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Research on Contour Plane Coverage of 20-unit Localizer Antenna Array

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Abstract. Localizer beacon provides horizontal indication to airplane. The signal radiated from localizer antennas makes aircraft aim at the center line of runway. Also, the localizer beacon provides its particular identified signal of Instrument Landing System (ILS). Whether the signal coverage zone radiated from the localizer antenna system is satisfied the coverage requirement plays a decisive role in flight check. The Earth curvature effect was considered, consequently, the corresponding error of height and distance were also revised in wide area situation. The three-dimensional mathematical model of localizer beacon of 7220A was established in detail. Both the horizontal (θ_h: 0°~360°) and vertical (θ_v: 0°~180°) electromagnetic field distribution of Logical Periodic Dipole Antenna (LPDA) array were presented. According to flight check procedure, the electromagnetic field distributed was further researched in specific contour plane. The height of the localizer antenna (h_a) has a close relationship to signal distribution. So it plays an important part in the intensity of radio frequency (RF). The contour plane higher (h_{fly}= 1200 m) and lower (h_{fly}= 300 m) than that of the routine flight altitude (h_{fly}= 600 m) with a series of height of antenna (h_a= 2.5 m, 3.0 m, 3.5 m, 4.0 m) were also analyzed.

Keywords: Localizer Beacon, Contour Plane, Signal Coverage, Antenna Height

1. Introduction

The Instrument Landing System (ILS), had its beginnings in the United States and England during the years 1939 to 1945[1]. Since then, ILS became the international standard system for approach and landing guidance. ILS was adopted by International Civil Aviation Organization (ICAO) in 1947 and will be in service until at least 2020. The ILS normally consists of a VHF "Localizer (LOC)" for runway alignment guidance, a UHF "Glide Path (GP)" for elevation guidance and "Marker Beacons (MB)" for providing key checkpoints along the approach. The MB are replaced or supplemented, at some time, by a "Distance Measuring Equipment (DME)" to provide continuous reading of distance.

The types of localizer beacon were the most abundant in ILS equipments. According to actual needs, they came out one after another. Such as series the early 3500-series: 3522[2], 3523B[3], 3524[4], 3525[5], 3526[6] and the later 7000-series: 7212A[7], 7212C[8], 7216A[9], 7216C[10], 7220A[11], 7220B[12] were produced by Normarc factory; and single frequency: 8-unit moderate-aperture, 12-unit medium-aperture, dual frequency: 13-unit wide-aperture, 21-unit ultra wide-aperture[13], and 420-series: 14-unit, 20-unit manufactured by Thales company; dual frequency:14-unit, 16-unit, 20-unit were designed one after another by Selex company.

In the paper, the mathematical model of LDPA array of localizer beacon was explicitly established to analyze the 7220A antenna array of ILS. The distribution of radiated electromagnetic signal was simulated by software Matrix Laboratory (Matlab). The theoretical analyze combined with the specific standard of ICAO was presented.

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2. Result and Discussion

2.1. Introduction of 7220A Antenna System

2.1.1 Antenna Distribution Unit (ADU)

The ADU feeds the antenna elements with the proper amplitude and phase of the Carrier and Sideband (CSB) and Sideband Only (SBO) signals. The CSB signal plays a major part in the coverage, consists of Course (COU) and Clearance (CLR). The former one provides a sharp lob near the course line (CL) (about ±5°) and the later one is used to satisfy the wide angle (more than ±35°) coverage requirement. By changing the amplitude of the SBO feeding the ADU, the Course Sector Width is adjusted. Table 1 shows design data for the antenna system. The SBO relative value is design for the Displacement Sensitivity (DS) is 4.0°. The Amplitude values are given in relative volts, phase in electrical degrees.

From the table, the test data can be measured by network analyser through four input ports and twenty output ports of ADU, the distance from the centre line of every antenna has been checked by flexible rule, the error between the theoretical and measured values is less than 0.02 m, and the theoretical distribution also can be found in the technical manual [11], and the information of CSB and distance of each antenna would be used in below discussion.

