# A Single Beam Smart Antenna for Underground Mine Communications

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*Abstract*–**Multipath reflections are prevalent in underground mine wireless communications systems and are less constructive when an omnidirectional antenna is used. This phenomena can be significantly controlled by eliminate the source of all multipath with a single beam. The single beam must be rotatable towards the desired user to be of any use. The single directed beam will avoid generating multipath reflections and efficiently consume the valuable stored energy. In this paper we present an analysis of an array antenna using dipoles that forms a singlebeam without the need for reflectors or complex arrangement of the array elements.It can be shown that dipole elements placed in a straight line is not effective in minimizing energy consumption and a minimumof three elements are sufficient for forming a single directed beam that is electronically rotatable to all directions. We have compared three,four and six elements for the accuracy.**

***Keywords – Smart Antenna; Phased Array; Undergound Mine; Undergound Communications***

## I. INTRODUCTION

The preformance of wireless communications systems using an omnidirectional antenna(1-3)in underground mines is significanlt degraded by multipath reflection phenomena among other impairments(4).The undergound mine tunnel walls creates a confinment that acts as a wave guide that allow the signal to reflect and thus propagate along the tunnel. The nature of signal propagating from an omnidirectional antenna create multiple reflected signals along the tunnel which are detected a mobile user with varing arrival times(5) and phase. The varing signal characeristics increases the complexity of modelling the channel(6). With a dynamic channel requires the communications system to be adaptive.

Smart antennas have improved about ground communications system and promises to be the better air interface for undergound communications challenges(7)to provide an effective and reliable communications system for use in normal circumstance and emergency(8, 9). To date most research in smart antennas have modeled array elements in a uniform linear array (ULA) (10, 11).When arranging dipoles in a ULA has the disadvantage of inefficient use of power and still suffer from multuple part reflection when as image of the main beam is produce in the opposite direction on the central axis(10, 11).The drawback of such an antenna is more significant at the receiving end, where reflected waves will also be received and processed. This may degrade signal quality and hence lower system performance.

Therefore we propose a single beam smart antenna for underground communications systems that will nullify undesired reflected signal and efficient use limited power. With a single beam accepted at the receiving end, all other signals are nullified. Less efficient use of power is observed when the dipole elements were arranged in linear array or complex array (12). Thus we analyzed a number of possible arrays with a sizeable number of elements in odd symmetrical geometry to form a steerable directed beam.

The results of this study are; our models show that it is possible to have a more directed single beam witha minimumof three elements, as the number of elements increased, the directivity and coverage range improved significantly and finally, we demonstrate that the single rotating beam can scan a full $360^0$area while nullifying all other beams outside the desired look angle.

## II. ADAPTIVE ARRAY MODEL

Analytically we can show that for any arbitrary set of dipoles arranged in a ULA would produce a radiation pattern that is symmetrical on both side of the plane where the dipoles are placed (10). As a result it is not possible to form a single beam and steer it in all directions by placingany number of dipoles in a straight line. However, our objective is to steer a single beam in the full $360^0$azimuth angle range. Therefore, the three dipole elements should not be placed in a ULA.Consequently, we model a general setup as shown in Fig. 1 where dipoles are not placed in a straight line.

The respective complex current phasors of the dipoles are taken as $I_1$, $I_2$, and $I_n$. Hence the electric field (far-field) at the observation point P could be given as:

$$E = A_0 I_1 e^{-j\beta r_1} + A_0 I_2 e^{-j\beta r_2} + \ldots + A_0 I_n e^{-j\beta r_n} \tag{1}$$

where$A_0$ and $\beta$ are a constant and the phase constant, respectively.
Substituting for $r_1$, $r_2$, and $r_n$ in terms of the distance from origin, equation (1) can be simplified to:

$$\begin{aligned} E = {} & w_1 e^{j\beta(x_1\cos\varphi + y_1\sin\varphi)} + w_2 e^{j\beta(x_2\cos\varphi + y_2\sin\varphi)} \\ & + \ldots + w_n e^{j\beta(x_n\cos\varphi + y_n\sin\varphi)} \end{aligned} \tag{2}$$

