텔레미터리 시스템에서의 링크 해석 및 수신 안테나 각 선정

A Link Analysis and Selection of a Receive Antenna Angle in Telemetry Systems

장 동 운*
Dhong Woon Jang

ABSTRACT

A three dimension(3D) link analysis is performed considering multipath effects caused by a reflected signal and the difference angle between the antenna bore-sight and Line-Of-Sight(LOS). In addition, a direction of a receive antenna is determined for a receiver to get maximum signal strength in a telemetry situation. For a fixed receive antenna, the angle is determined to maximize the average Carrier to Noise Ratio(CNR) over the interested part of a trajectory. For a tracking antenna, the angle at every position is selected to give maximum CNR or to direct the boresight to the flying projectile.

Key words : Telemetry, Link Budget, and Multipath

Ⅰ. Introduction

In telemetry links, it is very important to predict how reliably the information can be gathered. To accomplish this, it is necessary to determine the position of receiver, select an angle for the receive antenna to properly receive signals, and then to adjust system parameters in advance before actual tests. To this end, the design and estimation of many telemetry links make use of link equations[1]~[9] and most of the link analysis has been performed based on the assumption that the LOS between transmitter and receiver coincides with their bore-sights. In practice, however, there are several cases where LOS deviates from the bore-sight. This difference can cause the actual antenna gain to vary toward the LOS direction, thus seriously affecting the link performance, and causing the real CNR to be below the minimum required CNR level[1]. In addition, a transmitted signal can be reflected on the ground and is received by the

* Agency for Defense Development

receive antenna to be combined with a direct path signal. They can be destructively combined to degrade the link performance[2]. Therefore, the antenna's gain variation[1] and the multipath effect[2] should be taken into account simultaneously for the more precise link analysis. These facts motivate us to consider not only a link equation including the antenna gain variation caused by the difference angles and the multipath effect simultaneously, but also, the selection of a receive antenna's angle which helps give better link performance.

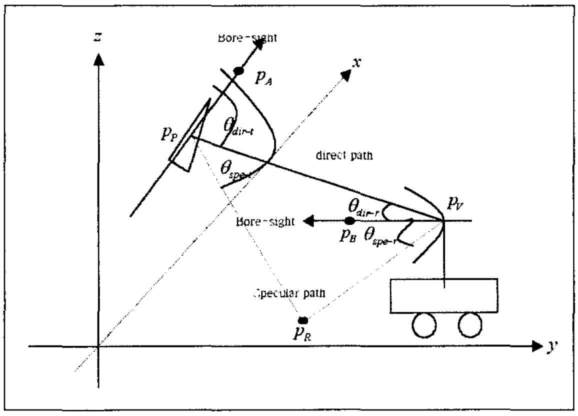
First, a link equation is modified to take into account multipath effects and antenna gain variations caused by difference angles. Given the angles of the projectile and the positions of the receiver and the projectile as well, the difference angle of the transmitter and receiver is obtained to give more practical antenna gains. The power of each path is calculated by inserting these antenna gains into a typical link equation. Finally, the modified CNR is obtained by combining the two signal powers at the receiver according to the phase difference between the two paths.

Second, the selection problem of the receive angle is considered using the modified link equation. For a fixed transmitter position, the receiver antenna angle is selected to give the maximum CNR among every possible receive antenna angle or direct the bore-sight of the receiver antenna to the flying projectile. But this cannot be directly applied when signals from more than one projectile's position are received over some part of the trajectory with a fixed receive antenna. For this case, the receive antenna angle is selected to give an averaged maximum value of link margin over the interested range. On the other hand, when a tracking antenna is used, the angle at every position can be selected to give maximum CNR or to direct the bore-sight to the flying projectile with a zero difference angle.

Ⅱ. 3D Link Analysis

1. A System Model

Let us consider a telemetry situation as shown in Fig. 1. A projectile fired from a gun is flying along with a specified trajectory in a three



[Fig. 1] A telemetry situation taking into account multipath effect and the difference angle between LOS and the bore-sight of antennas.

dimensional space for a certain time period.