Table.1: Normarc 7220A antenna system signal distribution and antenna elements (DS= 4.0°)

Note：The voltage amplitudes are relative to the CSB Course amplitude at antenna 9.

Antenna No.	Dist From CL (m)	COU CSB Ampl.(V)	COU CSB Phase(°)	COU SBO Ampl.(V)	COU SBO Phase(°)	CLR CSB Ampl.(V)	CLR CSB Phase(°)	CLR SBO Ampl.(V)	CLR SBO Phase(°)
1	-26.03	11	0	3.29	-90				
2	-22.54	15	0	4.20	-90			0.32	90
3	-19.23	29	0	5.75	-90	5.65	180	0.32	90
4	-16.09	45	0	6.59	-90	5.65	180		
5	-13.13	66	0	6.66	-90	11.72	180	0.54	-90
6	-10.34	82	0	6.00	-90	11.72	180	0.32	-90
7	-7.73	93	0	4.82	-90	32.17	180	4.32	-90
8	-5.30	100	0	3.38	-90	12.86	0	4.32	-90
9	-3.04	100	0	1.89	-90	94.60	180	9.25	-90
10	-0.95	93	0	0.55	-90	204.83	0	37.52	-90
11	0.95	93	0	0.55	90	204.83	0	37.52	90
12	3.04	100	0	1.89	90	94.60	180	9.25	90
13	5.30	100	0	3.38	90	12.86	0	4.32	90
14	7.73	93	0	4.82	90	32.17	180	4.32	90
15	10.34	82	0	6.00	90	11.72	180	0.32	90
16	13.13	66	0	6.66	90	11.72	180	0.54	90
17	16.09	45	0	6.59	90	5.65	180		
18	19.23	29	0	5.75	90	5.65	180	0.32	-90
19	22.54	15	0	4.20	90			0.32	-90
20	26.03	11	0	3.29	90				

2.1.2 Signal Synthesis

The frequency (f) of CSB signal is taken 110.1 MHz, then the corresponding wavelength (λ) is 2.72 m. The transmitter power of CSB is 20 W.

2.1.2.1 Horizontal Signal Synthesis

The 7220A antenna array consists of twenty elements, the mirror symmetry from center generates ten pairs. The width of the antenna array is 52 m, while the coverage zone of the radiated signal is far more than 5 km. So the horizontal synthesized formula of CSB fits to far field model [14], and the expression can be described as formula 1:

$$CSB(\theta_{\mathrm{h}}) = LPDA(\theta_{\mathrm{h}}) \cdot \sum_{n=1}^{10} 2E_n \cos(\frac{2\pi D_n}{\lambda} \sin\theta_{\mathrm{h}}) / \underline{\varphi_{\mathrm{n}}} \tag{1}$$

The horizontal CSB signal comprises COU and CLR. The final synthesis is adopt by capture effect, the 360° Omni-directional distribution can be seen in figure 1. There is a sharp lobe right ahead (about ±4°), devoted by COU, owns good anti-interference ability. The sector mainly supported by CLR is used to satisfy the wide-angle (more than ±35°) signal coverage.

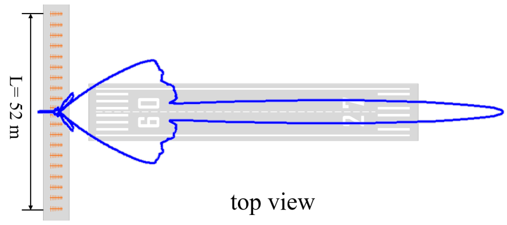

Fig.1: horizontal radiation pattern of 7220A

2.1.2.2 Vertical Signal Synthesis

Because the electromagnetic wave radiated by localizer beacon is horizontal polarization, the reflected signal would generate half wave loss (180° phase delay). The vertical synthesis signal comprised direct signal and it's reflected one. So the flat ground in front of the localizer beacon plays an important part in the quality of final synthesis signal. The vertical synthesis signal of CBS can be described as formula 2:

$$CSB(\theta_{\mathrm{v}}) = LPDA(\theta_{\mathrm{v}}) \cdot 2\sin(\frac{2\pi h_{\mathrm{a}}}{\lambda} \sin\theta_{\mathrm{v}}) \tag{2}$$

