NORMARC

NORMARC 7000 ILS

ILS PRINCIPLES AND EQUIPMENT THEORY

TECHNICAL HANDBOOK

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1 INTRODUCTION TO ILS

1.1 System description

Instrument Landing System (ILS) is the international standard system for approach and landing guidance. ILS was adopted by ICAO (International Civil Aviation Organization) in 1947 and will be in service until at least 2010.

Because of the worldwide-adopted ICAO's performance specifications, any ILS-equipped aircraft can expect satisfactory operation from the system at any airport equipped with an ILS installation.

The ILS normally consists of a VHF "Localizer" for runway alignment guidance, a UHF "Glide Path" for elevation guidance and "Marker Beacon" for providing key checkpoints along the approach. At some airports, the marker beacons are replaced by a "DME" (Distance Measuring Equipment) to provide continuous reading of distance. Geometry and general layout of an ILS are shown in Figure 1-1.

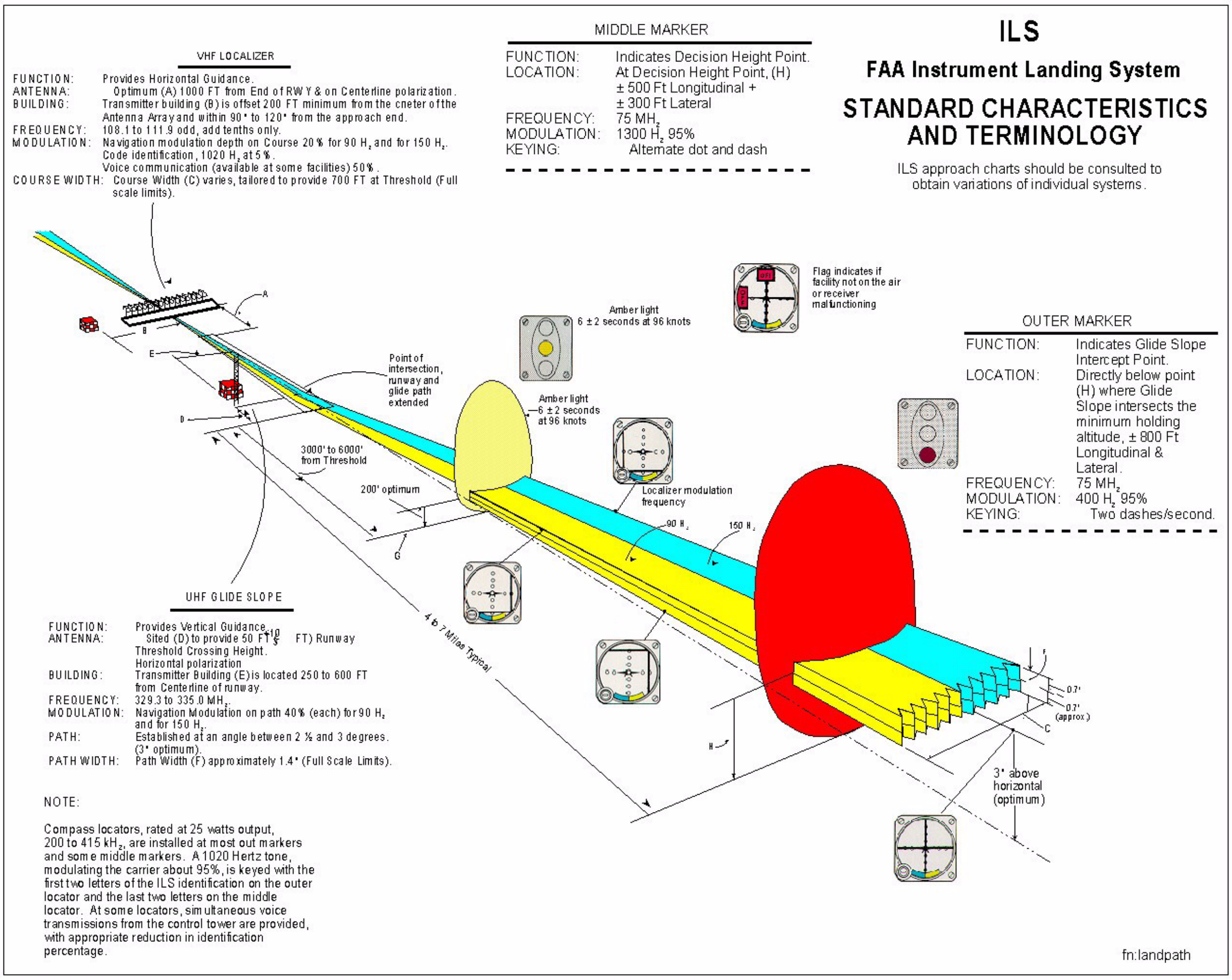

Figure 1-1 Typical location of ILS stations

The Localizer (LLZ), which provides lateral guidance, produces a course formed by the intersection of two antenna radiation patterns of equal amplitudes. One pattern is modulated by 90 Hz and the other by 150 Hz. The "course" is the vertical plane where the 90 Hz and 150 Hz modulations are equal.

The signals received by the airborne receiver will produce a "fly right" indication for the pilot when the aircraft is to the left of the course in the predominately 90 Hz region. Similarly, a "fly left" indication will be produced for the pilot on the opposite side of the course in the predominately 150 Hz region.

The Glide path (GP) produces two amplitude modulated radiation patterns in the vertical plane, which intercept at the descent angle, namely the glide path angle. Below the 150 Hz predominates giving a "fly up" indication. Above the glide path angle a "fly down" indication will be produced by the 90 Hz predominance. The GP is sited about 300 m behind the runway threshold to give the 15 to 18 m threshold crossing height. The glide path angle is about 3.0°.

The marker beacon (MB) system comprises two or three beacons, with fan-shaped vertical radiation patterns. The function of the "outer marker" located 4 to 7 nautical miles from the runway threshold, is normally to signal the start of the descent.

The radiation pattern is amplitude modulated by a 400 Hz tone keyed by dashes at a speed of two dashes per second and causes a purple light to flash on the instrument panel.
The "middle marker", nominally located at 1050 m from the threshold, alerts the pilot to the fact that CAT I (par. 1.3) decision height has been reached.
A 1300 Hz modulation tone, keyed by alternate dots and dashes, the dots keyed at a speed of 6 dots per second and the dashes at 2 dashes per second, flashes an amber light on the instrument panel.

For some configurations, an Inner Marker (IM) is used to signal CAT II decision height. The IM is normally located at a distance of 75m out to 450m from the landing threshold. A 3000 Hz modulation tone, keyed by dots at a speed of six dots per second, flashes a white light to indicate decision height.

All elements of the ILS are carefully monitored, and any malfunction causes a warning signal to alert the ground controller, the ILS is automatically switched off if the system is not functioning properly.

1.2 Functional analysis of ILS approach and landing

An ILS procedure begins with the transition from en route flight to final approach. This may be accomplished by departing from the last VHF Omni Range (VOR) navigation station of the en route flight on a radial that will intercept the localizer course approximately 7 to 10 nautical miles from the runway.

The aircraft intercepts the localizer course in level flight at an altitude (specified by the approach plate of the pilot's flight manual) and distance that place the aircraft below the glide path. This allows the pilot to become stabilized on the localizer course before starting descent.

The pilot continues level flight although the glide path indicator reads full-scale fly-up. As the aircraft intercepts the glide path sector, the indicator starts to move towards centre, and the pilot then makes the necessary power and trim adjustments to give a rate of descent consistent with the glide path angle. As he reaches the centre of the glide path, he receives the aural keying and visual flashing of the 75 MHz Outer Marker beacons. The approach plate indicates the proper altitude at which the glide path intercepts the outer marker for the specific facility being used. If he notes any significant deviation from the published value, before starting his decent he must determine whether an improper altimeter setting or a malfunction of some parts of the system causes the discrepancy. With a normal interception he is assured at this point that the key elements are working properly and he can safely begin his descent. An important check at this stage, or even earlier, is to positively identify the localizer by listening to the transmitted morse-code ident.

Descent from the Outer Marker involves keeping both Localizer and Glide path indicators centred by making small changes in heading and in rate of descent. Wind shear and turbulence during descent can cause deviations that must be corrected.

If the approach is being made to Category I weather minima (which can be down to 60 meters above airport level with 800 meters Runway Visual Range at a fully equipped airport), the pilot must have in view an element of the approach lights, runway lights or markings by the time he reaches his minima descent altitude. If he reaches this decision height and does not have adequate visual reference, he must abort the approach and execute a missed-approach procedure. This usually involves a climb-out to a navigational fix where Air Traffic Control (ATC) can instruct him further.

With the ground in sight the pilot continues his rate of descent until reaching a height of about 20 meters above runway elevation, he then slows his rate of descent so that he will further approach the runway on an exponential flight path.

The touchdown should be near the runway centreline and at a suitable longitudinal distance beyond the point where the glide path intersects the runway. This distance varies with the performance characteristics of the aircraft.

The final portion of the landing begins with touchdown and ends with the deceleration of the aircraft to taxi speed or when the aircraft turns off the runway to enter a taxiway. Guidance must be provided during rollout when aircraft are operating in the poorest conditions of visibility (CAT III). Guidance must also be available under these conditions in order to the aircraft to clear the runway quickly for the next landing aircraft.

The procedures for automatic approach and landing of ILS are essentially the same as those for manual flight. Some automatic systems are limited concerning the angle of intercept with the localizer, and this must be taken into account in the procedure. Automatic systems may also have a limitation in the amount of acceptable wind shear. The major difference between automatic and manual landing occurs after reaching decision height. The automatic system continues on both localizer and glide path until the radio altimeter signals a predetermined height of about 20 meter. The system then starts a programmed flare that continues until just prior to touchdown, when, again on signal from the radio altimeter, the aircraft heading is automatically brought into alignment with the runway. At touchdown there is a transition from aerodynamic control to wheel steering, and the aircraft is maintained on centreline by this means.

1.3 System requirements

1.3.1 Categories

The ILS shall have system specifications, which satisfy the requirements laid down by national authorities. The most commonly used are those formulated by ICAO in the document "Annex 10 to the Convention on International Civil Aviation".

The ICAO requirements concern the facility performance category of the ILS. The operational performance category used depends on several factors, such as traffic density, weather conditions and obstructions. A higher category allows operations down to lower minimum as given in Table 1.1.

Category	Non-precision approach guide	I	II	IIIA	IIIB	IIIC
Minimum desc. Altitude (MDA)	300 m (1000’)	60 m 200’	30 m 100’	0	0	0
Runway visual range	5 km (16000’)	800 m (2600’)	400 m (1200’)	200 m (700’)	50 m (150’)	0

Figure 1-2 Operation Performance Categories

The decision height or minima for a specific approach procedure is often higher than that for a category in the table due to obstructions or other limiting factor near the airport.

The facility performance category I-ILS should provide guidance information down to 30 m.
The facility performance category II-ILS shall provide guidance information down to 15 m (the threshold crossing height), and category III-ILS shall give guidance down to and along the runway centreline.

A CAT III ILS requires more sophisticated equipment than a CAT I ILS. A CAT III ILS could include "hot" stand-by transmitters and an advances monitor system. A CAT I ILS does not need a stand-by transmitter, and the monitor system may be in a single or dual configuration.

The facility performance requirements given in Annex 10 are different for the categories. The relevant pages of Annex 10 are reproduced in the following text. The applications of the paragraphs will be explained later.

1.4 Antenna System Requirements for Localizer

The radiated signals shall satisfy the requirements given in ICAO Annex 10, paragraph 3.1.2. The requirements concerning the antenna system are:

Paragraph	Item	Requirements
3.1.3.2.2.	Polarization	Horizontal. The vertical component of the radiation shall not result in a DDM> 0.016 for a cat. I, DDM> 0.008 for cat. II, when an aircraft is on course line and is in roll attitude of 20 degrees.
3.1.3.3.	Coverage	In the coverage volume given in figure 1.2. the field strength shall not be less than 40 μV/m (-114 dBW/m)
3.1.3.4.	Course structure	See figure 1.3.
3.1.3.6.	Course Alignment Accuracy	The mean course line shall be adjusted and maintained within ± 10.5 meters (Cat.I) or ± 7.5 meters (Cat.II) or ±6 meters (Cat III) from the runway centreline at the ILS reference datum.
3.1.3.7.2-3.	Displacement Sensitivity	The DS within the half course sector shall be 0.00145 DDM/meter. The DS shall be adjusted and maintained within ± 17 percent.
3.1.3.7.4.	Clearance	From the angle where the DDM is 0.180 to 10 degrees off the course line, the DDM shall not be less than 0.180. From 10 degrees to 35 degrees the DDM shall not be less than 0.155

1.5 Antenna System Requirements for Glide Paths

Paragraph	Item	Requirements
3.1.5.3.	Coverage	The minimum field strength within ±8° azimuth, 0.3 Θ - 1.75 Θ in elevation, to 10 nm distance must be more than 400 μV/m.
3.1.5.4.	Glide Path Structure	Bends must be less than ±30 μA for CAT I and ±20 μA for CAT II/III.
3.1.5.6.	Displacement Sensitivity	DDM of 75 μA at ±0.12 Θ from Θ. Tolerance: Cat.I 0.07 Θ - 0.14 Θ, Cat. II/III: 0.10 Θ - 0.14 Θ.
3.1.5.1.2.2.	Glide Path Angle	The glide path angle Θ must be maintained within 0.075 Θ for CAT I/II and within 0.04 Θ for CAT III

2 MODULATION THEORY

2.1 PHASOR ALGEBRA
2.1.1 Definition
2.1.2 Graphic addition of phasors
2.1.3 Numeric addition of phasors

2.2 MODULATION THEORY
2.2.1 Amplitude modulation
2.2.2 Double Sideband Suppressed Carrier
2.2.3 Modulation power

2.3 THE ILS SIGNAL FORMAT
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2.3.5 Principles of aircraft demodulation circuit
2.3.6 Some LLZ and GP definitions

2.4 PRINCIPLES OF NM7000 MODULATOR/TRANSMITTER GENERATION OF CSB AND SBO.

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2 MODULATION THEORY

2.1 PHASOR ALGEBRA

2.1.1 Definition.

A phasor represents both phase and amplitude of an AC voltage. The length represents the amplitude. The angle represents the phase.

Any phasor must be referred to a reference phase (0). The direction of angular revolution is defined to be counter clockwise.

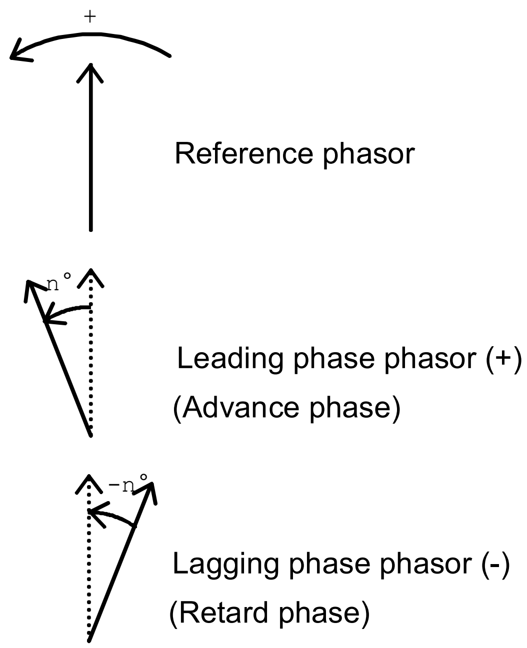

Figure 2-1 Phasor definitions

2.1.2 Graphic phasor addition

First draw phasor A in given direction and length. Next draw phasor B in given direction and length starting at the end of phasor A. Then draw a line from start point of phasor A to end point of phasor B. This is the result phasor R (phasor sum).

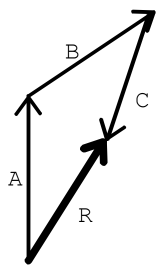

Figure 2-2 Graphic phasor addition of three signals

Numeric phasor addition

In order to find the result (amplitude and phase) of two or more phasors, each phasor is first decomposed into a real (RE) and imaginary (IM) component.

$$RE_{(n)} = A_{(n)} \cos\alpha_{(n)}$$
$$IM_{(n)} = A_{(n)} \sin\alpha_{(n)}$$

where

$A_{(n)}$ is amplitude

$\alpha_{(n)}$ is phase

Then the real $(RE_{(n)})$ and imaginary $(IM)_{(n)}$ components are separately added together:

$$\sum RE = RE_{(1)} + RE_{(2)} + \ldots + RE_{(n)}$$
$$\sum IM = IM_{(1)} + IM_{(2)} + \ldots + IM_{(n)}$$

The resultant phasor amplitude and phase are then computed by the formulas:

$$A_R = \sqrt{\sum RE^2 + \sum IM^2} \qquad \text{(amplitude)}$$

$$\alpha_R = a\tan\left(\frac{\sum IM}{\sum RE}\right) \qquad \text{(phase)}$$

Note the following conditions:

1. If $\sum RE < 0$, add 180° (π rad) to resulting phase α_R
2. If $\sum RE = 0$, the resulting phase is plus or minus 90° ($\frac{\pi}{2}$ rad) depending on the sign of Σ IM.

Example:

Add three phasor A, B and C given the following amplitude and phase:
A = 4∠0°
B = 3.6∠-56°
C = 3.2∠160°

First find the RE and IM components of each phasor:

A: RE = 4.0 cos0° = 4.0
IM = 4.0 sin0° = 0.0

B: RE = 3.6 cos -56° = 2.013
IM = 3.6 sin -56° = -2.985

C: RE = 3.2 cos 160° = -3.007
IM = 3.2 sin 160° = 1.094

Then add RE and IM separately:

ΣRE = 4.0 + 2.013 + (-3.007) = 3.006
ΣIM = 0.0 + (-2.985) + 1.094 = -1.890

The phasor sum amplitude:

$$A_{(R)} = \sqrt{3.006^2 + (-1.890)^2} = \underline{\underline{3.55}}$$

The phasor sum phase:

$$\alpha_{(R)} = \arctan\left(\frac{\sum IM}{\sum RE}\right) = \arctan\left(\frac{-1.890}{3.006}\right) = \underline{\underline{-0.561}} \text{ rad}$$

$$\alpha_{(R)} = \frac{180}{\pi} \cdot -0.561 = \underline{\underline{-32.16^\circ}}$$

2.2 MODULATON THEORY

2.2.1 Amplitude modulation

To give guidance information to the aircraft the transmitted signal is made to vary in response to the information. Thus, a periodic signal (sinusoid) does not transmit information. If the amplitude is varied by intelligence then a signal is obtained that can convey information.
The process by which the amplitude is made to vary in accordance with some specified intelligence is called amplitude modulation (AM).
The inverse process, that is, the recovering of the information from the signal is called demodulation or detection.

