Airborne Video Transmission for Naval and Coast Guard Applications

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Abstract: – In certain naval and coast guard security operations a video must be transmitted from an aerial platform – aircraft, helicopter, unmanned aerial vehicle or airship – to a surface station in real time. In this paper the radio channel characteristics and the antenna systems needed are examined in order to achieve a robust direct communication channel with enough bandwidth between the airborne vehicle and the base station. Simulation and experimental work has shown that for a reliable operation, diversity (spatial or frequency) techniques must be used in order to achieve the most reliable link between a moving and a stationary platform over any terrain, and any troposphere conditions.

Keywords – Airborne video. Diversity. Propagation.

Abbreviations:

C4I:	Computers Command Control Communications and Intelligence.
EIRP:	Equivalent Isotropic Radiated Power
DVB–S/T/H:	Digital Video Broadcasting – Sattelite/Terrestrial/Handheld
LOS:	Line Of Sight.
UAV:	Unmanned Airborne Vehicle.
VSB:	Vestigial Side – Band.

1. Introduction.

In certain military, police, other public security and even public broadcasting operations the transmission of on – line video is preferred than the recording and subsequent post processing for many reasons. Except time saved – some times critical –, quality of service is significantly improved, since the airborne platform can be an active node in a C4I System or can be redirected easily during cooperative missions. Combined with active surface (shipborne or ground) based control a real – time airborne video system is essential in UAV operations; it can be useful also in manned platforms lowering the aircrew's workload.

Quality of the received video signal is also important. Poor video on the Command Center due to channel irregularities means that some of the functions described cannot be implemented effectively. The communication channel is usually stochastic in one or more of its parameters. It is necessary to define its parameters and cope with any existing channel behavior.

In this case considering the scenario of an air to surface transmission the propagation medium is the troposphere and frequency bands used are in the upper UHF Band region, or in the lower SHF. In this paper an overview of diversity techniques alongside with some simulation results will be given in order to estimate the performance of an airborne video transmission system.

At first existing video transmitting systems will be overviewed and considered for probable airborne applications. After that simulation on a transmission channel will take place to clarify the performance of airborne video systems. It will be shown that significant improvement can be made with a little complexity by using diversity techniques when the propagation conditions are ambiguous.

2. Video Transmitting Standards Overview.

Today several standards of video transmission exist mainly for broadcasting reasons. Analog standards include NTSC PAL and SECAM while digital standards like DVB–S and DVB–T are increasing in popularity and they will probably replace analog systems in the near future. In analog systems when the video bandwidth varies from 4.2 to 6 MHz [1], thus, the transmission bandwidth is about 7 to 8 MHz with the use of VSB modulation or up to 12 MHz when conventional amplitude modulation is used. For compatibility reasons the 6 to 8 MHz bandwidth is retained in DVB–T [2].

As regards the carrier frequency used, the commercial TV Bands should be avoided for obvious reasons (unwanted reception by commercial TV sets). Instead civil or military bands (depending in the case and national standards) in L–Band or S–Band (1 to 4 GHz) offer economical solutions for LOS transmission as regards frequency allocation. For the calculations to follow 1200 MHz 2400 MHz and 3600 MHz carrier frequencies are to be used – and similar results can be extracted if necessary for any given frequency in the bands mentioned above.

3. The Link Budget Problem.

For calculating the link budget of a LOS link we must know the propagation loss and propagation factor of the special geometry of the problem.

Propagation loss is the ratio of the effective radiated power transmitted in the direction of maximum radiation of the antenna pattern to the power received at any point by an omni – directional antenna.