It should be noted that the vertical signal distribution is related no only to the elevation angle but also to the height of the antenna (h_a). Supposing the land is smooth. The lobes of synthesis signal in vertical plane (from 0° to 180° with flatten ground) with four different height are given in figure 2. The phenomenon of uneven interval distribution (several lobes) is contributed to the mirror synthesis. While the poor amplitude of back lobe is originated from the function of LPDA. The front-to-back ratio of LPDA is designed for 26 dB.

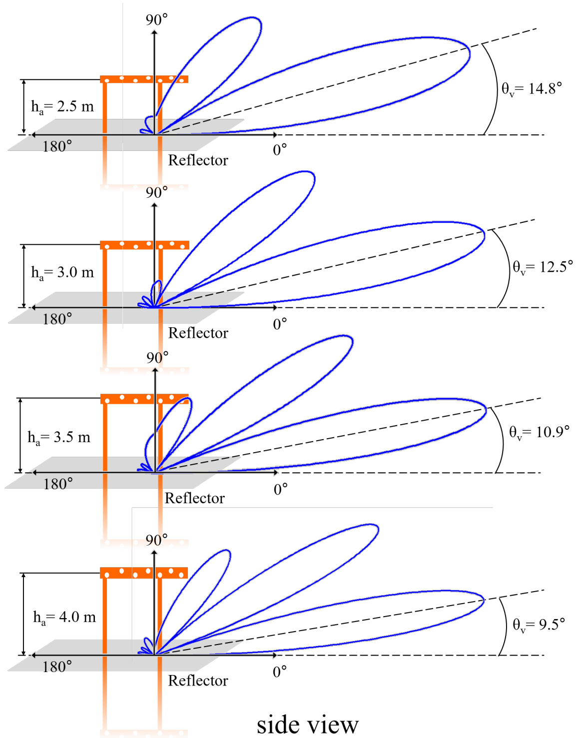

Fig.2: vertical radiation pattern of 7220A with different height of antenna. This vertical signal synthesis is based on the hypothesis that the reflector is smooth and flatten. The radiation signal of localizer antennas is horizontal polarization, the synthesis signal consists of direct signal and reflected signal. The reflected one from the reflector generates 180° phase delay.

The coverage zone of localizer beacon depends on the first lobe in front. Because of the LPDA function, the first lobe owns the maximum amplitude of all lobes distributed from 0° to 180° in vertical plane. The elevation angle (θ_v) of first lobe has a strong relationship to h_a. The θ_v would be depressed with increasing of h_a. There are four height of antenna (h_a= 2.5 m, h_a= 3.0 m, h_a= 3.5 m, h_a= 4.0 m) would be researched below. In detail, there are two lobes for h_a= 2.5 m and three lobes for the other three one in first quadrant. Consequently, there are one zero zone for h_a= 2.5 m and double zero zone for the latter three height. Discussion below would analyze the interval coverage characteristics of the circle effect.

2.2. Error Correction by Earth Curvature

When the aircraft flies in sky with a certain altitude, the orbit in space is a contour plane. The contour plane is just like the surface of a sphere instead of a flat surface in fact. So the precise position on the contour plane should be revised for Cartesian coordinates of antenna system. The calculation discussed below is based on the hypothesis that the Earth is a spheroidal ball with flatten surface.

2.2.1 Relationship between Coverage Altitude and Antenna Position

It can be seen in figure 3 that the altitude of orbit of aircraft is changeable relative to the localizer. When the aircraft flies over the antenna, the height of aircraft relative to antenna (H_a) is equal to the fly altitude (h_{fly}). Besides, H_a is lower than h_{fly}.

The position that aircraft relative to the antenna should be achieved firstly, then the radio frequency (RF) level could be calculated in Cartesian coordinates accurately.