Modulation may take on other forms than varying the amplitude. For instance, frequency or phase modulation is commonly used. However, as amplitude modulation is the only form used in ILS, only this will be discussed here.

The sinusoid signal is represented by a function of the time, t

$$\underline{v(t) = A(t) \cdot \sin \omega_C t}$$

where the parameters describing the signal are A(t), the amplitude, and ω_c, the angular frequency. The frequency f_c is given by the relationship

$$\underline{f_c = \frac{\omega_c}{2\pi}}$$

The frequency f_c is called the carrier frequency of RF (Radio Frequency). For the localizer it is about 110 MHz, for the glide path about 330 MHz.

For an AM signal the amplitude A(t) is varied around a mean value of A(t), A_c. Thus the AM signal is described by the equation:

$$\underline{v(t) = A_c(1 + m(t)) \cdot \sin \omega_C t}$$

For ILS, the modulation signal m(t) is sinusoidal, such that

$$\underline{m(t) = m \cdot \sin \omega_m t}$$

where

$$\underline{f_m = \frac{\omega_m}{2\pi}}$$

is the modulation frequency and m is the index of modulation, or depth of modulation. It is sometimes multiplied by 100 and called the percentage modulation.

The complete expression for the AM signal is

$$\underline{v(t) = A_c\left[1 + m \cdot \sin \omega_m t\right] \sin \omega_c t}$$

A plot of v(t) is given in Figure 2-3. The curves marked envelope of modulation represent upper and lower limits on the value of v(t). The equation for envelope of the modulation is

$$\pm A_c\left[1 + m \cdot \sin\omega_m t\right]$$

where the plus sign is used for the upper envelope and the minus sign for the lower one.

The index of modulation can be determined by

$$m = \frac{V_{max} - V_{min}}{V_{max} + V_{min}}$$

If m > 1, then the expression for the upper (lower) envelope will become negative (positive) for some values of time. The detectors used for ILS are such that the output is zero for those values of time.
The envelope of v(t) will then no longer have the shape of the modulating signal and distortion will result. To avoid distortion due to the modulation process, we shall assume that 0 < m < 1.

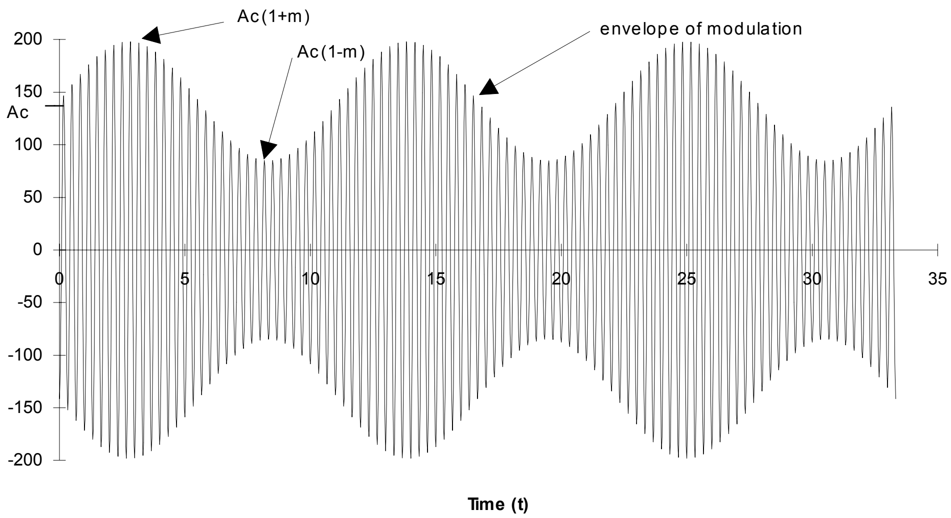

Figure 2-3 An amplitude modulated signal

Considering the expression for v(t) we have, by using trigonometric identity for the product of two sines

$$\sin x \cdot \sin y = \frac{1}{2}\left(\cos(x-y) - \cos(x+y)\right)$$

$$v(t) = A_c + m\frac{A_c}{2}\cos(\omega_c - \omega_m) - m\frac{A_c}{2}\cos(\omega_c + \omega_m)$$

Thus, we see that the modulation process produces additional frequency components above and below the carrier frequency. These are called the sidebands and differ from the carrier frequency by plus or minus the modulating frequency. The carrier frequency itself is unaffected by the modulation.

A plot called a frequency spectrum is sometimes made to indicate the relative magnitudes of the frequency components of a waveform. Such a plot is shown in Figure 2-5

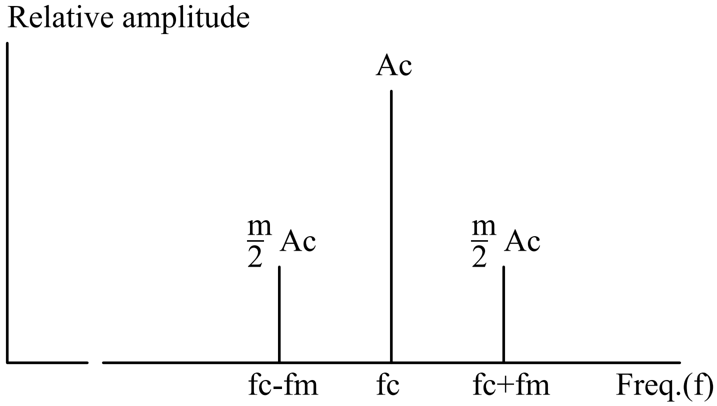

Figure 2-4 The frequency spectrum of an AM signal

For ILS, the modulation consists of two signals 90 Hz and 150 Hz. By analogy, the expression for the AM signal will be

$$v(t) = A_c\left[1 + m_{90}\sin\omega_{90}t + m_{150}\sin\omega_{150}t\right]\sin\omega_c t$$

In this case there will be four sidebands above and below f_c . The sidebands differ from f_c (110 MHz or 330 MHz) by plus or minus 90 Hz or 150 Hz.

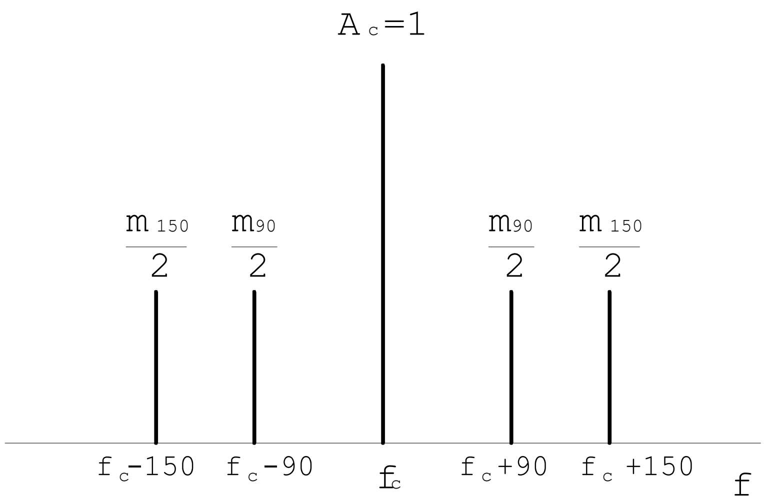

Figure 2-5 Frequency spectrum of a AM signal modulated with 90 Hz and 150 Hz (CSB)

2.2.2 Double Sideband Suppressed Carrier.

Another type of AM is also used in ILS. That is Double Sideband - Suppressed Carrier (DSB SC). This signal has the following expression for two modulation signals

$$v(t) = A_c\left[m_{90}\sin\omega_{90}t - m_{150}\sin\omega_{150}t\right]\sin\omega_c t$$

A plot of v(t) with only one modulation signal $(m_{150} = 0)$ is given in Fig. 2.6.

The frequency spectrum is shown in Figure 2-7.

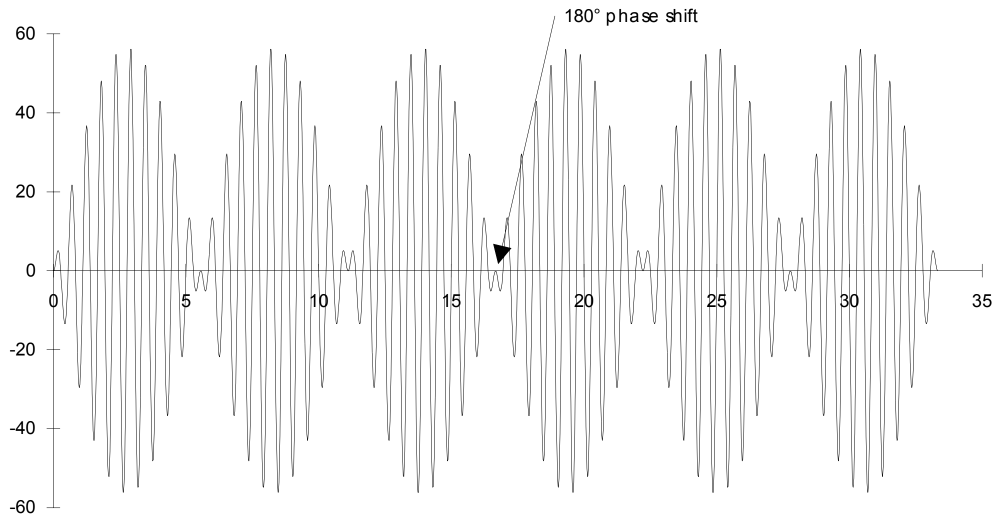

Figure 2-6 A DSB - SC signal modulated with 90 Hz

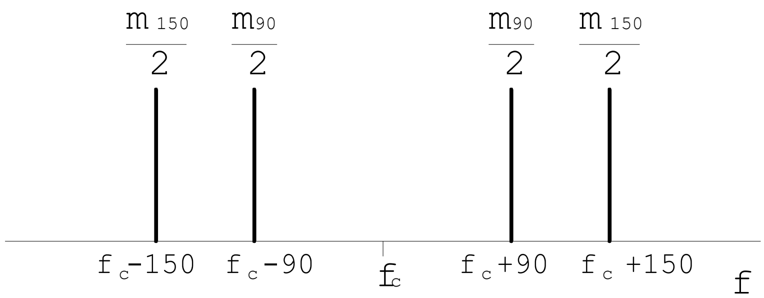

Figure 2-7 Frequency spectrum of a DSB-SC signal modulated with 90 Hz and 150 Hz (SBO)

2.2.3 Modulation power considerations

The power distribution for the frequency components is of interest. The **power** of a sinusoid signal will be proportional to the **square of the maximum amplitude divided by two**. (This is the same as the square of the rms value.)

Thus, P_c , the carrier power will be proportional to $\frac{A_c^2}{2}$ while the total power contained in both sidebands will be proportional to $\frac{m^2 A_c^2}{4}$.

Thus, the ratio of the power of both sidebands to the carrier power is

$$\frac{P_{sideband}}{P_{carrier}} = \frac{m^2}{2}$$

Sideband power.

General formula:

$$\underline{P_{SB} = P_C \frac{m^2}{2}}$$

$$\underline{P_{SBO} = P_C \left(\frac{{m_{90}}^2 + {m_{150}}^2}{2} \right)}$$

Example 1:

LLZ SBO power:

$$\underline{P_{SBO} = 15 \left(\frac{0.2^2 + 0.2^2}{2} \right) = \underline{\underline{0.6W}}}$$

Example 2:

GP SBO power:

$$\underline{P_{SBO} = 5 \left(\frac{0.4^2 + 0.4^2}{2} \right) = \underline{\underline{0.8W}}}$$

Carrier plus Sideband power:

$$\underline{P_{tot} = P_C \left(1 + \frac{m^2}{2} \right)}$$

$$\underline{P_{CSB} = P_C \left(1 + \frac{{m_{90}}^2 + {m_{150}}^2}{2} \right)}$$

2.3 THE ILS SIGNAL FORMAT

2.3.1 The guidance signal

The ILS guidance information is based upon comparison of the depth of modulation of the 90 Hz and 150 Hz modulation signals (called guidance tones). This **difference in depth of modulation (DDM)** is the main parameter by the airborne receiver.

The variation of DDM in space is obtained by radiation of the amplitude modulated (AM) signals, both modulated with 90 Hz and 150 Hz. The signals are named **CSB** and **SBO**.

The **CSB** (Carrier and Sideband) is a signal which is amplitude modulated to equal depths by the guidance tones.

The **SBO** (Sideband Only) signal takes the form of a double sideband, suppressed carrier with the two guidance tones modulated in **opposite audio phases.**
The CSB and SBO signals are shown in Figure 2-8 and Figure 2-9 respectively, expressed in the time domain.

With no SBO signal, the depth of modulation of the received signal is identical for the two guidance tones (DDM = 0).
At the localizer course and the glide path DDM = 0.
For other angles in space the SBO is not zero, consequently the amplitude of the in-phase guidance tone and accordingly the depth of modulation will increase.
For the other guidance tone the amplitude will decrease, as the CSB guidance tone and the SBO guidance tone are in opposite phase, resulting in lower depth of modulation.
This will give a DDM different from zero. The DDM depends on the ratio of the received **SBO** and **CSB** signals.

The expression for the composite signals CSB and SBO are:

$$\underline{E_{CSB}(t) = E_{CSB}\left(1 + m\sin\omega_{90}t + m\sin\omega_{150}t\right)\sin\omega_c t}$$

$$\underline{E_{SBO}(t) = E_{SBO}\left(-m\sin\omega_{90}t + m\sin\omega_{150}t\right)\sin\omega_c t}$$

where
$\underline{\mathrm{E_{CSB}}}$ and $\mathrm{E_{SBO}}$ are amplitude constants
$\underline{\omega = 2\pi f}$ (angular frequency)

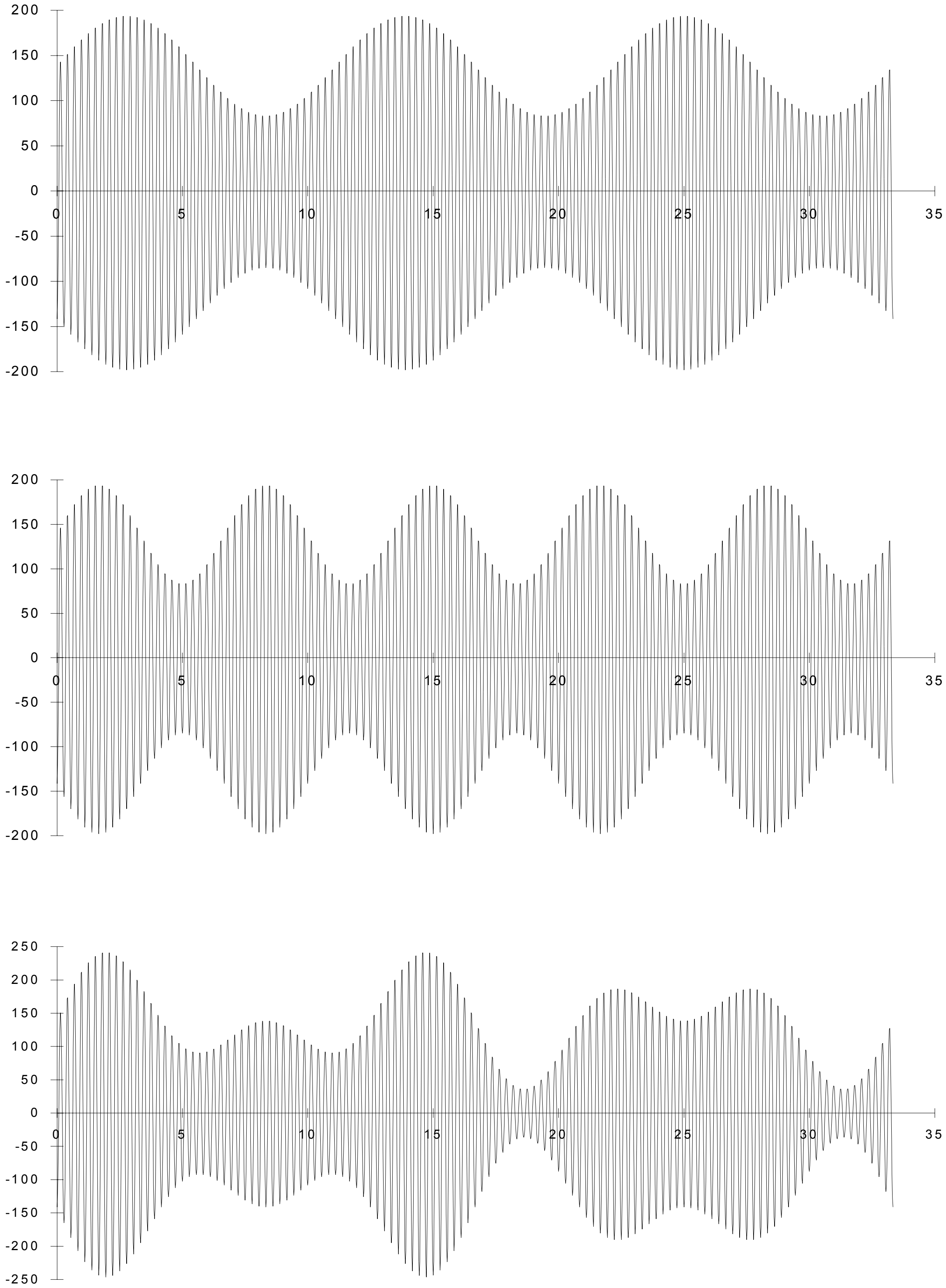

Figure 2-8 The CSB waveform seen in the time domain. Upper diagram is 90 Hz, middle is 150 Hz, and lower is combined 90 + 150. Time scale in milliseconds