where$w_1$, $w_2$, and $w_n$ are the complex weights and in proportional to the complex current phasors$I_1$, $I_2$, and $I_n$, respectively. To achieve the objective of forming a resultant single beam, the value of the complex weights $w_1$, $w_2$, and $w_n$needs to be optimized such that the resultant field must matched a desired single beam function $f(\varphi)$. Thus equation (2) can be written as,

$$w_1 e^{j\beta(x_1\cos\varphi+y_1\sin\varphi)} + w_2 e^{j\beta(x_2\cos\varphi+y_2\sin\varphi)} + \ldots + w_n e^{j\beta(x_n\cos\varphi+y_n\sin\varphi)} = f(\varphi) \qquad (3)$$

The optimization of complex weights,$w_1$, $w_2$, and $w_n$, can be done either analytically or iteratively(13). Since the number of dipole elements will be confined to as few as possible, an analytical optimization method is more appropriate.

## III. ANALYTICAL SOLUTIONS

The analytical methodemployed to optimize the complex weights $w_1$, $w_2$, and $w_n$ is as follows. Each term in equation (3), is multiplied by its complex conjugate. We begin with the first term multiplying equation (3) with $e^{-j\beta(x_1\cos\varphi+y_1\sin\varphi)}$ and integrate byangle $\varphi$over the limit from 0 to 2π, we get,

$$w_1\int_0^{2\pi} d\varphi + w_2\int_0^{2\pi} e^{j\beta[(x_2\cos\varphi+y_2\sin\varphi)-(x_1\cos\varphi+y_1\sin\varphi)]}d\varphi + \ldots + w_n\int_0^{2\pi} e^{j\beta[(x_n\cos\varphi+y_n\sin\varphi)-(x_1\cos\varphi+y_1\sin\varphi)]}d\varphi = \int_0^{2\pi} f(\varphi)\,e^{-j\beta(x_1\cos\varphi+y_1\sin\varphi)}d\varphi \qquad (4)$$

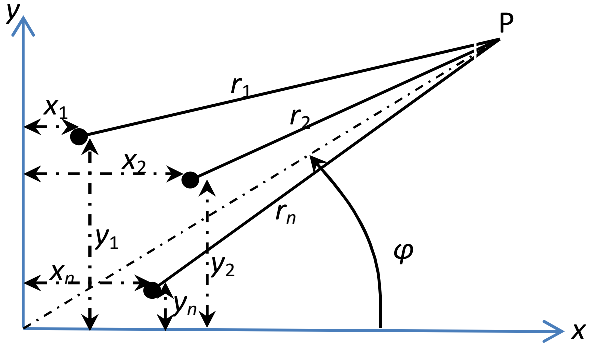


Fig.1. Schematic Diagram of Dipole Placement

Similarly, multiplying equation (3)with the complex conjugates of the second and integrating over 0 to 2π, we obtain equation (5) and repeating up to the n^th^ term.

$$w_1\int_0^{2\pi} e^{j\beta[(x_1\cos\varphi+y_1\sin\varphi)-(x_2\cos\varphi+y_2\sin\varphi)]}d\varphi + w_2\int_0^{2\pi} d\varphi + \ldots + w_n\int_0^{2\pi} e^{j\beta[(x_n\cos\varphi+y_n\sin\varphi)-(x_2\cos\varphi+y_2\sin\varphi)]}d\varphi = \int_0^{2\pi} f(\varphi)\,e^{-j\beta(x_2\cos\varphi+y_2\sin\varphi)}d\varphi \qquad (5)$$

$$w_1\int_0^{2\pi} e^{j\beta[(x_1\cos\varphi+y_1\sin\varphi)-(x_n\cos\varphi+y_n\sin\varphi)]}d\varphi + w_2\int_0^{2\pi} e^{j\beta[(x_2\cos\varphi+y_2\sin\varphi)-(x_n\cos\varphi+y_n\sin\varphi)]}d\varphi + \ldots + w_n\int_0^{2\pi} d\varphi = \int_0^{2\pi} f(\varphi)\,e^{-j\beta(x_n\cos\varphi+y_n\sin\varphi)}d\varphi \qquad (6)$$