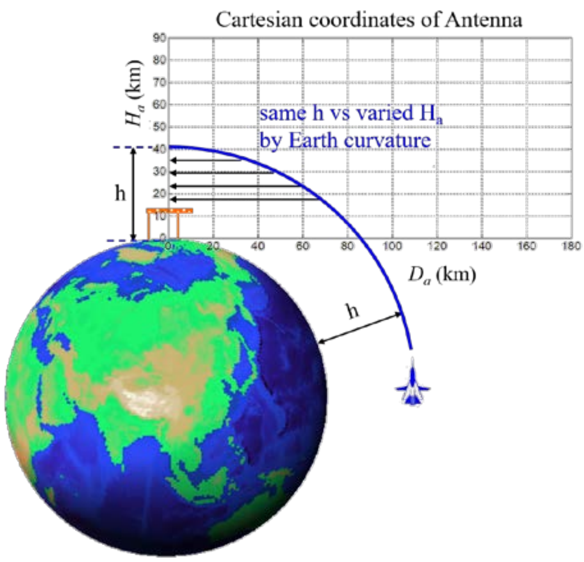

Fig.3: the height error caused by Earth curvature

2.2.2 Coordinates Transformation

In figure 4, the transmitter point (P_T) is the position of the antenna and the receive point (P_R) is the position on fly orbit. On the aircraft, the distance to P_T consists of horizontal coordinate distance, gap between two projections of longitude and latitude (d), and vertical difference of altitude, the height above sea level (h). In Cartesian coordinates, P_T is original point, and the coordinate of the P_R is D_a for distance (x-axis) and H_a for height (y-axis). The relationship between (d, h) and (D_a, H_a) is given below:

$$\begin{aligned} D_a &= (h+r)\cdot\sin(d/r) \\ H_a &= (h+r)\cdot\cos(d/r)-r \end{aligned} \tag{3}$$

The r_0 is the radius of Earth, namely 6370 km. But considering the atmospheric refraction, r is the equivalent radius of r_0.

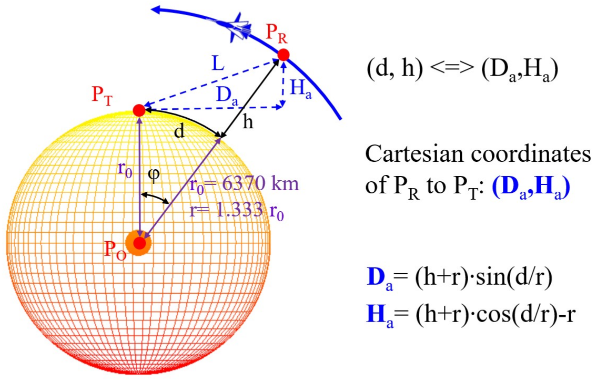

Fig.4: coordinates transformation relationship between (d,h) and (D_a,H_a)

2.2.3 Error Analysis

According to the transformation formula 3, the space coordinate of the fly orbit can be calculated in Cartesian coordinates. And the geometric error caused by Earth curvature can be compared.

There are two kind of error would be discussed: distance error and height error. With the variety of the distance between P_T and P_R, distance error (ΔD_a) is the difference value between D_a and d. while height error (ΔH_a) is the difference value between h_{fly} and H_a.

2.2.3.1 Distance Error

To understand the difference of error specifically, there are three altitude of contour plane (h_{fly}= 30 m, h_{fly}= 300 m, h_{fly}= 600 m,) the calculation result can be found in figure 5. The calculation was taken from formula 3. The distance was scanned until 300 km, but for various h_{fly}, each ΔD is negligible comparative to D_a. It can be seen in the insert that the lower ΔD_a of contour plane changes little within 30 km, but shot up quickly outside 150 km. The maximum value is just 60 m at 300 km for h_{fly}= 30 m. So the ΔD_a doesn't play a decisive role in error revision.