Propagation factor is the magnitude ratio of the actual field strength at a point, to the field strength that would occur at the same point in free-space propagation conditions in the direction of maximum radiation. Both ratios can be expressed in either dimensionless form or decibels

In this case in free space:

$$P_R = P_T + G_T - L_{FS} + G_R \tag{1}$$

And subsequently in atmosphere over ground:

$$P_R = P_T + G_T - L_{FS} + G_R + 20\log\left(\left|\frac{E_{R,NA}}{E_{FS}}\right|\right) \tag{2}$$

In both equations P_R and P_T are the received and transmitted power respectively (in dBW units). Then G_R and G_T are the gains (expressed in dB) of the receiver and transmitter antennas and L_{FS} in eq. (1) is the free space loss depending only on frequency f and link distance R and calculated as follows (frequency in MHz and distance in kilometers):

$$L_{FS} = 32.44 + 20\log(f) + 20\log(R) \tag{3}$$

In the eq. (2) however the loss may be different including absorption loss of the atmosphere. In general form it is exponentially dependent to the range thus giving:

$$L_A = L_{FS} + A_{ATM} R \tag{4}$$

Here A_{ATM} is the absorption ratio (in dB per Km). The final term of the equation (2) is the propagation factor for non-absorbing atmosphere, which is dependent only by the geometry of the problem (link) and is expressed here in dB. It is also the term that quantifies the fading phenomenon due to multipath propagation, and can be as high as 6 dB or as low as –30 dB.

Actually this is the term causing the most of the difficulties since it is easy to be calculated in fixed links only with the uncertainty of the atmospheric conditions. This is the case described thoroughly in [3] and many other manuals. In a mobile link though and the link geometry is variable and thus either statistical analysis can be done or computer simulation of the link.

4. Inversing the Link Budget Problem.

Leaving the academic part aside it is useful to know if the link is possible in any given circumstances. This is by defining the minimum acceptable signal for good reception and then with given antenna gain and transmitter EIRP. Computing the noise of the system in dBW we get:

$$N = 10\log(kT_eB) \tag{5}$$

With overall stages noise temperature as high as $600^{O}K$ (a common situation in conventional systems in these bands) and Boltzman's constant $k = 1.3808\times10^{-23} J/{}^{O}K$ then for 8MHz systems the noise level will be at $N = -132\,dBW$ (or –102 dBm). For the worst case of a conventional VSB analog transmission the signal to noise ratio is about 45 dB for fine and 54 dB for excellent reception [4,5,6]. This calls for a signal power of at least $P_R = -87\,dBW$ (or – 57 dBm) at the receiver's antenna end. On the other hand a DVB–T system has an excellent performance at an SNR of 30 dB thus requiring a $P_R = -102\,dBW$ (or – 72 dBm).

Knowing the power at the receiver antenna there is left to define the transmitter's EIRP and the receiver's antenna gain. Assuming the transmitter to be on a light airborne vehicle with limited electric power and limited space for the antenna available a judgment for the EIRP is:

$$EIRP = P_T + G_T \cong 20\,dBW \tag{6}$$

This judgment is based on either a transmitter of 100W with negligible gain (nearly omnidirectional) antenna system that would allow the aircraft to maneuver without limits, or a 20W transmitter with a limited tracking and limited gain – a mere 7 dB antenna.

The receiver's antenna then must be a tracking high gain antenna. It must be considered though that the limitation of the steering mechanism confines its physical area to $A = 0.25m^2$ which gives with 50% effectiveness at the selected frequencies:

Freq.(MHz):	1200	2400	3600
Gain (dB):	14	20	23.5

These antennas are easily constructed as grid dish antennas with crossed dipole Yagi or helical feeding elements. The above analysis and estimation then can be used define the maximum loss allowed by rearranging eq. (2) as follows:

$$L_{\max} = L_{FS} + A_{ATM}R - 20\log\left(\left|\frac{E_{R,NA}}{E_{FS}}\right|\right) \qquad (8)$$

$$= EIRP + G_R - P_{R\min}$$

Compared to the propagation factor in non-absorbing atmosphere in free space then the total propagation factor is – by its definition –:

$$F_P = 20\log\left(\left|\frac{E_{R,NA}}{E_{FS}}\right|\right) - A_{ATM}R \qquad (9)$$

Frequency (MHz):	1200	2400	3600
Maximum Loss (dB) – VSB	121	127	130
Maximum Loss (dB) – DVB–T	136	142	145

In the systems under consideration though, absorption is negligible in most situations so A_{ATM} is nearly zero.