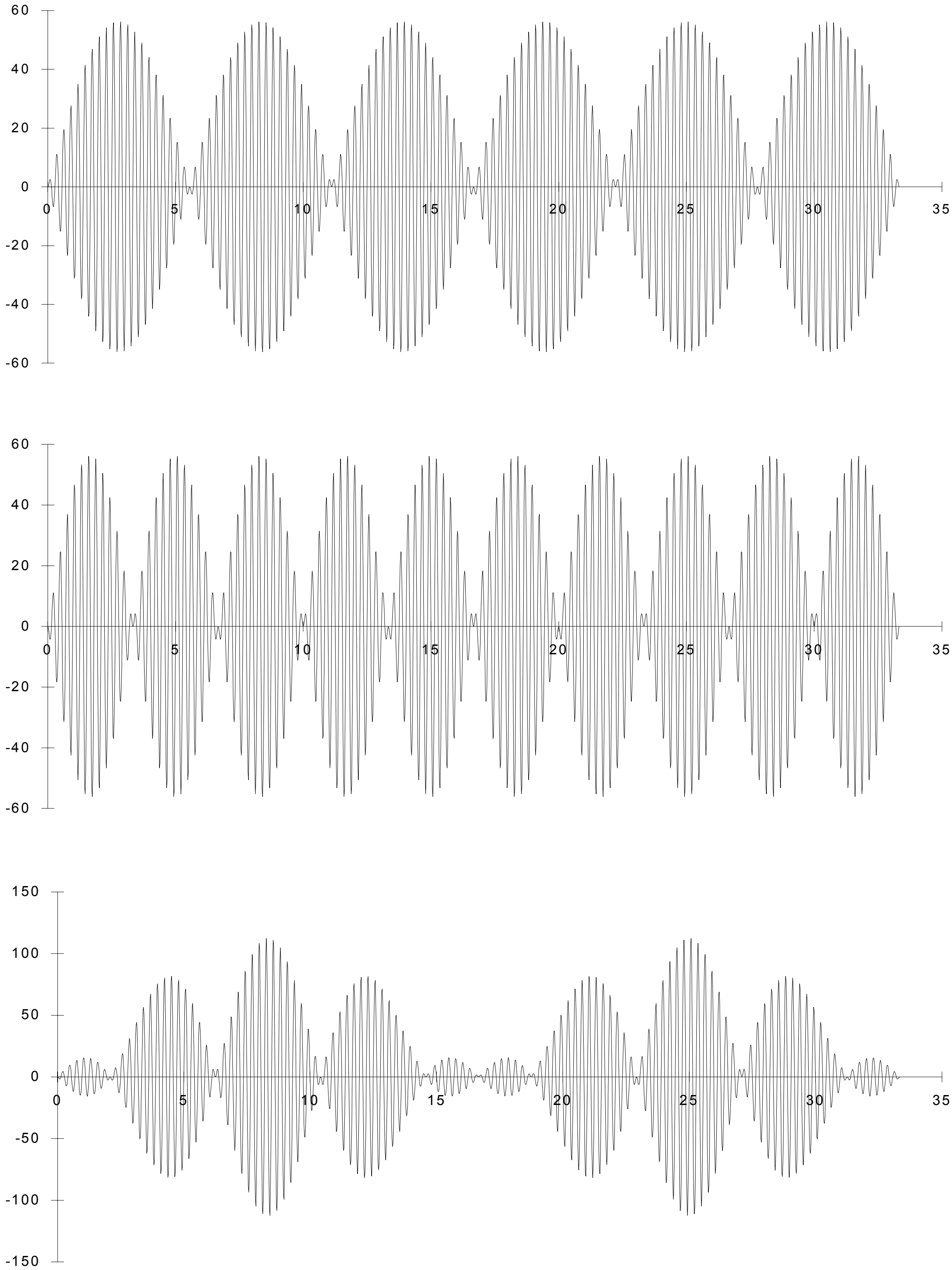

Figure 2-9 The SBO waveform seen in the time domain. Upper diagram is 90 Hz, middle is 150 Hz, lower is combined 150 - 90. Time scale in milliseconds

2.3.2 DDM and SDM definitions

DDM is defined as

$DDM = m_{150} - m_{90}$ for modulation level <2m
DDM = 2m for modulation level >2m

SDM is defined as

$SDM = m_{150} + m_{90}$ for modulation level > 2m
SDM = 2m for modulation level <2m

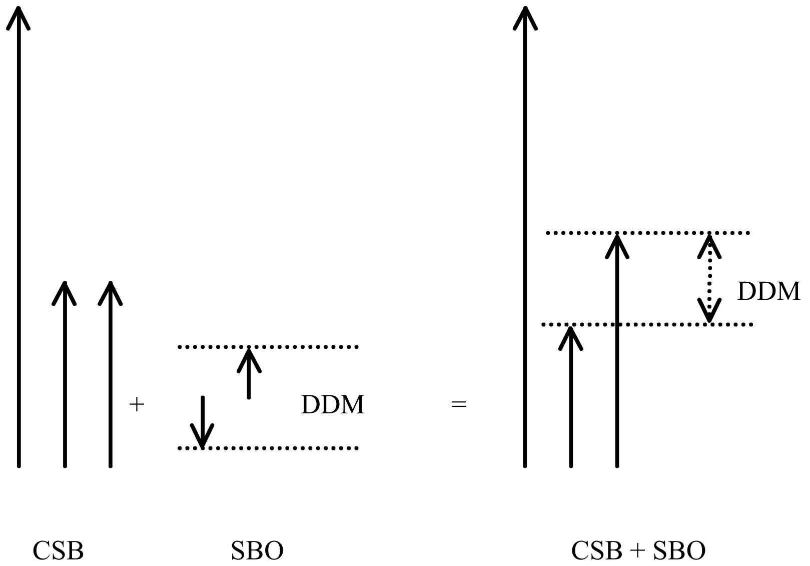

Figure 2-10 Combined CSB and SBO

When SBO amplitudes are less than the CSB modulation depth, DDM is equal to the magnitude of the SBO amplitudes 90 plus 150 in reference to the carrier amplitude.

By convention 90 Hz and 150 Hz SBO amplitudes are equal, consequently

$$DDM = \frac{2 \cdot SBO}{CSB}$$

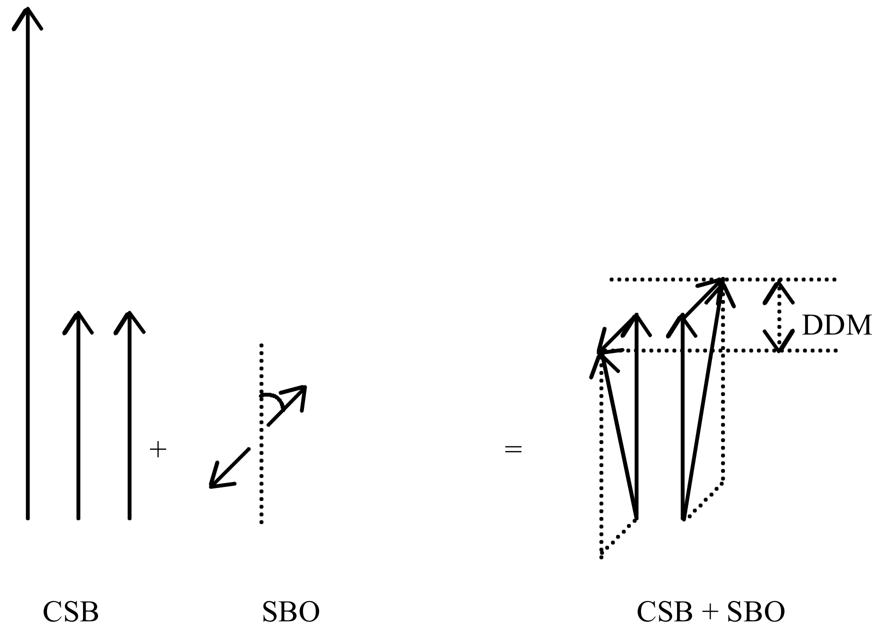

Figure 2-11 Phasing error between CSB and SBO. SBO is retarded by φ degrees

DDM is proportional to the cosine of the phase angle between CSB and SBO. The complete formula for DDM including CSB/SBO phase relation is:

$$\mathrm{DDM} = \frac{2 \cdot \mathrm{SBO}}{\mathrm{CSB}} \mathrm{COS}\varphi$$

Any phase error φ will reduce the DDM magnitude.

Example.

Given far field values for CSB and SBO:
CSB = 100∠0°
SBO = 11.7∠-10°

$$\mathrm{DDM} = \frac{2 \cdot 11.7}{100} \cos(-10°) = 0.23$$

DDM= 23%

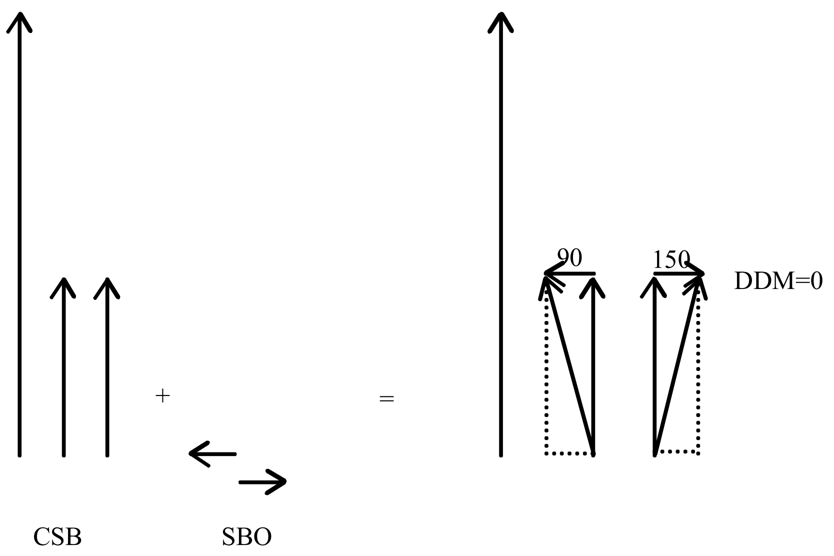

Figure 2-12 CSB and SBO in quadrature. (90° phase)

For $\varphi = \frac{\pi}{2}$, cosφ = 0 consequently DDM = 0.

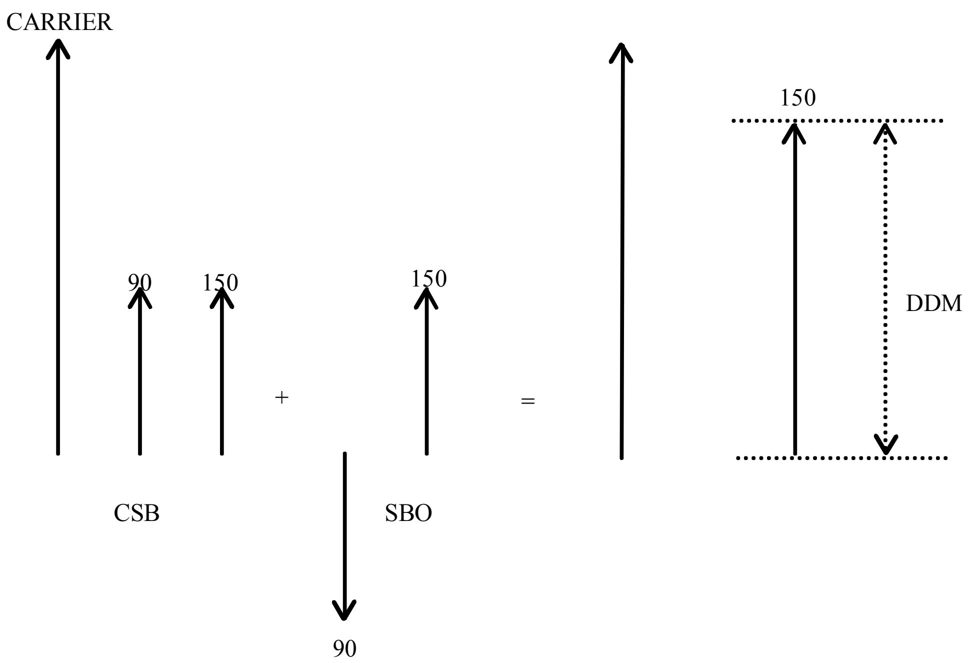

Figure 2-13 SBO amplitude is equal to CSB modulation depth

The result is maximum DDM, cancellation of the 90 Hz component.

2.3.3 Localizer DDM distribution

DDM is a linear function of azimuth inside the sector width segments (15.5%(90) to 15.5%(150).

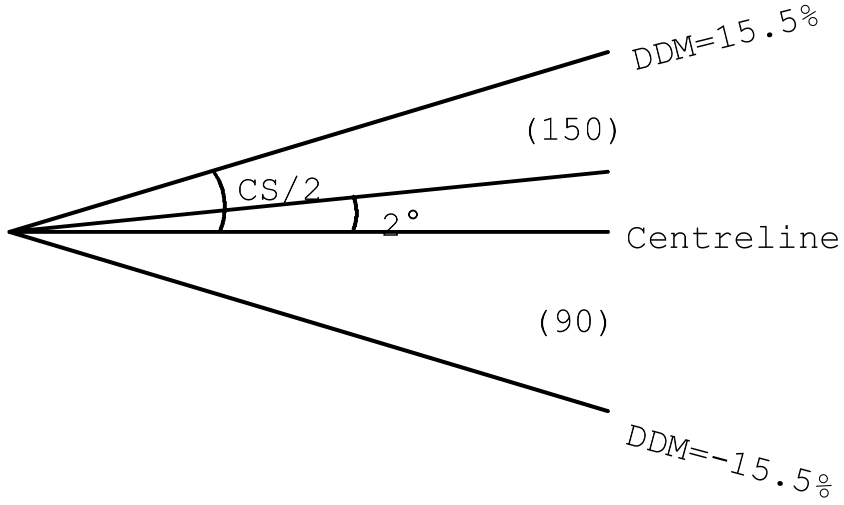

Figure 2-14 Localizer DDM distribution

Example:

Course Sector (CS) = 5°

DDM at 2° azimuth:

$$\frac{15.5\% \cdot 2°}{\frac{5°}{2}} = \underline{\underline{12.4\%}}$$

2.3.4 Glide Path DDM distribution

DDM is a linear function of elevation angle from lower sector (17.5% DDM) to upper sector
(-17.5% DDM).

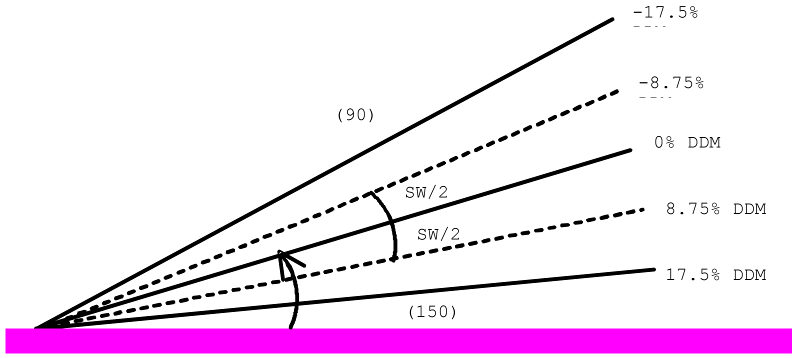

Figure 2-15 Glide Path DDM distribution

Example:

$\theta_0 = 3°$, find DDM at 2.9°:

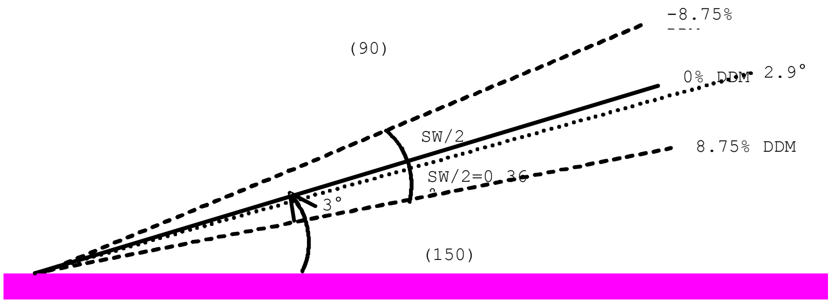

Figure 2-16 Example DDM distribution

$$\frac{3° - 2.9°}{x} = \frac{0.36°}{8.75\%}$$

$$x = \underline{\underline{2.43\%DDM}}$$

Converted to µA:

2.3.5 Principles of aircraft demodulation circuit

The principle of the airborne receiver is shown in Figure 2-17.
The signal received by the aircraft's antennas is amplified and transformed to IF and then demodulated. The output of the demodulator is a LF signal consisting of 90 Hz and 150 Hz tones.
These two tones are filtered separately and rectified. The dc level difference determines the DDM, which indicates the deviation from the course line.
This information is shown by the position of a bar on a "cross pointer".
The sum of the detected 90 Hz and 150 Hz tones, which is the SDM, gives the "flag current". A low SDM indicates something is wrong and a red flag appears on the cross pointer.