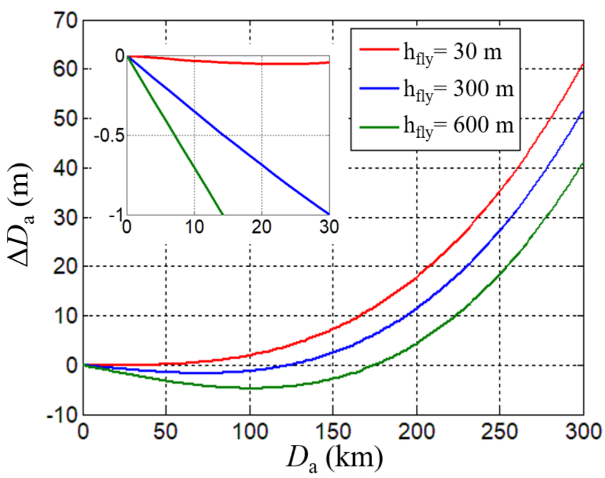

Fig.5: Distance errorcalculation with different fly height v.s. distance internal

2.2.3.2 Height Error

It can be seen in figure 6 that the difference of h_{fly} has little influence on ΔH_a, two curves are (h_{fly}= 30 m and h_{fly}= 300 m) almost coincident from the range up to 30 km far away. ΔH_a is monotonically increasing and has reached 53 m at 30 km. The corresponding error of elevation angle ($\Delta\theta_v$) arrives at 0.1°. For glide angle (θ_v= 3°), this error value seems dramatically serious, especially for glide path beacon, while relevant error of radio frequency (ΔRF) is 0.27 dB. Evidently, height error carry a big weight on the effect of Earth curvature.

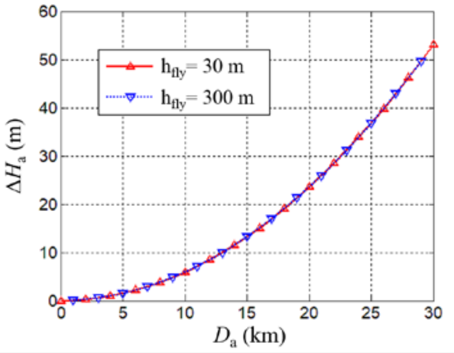

Fig.6: height error calculation with different fly height v.s. distance internal

To understand the characteristics of the vertical error systemically, three important parameters (ΔH_a, $\Delta\theta_v$, ΔRF) are systematically simulated from the distance span 10 km to 300 km, the calculation of parameters are listed in formula 4 and formula 5. From table 2, at distance of 100 km, the corresponding ΔRF (comparative to flatten surface) arrives at 0.87 dB. From the table 2, it can be find that $\Delta\theta_v$ (the space geometric error caused by Earth Curvature) and ΔRF are proportional to D_a within 100 km. Over this distance, the linear change rule still fits to $\Delta\theta$, but fades away for ΔRF. The change of ΔRF was abated with the corresponding distance increasing.

$$\Delta\theta_{\mathrm{v}} = \arctan\frac{\Delta H_a}{D_a} \tag{4}$$

$$\Delta RF = 20\lg\frac{\sin\frac{2\pi h}{\lambda}\sin(3^\circ+\theta_{\mathrm{v}})}{\sin\frac{2\pi h}{\lambda}\sin(3^\circ)} \tag{5}$$

Table.2: several error parameters with different distance

The data is from the case of h_a= 3 m and RF is chosen from the circumstance of θ_v=3°

D_a(km)	ΔH_a(m)	$\Delta\theta_v$(°)	ΔRF(dB)
10	6	0.03	0.09
20	24	0.07	0.18
30	53	0.10	0.27
50	147	0.17	0.45
100	589	0.34	0.87
200	2355	0.67	1.66
300	5298	1.01	2.37

2.3. Analysis of Contour Plane Coverage

The coverage performance in contour plane is directly related to the flight check procedure. The coverage requirement of localizer beacon and coverage characteristics of 7220A system would be discussed below. The calculation is based on a hypothesis that the signal is spread through free space loss, the height of building and special terrain are not taken into account, and the blocking loss is neglected. The details of concrete simulated method of signal synthesis can be found in reference [14]. The coverage zone in identical altitude is a spherical surface called “contour plane coverage”. Comparative to flatten ground, the calculation in wide area need consider the Earth curvature revision, which has been discussed above.