Its azimuth θ_P and elevation φ_P at every position, $p_P(x_P, y_P, z_P)$ and a time, t are assumed to be known. It is spinning but the speed is unknown. The transmitted signal is reflected at a position, P_R and combined with the direct path signal at the receive antenna. A receiver located at a position $p_V(x_V, y_V, z_V)$ is gathering telemetry information from the transmitter of the projectile. Its azimuth and elevation are θ_V and φ_V respectively. θ_{dir-t} represents the angle between transmit antenna's bore-sight and the direction of the transmitter toward the receiver through the direct path, θ_{dir-r} reversely depicts the angle between the receive antenna's bore-sight and the direction of receiver toward transmitter through the direct path, θ_{spe-t} is the angle between transmit antenna's bore-sight and the direction of transmitter toward the reflecting point through the specular path, and θ_{spe-r} is the angle between receiver antenna's bore-sight and the direction of the receiver toward the reflecting point through the specular path.

2. Link Equation

The powers of the direct and the specular path received at the receiver are given as follows[2] :

$$P_{dir} = P_t G(\theta_{dir-t}) L_{dir-S} G(\theta_{dir-r}) \quad (1)$$

and

$$P_{spe} = P_t G(\theta_{spe-t}) L_{spe-S} \Gamma^2 G(\theta_{spe-r}) \quad (2)$$

respectively, where Γ represents reflection coefficient, P_{dir} is the signal power at the input of the receive antenna received through direct path, P_{spe} is the signal power at the input of the receive antenna received through the specular path, P_t is the transmitted power, $G(\theta_{spe-t})$ is transmitter antenna gain to the direction of p_R over the specular path, $G(\theta_{spe-r})$ is the receive antenna gain to the direction of p_R over the specular path, $G(\theta_{dir-t})$ is the transmit antenna gain to the direction of the receiver over the direct path, $G(\theta_{dir-r})$ is the receive antenna gain to the direction of the projectile over the direct path, L_{spe-S} is the path loss over the specular path, and L_{dir-S} is the path loss over the direct path.

Defining $\Gamma^o = \sqrt{\frac{P_{spe}}{P_{dir}}}$ and $A = \sqrt{P_{dir}}$, and assuming $\sqrt{2P_t}\cos w_o t$ is transmitted, the received signal can be given by

$$r(t) = A\cos w_o t + A\Gamma^o \cos(w_o(t-\tau)+\gamma) \quad (3)$$

where the first term of the right hand side is the signal coming through the direct path, the second term is the signal coming through the specular path, γ is the phase shift induced by the reflecting medium, and w_o is the carrier frequency.

Let $\delta = \gamma - w_o t$. Then (3) can be transformed into

$$r(t) = \sqrt{\left(A + \Gamma^{o} A\cos\delta\right)^2 + \left(\Gamma^{o} A\sin\delta\right)^2}\,\cos\left(w_o t + \tan^{-1}\frac{\Gamma^{o} A\sin\delta}{A + \Gamma^{o} A\cos\delta}\right) \quad (4)$$

Therefore the total received power is given by

$$P_R = A^2\left(1 + 2\Gamma^{o}\cos\delta + \left(\Gamma^{o}\right)^2\right) \quad (5)$$

Then the link equation is represented by

$$P_R / N_o(dB) = P_r / (L_M \,\mathrm{o} SF \,\mathrm{o} N_o) \quad (6)$$

where L_M represents miscellaneous loss, SF depicts safety factor, and N_o is the total noise power. In order to get the above equation, calculation of θ_{dir-t}, θ_{dir-r}, θ_{spe-t}, and θ_{spe-t} are necessary(See Appendix A for details).

Ⅲ. Selection of A Receive Antenna Angle

In the previous section, A 3D link equation was obtained in a telemetry situation, where the receiver position p_V, the receive antenna's boresight with elevation φ_V and azimuth θ_V was to be given. In reality, however, a receiver angle had better be selected to provide better link performance. In what follows, three cases will be considered for practical purposes.