A too low signal input level will cause a "flag warning"

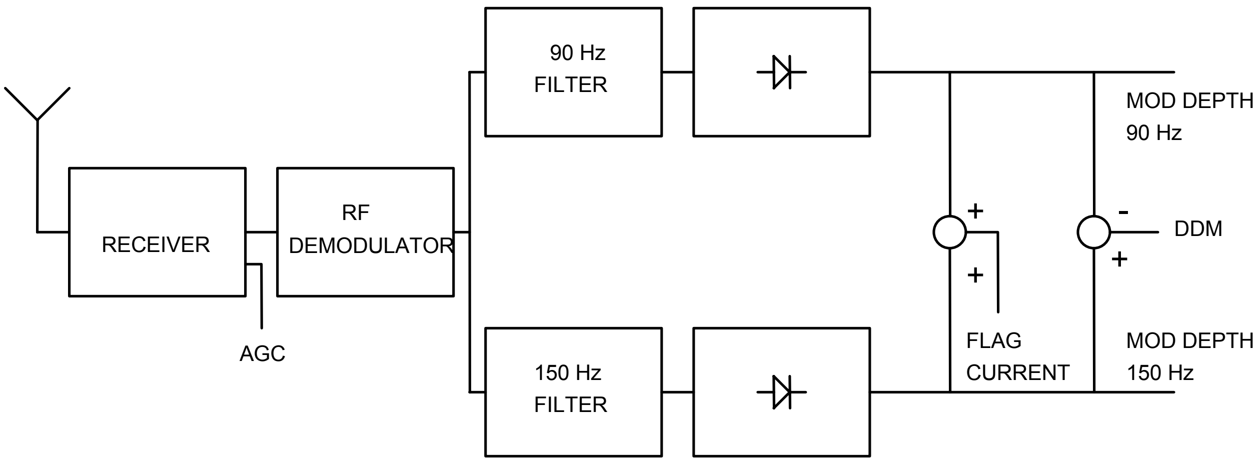

Figure 2-17 ILS receiver

In the receiver, the DDM is measured as a difference in currents through the 90 Hz and 150 Hz circuits. The receiver is calibrated to give a current to the cross-pointer equal to 150 µA for a sector width indication, both for Localizer and Glide Path.
As the sector width for LLZ is 0.155 DDM, and the GP is 0.175 DDM, the correspondence between DDM and µA is different.

2.3.6 Some LLZ and GP definitions

Localizer.
Negative DDM indicates 90 Hz dominance: FLY RIGHT.
Positive DDM indicates 150 Hz dominance: FLY LEFT.
Sector Width = 15.5% DDM or 150 µA in the cross pointer.

Glide Path.
Negative DDM indicates 90 Hz dominance: FLY DOWN.
Positive DDM indicates 150 Hz dominance: FLY UP.
Sector Width = 17.5% DDM or 150 µA in the cross pointer.
Commonly used term is half Sector Width = 8.75% DDM (75µA).

2.4 Principles of NM7000 Modulator/Transmitter Generation of CSB and SBO

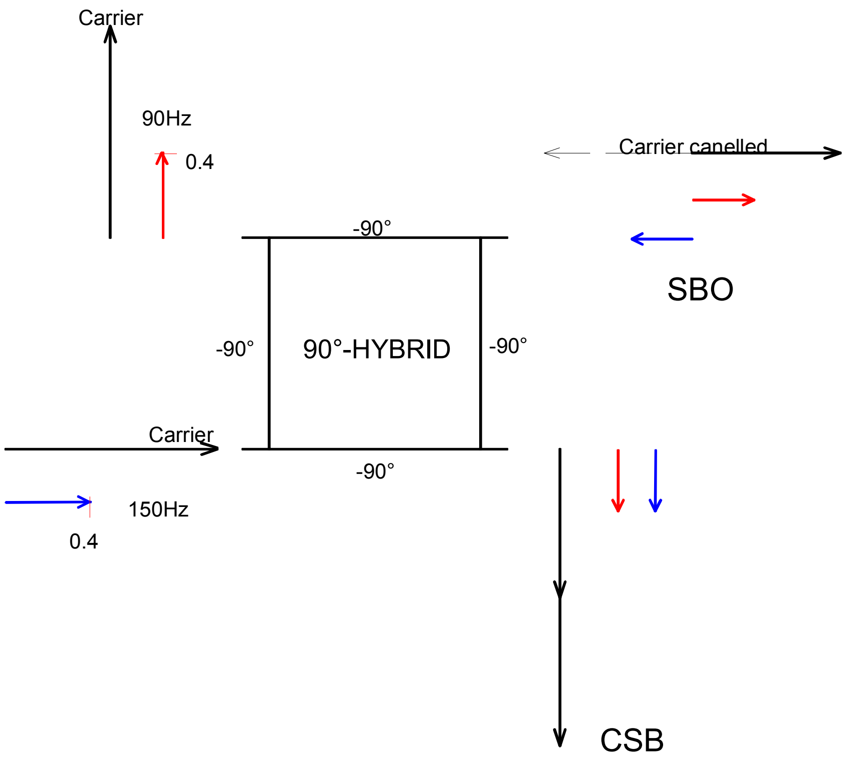

Figure 2-18 CSB and SBO generation in a Quadrature Hybrid in NM7000 Transmitter

Definitions:
C: Carrier only
SB90: Total 90Hz sideband signal (upper + lower sideband)
SB150: Total 150Hz sideband signal (upper + lower sideband)

C+SB90 and C+SB150 is applied in quadrature at two adjacent ports of a 90°-Hybrid. The result is Carrier + Sideband (CSB) and Sideband Only (SBO), appearing at the remaining two ports as shown in the Figure 2-18.
The Carrier will add in-phase at the CSB port and cancel at the SBO port. The 90 Hz and 150 Hz modulations at the input ports will distribute evenly to the CSB and SBO ports (half power to each port). Therefore the modulation depth at the input ports must be twice the desired CSB modulation depth, i.e. 0.4 for localizer, 0.8 for glide path.
Due to the phasing characteristics of the 90°-hybrid, the 90 Hz sideband will be 180° out of phase with the 150 Hz sideband at the SBO port; the sidebands at the CSB port will be in-phase (starting in the same direction at the same time).

A power imbalance between the C+SB90 and C+SB150 (at the input of the hybrid) will result in the same imbalance at the SBO port between the SB90 and SB150 power. At the CSB port modulation depth of 90 Hz and 150 Hz will be unequal resulting in a DDM different from zero.
Secondly, there will be a carrier rest at the SBO port. This carrier rest will be in phase with the greater of the two sidebands.

Example: 0.2 dB power imbalances of C+SB90 and C+SB150 will return a waveform pattern as shown in Figure 2.19, compared with the perfect pattern in Figure 2.21. At the CSB port a DDM value of 0.0046 (4.5μA) will exist.

A phasing error (different from 90°) between the C+SB90 and C+SB150 will result in a residual carrier appearing at the SBO port.

Example: 3.6° RF phase error at the input ports will create a carrier level of -30dB at the SBO port referred to the CSB level.
Figure 2.20 shows demodulated SBO corresponding to -30 dB carrier rest.

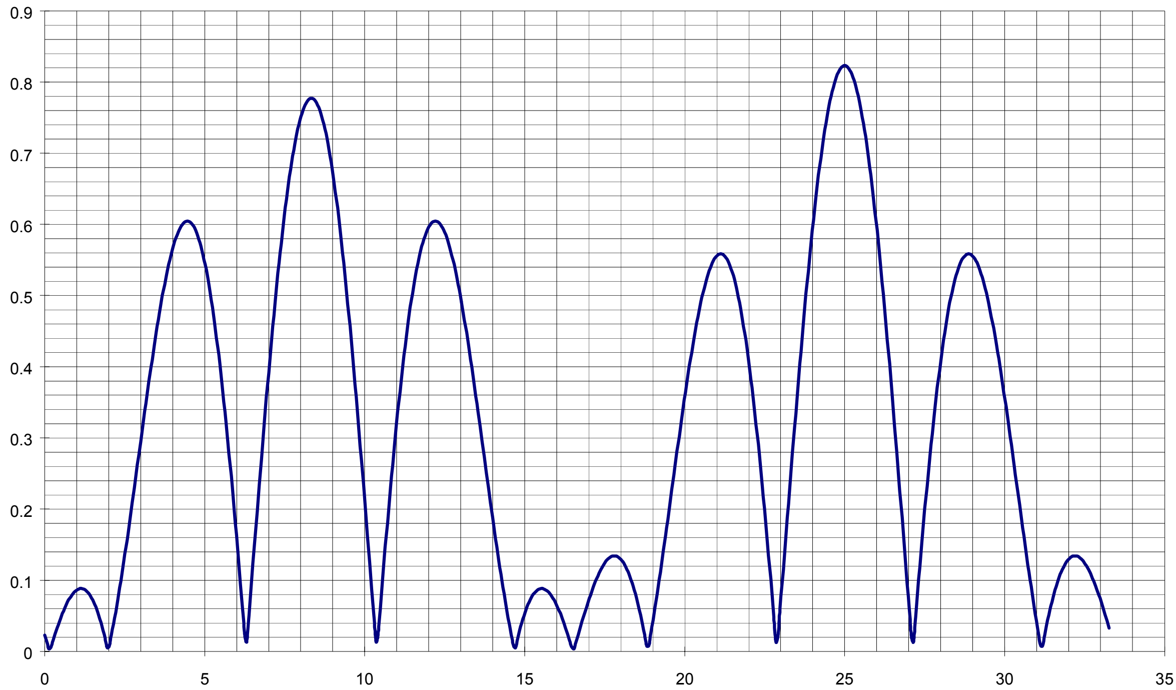

Figure 2-19 Demodulated SBO with 0.2 dB unbalanced C+SB90 and C+SB150

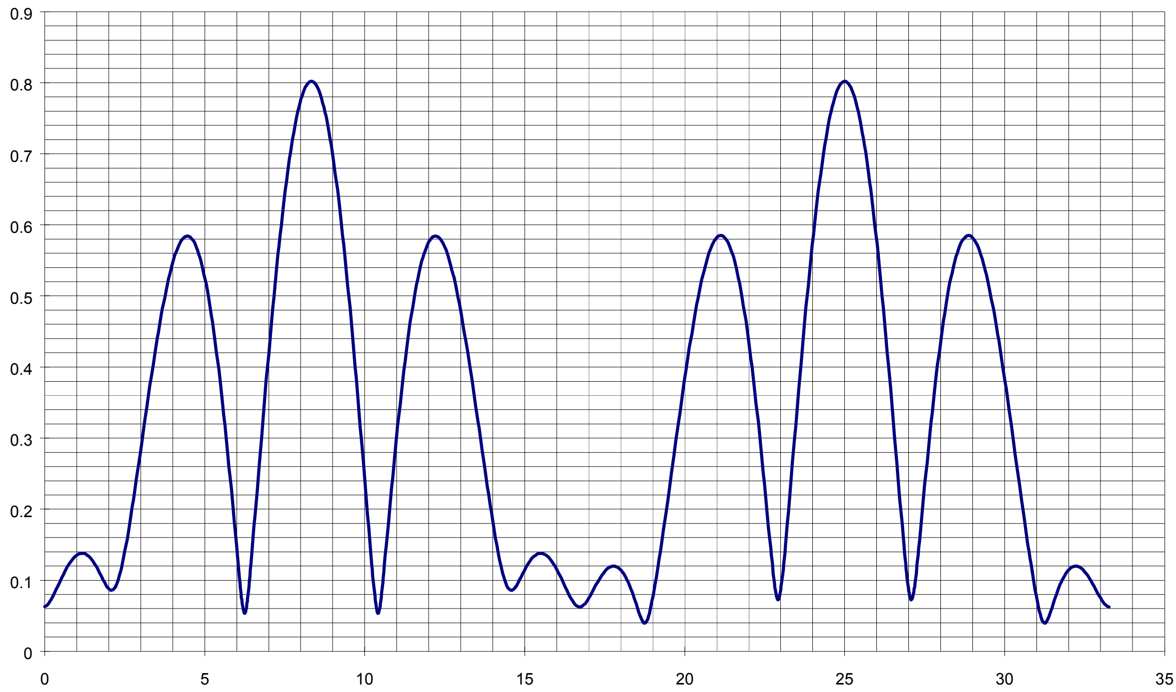

Figure 2-20 Demodulated SBO with 3.6° internal phasing error corresponding to -30 dB carrier residual

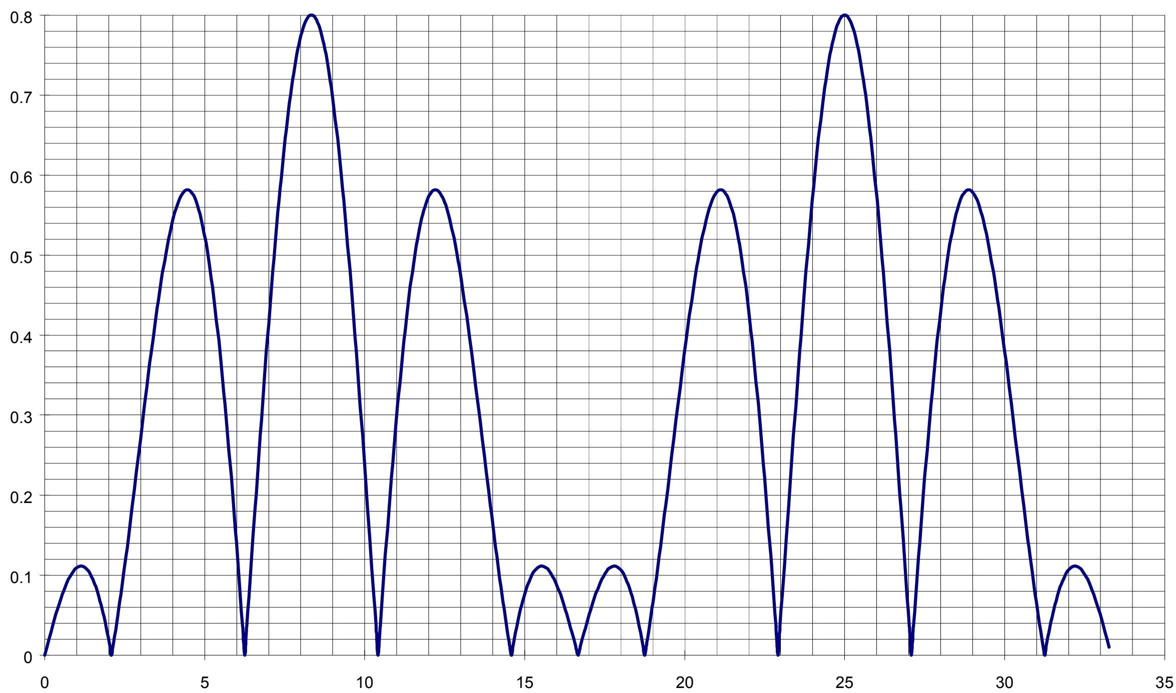

Figure 2-21 Demodulated SBO perfect

3. ANTENNA THEORY

3.1 BASIC CONCEPTS
3.1.1 Induction and Radiation fields
3.1.2 Near field, Far field
3.1.3 Radiation pattern
3.1.4 Directivity, Beam-width and Gain
3.1.5 Isotropic Radiator, Power Density, Field Strength
3.1.6 Half-wave Dipole Antenna

3.2 ANTENNA ARRAYS
3.2.1 Two antenna elements
3.2.2 Radiation patterns

3.3 MULTI-ELEMENTS ARRAY

3.4 IMAGE THEORY

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3 ANTENNA THEORY

3.1 Basic concepts

An antenna (aerial) is a device used for radiating or receiving energy in the form of electromagnetic waves.
Such waves, which travel with the velocity of light, posses an **electric** and a **magnetic** field that are at right angles to one another and to the direction of propagation.
These electric and magnetic fields are produced by current flow in the antenna.

The direction of the electric field (E-vector) determines the polarization. ILS waves are horizontally polarized as shown in Figure 3-1.

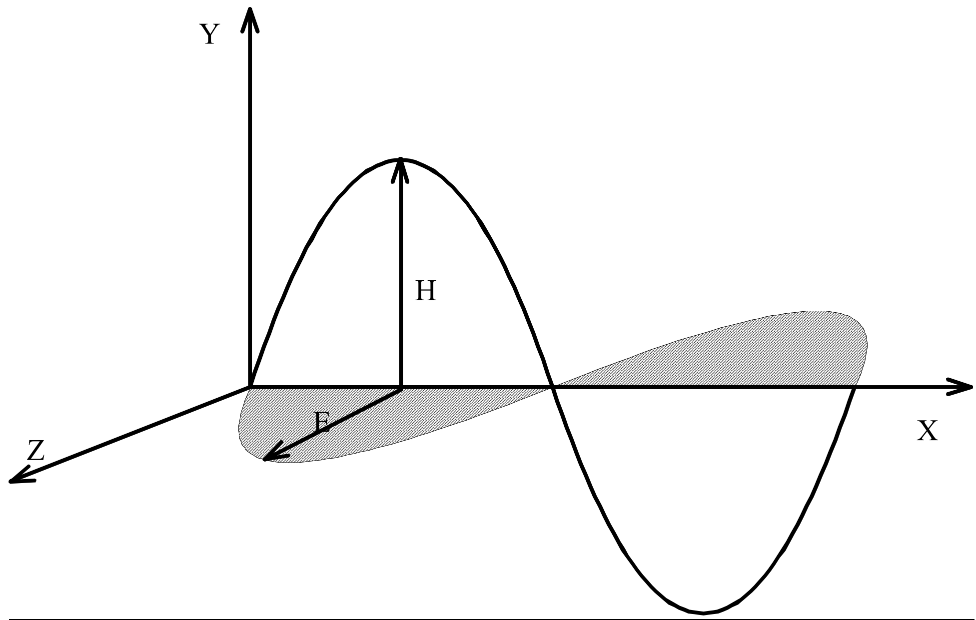


Figure 3-1 Electromagnetic wave with E- and H-field lines

3.1.1 Induction and Radiation Fields

An electromagnetic wave can be launched from an antenna such as a dipole. The antenna can be considered a two-wire transmission line, which has been opened up. The electric an magnetic lines appear as in Figure 3-1.
The electric and magnetic energy associated with the fields can be divided into two components.

The first is called the **induction component**. It is assumed that the Energy in this component is returned to the antenna.
The strength of the induction component varies inversely with the square of the distance from the antenna.

The second component is called the **radiation component**. Energy contained in the electric and magnetic fields of the component is lost or radiated from the antenna.
The strength of the radiated component varies inversely with the first power of the distance from the antenna.

At a distance of approximately four wavelengths the strength of the **induction field** becomes **negligible** with respect to the radiation component, and beyond this distance the radiation component predominates.
It is the **radiation component** that is of principal interest in the study of antennas.

3.1.2 Near Field and Far Field

The area where the radiation component predominates can be split into two regions:
The **near field** and the **far field** regions.
The **near field** region extends from a few wavelengths from the antenna to a distance where all the rays from the antenna to the observation point may be considered parallel to one another.