2.3.1 Flight Check and Signal Coverage

According to flight check procedure, the height of aircraft in approaching is 600 m, taking the antenna array as the center with a radius of 100 km. On this surface, the localizer filed signal was totally scanned, exhibited in figure 7. The RF of the signal more than -93 dBm was marked by gradation color from cyan to violet. This is the effective coverage zone. The signal focus on the center owns the higher RF level, the maximum value reached -17 dBm. But the center area was covered by the red sector and not seen clearly.

The unshielded distribution for h_{fly}= 2.5 m can be found clearly in figure 8. This red zone representatives the coverage requirement. This horizontal coverage ruled by Annex 10 [15], where a distance at least 46.3 km (25 Nm) within ±10° from the course line, and the limits reduced to 31.5 km (17 Nm) between 10~35° from the front course line. The minimum field in this region must be more than 40 μV/m.

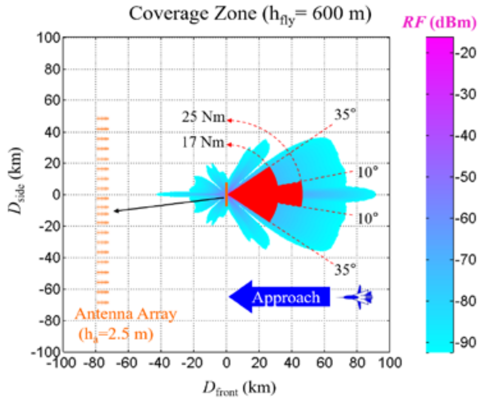

Fig.7 the simulated result (horizon distribution marked in cyan) of coverage zone of 7220A with coverage requirement. In Chinese flight check rule, the minimum RF is -93 dBm, the red sector zone marked in the center of the figure. The gradation from cyan (-93 dBm) to violet (-17 dBm) is the contour plane of CSB coverage in 600 m (h_{fly}= 600 m) for h_a= 2.5 m. This RF level responds to the lambda of localizer beacon is satisfied to the value ruled by Annex 10.

In the contour plane, the distribution pattern is different from the horizontal radiation pattern showed in figure 1. Just like the LPDA, the front-to-back rate of horizon pattern is 26 dB. However, for the contour plane, the maximum coverage distance (d_{max}) is about 92 km in front of the antennas and approximately 42 km behind it. The front to back rate of the distance is just about 6.81 dB, far less than 26 dB. Right ahead the antenna array, marked in figure, the sharp lobe (±4°) devoted by COU in figure 1 is serious shriveled in this contour plane, just has a poor coverage affect. While the CLR signal plays a significant role in coverage, meanwhile, the CLR owns a good steady fan-shaped distribution up to ±40°. This design of 7220A perfectly satisfies the coverage requirement (red zone). After that, the CLR signal is quickly reduced outside ±40°, just a "tail" in 40~60°. In horizontal distribution, seen in figure 1, the "small tail" is only inconspicuous but become strengthened in contour plane. This phenomenon doesn't come singly but in pairs, behind the antenna array, the lobes are also enlarged, especially the back one, almost longer than the main lobe.

Above all, the little lobes with large azimuth in horizontal distribution, the amplitude of the lobes would strengthen in contour plane. Consequently, the wide angle zone from 40° to 180° was still covered unnecessary in contour plane.

