of this popular array of CPA leads to an improved over-all performance of the antenna system in providing signal quality within the service area of the station as well as avoiding the adverse effects of excessive radiation. At the very least, with the proper knowledge of these characteristics, engineers and technicians would optimise (to do the best possible) the use of the antenna system under consideration.

2. RESEARCH METHOD

The set-up of the four-bay collinear array is shown in Figure 3. The bays are vertically spaced one wavelength apart and are fed in-phase. The radiation characteristics of the array are determined using Feko, an advance antenna simulation software that uses diverse computation and optimization processes [3, 14, 15]. In the simulation, the center frequency of the FM band is used if a single frequency is desired, otherwise, the whole FM band (88-108 MHz) is used. Two of the more common tower distance values (referred to bay center) are cosidered: 0.375 and 0.625 wavelength. Tower diameter is either 4 inches or 10 inches. Each bay in the array has dimensions and specifications shown in Table 1. In this study, the radiation patterns of the collinear array are simulated and presented with the following conditions: no tower; with 4-inch diameter tower, 0.375 and 0.625 wavelengths away from the bay center; and with 10-inch diameter tower, 0.375 and 0.625 wavelength away from the bay center. In each condition, the polar plots of the total gain on the azimuth (horizontal plane) and elevation (vertical plane) are presented and discussed. Again, all gain values in this paper are referred to an isotropic antenna. The beamwidth and minor lobe details are determined from the elevation pattern. Also, polar plots of the H-pol and V-pol components of the total gain are presented to determine the superiority of the H-pol over the V-pol. The gain of the array over the entire FM band is plotted in cartesian to determine the bandwidth of the array.

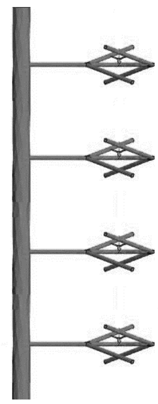


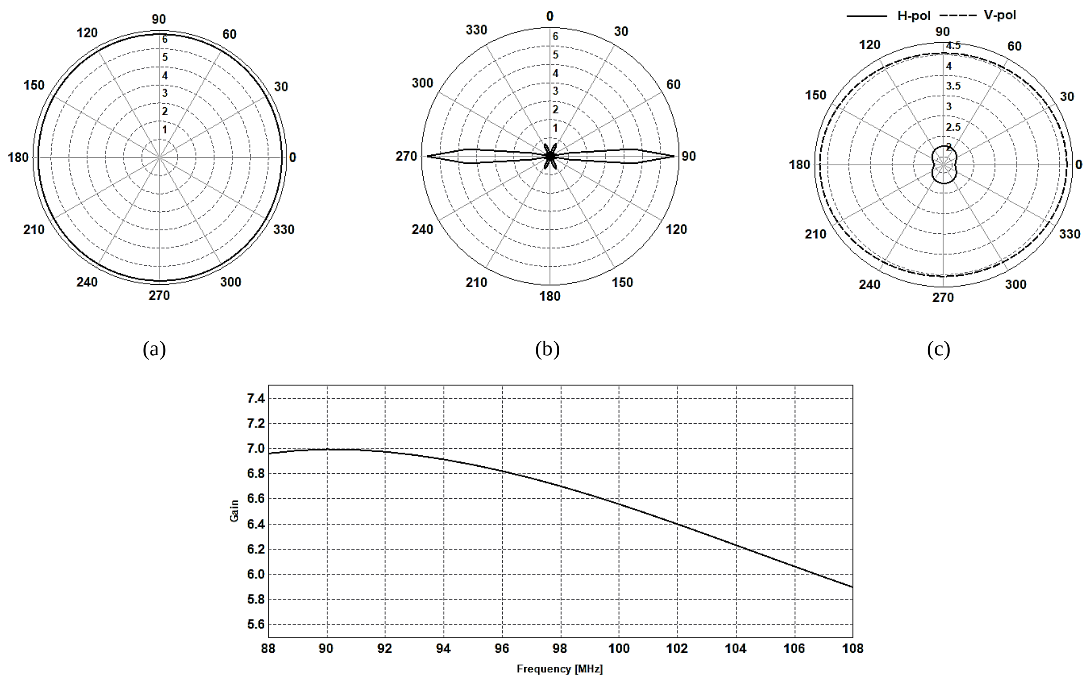
Figure 3. The four-bay collinear array sidemounted to a metallic tower