The distance depends on the dimensions of the antenna (D) and on the phase error (δ) which can be tolerated.
For ILS, which is a phase critical system δ should be $\lambda/32$ (about 12°) for most applications.
The near field then extends to a distance $R \approx \frac{4D^2}{\lambda}$ as shown in Figure 3.2.

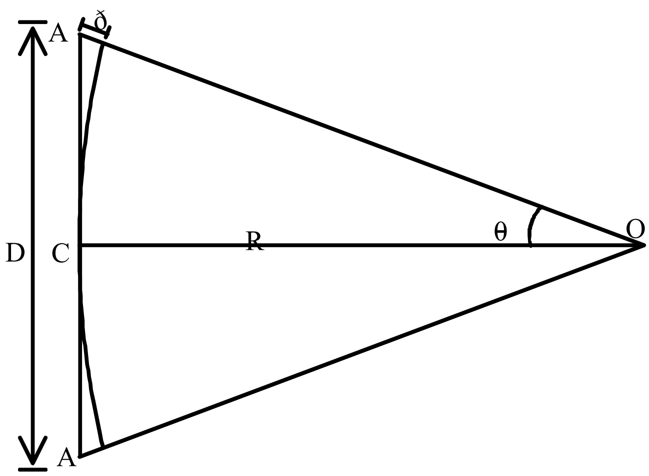


Figure 3-2 Calculation of the extent of near field with an acceptable phase error ($\lambda/32$) from an antenna of length D

OC = R, OA = R+λ/32

$$(R+\delta)^2 = \left(\frac{D}{2}\right)^2 + R^2$$

$$R^2 + 2R\delta + \delta^2 = \frac{D^2}{4} + R^2$$

$$R \approx \frac{D^2}{8\delta} = \frac{4D^2}{\lambda}$$

3.1.3 Radiation pattern

A diagram showing the variation of electric field intensity at a constant radius (r) as a function of angle (θ, φ) is called a radiation pattern or field pattern.

When the field intensity is expressed in **volts per meter** it is an **absolute radiation pattern**.

If, however, the field intensity is expressed in units relative to it's value in some reference direction, it is called a **relative radiation pattern**.

The reference direction is normally taken in the direction of maximum field intensity.
The relative pattern is the most commonly used.

Representation of two types of patterns is illustrated in Figure 3-3 and Figure 3-4.

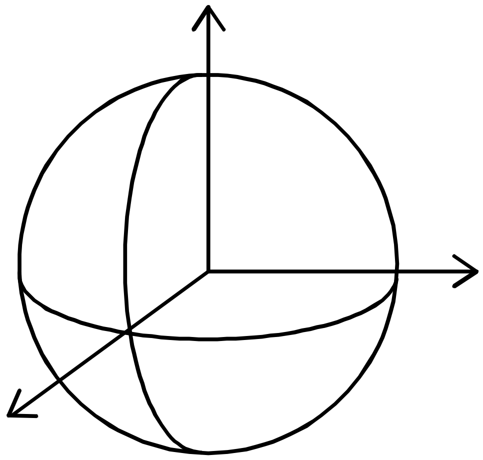


Figure 3-3 Isotropic Radiation Pattern

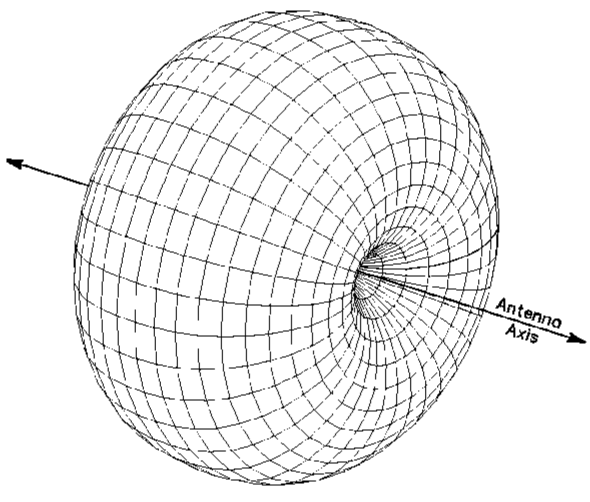


Figure 3-4 Omni directional Radiation Pattern

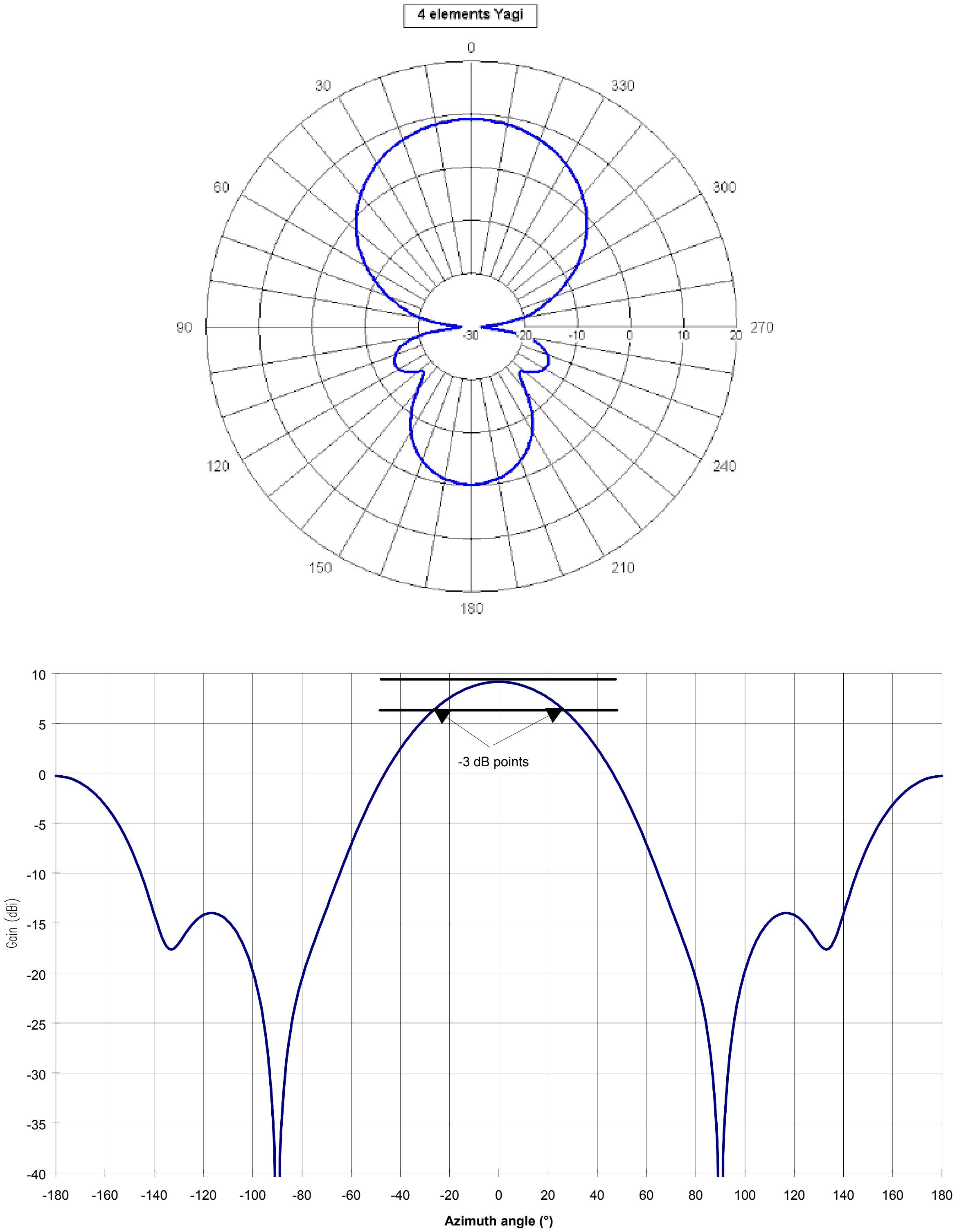


Figure 3-5 Polar diagram (top) and rectangular diagram (bottom) of same antenna pattern

Upper diagram shows antenna radiation pattern in polar coordinates and logarithmic scale. Lower diagram shows the same radiation pattern in rectangular coordinates, also logarithmic scale (dBi).
By reciprocity this pattern is the same for both transmitting and receiving conditions.

3.1.4 Directivity, Beam-Width and Gain

The **directivity (D)** of any given antenna is defined according to the following:

$$D = \frac{\text{maximum field strength}}{\text{average field strength}} = \frac{E_m}{E_0}$$

The average field strength can be found by integration of the total power radiated (P_0) and dividing this by 4π, which is the surface of a unit sphere.
Hence:

$$D = \frac{4\pi E_m}{\iint E(\varphi,\theta)ds} = \frac{4\pi E_m}{P_0}$$

The definitions of directivity are determined entirely by the shape of the radiation pattern, losses in the antenna are not included.

The **efficiency (η)** of an antenna is defined as the ratio of the total radiated power to the total input power.

The difference between these two powers is the antenna loss caused by mismatch, the feeder system loss, and the finite conductivity of the antenna.

The **gain (G)** of an antenna is given by the directivity modified by the efficiency:

$$G = \eta \cdot D.$$

In practice, gain is more interesting than directivity as the gain gives information concerning the maximum field density radiated from isotropic antenna.

Both gain and directivity are normally expressed as decibel ratios by taking 10 times $\log_{10}$.

Example:
The gain of a $\frac{\lambda}{2}$ dipole antenna is 1.64 times an isotropic antenna. Expressed in decibels:
$G_{dBi} = 10\log_{10} 1.64 = 2.15\ \text{dBi}.$

3.1.5 Isotropic Radiator, Power Density, Field Strength

The **Isotropic antenna** is a hypothetical antenna, which radiates energy uniformly in all directions.

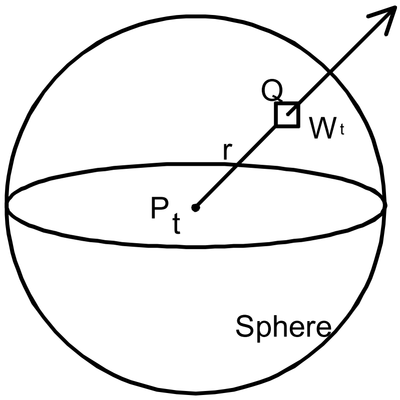


Figure 3-6 Radiation of the Power P_t from an Isotropic Radiator

Consider an isotropic antenna radiating equal energy in all directions, fed with power P_t (see Figure 3-6).
The power flows outward from Origo, and at any time t it must flow through the spherical surface of radius r.
Hence, the power density W_r at point Q is given by:

$$W_r = \frac{P_t}{4\pi r^2}$$

where $4\pi r^2$ is the sphere surface area.

The isotropic may be considered as a standard reference antenna with power gain $G_t = 1$ ($G_t = 0\text{dBi}$).
If any practical antenna with gain G_t is placed at Q, the power density at Q will be modified by the factor G_t.
The complete expression for **power density** W_r is:

$$W_r = \frac{P_t}{4\pi r^2} \cdot G_t$$

For some applications it is useful to express the power density as an electro magnetic field strength. The power density is the product of the electrical and magnetic field strengths:

$$W_r = E \cdot H = \frac{E^2}{120\pi} \quad (\text{watts}/\text{m}^2)$$

The free space impedance is the ratio between the electrical and the magnetic field strength:

$$\frac{E}{H} = 120\pi$$

Applying Ohms Law for power:

$$\frac{E^2}{120\pi} = \frac{P_t}{4\pi r^2} \cdot G_t$$

Field strength: $E = \frac{\sqrt{30 P_t G_t}}{r}$ (volts/meter)

Maximum effective area of an antenna.
It can be shown that the maximum effective area A_{ei} of the isotropic antenna is

$$A_{ei} = \frac{\lambda^2}{4\pi}.$$

The gain of the isotropic antenna is 1, defined as the reference antenna. The gain G of any other practical antenna is

$$G = \frac{1}{A_{ei}} A_e$$

where A_e is the maximum effective area of the antenna.

Antenna Gain : $G = \frac{4\pi}{\lambda^2} A_e$.

Maximum effective area: $A_e = G \frac{\lambda^2}{4\pi}$

Power in Receiving Antenna.
The power P_r induced in the receiving antenna is equal to the power density W_r multiplied by the maximum effective area A_e.

$$P_r = W_r \cdot A_e$$

Inserting the expression for the power density W_r and effective area A_e into the formula for the **power in receiving antenna** P_r gives the **Friis free-space equation***:*

$$P_r = P_t \frac{G_t G_r}{\left(\frac{4\pi r}{\lambda}\right)^2}$$

The denominator of the expression is the *spatial attenuation*.

P_t : Power transmitted (watts)

G_t : Gain in transmitting antenna
G_m : Gain in receiving antenna
r: Distance from transmitting antenna to receiving antenna (meters)
The expression above is valid in free space only.

3.1.6 Half-wave Dipole Antenna

The radiation pattern of a half-wave dipole antenna is of special interest as this antenna is often used as a reference for other antennas.
The patterns in the dipole plane and in a perpendicular plane are illustrated in Figure 3-6 and Figure 3-7, respectively.

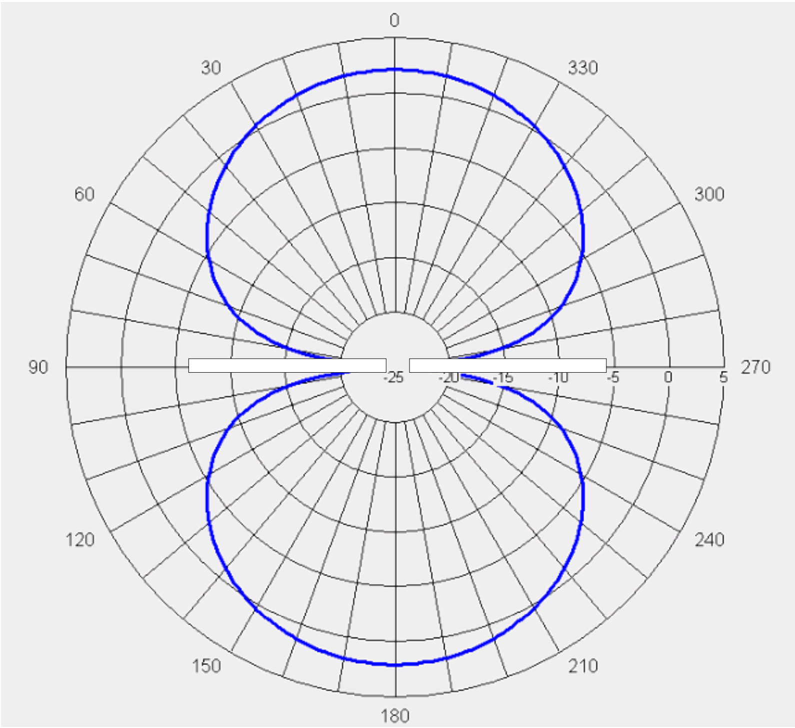


Figure 3-7 Radiation pattern of a $\lambda/2$ Dipole antenna in the plane of the dipole

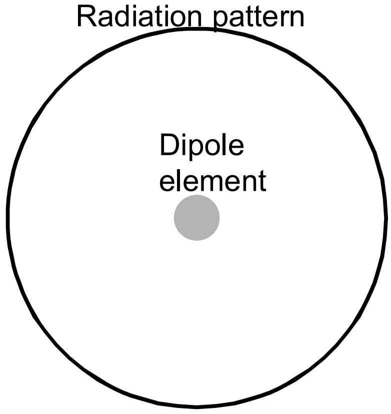


Figure 3-8 Radiation pattern of a λ/2 Dipole antenna in the plane perpendicular to the dipole

The field intensity in the plane perpendicular to the dipole is the same in all directions and the pattern is therefore said to be omni-directional.

The radiation resistance R_{rad} of a thin half-wave dipole is theoretically 73.2 Ω (in free space).

The **half power beam-width** is 78°.

The **directivity** is 1.64. (2.15 dBi).

The **effective area** of a thin half-wave dipole is $0.13\lambda^2$ which approximates to an area of $\frac{\lambda}{4} x \frac{\lambda}{2}$.

3.2 ANTENNA ARRAYS

All ILS antenna systems comprise more than one radiating element. When two or more antenna elements, fed from the same transmitter, are located in a straight line they form a linear antenna array (normally referred to namely as an antenna array). The radiation pattern from the array is the product of the antenna pattern and the pattern from the antenna array with isotropic elements.

3.2.1 Two antenna elements

The simplest array comprises two isotropic antenna elements spaced a distance 2D apart. At a distance point P the field strength of each is about equal, bur there is a phase difference, due to a path difference, as shown in Figure 3-7.