First, when given the position of a specific projectile and a receive antenna position, the required receive antenna angles(elevation and azimuth) can be selected to maximize CNR among all the possible receive antenna angles or the required receive antenna's boresight is determined to coincide with LOS as follows(See Appendix D for details):

$$azimuth = sign(x_P - x_V)\times \cos^{-1}\left(\frac{d_{VP'}^2 + d_{VB}^2 - d_{P'B}^2}{d_{VB}d_{VP'}}\right),$$

$$elevation = \tan^{-1}\left(\frac{z_P - z_V}{\sqrt{(x_P - x_V)^2 + (y_P - y_V)^2}}\right) \quad (7)$$

Second, when interested in selecting an antenna angle to give better link performance over some part of the trajectory, the angle is chosen to give a maximum averaged CNR over the interested part by the following procedures:

Step 1. Over the interested range of the trajectory, select one receive angle using one of the previous methods at every position of the projectile.

Step 2. Take median value of selected angles

Step 3. Define a range around the median value as follows:

Elevation Angle:

$$El_{median} - \Delta El \le El \le El_{median} + \Delta El \quad (8.1)$$

Azimuth Angle:

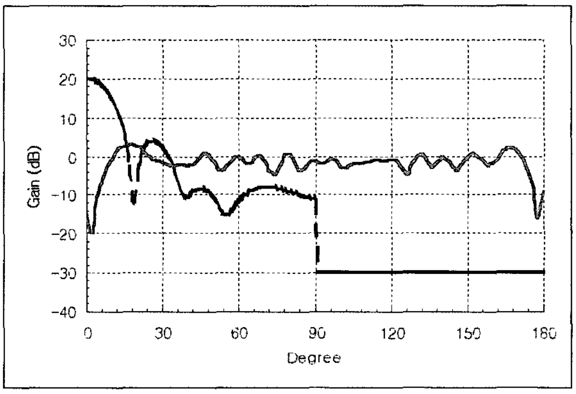
$$Az_{median} - \Delta Az \le Az \le Az_{median} + \Delta Az \quad (8.2)$$

Step 4. Select the angle giving maximizing averaged link CNR over the interested range.

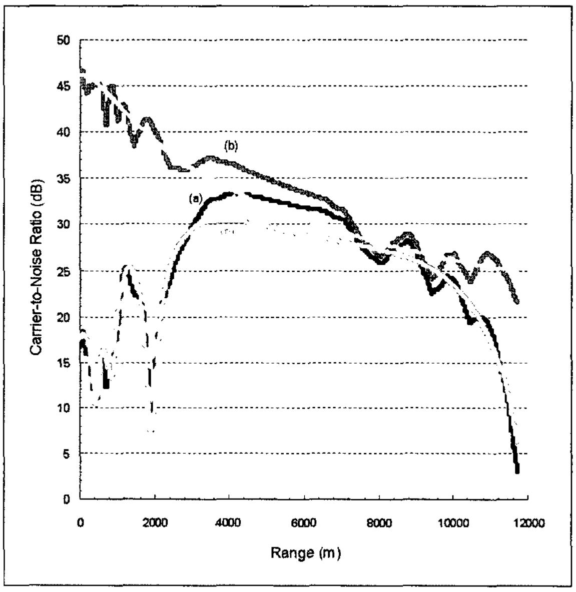
Finally the receive antenna angle of the tracking antenna is selected to give a CNR or to make them coincide with the LOS at every position of projectile.