Aside from the broadcast standards to be observed, the national association of broadcasters (NAB) of the United States maintains the value of 115 dBu (dB referred to 1 uV/m) of electric field to be the minimum value that causes blanketing in FM receivers and the power density value of 0.01 w/cm^2 to be the limit for a safe day-to-day exposure to RF fields. Other standards, however, are adopted in different countries and territories. Also, the regulatory bodies of the Philippines, the United States and of other countries accept characterization results from antenna simulation (computation) as proof-of-performance of broadcast antennas.

3. RESULTS AND ANALYSIS

In the presentation of results, especially involving polar plots, the horizontal plane is referred to the x-y plane in cartesian coordinates. In spherical coordinates, the angle Φ is varied from 0^0 to 360^0 and the value of θ is fixed at 90^0. Also, most of the vertical plane patterns presented in the paper are taken from the x-z plane. This is the same plane as $\Phi = 0^0$, and θ ranging from 0 to 180^0 in spherical coordinates. Lastly, the tower is located at the back of the array, $\Phi = 180^0$; the front of the array is at $\Phi = 0^0$ and $\theta = 90^0$.

The radiation patterns of a four-element collinear array in free-space, i.e. without the tower, is illustrated in Figure 4. Referring to Figure 4(a), the array has a maximum power gain of 6.802 (8.326 dBi) at 70^0 on the horizontal plane; the circularity is ±0.031 dB, which is better than the circularity of a bay. As discussed in [16-22], all collinear arrays have minor lobes in the radiation pattern. The elevation pattern shown in Figure 4 (b) is produced with the cutting plane passing through the x-z plane. In the figure, the radiation pattern has downward radiation due to the minor lobe occurring at 65^0 below the horizon, with a power gain ranging from 0.752 to 1.096 (-1.238 to 0.398 dBi). The beamwidth between half-power points of the elevation pattern is about 13.40. Figure 4(c) shows the H-pol and the V-pol components of the total gain of the array on the azimuth. As shown, the V-pol component is much higher than the H-pol component. The array, therefore, does not conform to the requirement on polarization. Figure 4(d) shows the plot of the antenna gain infront of the array versus the frequencies in the FM broadcast band. In the figure, the array gain does not vary too much within the entire FM band. The gain variation within the 88-108 MHz band is no greater than 0.620 dB from the gain at the center frequency; the bandwidth between half-power points is more than 20 MHz.



(a) (b) (c)

(d)

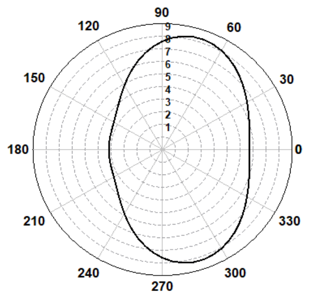
Figure 4. Radiation pattern of the total gain of the four-bay collinear array in free-space at 97.488 MHz: (a) azimuth pattern, (b) elevation pattern, (c) H-pol and V-pol components; (d) gain infront of the array over the FM band

3.1. Four-inch tower

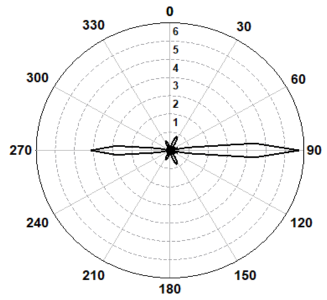
The patterns are significantly altered, when the array is mounted to a metallic tower with a diameter of 4 inches, and 0.375 wavelength away from the bay center. Figure 5 (a) shows the total power gain pattern of the array on the horizontal plane. The maximum gain shown in the azimuth pattern is 9.284 (9.677dBi) at 70^0, minimum gain is 4.146 (6.176 dBi) in the direction of the tower; and the gain infront of the array is 6.719 (8.273 dBi). The circularity is altered and is reduced to ±1.751 dB.