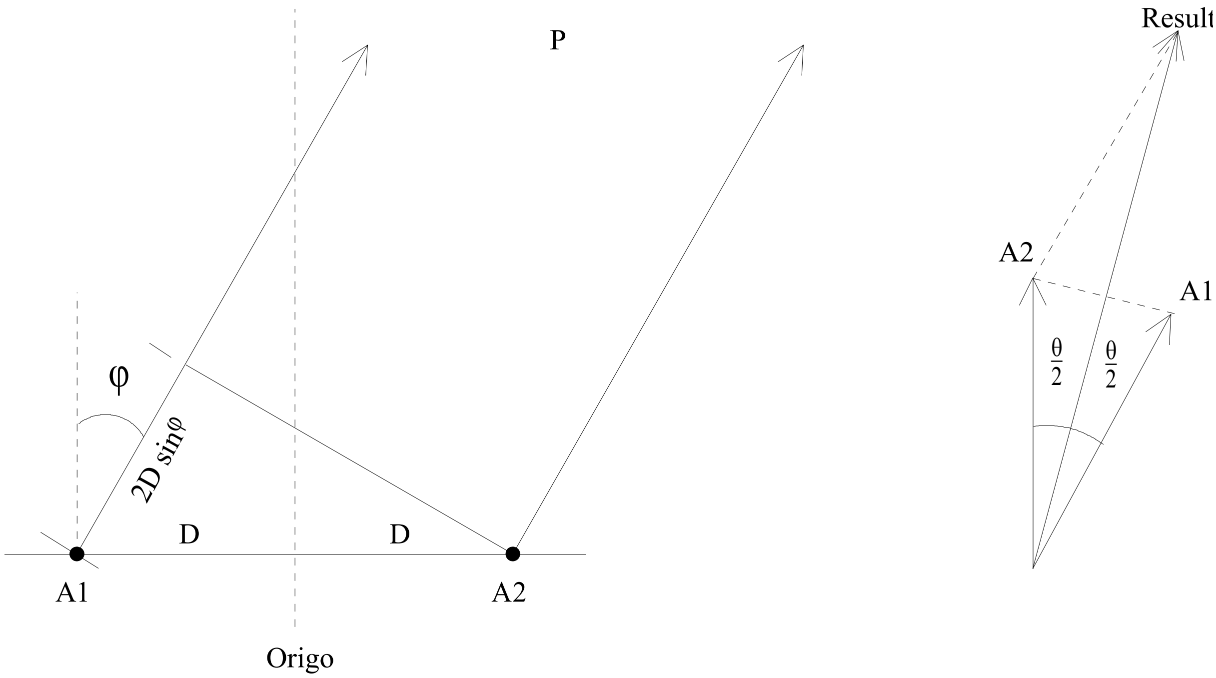


Figure 3-9 Path delay between two antenna elements

The difference in path length is **2D sin**φ, which produces a phase difference between the fields Eo of each antenna. The phase difference is in radians.

$$\theta = \frac{2\pi}{\lambda} \cdot 2D \cdot \sin\varphi$$

The signal from element A1 is delayed with respect to the signal from element A2 by θ, as indicated by the figure. The total received signal is the vector sum of each signal.

$$E_a = E_a(\varphi) = 2E_0 \cos\left(\frac{\theta}{2}\right) = 2E_0 \cos\left(\frac{2\pi}{\lambda} D \cdot \sin\varphi\right)$$

This is also the expression for the radiation pattern of **two** isotropic antennas spaced a distance 2D fed with **equal** amplitude **in-phase**. For simplicity Eo is set equal to one when drawing the pattern.

For an array with antenna elements where each of the elements has the radiation pattern Ee(φ) , the total pattern will be

$$E_{tot}(\varphi) = E_{element}(\varphi) \cdot E_{array}(\varphi)$$

$$E_{tot}(\varphi) = 2E_0 E_{element}(\varphi) \cdot \cos(\frac{2\pi}{\lambda} D \cdot \sin(\varphi))$$

If the two isotropic antenna elements are fed 180° out of phase, the total received signal will be according to Figure 3-10.

$$E_a(\varphi) = 2E_0 \cos\left(\frac{\pi}{2} - \frac{\theta}{2}\right) = 2E_0 \sin\left(\frac{2\pi}{\lambda} D \cdot \sin\varphi\right)$$

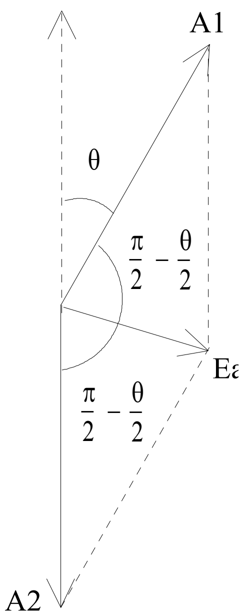


Figure 3-10 Radiation from the elements fed 180° out of phase

Summary.
Two antenna elements fed **in phase** (0°) spaced 2D apart:

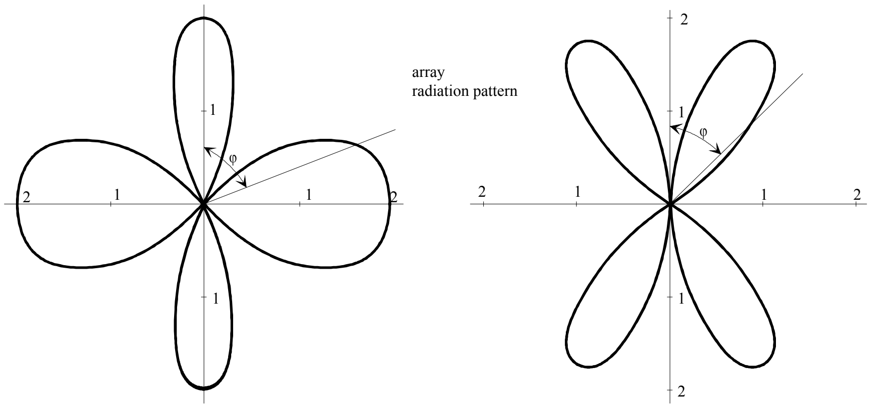
$$E_a = 2E_0 \cos\left(\frac{2\pi}{\lambda} D \cdot \sin\varphi\right)$$

Two antenna elements fed **out of phase** (180°) spaced 2D apart:

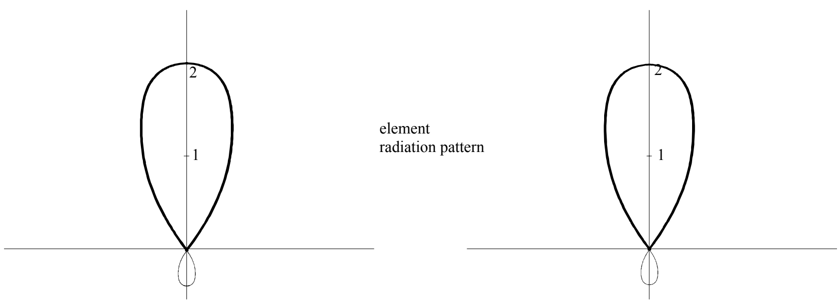
$$E_a = 2E_0 \sin\left(\frac{2\pi}{\lambda} D \cdot \sin\varphi\right)$$

3.2.2 Radiation patterns

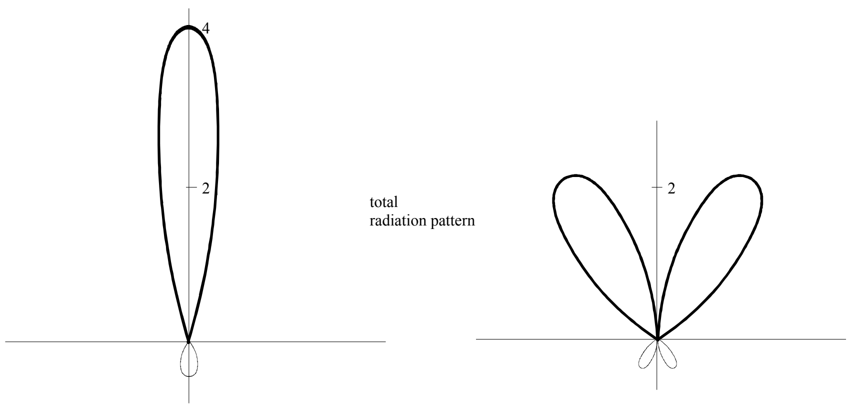
The radiation patterns of two antenna elements fed in-phase and 180° out-of -phase are given in Figure 3-11 for d = λ.



$$E_a(\varphi) = 2\cos(\pi \sin\varphi) \qquad E_a'(\varphi) = 2\sin(\pi \sin\varphi)$$



$$E_{element}(\varphi) \qquad E_{element}(\varphi)$$



$$E_{tot}(\varphi) = E_a(\varphi)\cdot E_{element}(\varphi) \qquad E_{tot}(\varphi) = E_a'(\varphi)\cdot E_{element}(\varphi)$$

Figure 3-11 Radiation patterns of two antenna elements spaced d = λ:

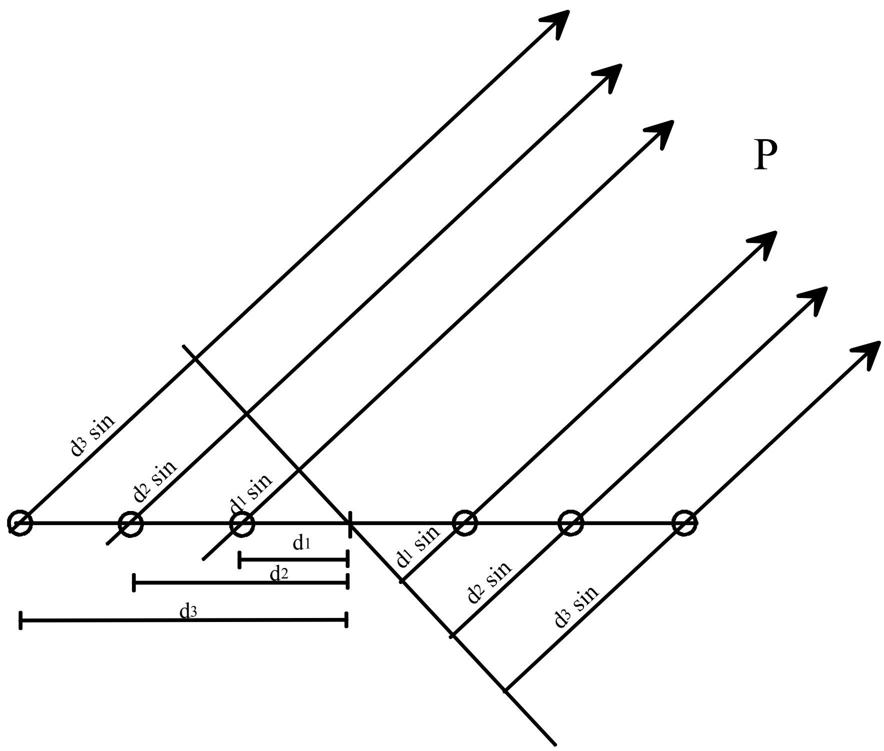
Left hand side: In-phase, right hand side: 180° out-of-phase

3.3 MULTI ELEMENTS ARRAY

The analysis of an antenna array of more than two elements is based upon superimposition of the radiation patterns of each element pair.
To simplify the expression, the phase reference point is taken to be in the centre of the array.

An array comprising six isotropic antenna elements arranged symmetrically around the centre 0 is shown on Figure 3-12.

$$\theta_1 = 2d_1 \sin\varphi$$
$$\theta_2 = 2d_2 \sin\varphi$$
$$\theta_3 = 2d_3 \sin\varphi$$



$$E_1 = 2A_1 \cos\left(\frac{\theta_1}{2}\right)$$

$$E_2 = 2A_2 \cos\left(\frac{\theta_2}{2}\right)$$

$$E_3 = 2A_3 \cos\left(\frac{\theta_3}{2}\right)$$

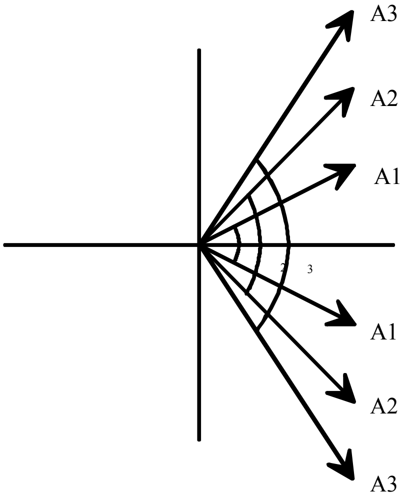


Figure 3-12 Six Elements Antenna Array fed in-phase, and associated radiation vectors

With reference to radiation from an element at O, the phase of the radiation from the three elements left of O is retarded, and the phase of the radiation from the elements on the right is advanced.
From Figure 3-12, the total radiation from the six elements is

$$E_a(\varphi) = 2A_1\cos(kd_1\sin\varphi) + 2A_2\cos(kd_2\sin\varphi) + 2A_3\cos(kd_3\sin\varphi)$$
$$= \sum_{n=1}^{3} A_n \cos(kd_n \sin\varphi)$$

$$E_1 = 2A_1\cos\left(\frac{\theta_1}{2}\right)$$

$$E_2 = 2A_2\cos\left(\frac{\theta_2}{2}\right)$$

$$E_3 = 2A_3\cos\left(\frac{\theta_3}{2}\right)$$

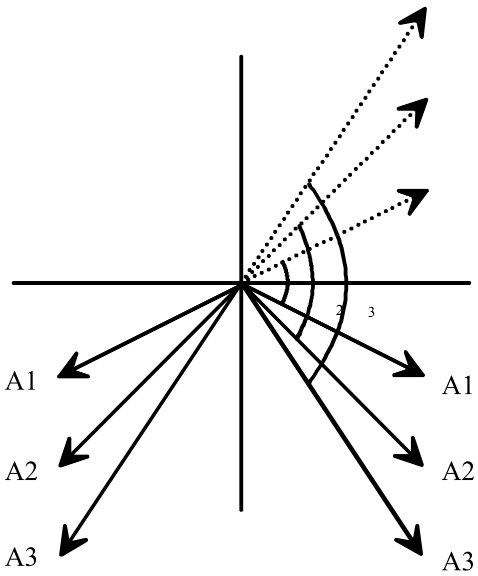


Figure 3-13 The radiation vectors for an antenna array of six elements with three of the elements fed 180° out of phase

As for two elements fed 180° out-of-phase, the total radiation will be at the observation angle φ:

$$E_a(\varphi) = 2A_1 \sin(kd_1 \sin\varphi) + 2A_2 \sin(kd_2 \sin\varphi) + 2A_3 \sin(kd_3 \sin\varphi)$$
$$= \sum_{n=1}^{3} A_n \sin(kd_n \sin\varphi)$$

For antenna elements other than the isotropic antenna, the total radiation pattern must include the pattern of the antenna element, $E_e(\varphi)$.

Hence, the patterns:

$$E_{tot}(\varphi) = E_e(\varphi) \cdot E_a(\varphi)$$

3.4 IMAGE THEORY

Consider a horizontally polarized antenna (A) above ground plane Figure 3-14.
In the far field the rays from this antenna consists of **two** components, the **direct** radiated signal and the **ground reflected** signal. Both these signals can be considered in parallel to each other.
The reflected signal can be modelled as radiated from an **image antenna** (-A) located a distance (H) below ground.

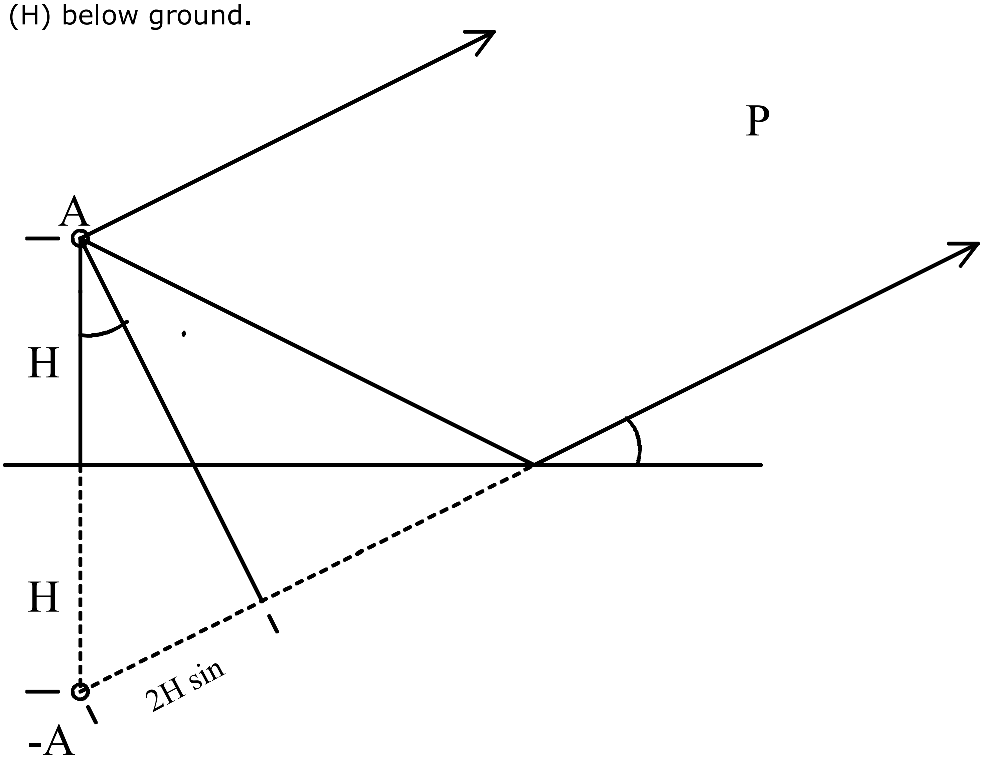


Figure 3-14 Horizontally polarized antenna above ground plane

2H sinθ is the additional signal path length from the image antenna.
The reflected signal will be 180° phase shifted at the point of reflection; in addition the phase delay equal to **2H sin**θ is added to the reflected signal as seen in point P.
φ is the equivalent **electrical** signal strength.

$$\varphi = \frac{2\pi}{\lambda} 2H \sin\theta$$

$$\frac{\varphi}{2} = \frac{2\pi}{\lambda} H \sin\theta$$

Figure 3-15 shows the phasors of the direct signal (A), the reflected signal (-A) and the sum signal (E) in point P

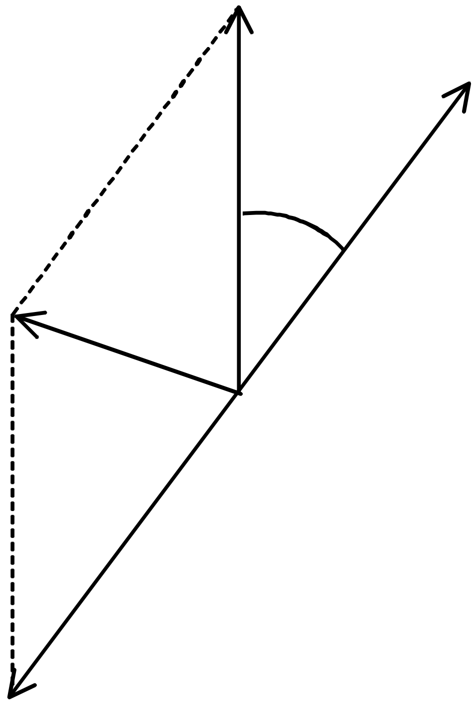


Figure 3-15 The phasor signals from an antenna above ground plane and the image antenna

$$E = 2A\sin\frac{\varphi}{2}$$

$$E = 2A\sin\left(\frac{2\pi}{\lambda}H\sin\theta\right)$$

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ILS ANTENNA THEORY

4.1 TWO-ANTENNA LOCALIZER ARRAY
4.1.1 CSB and SBO lobes
4.1.2 Example

4.2 LOCALIZER ANTENNA ABOVE GROUND
4.2.1 Example
4.2.2 Reflection coefficient
4.2.3 Antenna Array Gain
4.2.4 Antenna System SBO/CSB Power requirements

4.3 THE LOGPERIODIC DIPOLE ANTENNA FOR LOCALIZER

4.4 GLIDE PATH ANTENNA ARRAY PRINCIPLES

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4 ILS ANTENNA THEORY

4.1 Two-antenna Localizer Array

A simple way of illustrating the principle of composition of a localizer signal in space is to look at the feeding data for a six elements array given in Table 4-1, then apply the feeding phases of CSB and SBO for a pair of antennas, and draw the vectors for the modulation components.