In the paragraphs to follow simulation work is each of this six cases using the AREPS [7] software, which is specially designed and composed to calculate propagation parameters. Then MATLAB v6.5® is used for further processing to obtain graphic and probabilistic results.

5. Simulation results.

In figures fig.1 to fig.9 in the appendix the propagation loss is shown for typical scenario. A helicopter or light aircraft flying at 100, 200, or 400 m carrying one transmitter at 1200, 2400, or 3600 MHz band over terrain of modest conductivity and dielectric constant. The static receiver's antenna is located 20 or 30 meters over mean height of the terrain, in a position rather arbitrary.

Thresholds are given for VSB and DVB–T systems in order to compare the range with a single or both receivers in diversity. The technique used is the maximum signal reception (switched combining [8]).Polarization is vertical. It was observed that horizontal polarization was fading more deeply.

First of all it is observable that a DVB – T system is preferable due to its lower threshold needed and it can be under consideration for airborne video application.

Secondly it is clear that spatial diversity improves the systems performance in a critical way when conventional analog transmission is used. The same can be observed in the propagation factor seen in figures fig.10 to Fig.12 (presented for flight altitude of 200 metes for all systems).

In the tables below it is shown how the propagation factor is improved with diversity. Two parameters are considered the probability of F_P<0 (propagation worse than free space) and F_P<-3 dB (worse than half the power at free space). Examples of cumulative density functions with single or diversity receivers are given to fig.14 and fig 15.

100m/1200MHz	H=20m	H=30m	Diversity
P (F_P<0dB)	0.3980	0.3354	0.1556
P (F_P<-3dB)	0.2505	0.1697	0.0485

200m/1200MHz	H=20m	H=30m	Diversity
P (F<0dB)	0.2768	0.3394	0.0788
P (F<-3dB)	0.1636	0.2000	0.0323

400m/1200MHz	H=20m	H=30m	Diversity
P (F_P<0dB)	0.46263	0.35152	0.15556
P (F_P<-3dB)	0.26667	0.18384	0.062626

100m/2400MHz	H=20m	H=30m	Diversity
P (F_P<0dB)	0.34747	0.30505	0.062626
P (F_P<-3dB)	0.18788	0.1899	0.038384

200m/2400MHz	H=20m	H=30m	Diversity
P (F_P<0dB)	0.37172	0.40808	0.11717
P (F_P<-3dB)	0.21414	0.25253	0.054545

400m/2400MHz	H=20m	H=30m	Diversity
P (F_P<0dB)	0.42424	0.40606	0.2
P (F_P<-3dB)	0.21414	0.19798	0.086869

100m/3600MHz	H=20m	H=30m	Diversity
P (F_P<0dB)	0.34343	0.32121	0.086869
P (F_P<-3dB)	0.18586	0.21212	0.052525

200m/3600MHz	H=20m	H=30m	Diversity
P (F_P<0dB)	0.4101	0.38586	0.15152
P (F_P<-3dB)	0.24242	0.23434	0.066667

400m/3600MHz	H=20m	H=30m	Diversity
P (F_P<0dB)	0.4	0.42424	0.15758
P (F_P<-3dB)	0.19394	0.23434	0.058586

It is interesting that in with spatial diversity the improvement is significant since in the worst case observed (400m/2400MHz) the probability to have better performance than free space conditions is 80%, and deep fading occurs only in 9%.