2.3.2 Antenna Height Effect

The height of transmitter antenna has an impact on vertical distribution, which was discussed above. The higher h_a would bring the vertical radiated lobe down, the lower angle lobe is directly related to the coverage area of contour plane. The common height of antenna from 2.5 m to 4.0 m was taken into account. Applying the flight check altitude with 600 m, the ideal situation (without obstacle shading) of coverage calculation results were showed in figure 8. Compare to the coverage area of effective signal in figure 7 for h_a= 2.5 m, the coverage zones of the other height (h_a= 3.0 m, 3.5 m, 4.0 m) were expanded several kilometer in front ($d_{max}\approx$ 92 km for h_a= 2.5 m to $d_{max}\approx$ 95 km for h_a= 4.0 m), and position for other azimuth also was enlarged simultaneously.

Referred in figure 2 above, the lower angle lobe with higher h_a, could satisfied the further distance coverage. The coverage area expanded gradually with the increase of corresponding h_a. When the ILS equipment has completed, if the localizer coverage was insufficient in first flight check. In special situation, raised h_a to strengthen RF lever is advisable.

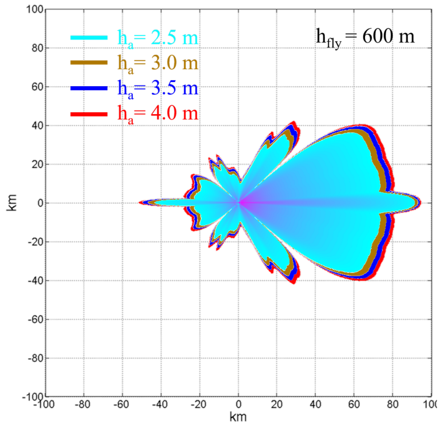

Fig.8: coverage zone in the altitude of h_{fly}= 600 m with different h_a. The maximum zone with h_a= 4.0 m (red area) placed at the bottom layer, the next one with h_a= 3.5 m (blue area) was placed on the bottom on, the minimum coverage zone with h_a= 2.5 m (cyan area) was placed on the top of the other three layers.

2.3.3 Contour Plane Coverage Responding

The vertical coverage corresponding exhibited that the signal is monotonically increasing below 9.5° with a series of h_a, seen in figure 2. From a wide coverage zone perspective, the higher contour plane owns a larger area. To understand the circumstance of neighboring contour plane exactly, the altitudes above and below h_{fly}= 600 m were also researched in further simulation, the analyze result are listed in figure 9 and figure 10 respectively.

Lower contour plane (h_{fly}= 300 m): the identical simulation method with the circumstance for h_{fly}= 600 m, just change the altitude information, not other extra condition mixed. The result in lower contour plane, half of the altitude with h_{fly}= 600 m, there exists similar distribution patterns to that of h_{fly}= 600 m. the coverage distribution also follows the rule that the higher h_a owns the larger coverage zone. The difference is that the coverage area in this contour plane is shrunk. However, the shrunken zone with lower altitude remains satisfied the coverage requirement in this altitude.

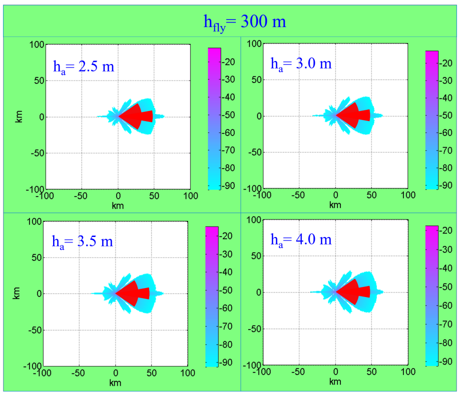

Fig.9: contour plane in 300 m high with various h_a. All of four simulated coverage zones can satisfied the coverage requirement. They also exhibited similar distribution feature.

Higher contour plane (h_{fly}= 1200 m): In higher contour plane for double of the altitude with h_{fly}= 600 m, the simulated result showed that the coverage area was enlarged, and beyond the scanned area with a radius of 100 km in front. Still, the higher h_a owns the wider coverage sector. In actual, the maximum coverage distance (d_{max}) has arrived at 127 km for h_a= 2.5 m and 133 km for h_a= 4.0 m. Far more than the required coverage zone with 46.2 km in front. The required zone (red one) is just a little bit in coverage area (cyan one). In this altitude, the airplane just entered into approaching procedure. And the Earth curvature effect plays an important role in such wide coverage area. This revised calculation result is more accurate for high altitude wide range coverage distribution.