We can obtain $n$ such equations, if we consider $n$ dipole elements. Hence the above $n$ such equations can be written into a matrix form as,

$$\begin{bmatrix} A_{11} & A_{12} & \ldots & A_{1n} \\ A_{21} & A_{22} & \ldots & A_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ A_{n1} & A_{n2} & \ldots & A_{nn} \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ \ldots \\ w_n \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \\ \ldots \\ b_n \end{bmatrix} \qquad (7)$$

where $A_{ij} = \int_0^{2\pi} e^{j\beta[(x_j\cos\varphi+y_j\sin\varphi)-(x_i\cos\varphi+y_i\sin\varphi)]}d\varphi$ and $b_i = \int_0^{2\pi} f(\varphi)\,e^{-j\beta(x_i\cos\varphi+y_i\sin\varphi)}d\varphi$. Thus the optimized coefficients can be obtained by

$$\begin{bmatrix} w_1 \\ w_2 \\ \ldots \\ w_n \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & \ldots & A_{1n} \\ A_{21} & A_{22} & \ldots & A_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ A_{n1} & A_{n2} & \ldots & A_{nn} \end{bmatrix}^{-1} \begin{bmatrix} b_1 \\ b_2 \\ \ldots \\ b_n \end{bmatrix} \qquad (8)$$

where the matrix elements $A_{ij}$ and $b_i$ are numerically calculated.

## IV. SIMULATION RESULTS

We have considered three, four and six element arrays as shown in Fig.2.The desired function is selected as defined equation (9) to form a single beam.

$$f(\varphi)=\operatorname{sinc}(\varphi-\varphi_0) \tag{9}$$

where $\varphi_0$ is the desired angle.

With these simulation parameters, we turn to MATLAB to verify our analytical results.The radiation pattern in Fig. 3 – 6 shows the results obtain from conducting the MATLAB simulations. The radiation patterncompares the significant of matching between the desired pattern and the optimized pattern.

It can be observed from Fig. 3 that as the number of elements increases the optimized beam patterndevelops to an almost perfect match to the desired beam from three to four to size elements. In addition to beam pattern matching, the beam width is also reduced. A narrow beam would have a greater coverage while utilizing less power as compare to an Omni-directional antenna.

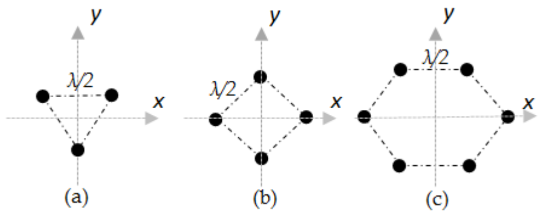
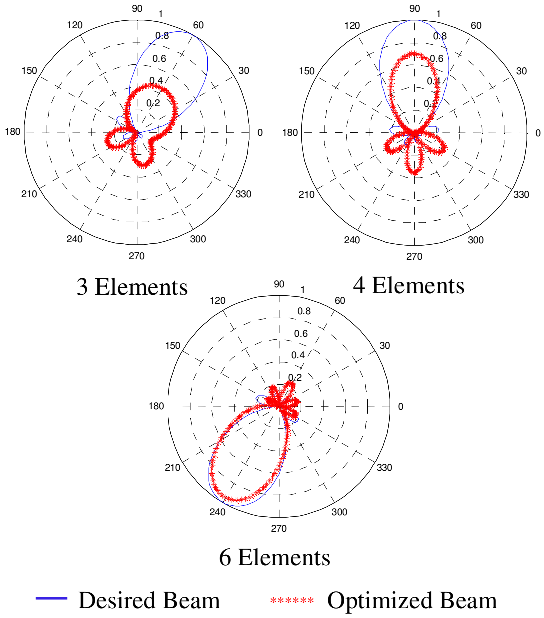