The pattern on the vertical plane is illustrated in Figure 5 (b) and is taken with the cutting plane passing through the x-z plane. The beamwidth between half-power points of the main lobe is 13.059^0.

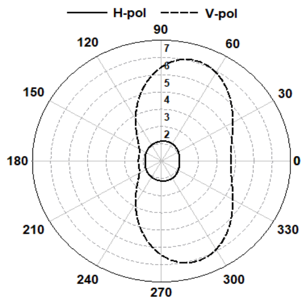
The minor lobe has a maximum power gain of 1.050 (0.213 dBi) and a minimum of 0.569 (-2.447 dBi) at 65^0 below the horizon. Figure 5 (c) shows the H-pol and V-pol components of the radiation pattern on the azimuth. The V-pol component is greater than the H-pol component, which makes the array basically a V-pol antenna. This is against the standard that FM antenna systems should be basically H-pol. Further, the H-pol component is less affected with the presence of the tower than the V-pol. Figure 5 (d) shows the plot of the gain infront of the array over the entire FM broadcast band. The gain variation within the band is no greater than 1.355 dB from the gain at the center frequency; the bandwidth between half-power points is more than 20 MHz.



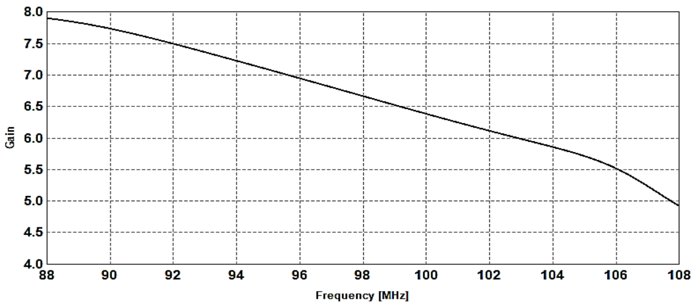
(a)



(b)



(c)



(d)

Figure 5. Radiation pattern of the total gain of the four-bay collinear array with a 4-inch diameter tower, 0.375 wavength away from the bay center at 97.488 MHz: (a) azimuth pattern, (b) elevation pattern, (c) H-pol and V-pol components; (d) gain infront of the array over the FM band

The maximum power gain of the sidelobe transmitted downward is quite small compared to the main lobe. However, since this downward radiation occurs at a relatively large angle of depression, i.e. 65^0, it may pose adverse effects. Consider the condition of an FM broadcast station with a transmitter power of 1000 watts (this is the minimum power of a commercial station in the Philippines and is classified as Class B station) and having a typical tower height of 30 meters. A four-element collinear array would be transmitting a maximum effective radiated power of about 1050 watts at a point 14 meters from the base of the tower, producing a power density of 0.076 w/m^2 and a field intensity of about 135 dBu. With these values, the RF field is above the limit and may not be safe for day-to-day exposure, and the signal level is large enough to create blanketing in receivers.

Increasing the distance of the tower to the bay center by one-fourth of a wavelength improves the circularity of the total power gain to ±1.254 dB, a maximum gain of 9.151 is observed and is located nearer and toward the tower (at 100^0 and 260^0). Also, the gain infront (at 0^0) and at the back (at 180^0) of the array is increased to 7.1840 and 5.138, respectively. However, the V-pol component of the radiation pattern remains to be more dominant than the H-pol. In the elevation pattern (x-z plane), the beamwidth is slightly increased to 13.506^0 and the minor lobe has a downward gain of anywhere between 0.725 and 1.189 at 65^0 around the antenna system. Also, the bandwidth is way above the required value.