Ⅳ. Simulation Results

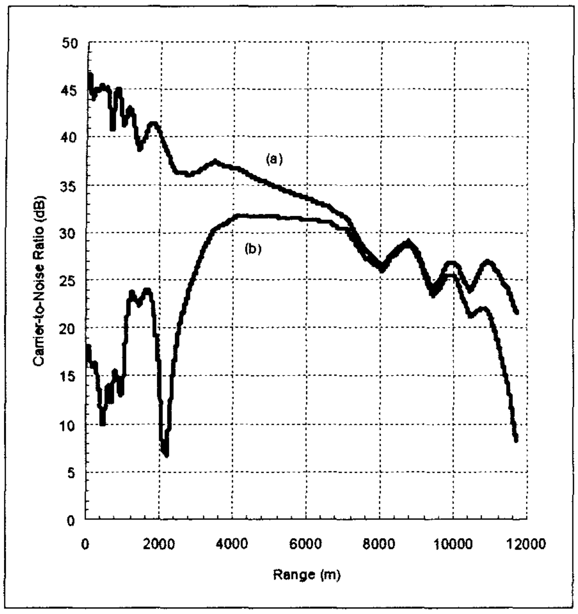
In order to see the effect of difference angle between boresight and LOS, a simulation was performed with antenna gains of Fig. 2 and the results are plotted in Fig. 3. For this simulation, a trajectory of a projectile was generated(not shown here); the position of receiver was assumed to be(-30m, 1000m, 2m) in 3D space; the azimuth and elevation of the boresight of receive antenna were assumed to be 101° and 15° ; the initial position of the projectile is (0,0,0). $P_t = 6dB$, $L_M = 5dB$, $SF = 0dB$, $N_o = 138.7dB$, and $\gamma = 0$ were assumed. In Fig. 3 plot (a), the angle difference of both transmitter and receiver were considered; in Fig. 3 plot (b), only the angle difference of transmitter was considered; in Fig. 3 plot (c), the gain of transmitter was assumed to be-1 and the angle difference of receiver was assumed to be 0° ; in Fig. 3 plot (d), only the angle difference of receiver was considered. Plots show that



[Fig. 2] Antenna gain (dB): ▬ Transmitter, ▬ ▬ Receiver



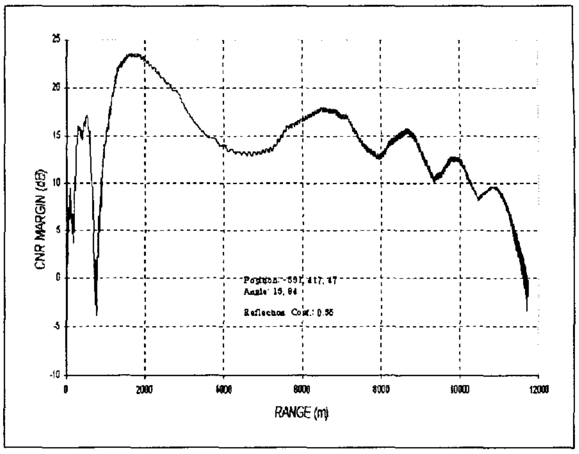
[Fig. 3] Carrier-to-Noise Ratio versus Range according to antenna gain options.



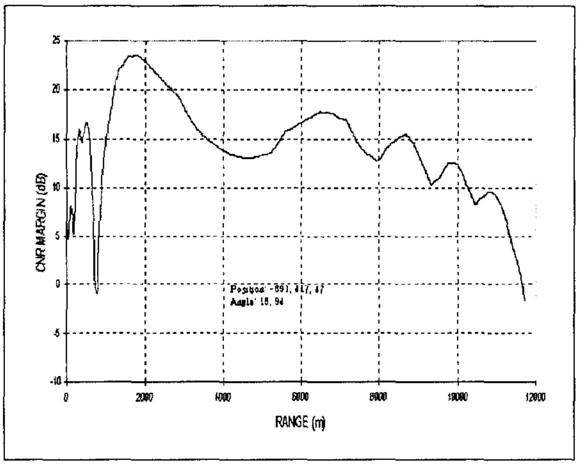
[Fig. 4] CNR versus Range for (a) tracking antenna (b) fixed antenna with the estimated angle.

ignoring the angle difference can give incorrect results. Estimation of receiver angle and CNR were simulated in Fig. 4. The estimated median value is: azimuth = 15.1646° and elevation = 97.0713°. ΔAz and ΔEl are assumed to be 5°. The estimated azimuth and elevation are 99° and 14° respectively. Fig. 4 plot (a) is the CNR for tracking antenna and Fig. 4 plot (b) is the CNR for the fixed antenna with the estimated angle.