The vectors are combined to 90 Hz and 150 Hz modulation depth results.
As an example we are looking at the two centre antennas given the following feeds:

	A3	A4
CSB	0°	0°
SBO 90	90°	-90°
SBO 150	-90°	90°

Table 4-1 Feed phasing data for 6 el. localizer centre pair antennas

Figure 4-1 and Figure 4-2 show CSB and SBO vectors as given above.

In the far field (point p) we assume that the rays from each antenna are in parallel. The signal phase arriving from A3 is retarded in respect to the A4 signal phase.

The phase delay θ is equal to $2d\sin\varphi$ meters, and converted to electrical degrees:

$$\theta(°) = \frac{2\pi}{\lambda} \cdot 2d \sin\varphi \, .$$

If we compare the resulting vectors for 90 Hz and 150 Hz modulations we see that the 90 Hz amplitude is larger than the 150 Hz amplitude. Consequently at point P located to the right hand side of the centreline between the antennas (seen from the antenna) the tone dominance is 90 Hz.
Along the centreline the 90 and 150 Hz modulation levels are equal due to the same path lengths from each antenna.

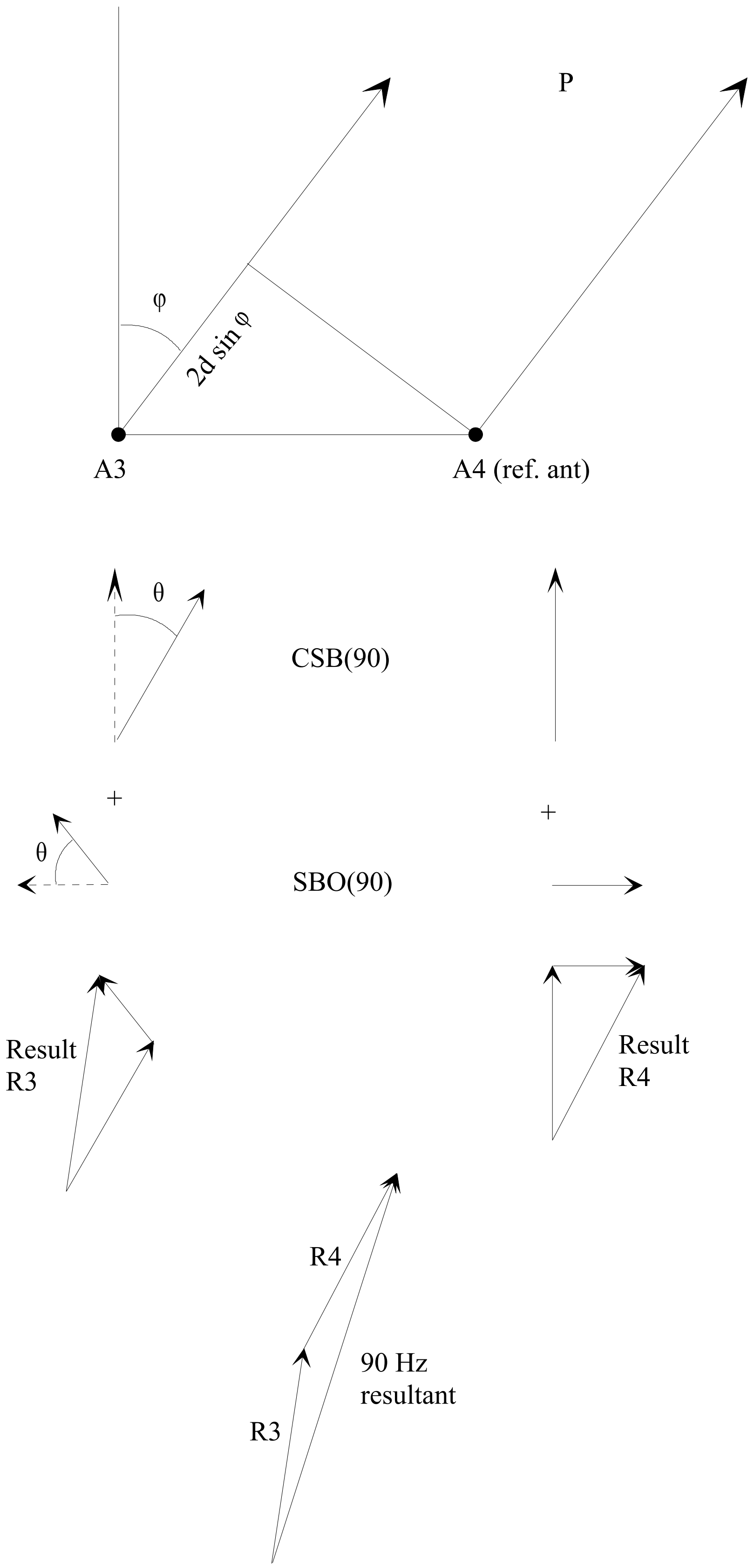


Figure 4-1 Resulting 90 Hz sideband from two-antenna feeds

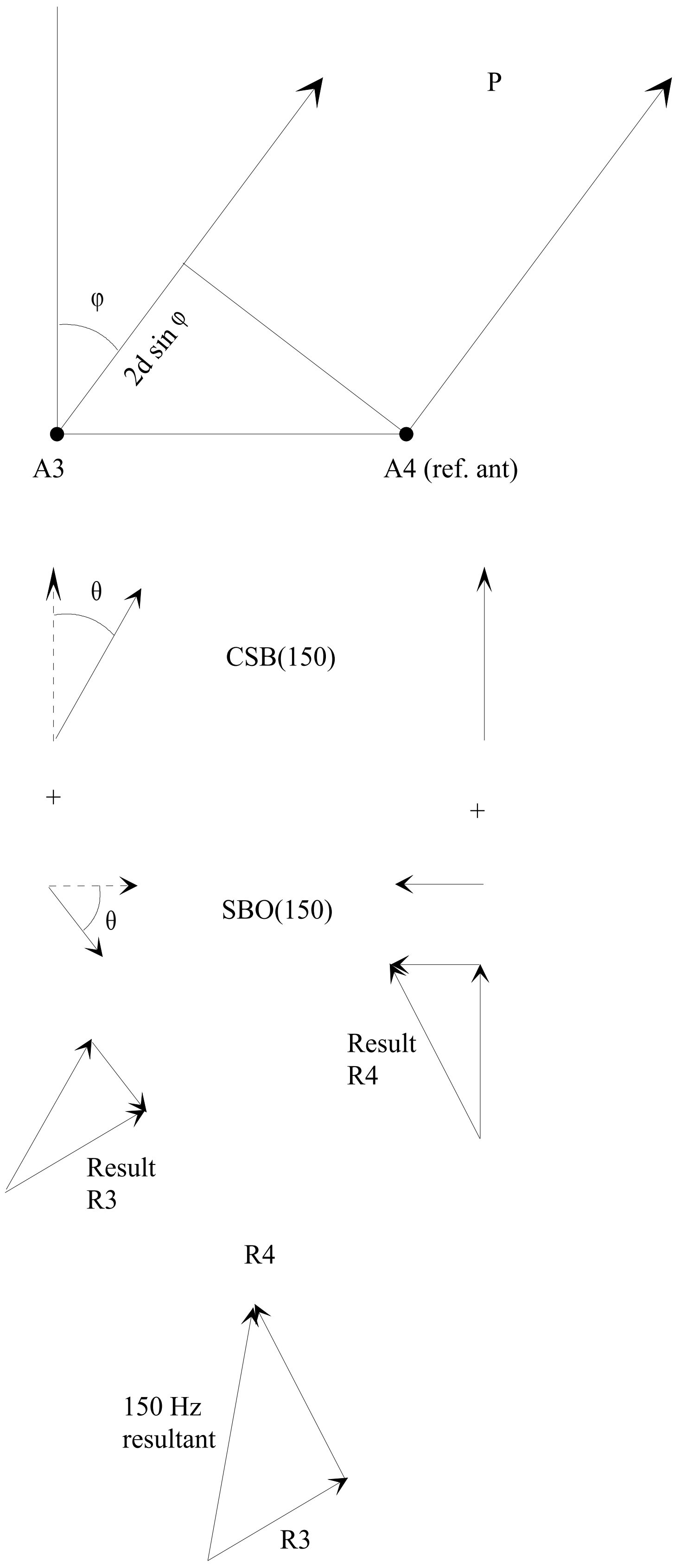


Figure 4-2 Resulting 150 Hz sideband from two-antenna feeds

4.1.1 CSB and SBO lobes

Consider the radiation patterns for two antenna elements fed in-phase and fed out-of-phase as shown in Figure 3.11 top, and Figure 4-3.
Consider feed date for A3, A4: CSB is fed **in-phase** and SBO is fed **out-of-phase**.

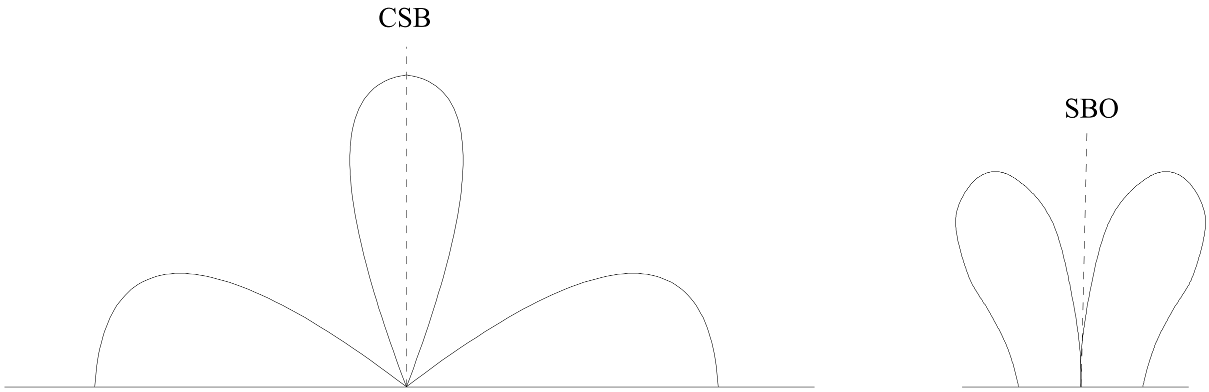


Figure 4-3 Two antennas radiation patterns in polar coordinates for CSB and SBO feeds. Distance between antennas 0.87λ

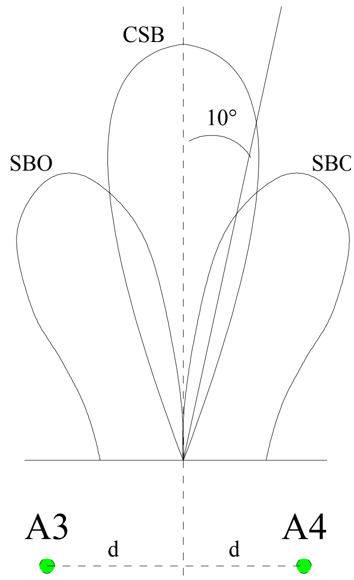
The CSB pattern has a maximum in the centreline direction, and provides the on-course field strength and modulation balance.

The SBO has a null in the centreline direction. This means the SBO signal is not radiating along the centreline but influences the DDM distribution at all other angles within the coverage area.

The radiation patterns shown above are for isotropic antennas. The true (total) radiation patterns can be determined by multiplying the array pattern by the element pattern.
(Reference Figure 4-3)

4.1.2 Example

Consider the antenna pair in Figure 4-3
Calculate relative CSB and SBO signal levels and the resulting DDM at 10° azimuth.



	A3	A4
CSB:	1∠0°	1∠0°
SBO:	0.1637∠-90°	0.1637∠90°

d = 1.19 m (0.87λ)
λ = 2.72 m
φ = 10°

Signal levels:

$$E_{CSB} = 2A_{CSB}\cos\left(\frac{2\pi}{\lambda} d \sin\varphi\right)$$

$$E_{CSB} = 2\cdot 1\cdot\cos\left(\frac{2\pi}{2.72}1.19\sin 10°\right) = \underline{1.7764}$$

$$E_{SBO} = 2A_{SBO}\sin\left(\frac{2\pi}{\lambda} d \sin\varphi\right)$$

$$E_{SBO} = 2\cdot 0.1637\cdot\sin\left(\frac{2\pi}{2.72}1.19\sin 10°\right) = \underline{0.1504}$$

$$\mathrm{DDM} = \frac{2\cdot \mathrm{SBO}}{\mathrm{CSB}} = \frac{2\cdot 0.1504}{1.7764} = \underline{0.169}$$

$$\mathrm{DDM}_{(\%)} = \underline{\underline{16.9\%}} \qquad \mathrm{DDM}_{(\mu A)} = \frac{150}{15.5}\cdot 16.9 = \underline{\underline{164\mu A}}$$

4.2 LOCALIZER ANTENNA ABOVE GROUND

The localizer antenna array is located above a ground plane, which will create an "image" antenna. The resulting radiation pattern in the vertical plane is determined by the free space pattern and the reflection properties of the ground.

As the angles of interest are below 7°, a perfect reflection plane (R = -1) can be assumed.

By using the equation for the radiation pattern of an isotropic antenna above ground:

$$E = 2A\sin\left(\frac{2\pi}{\lambda} h \sin\theta\right)$$

the gain modified by the ground interference can be calculated.

4.2.1 Example

θ = 3°
h = 3 m
A = 1

$$E = 2\sin\left(\frac{2\pi}{2.72} 3\sin 3°\right) = \underline{0.71}$$

$$\underline{E_{(dB)} = 20\log_{10} 0.71 = \underline{\underline{-2.9dB}}}$$

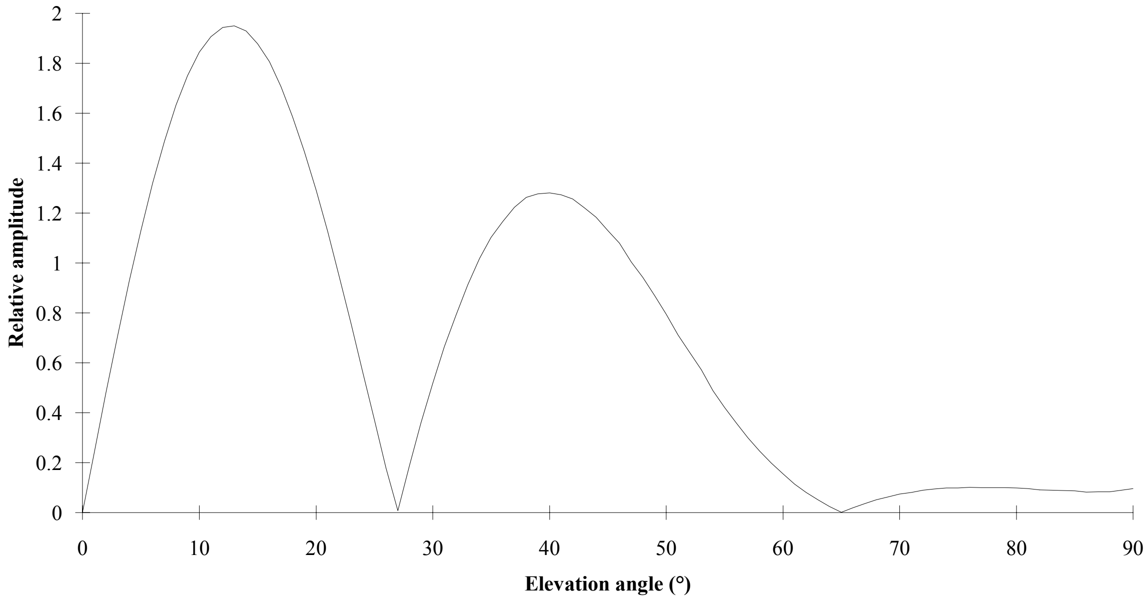


Figure 4-4 Vertical radiation pattern of LPDA 3 m above ground

4.2.2 Reflection coefficient

In practice the ground is not a perfect conductor, but has losses. This effect will reduce the induced current in the ground and accordingly the radiation from the "image" antenna.

In addition to the conductivity the induced current depends also on the angle of incidence to the ground plane.
The amplitude of the ground reflected signal can be described by the ground reflection coefficient, called the **Fresnels Reflection Coefficient R(θ).**
R(θ) for horizontal polarization is given in Figure 4.5 for dry ground, wet ground, fresh water and salt water.