3.2. Ten-inch tower

Figure 6 illustrates the patterns derived when the tower diameter is increased to 10 inches, 0.375 wavelength away from the bay center. Figure 6(a) shows the total power gain pattern of the array on the horizontal plane. Relatively, the front and back radiations, and side radiations (90^0 and 270^0) are more balanced compared to the radiation pattern of the array with 4 inches diameter tower. There is an observed improvement on the backward radiation and a reduction in the forward radiation compared to the radiation when the tower diameter is smaller. The maximum gain shown in the azimuth pattern is increased to 9.638 located at 90^0 and 270^0. The minimum value is infront of the array (at 0^0) with 4.952; the gain in the direction of the tower is 4.978. The circularity of the pattern is ±1.446 dB, also compromised compared to the circularity of the array in free-space but is better than the array with a smaller diameter tower.

The pattern on the vertical plane is illustrated in Figure 6 (b) and is taken with the cutting plane passing through the x-z plane. The beamwidth between half-power points of the main lobe is 13.324^0, closer in value to that of the array in free-space. However, the minor lobe has a power gain that falls between 0.705 and 1.193 at a depression angle of 65^0 below the horizon around the antenna. Figure 6 (c) shows the H-pol and V-pol components of the radiation pattern on the azimuth. The V-pol component is still much greater than the H-pol component making the array still basically a V-pol antenna and therefore, unable to comply with existing broadcast standards. Figure 6 (d) is the gain infront of the array plotted within the FM band. Within the band, the gain changes only within a maximum value of 0.487 dB from the gain at the center frequency; the array has a bandwidth that covers the entire band.

When the tower distance is increased by one-fourth of a wavelength while maintaining the tower diameter of 10 inches, the maximum gain became 8.375, a decrease from the previous condition. However, an increased gain is introduced in the forward radiation with a value of 8.330 from the previous value of about 5. The increase in gain comes with the improvement in the circularity of the pattern to ±1.133 dB, i.e. an improvement from the previous condition of ±1.446 dB. The backward radiation is, however, decreased to 4.970. The V-pol component of the radiation pattern remains to be more dominant than the H-pol. In the elevation pattern (x-z plane), the beamwidth increased to 13.467^0 and the minor lobe has a gain of 0.692 and 1.097 at 65^0 below the horizon and around the antenna. The array has a bandwidth that covers the entire FM band whose gain varies no more than 0.743 dB from the gain at center frequency.

In summary, all the array conditions presented conform to the circularity and bandwidth requirements. The gain is increased commensurate to the number of bays. However, the arrays fail to perform as a basic H-pol radiator. Further, the sidelobes of the array produce downward radiation that can pose adverse effects near the base of the tower. Lastly, the beamwidth of the array is quite small that can introduce coverage issue, especially for high elevation antennas. Wireless systems requiring high antenna gains using the proposed array, such as the ones discussed in [23-25], should consider such limitations.