6. Doppler effects in DVB – T:

For estimating Doppler effects in a DVB – T channel experiments have been done by industrial organizations such as TeamCast® [9] mainly for developing the DVB – H standard for mobile services. Here simulated data are given for a QPSK – based DVB –T mobile system using the statistical calculator described in [9] for obtaining Doppler effect tolerance in case of mobile platforms, and extrapolating in order to cover the bands described in the paragraphs above. Doppler frequency offset is given for an one – way radiolink by the equation

$$f_D = f_{RF}\frac{v\cdot\cos(\phi)}{c} \qquad (10)$$

Where f_D, the Doppler frequency for every radiofrequency is f_{RF}, v is the flight velocity and ϕ is the angle between the link path and the flight path. Results are given to the tables below:

RF Channel Bandwidth	8 MHz
Segmented Bandwidth	1/1
Transmission Mode	2K
Guard Interval	1/4
Constellation	QPSK
Code Rate	1/2
DVB-T Bitrate	5.0 Mbps

Elementary Period (T)	7/64	(109.38 ns) (9.14 MHz)
RF signal Bandwidth	7.61 MHz	(7,611,607 Hz)
Total Symbol	280 µs	(Ts=Tu+Tg)
Useful Symbol Part	224 µs	(Tu)
Guard Interval	56 µs	(Tg)
Inter Carrier Spacing	4.5 KHz	(4,464 Hz)
DVB-T Bitrate	5.0 Mbps	(4.976 Mbps)
DVB-T Spectrum Efficiency	0.65 b/s/Hz	
C/N @ QEF	5.4 dB	(DVB-T in Rayleigh)
Mobile Penalty	*-8.1 dB* *	
C/N @ FER 5%	*13.5 dB**	(DVB-T in TU6)
DVB-T Max Doppler	*500 Hz* *	(500.03 Hz)

Interpolating the results for the bands in interest we get the empirical equation:

$$V_{rad}(m/s) = \frac{149500}{f_C(MHz)} \qquad (11)$$

This corresponds to:

Band (MHz):	1200	2400	3600
Radial velocity (m/sec):	124.58	62.29	41.53
Radial velocity (Km/hr):	448.5	224.25	149.5

These are actually the velocity margins that helicopters and light surveillance UAV operate. Interpolated values can be seen in fig.16 and fig.17.

7. Conclusions:

Real observations with a Hellenic Police helicopter flying at 200 to 400m transmitting nearly at 2400 MHz exposed problems nearly as severe as simulated here. This study is a worst-case one, and implementing spatial diversity would enhance the performance of an airborne VSB coded video transmission system.

Further more as DVB – T is the new television transmission standards it can be also find its way to military and police application. Especially these days those commercial components are readily available.

Another advantage of any digital system is its ability to accept cryptography easier than an analogue counterpart.

As regards useful link range it exceeds the territorial waters from a coastal station and so it is useful for

Finally in manned aircraft DVB based video transmission plus spatial diversity is a reliable solution. In UAV though, when loss of communication may mean the total loss of the drone, then either frequency, or polarization diversity must be used too, even if that doubles the load of the electric power system.

References

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[2] ITU-R: Recommendation ITU-R BT.1306-1 “Error-correction, data framing, modulation, and emission methods for digital terrestrial television broadcasting.”(ITU 1997-2000)

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[5] CCIR Rec 568 “Single Value for Signal to Noise Ratio for All Television Systems.” XVI Plenary Session, Dubrovnik 1986 Vol. XII

[6] "Electrical Performance Standards for Television Relay Facilities" EIA RS-250B, EIA Washington D.C., 1976

[7] "Advanced Refractive Effects Prediction System" V3.04 developed by Wayne Patterson, Gary Lindem and Amalia Barrios, Space and Naval Warfare Systems Center, San Francisco, 2004.

[8] Simon R. Saunders "Antennas and Propagation for Wireless Communication Systems" Wiley 1999 Chap.15

[9] Gerard Faria: "DVB-H Digital TV in the hands"*IBC'05* - September 2005 - Amsterdam (The Netherlands)

Appendix: Figures and diagrams.