In Fig. 5 the CNR considering multipath effect caused by reflection(plot (a)) was compared with that without considering multipath effect(plot (b)). Γ was assumed to be 0.3. It is shown that the fluctuation of the CNR is around 3dB at far distance when the multipath effect is considered.



(a)



(b)

[Fig. 5] CNR Margin against Range (a) without taking into account multipath (b) with taking into account multipath.

V. Summary

We have considered a 3D link analysis in telemetry situations and the selection of receive antenna angle to optimize receiving signals from a flying projectile as well. By calculating the difference angle between the boresight and the LOS and then inserting it into a typical link equation the uncertainty of the antenna gain is greatly reduced resulting in a more accurate link performance prediction. Based on this 3D link analysis, the angle of receive antenna is selected to receive the maximum of averaged signal power. To reduce the complexity of calculation the bore-sight of the receiver is selected to coincide with the LOS between transmitter and receiver. Usefulness of the above methods was confirmed through some real tests.

References

[1] Moises Pedroza, "Antenna Pattern Evaluation for Link Analysis", ITC, 1996.

[2] Michale Rice and Daniel H. Friend, "Antenna Gain Pattern Effects on Multipath Interference in Aeronautical Telemetering", ITC, 1997.

[3] Norman F. Lantz, Basic Telemetry System Design, presented at ITC/USA 2000.

[4] Elliot L. Gruenberg, *Handbook of Telemetry and Remote Control*, McGraw-Hill Book Company, 1967.

[5] M. K. Simon, Samin M. Hinedi, and William C. Lindesy, *Digital Communication Techniques*, Prentice Hall, 1995.

[6] Juan M. Guadiana, "Canister Multipath and the Close Coupled Antenna", ITC, 1996.

[7] Kenneth Welling, "A Narrowband Model for Aeronautical Telemetry Channels", ITC 1996.

[8] Michale Rice, "Aeronautical Telemetry Fading Sources at Test Ranges", ITC, 1997.

[9] Ricky G. Dye, "Parameter Characterization on a Telemetry Channel Including the Effects of the Specular Ray", ITC. 1996.

Appendix A the difference angles θ_{dir-t}, θ_{dir-r}, θ_{spe-t} and θ_{spe-r}

Assuming a temporary point, with distance d_{PA} from p_P on the axis of the projectile, its position p_A is given by

$$\begin{aligned} x_A &= x_P + d_{PA}\cos\varphi_P \sin\theta_P, \\ y_A &= y_P + d_{PA}\cos\varphi_P \cos\theta_P, \\ z_A &= z_P + d_{PA}\sin\varphi_P \end{aligned} \qquad \text{(A1)}$$

Then the three positions, p_P, p_V and p_A makes a triangle together. From this triangle the required difference angle of the transmitter side is simply obtained as follow:

$$\theta_{dir-t} = \cos^{-1}\left(\frac{d_{PA}^2 + d_{PV}^2 - d_{AV}^2}{2d_{PA}d_{PV}}\right) \qquad \text{(A2)}$$

where d_{PA} is the distance between p_A and p_P, d_{PV} is the distance between p_P and p_V, and d_{AV} is the distance between p_A and p_V.