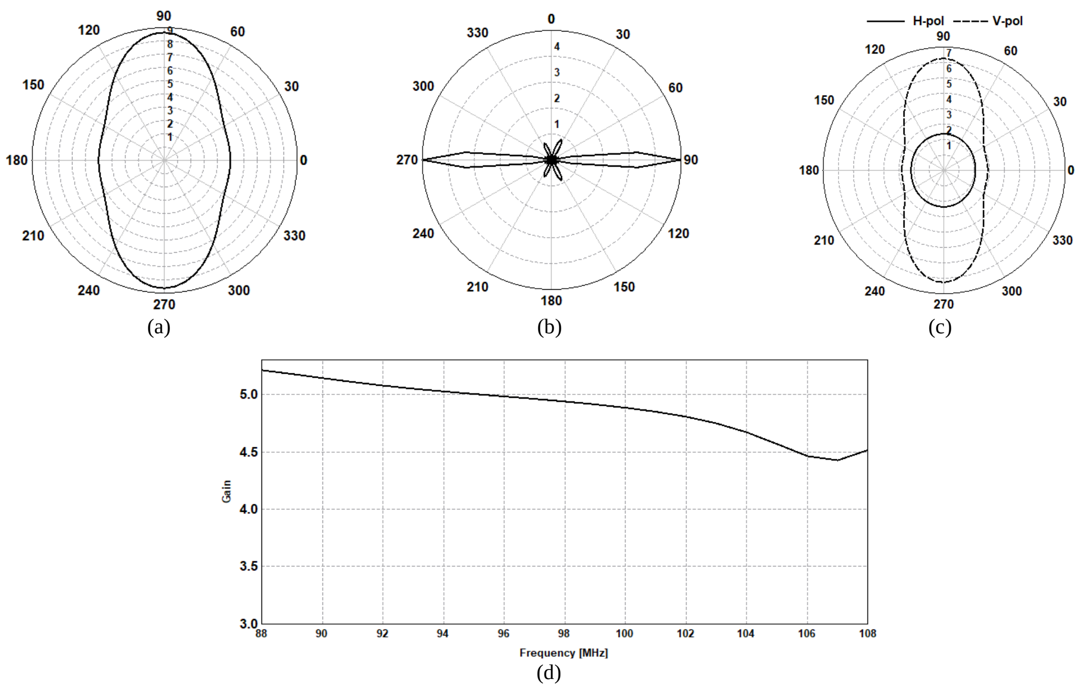


Figure 6. Radiation pattern of the total gain of the four-bay collinear array with a 10-inch diameter tower, 0.375 wavength away from the bay center at 97.488 MHz: (a) azimuth pattern, (b) elevation pattern, (c) H-pol and V-pol components; (d) Front gain of the array over the FM band

4. CONCLUSION

This paper presented and discussed the radiation characteristics of a sidemounted four-element CPA collinear array. Three things can be construed from the presentation: the presence of significant downward radiation at high depression angles, the low beamwidth of the mainlobe towards the horizon and the array is basically a V-pol antenna. In all conditions that were considered in the paper, the maximum gain of the sidelobe causing the downward radiation has a maximum gain that does not go below 0 dBi, with or without the tower, irrespective of the tower diameter and tower distance. Even with Class B FM broadcast stations, the occurrence of blanketing near the base of the antenna is inevitable. Also, depending on the standard, the environment maybe exposed to excessive radiation. Some methods must be adopted to reduce, if not completely remove, the sidelobe. Typically, the service area of an FM broadcast station is served by that part of the elevation pattern from an angle of depression of 0^0 to 10^0. With the beamwidth of the array of about 13^0, the service area of any FM station utilizing a 4-bay collinear array is just served by the elevation pattern within the range of 0^0 to about 6.5^0 of depression angle. Therefore, there is a reduction in the effective coverage area near the antenna tower base. To emphasize on this, if the tower height is 30 meters, the coverage area of the station starts at about 170 meters away from the tower base at a depression angle of 10^0. At 6.5^0 angle, the coverage area starts farther away at about 260 meters. If there is a large volume of target listeners around the vicinity of the station, a high-elevation antenna system is not recommended. Lastly, to correct the polarization issue of the array, the bay must be first converted to become an H-pol antenna. Previous papers show that adjusting the skew angle of the bay can solve this problem.

Because of the effect of the tower, the radiation pattern somewhat becomes directional. Particularly, it becomes bidirectional when the tower distance is 0.375 wavelength from the bay center. To do the best possible or optimize the use of the array, this set-up is best recommended when, in the service area, greater gain is needed towards the 90^0 and 270^0 directions on the azimuth. When the tower distance is 0.625 wavelength from the bay center, the higher gains are not just observed at 90^0 and 270^0, but also infront (0^0) of the tower. The pattern is recommended for applications where the target area is all around the antenna, except towards the tower direction (180^0). For future directive, the array needs improvement in H-pol and V-pol ratio, sidelobe reduction and other characteristics.

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Gerino P. Mappatao was born in Tuao, Cagayan, Philippines. He received the B.S. degree in electronics and communications engineering (ECE) from Saint Louis University, Baguio City, Philippines in 1989, the M.S. and PhD degrees in ECE from De La Salle University-Manila, Philippines in 1998 and 2012, respectively. He is currently an Associate Professor of Electronics and Communications Engineering at De La Salle University-Manila. He authored and co-authored papers in conference proceedings and journals on antennas, broadcast engineering, wireless communications and image processing.