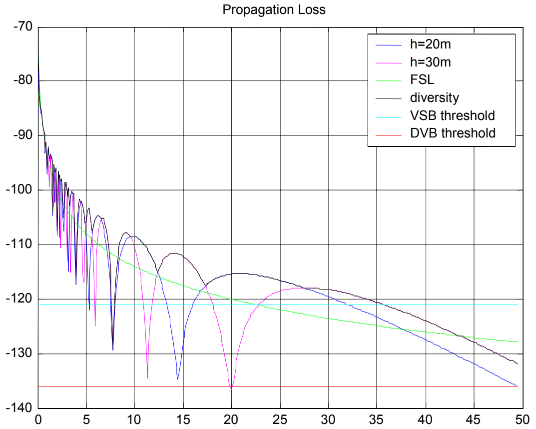

Fig.1 Flight at 100m, 1200MHz.

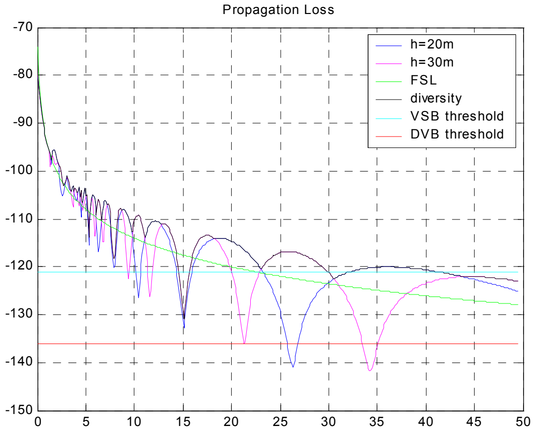

Fig.2 Flight at 200m, 1200MHz.

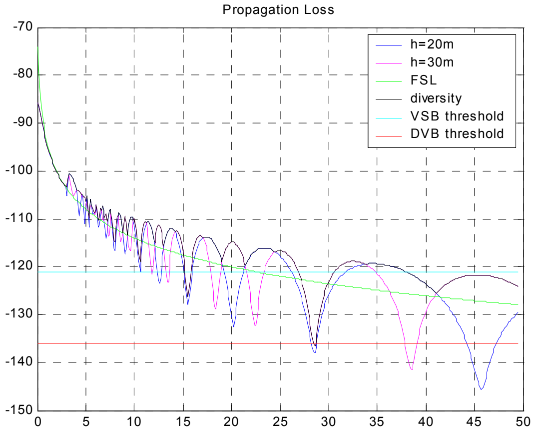

Fig.3 Flight at 400m, 1200MHz.

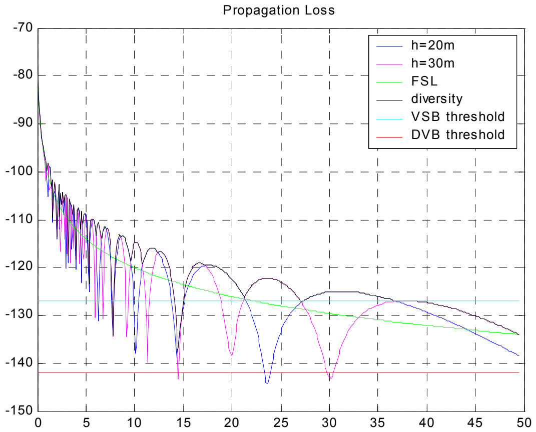

Fig.4 Flight at 100m, 2400 MHz

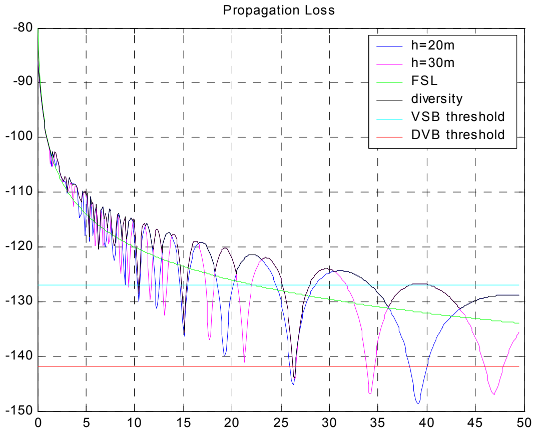

Fig.5 Flight at 200m, 2400 MHz.