Similarly, another temporary position with distance d_{PB} in the direction of receive antenna bore-sight, p_B can be obtained as follows:

$$x_B = x_V + d_{PB} \cos\varphi_V \sin\theta_V,$$
$$y_B = y_V + d_{PB} \cos\varphi_V \cos\theta_V, \quad \text{(A3)}$$
$$z_B = z_V + d_{PB} \sin\varphi_V$$

Also the positions, p_P, p_V and p_B makes a triangle together to give the difference angle θ_{dir-r} at the receiver side

$$\theta_{dir-r} = \cos^{-1}\left(\frac{d_{PB}^2 + d_{PV}^2 - d_{BV}^2}{2d_{PB}d_{PV}}\right) \quad \text{(A4)}$$

where d_{BV} is the distance between p_B and p_V.

Assuming the position $p_R(x_R, y_R, 0)$ of the reflecting point is given, we can calculate θ_{spe-t} and θ_{spe-r} with the positions p_R, p_P, p_A, p_B and p_V as follows(see Appendix C for $p_R(x_R, y_R, 0)$):

$$\theta_{spe-t} = \cos^{-1}\left(\frac{d_{PA}^2 + d_{PR}^2 - d_{AR}^2}{2d_{PA}d_{PR}}\right) \quad \text{(A5)}$$

and

$$\theta_{spe-r} = \cos^{-1}\left(\frac{d_{RB}^2 + d_{RV}^2 - d_{BV}^2}{2d_{RB}d_{RV}}\right) \quad \text{(A6)}$$

where d_{PR} is the distance between p_P and p_R, d_{AR} is the distance between p_A and p_R, d_{RB} is the distance between p_R and p_B, d_{RV} is the distance between p_R and p_V.

Appendix B the phase difference Angle δ

First we assume γ is given. From Figure A1, we get the following equations[2]:

$$p = \frac{h_t d}{h_t + h_r} \quad \text{(A7.1)}$$

$$m_1 = \sqrt{h_t^2 + p^2} \quad \text{(A7.2)}$$

$$m_2 = \sqrt{h_r^2 + (d-p)^2} \quad \text{(A7.3)}$$

$$r = \sqrt{d^2 + (\max(h_t, h_r))^2 - (\min(h_t, h_r))^2} = \sqrt{(x_P - x_V)^2 + (y_P - y_V)^2 + (z_P - z_V)^2} \quad \text{(A7.4)}$$

From the above equations we get the time difference

$$\tau = \frac{m_1 + m_2 - r}{c} \quad \text{(A7.5)}$$

Therefore, the phase difference between the two paths is given by

$$\delta = \gamma - w_o \tau \quad \text{(A7.6)}$$

Appendix C The position of $p_R(x_R, y_R, 0)$

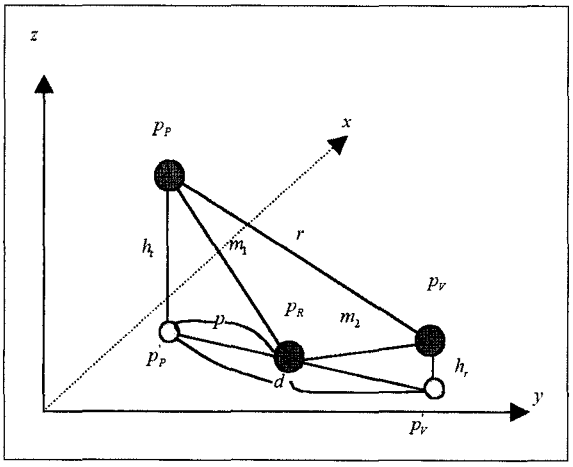
In Fig. A1, p_R represents the reflecting point on the ground. Projecting p_V and p_P onto the xy plane(i.e. ground plane), we can get the projected points $p_G' = (x_G, y_G)$ and $p_V' = (x_V, y_V)$ as shown Fig. A2.