Fig.2: Schematic Diagram of Array Models (a) Equilateral Triangular Model, (b) Square Model and (c) Regular Hexagonal Model



3 Elements

4 Elements

6 Elements

Fig. 3: Comparison of Radiation Patterns of 3, 4 and 6 Elements

Fig. 4 to 6 demonstrates the ability to rotate the beam to effectively cover an area of $360^0$ angle in the azimuth. Irrespective of the number of elements it is shown here that for whatever the desired look angle, we can electronicallysteer the beam to that desired direction.

## V. DISCUSSION OF RESULTS

It is proven that a three element array antenna would be sufficient for communications in underground environment. However, these three elements can be arranged in a ULA to produce a single beam. We therefore, proposed the equilateral triangle model for the three element antenna system. Fig.3 shows that it is possible to generate a single beam in the desired directionwith no image in the opposite direction thus conserving power. Fig. 4 to 6 shows that with increasing number of elements will certainly improve power utilization which dissipates only in the desired direction extending the range.

We have shown that three elements is sufficient for underground mine devices where space, power and improve performance are vital in systems design. Therefore, further analysis needs to be conducted to conclude that the equilateral triangular model is the best model when multiple dipoles are used.

## VI. CONCLUSION

In this paper an equilateral triangle model is developed for use in underground mines. It can be concluded that with three elements it is possible to direct a single beam to or receive from only one desired location. In additional, it is conclusive that as the number of elements increased, the radiation pattern narrows thus increasing the area of coverage. Finally, the results confirm that the single beam is capable of rotating to any direction while minimizing interference from other direction.