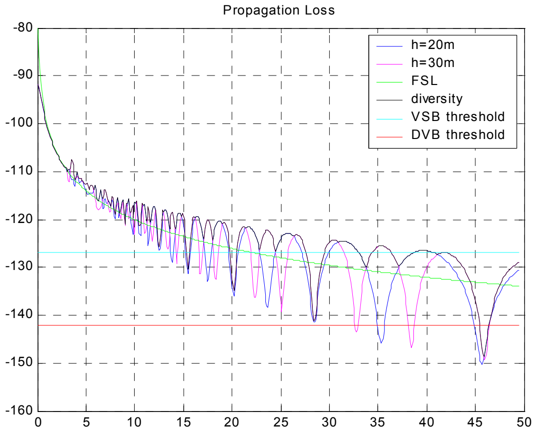

Fig.6 Flight at 400m, 2400MHz.

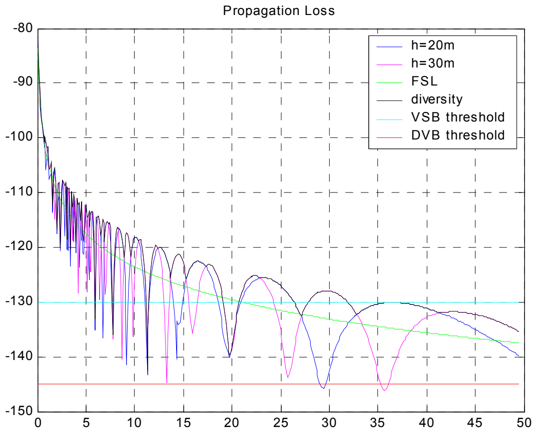

Fig.7 Flight at 100m, 3600 MHz.

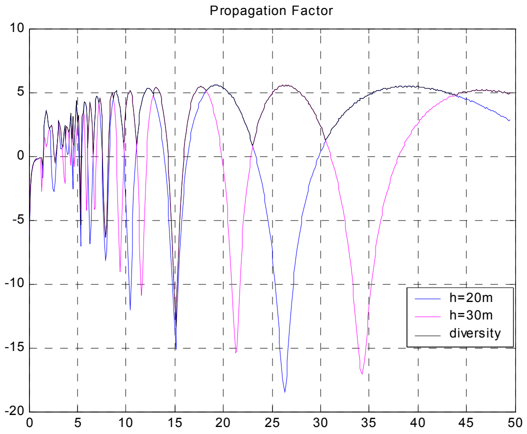

Fig.10 Flight at 200m, 1200MHz.

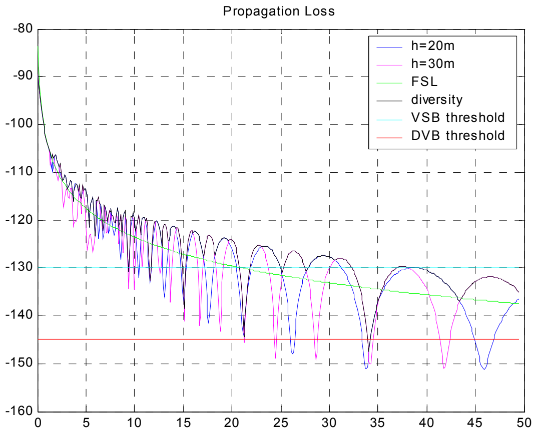

Fig.8 Flight at 200m, 3600MHz.