Then a line equation can be obtained as follows:

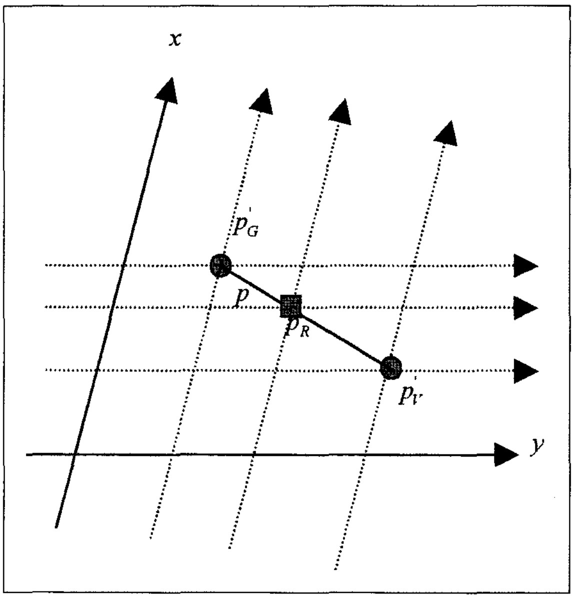
$$x = \frac{x_P - x_V}{y_V - y_P}(y - y_P) + x_P \qquad \text{(A8)}$$

Substituting x and y with x_R and y_R, respectively, x_R is represented by

$$x_R = \frac{x_P - x_V}{y_V - y_P}(y_R - y_P) + x_P \qquad \text{(A9)}$$



[Fig. A1] A geometry diagram for calculating the phase difference(A7.6) in a multipath environment.



[Fig. A2] A geometry for calculation of the reflecting point

The angle consisting of the line, $p_G' p_V'$ and a line paralleled with $y-axis$ y_R is given by

$$\theta' = Cos^{-1}\left(\frac{x_V - x_G}{y_V - y_G}\right) \qquad \text{(A10)}$$

Then the $y-axis$ of the reflecting point is given by

$$y_R = y_G + sign(y_V - y_P)pCos\left(Abs\left(Cos^{-1}\theta'\right)\right) \qquad \text{(A11)}$$

Appendix D The Equation (7)

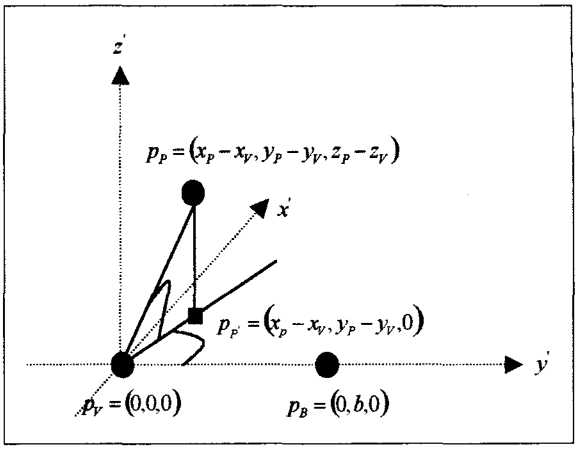
Let us consider a new coordinate system with the position of the receive antenna as the origin as shown in Fig. A3 and assume the elevation and azimuth of the receive antenna to be 0° and 0°, respectively. Selecting a temporary position p_B to be identified by $x_B = x_V$, $y_B = y_V + d$ and $z_B = z_V$ the azimuth and elevation are calculated as follows:

$$azimuth = sign(x_P - x_V) \times \cos^{-1}\left(\frac{d_{VP'}^2 + d_{VB}^2 - d_{P'B}^2}{d_{VB} d_{VP'}}\right) \quad \text{(A12.1)}$$

and

$$elevation = \tan^{-1}\left(\frac{z_P - z_V}{\sqrt{(x_P - x_V)^2 + (y_P - y_V)^2}}\right) \quad \text{(A12.2)}$$

respectively. d_{VB} is the distance between p_B and p_V, $d_{VP'}$ is the distance between p_V and $p_{P'}$ and $d_{P'B}$ is the distance between p_B and $p_{P'}$; $sign(x)$ function takes sign of x ; $p_{P'}$ is the projection of p_P on the $x'y'$ plane gives.



[Fig. A3] A new coordinate with the position of receive antenna as a new origin