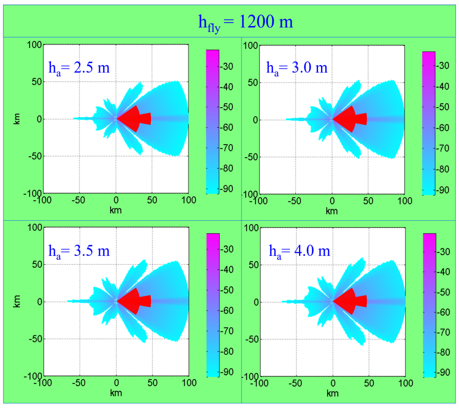

Fig.10: contour plane in 1200 m high with various h_a. The scan area was just a circle with a radius limited in 100 km. In factor, all of four simulated coverage zones own more than 100 km with about ±40° sector. The color bar reflected the RF level of every coverage distribution.

2.3.4. Near Field Situation----Circle Effect

Intensively, the signal in coverage zone does not totally meet coverage requirement. To perfectly understand the coverage characteristics, the near-field area with a simulated radius of 5 km has been investigated. There are some blind regions above the antenna array, seen in figure 11. Two kind of h_a have been taken to analyze. For h_a= 2.5 m, there is only one circle can be found. The circle is hard to find in 300 m high, and can been seen vaguely in 600 m high. However, it can been found clearly in 1200 m high. This blind circle originated from the vertical lobe interval, seen in figure 2. Between the first lobe and second one, there is a zero zone. The zero zone caused the coverage insufficient. And the other coverage insufficient region like hyperbolic curves is due to CLR distribution feature. For h_a= 4.0 m, three lobes appear in first quadrant. So there are two zero zones among them, thereby, generate two circles in contour plane. However, the distance of circle zone is located in the runway. For approaching, this coverage insufficient area is not in use.

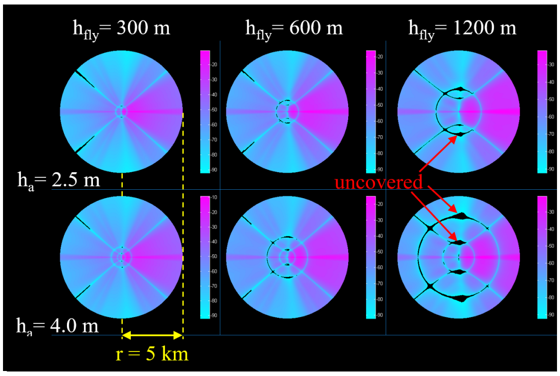

Fig.11: high precision scanning: the case of h_a= 2.5 and h_a= 4.0 m in three king of contour planes. The scanning range is a circle with a radius of 5 km. There are some uncovered zone can be found at eight and ten o'clock, as well as single circle for h_a= 2.5 m and dual circles for h_a= 4.0 m with the altitude of h_{fly}= 1200 m.

3. Summary

The signal coverage in contour plane of localizer beacon 7220A system has been investigated in series. Both horizontal and vertical distribution of radiated patterns have been systematically presented. To achieve accurate data, the height error caused by Earth curvature has been revised. The 7220A antenna array radiates a good steady fan-shaped distribution up to ±40°. There are three altitude of contour plane have been researched. The three height values (h_{fly}= 300 m, 600 m, 1200 m) represent the altitude of flight check, below and above it. All of these three contour plane could answer the needs of coverage requirement. The higher one owns larger coverage area but exists a little coverage insufficient near the top of antenna array. Also, in vertical distribution study, there are four representative kind of height of antenna (h_a= 2.5 m, 3.0 m, 3.5 m, 4.0 m) have been compared. The higher radiated antenna array possesses comparatively larger coverage region, and embodies linear increasing rule.

4. Acknowledgements

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