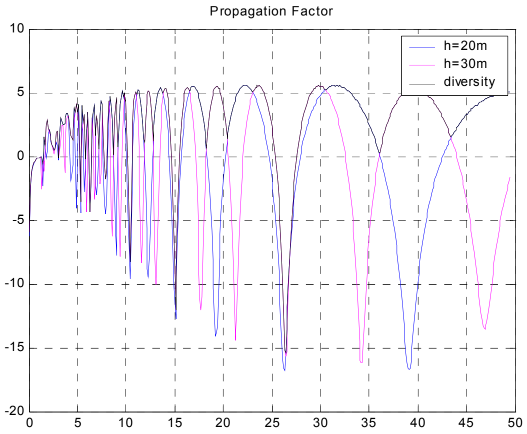

Fig.11 Flight at 200m, 2400MHz.

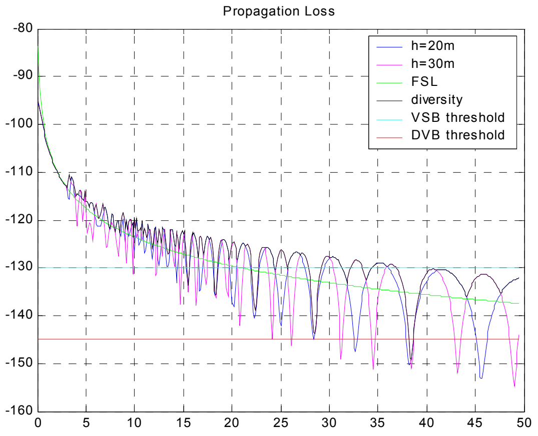

Fig.9 Flight at 400m 3600MHz.

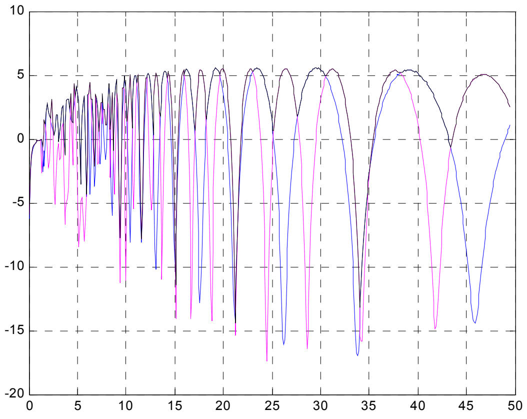

Fig.12 Flight at 200m, 3600 MHz

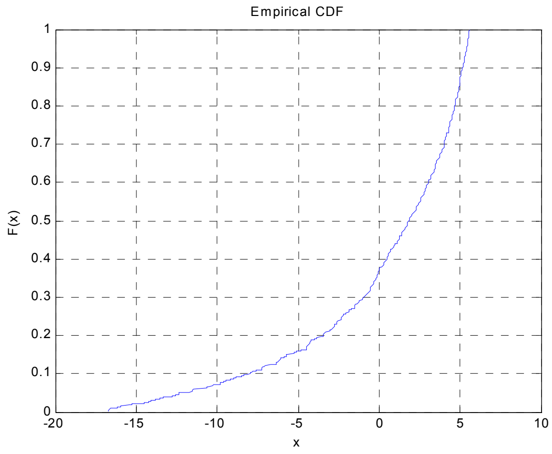

Fig13. Flight at 200m, 2400MHz. CDF plot of propagation factor. Ground antenna height 20m.

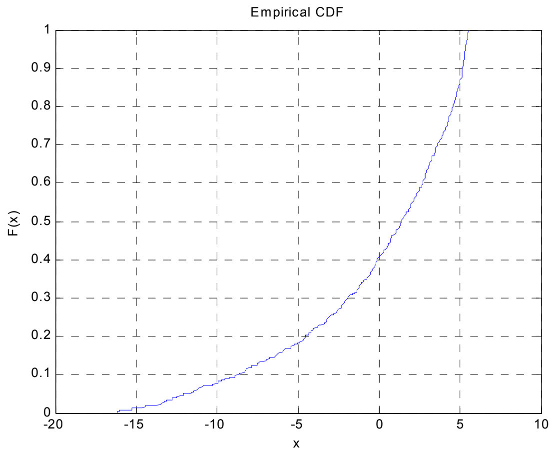

Fig14. Flight at 200m, 2400MHz. CFD plot of propagation factor. Ground antenna height 30m.