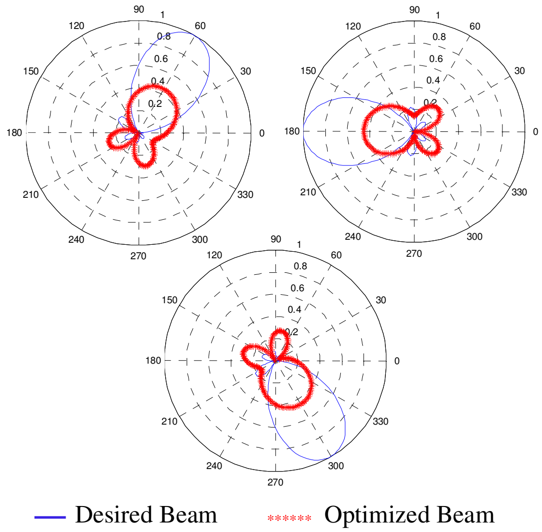


Fig. 4: Beam Rotation of 3 Element Array

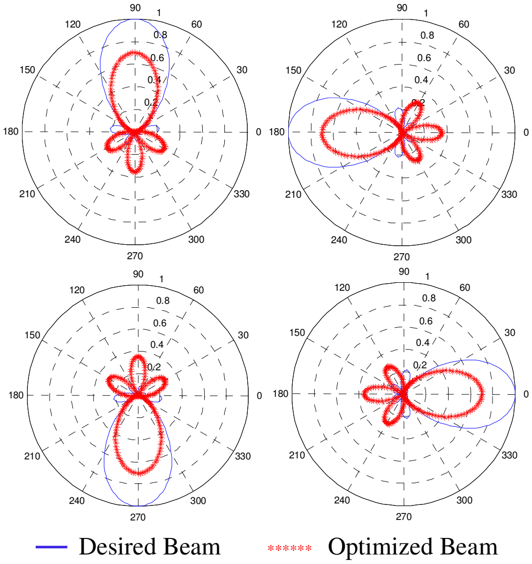


Fig. 5: Beam Rotation of 4 Element Array

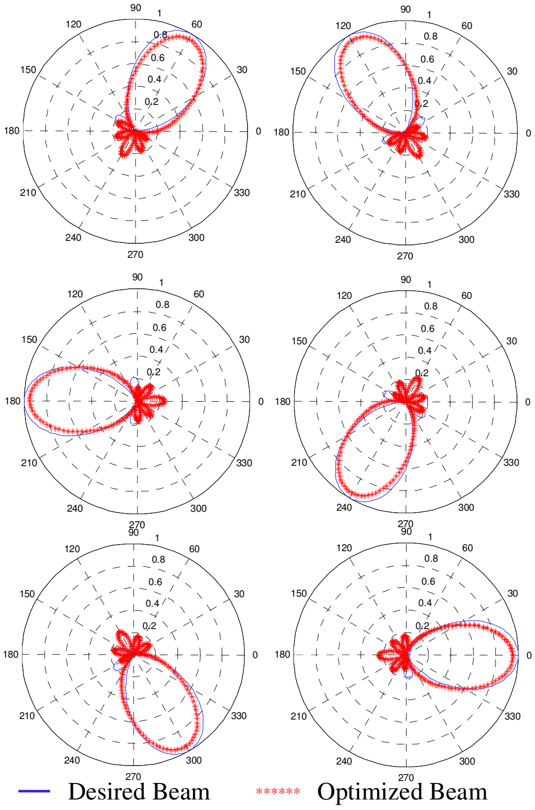


Fig. 6: Beam Rotation of 6 Element Array

## References

[1] Ferrer-Coll, J., et al., *Characterisation of Electromagnetic Properties in Iron-Mine Production Tunnels.* Electronics Letters, 2012. **48**(2): p. 62.

[2] Forooshani, A.E., et al., *A Survey of Wireless Communications and Propagation Modeling in Underground Mines.* Communications Surveys & Tutorials, IEEE, 2013. **15**(4): p. 1524-1545.

[3] Sun, Z. and I.F. Akyildiz, *Channel Modelling and Analysis for Wireless Networks in Underground Mines and Road Tunnels.* IEEE Transactions on Communications, 2010. **58**(6): p. 11.

[4] Akyildiz, I.F. and E.P. Stuntebeck, *Wireless Underground Sensor Networks: Research Challenges.* Ad Hoc Networks, 2006. **4**: p. 669-686.

[5] Forooshani, A.E., S. Noghanian, and D.G. Michelson, *Characterization of Angular Spread in Underground Tunnels Based on the Multimode Waveguide Model.* Communications, IEEE Transactions on, 2014. **62**(11): p. 4126-4133.

[6] Guan, K., et al., *Complete Propagation Model in Tunnels.* Antennas and Wireless Propagation Letters, IEEE, 2013. **12**: p. 741-744.

[7] Coulibaly, Y., et al., *Design of High Gain and Broadband Antennas at 60Hz for Underground Communications Systems.* International Journal of Antennas and Propagation, 2012.

[8] Sun, Z. and I.F. Akyildiz, *Channel Modelling and Analysis for Wireless Networks in Underground Mines and Road Tunnels.* IEEE Transactions on Communicatons, 2010. **58**(6): p. 11.

[9] Terwilliger, M., et al., *A Localization System using Wireless Network Sensors: A Comparision of Two Techniques.* Proceedings of The First Workshop on Positioning, Navigation and Communication, 2004: p. 95-100.

[10] Widrow, B., et al., *Adaptive Antenna Systems.* Proceedings of The IEEE, 1967. **55**(20).

[11] Uluisik, C., *Antenna Systems with Beam Forming and Beam Steering Capabilities for HF Skywave Radars.* Turkish Journal of Electrical Engineering and Computer Science, 2010. **18**(3).

[12] Sun, Z. and I.F. Akyildiz, *Optimal MIMO Antenna Geometry Analysis for Wireless Networks in Underground Tunnels.* IEEE GLOBALCOM, 2009.

[13] Griffiths, L.J. *A Simple Adaptive Algorithm for Real-Time Processing in Antenna Arrays*. in *IEEE*. 1969.