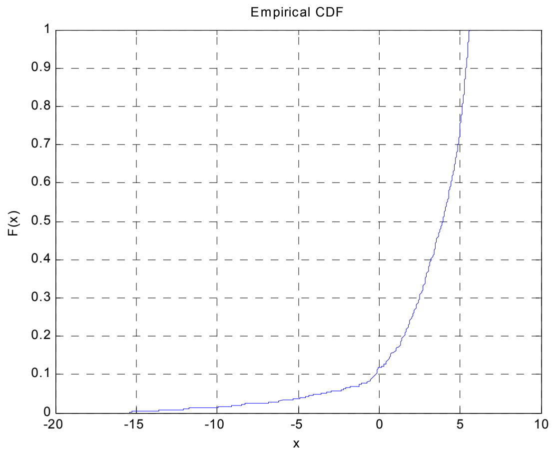

Fig15. Flight at 200m, 2400MHz. CFD plot of propagation factor. Diversity.

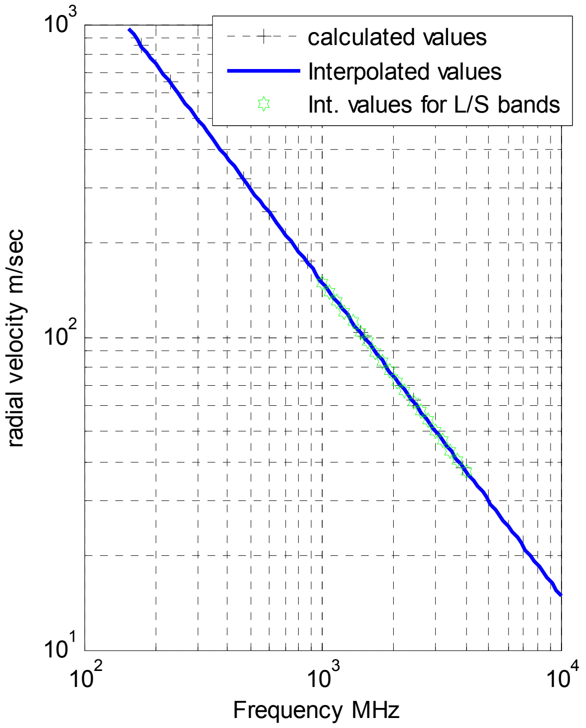

Fig16. Doppler effect tolerance.(Calculated, Interpolated in all possible bands and interpolated in L/S bands.)

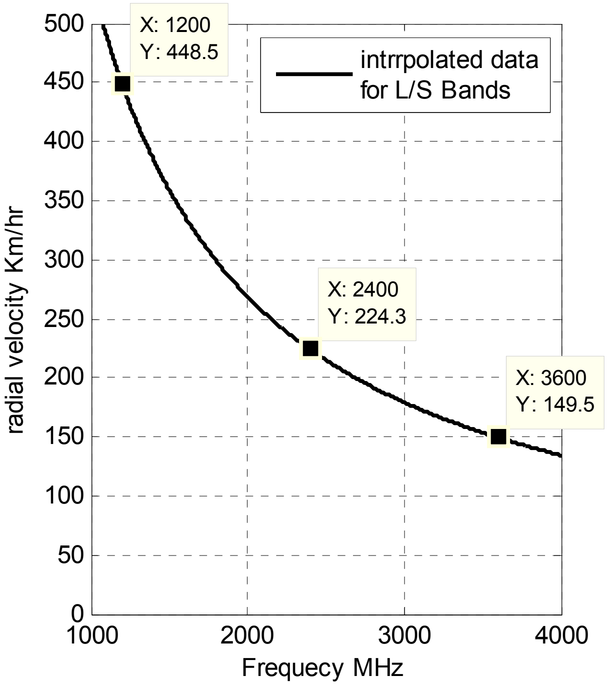

Fig17. Doppler effect tolerance in L/S bands