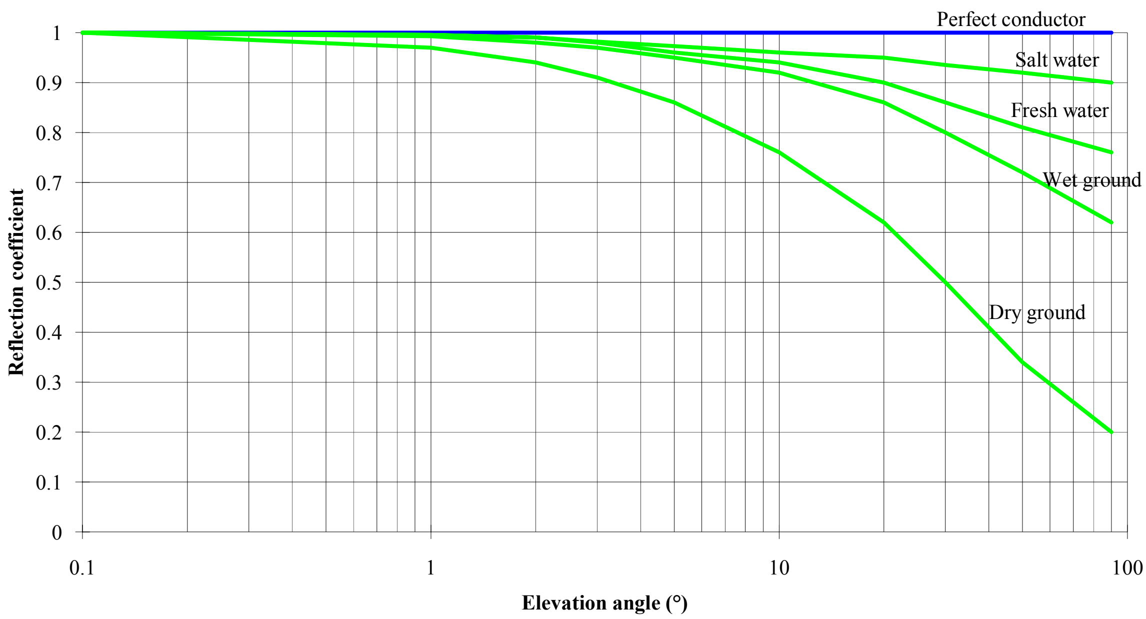


Figure 4-5 The reflection coefficient for different materials

The graph represents typical values of R(θ) in the frequency range 10 MHz to 1GHz.

4.2.3 Antenna array gain

The gain of the array (G_{array}) is the product of the gain of a LPDA (G_{LPDA}) and the gain of the array with isotropic antenna elements (G_a) modified by the gain (G_{lobing}) due to the ground reflections:

$$G_{array} = G_a \cdot G_{LPDA} \cdot G_{lobing}$$

$$G_a = \frac{(\Sigma A_n)^2}{\Sigma A_n^{\ 2}}$$

$A_n =$ Amplitude feed to element no. n

$(\Sigma A_n)^2$ is maximum power density.
$\Sigma A_n^{\ 2}$ is total power radiated.

$$G_{lobing} = 2\sin\left(\frac{2\pi}{\lambda} h \sin\theta\right)$$

h = Antenna element height in meters.
θ = Elevation angle of interest for (G_{array}).

Example.

Calculate (G_{array}) for a 6 elements LLZ antenna array, h = 3 m, θ = 3°, (G_{LPDA}) = 10

$$G_a = \frac{(2+5+10+10+5+2)^2}{4+25+100+100+25+4} = \underline{4.48}$$

$(G_{lobing}) = \underline{0.71}$

$$G_{array} = 10\log G_a + 10\log G_{LPDA} + 20\log G_{lobing}$$

$= 10\log 4.48 + 10\log 10 + 20\log 0.71 = \underline{\underline{13.5\text{dB}}}$

4.2.4 Antenna System SBO/CSB Power Requirements

The relative output power to antenna $\mathrm{A_n}$ is:

$$P_{CSB(A_n)} = E^2{}_{CSB(A_n)}\left(1 + \frac{m_{90}{}^2 + m_{150}{}^2}{2}\right)$$

$$P_{SBO(A_n)} = \frac{E_{SBO90(A_n)}{}^2 + E_{SBO150(A_n)}{}^2}{2}$$

$E_{CSB(A_n)} =$ Relative amplitude of CSB to antenna $\mathrm{A_n}$

$E_{SBO90(A_n)} =$ Relative amplitude of $\mathrm{SBO_{90}}$ to antenna $\mathrm{A_n}$

$E_{SBO150(A_n)} =$ Relative amplitude of $\mathrm{SBO_{150}}$ to antenna $\mathrm{A_n}$

The required SBO power referenced to CSB for the antenna system is the sum for the SBO power to each antenna divided by the sum of the CSB power to each antenna.

Modulation depth for 90 and 150 Hz tones are 0.2, hence

$$P_{CSB(A_n)} = E^2{}_{CSB(A_n)}\left(1 + \frac{0.2^2 + 0.2^2}{2}\right) = E^2{}_{CSB(A_n)} \cdot 1.04$$

SBO/CSB power ratio

$$P_{(SBO\,/\,CSB)} = \frac{\Sigma P_{SBO(A_n)}}{\Sigma P_{CSB(A_n)}}$$

Example: NM3522 6el Antenna system

CSB	SBO90	SBO150	P(CSB)	P(SBO)
20	8.70	8.70	416	75.69
50	8.70	8.70	2600	75.69
100	16.37	16.37	10400	267.98
		Sum	13416	419.36

The CSB, SBO distribution to antennas 4,5,6 is symmetrical, hence only one half of the distribution needs to be calculated

Ratio 0.031258 = **-15.1 dB**

4.3 LOG-PERIODIC DIPOLE ANTENNA FOR LOCALIZER

The LPDA belongs to a class of antennas with broadband properties. These antennas will in theory have an infinite bandwidth if their dimensions were unlimited.
The term "log-periodic" refers to the logarithmical frequency periodic variation of antenna properties.

Figure 4-6 shows a LPDA consisting of seven dipoles. The dipole length and spacing are adjusted so that

$$\frac{L_{n-1}}{L_n} = \frac{R_{n-1}}{R_n} = \frac{d_{n-1}}{d_n} = \tau$$

and

$$\frac{L_n - L_{n-1}}{R_n - R_{n-1}} = \frac{L_n - L_{n-1}}{d_n} = \tan\alpha$$

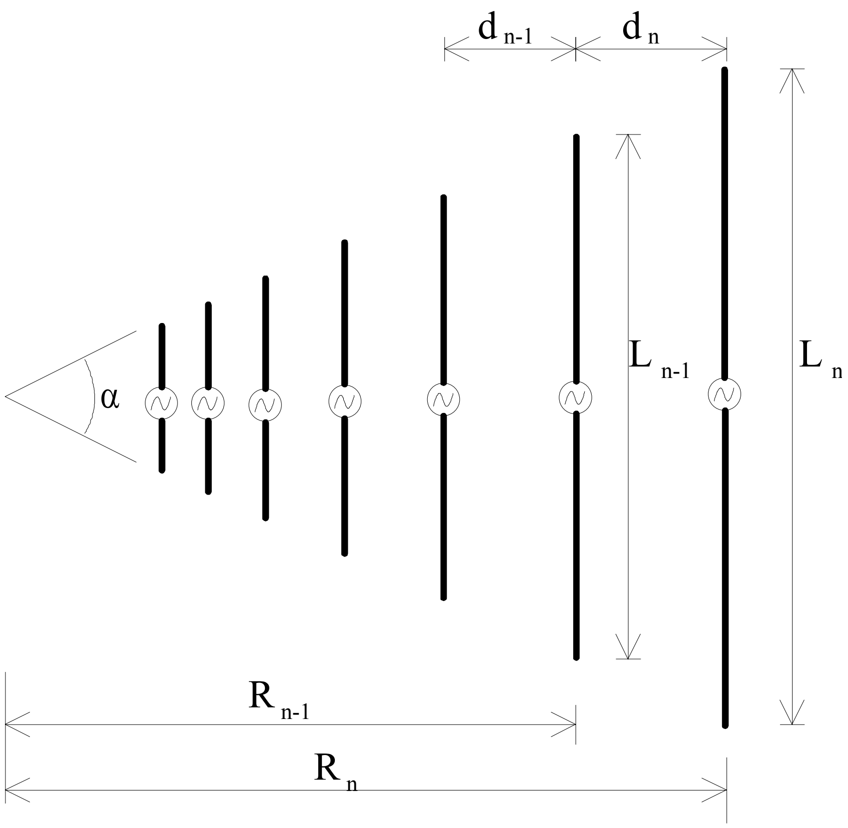


Figure 4-6 LPDA with seven dipoles

The feeding of the LPDA is to the apex (the smaller end) and is such that each consecutive dipole element is fed 180° in respect to the next element.
The resultant field backwards from two elements will be cancelled due to the small distance compared to a wavelength.
Due to the distance d_n between elements the phase difference between these leads to an in-phase forward field from the element.
The radiation then is off the apex of the antenna.

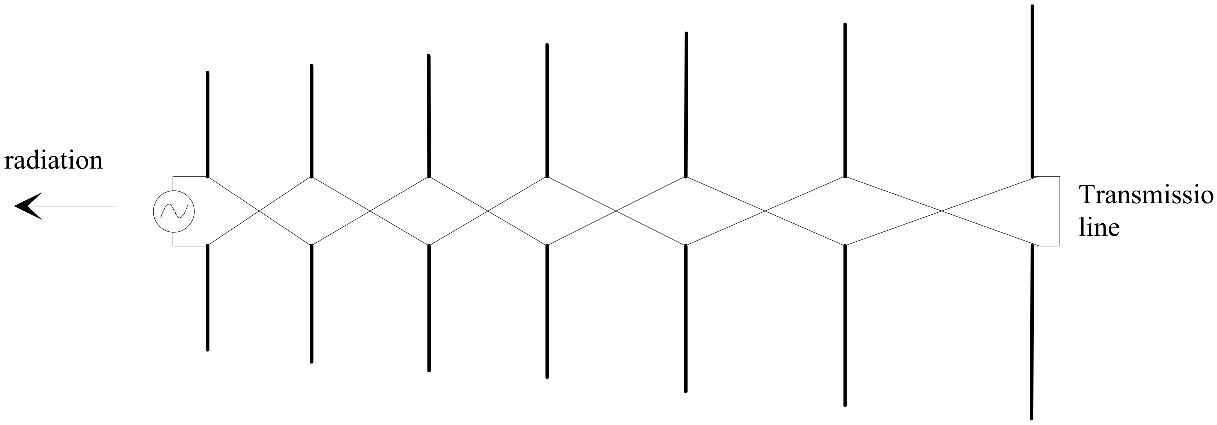


Figure 4-7 Localizer LPDA. τ = 0.93, α = 10°

The frequency independency over a certain bandwidth can be explained as follows:
The amount of energy that is extracted from the passive wave in the feeder line (and radiated) by a given dipole depends on the electrical length of that particular dipole at the operating frequency.

Frequency independent performance is obtained from the LPDA by virtue of the fact that the dipole lengths and spacing vary in such a manner that the function of the resonant element (the electrical length is $\frac{\lambda}{2}$) is transferred smoothly along the structure, from one dipole to the next, as the operating frequency changes.

Transportation of the polarity of the driven signal applied to alternate dipole along the balanced feeder line is necessary in order to achieve a concentration of radiation energy towards the front of the structure, even though the wave on the line progresses towards the back end.
A layer of ice and snow on the dipoles will increase their electrical length and reduce their resonant frequency. For a constant frequency, the position of the resonant element will then move towards the apex.
Accordingly, the phase centre of the LPDA will also move, and if shift of the phase centre position differs for the other LPDA's this will give a change of the localizer course line.

The influence of rain, ice and snow on the impedance of the dipoles, and the shift of the phase centre is reduced by using "thick" dipoles.
An ordinary dipole has often a length - thickness ratio of about 100, the dipoles used in this LPDA the ratio is approximately 20.

The impedance of the LPDA is given by the feeder line impedance and the thickness of the dipoles. The LPDA is designed for 50Ω impedance.
A matching network is used to ensure that matching and phase centre are within specification.

The feeder line is short-circuited at the end of the line.
The signal level at the end is very low as nearly all of the power fed to the line is radiated.
The position of the short circuit has a small influence on the design of the LPDA.

Typical impedance characteristic is shown in Figure 4-8.

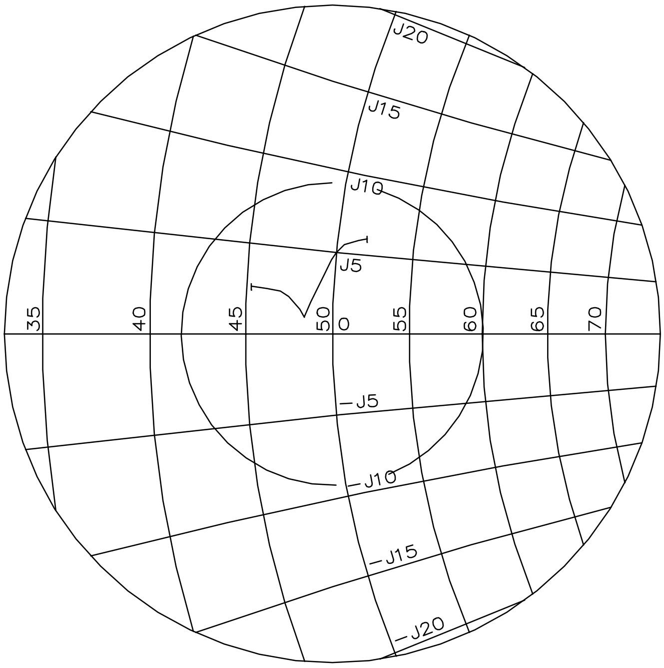
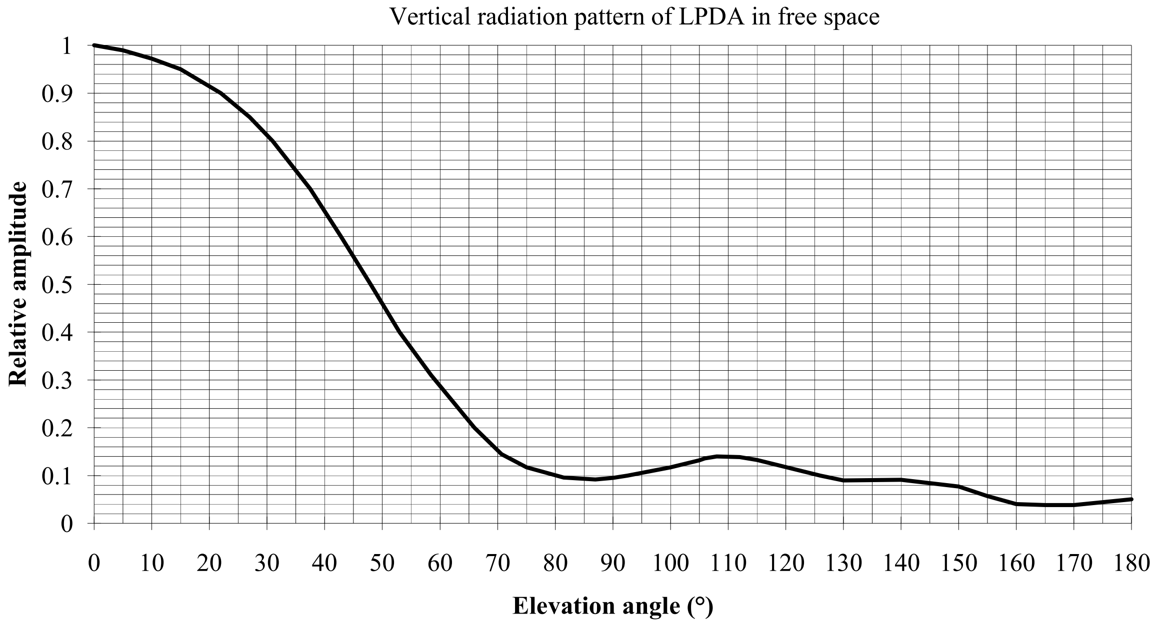


Figure 4-8 Typical impedance characteristics of a localizer antenna element

Figure 4-9 shows the horizontal and vertical radiation patterns respectively for a localizer LPDA.



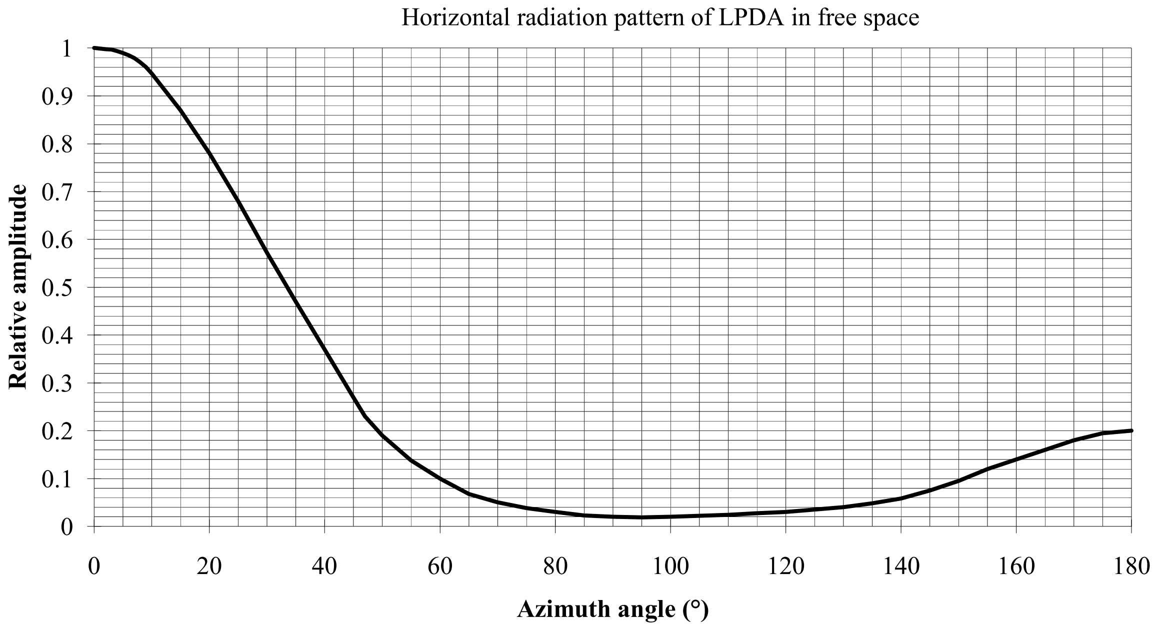


Figure 4-9 Radiation pattern of the localizer LPDA

4.4 GLIDE PATH ANTENNA ARRAY PRINCIPLES

An isotropic antenna that is positioned above a ground plane creates a reflected signal, which is equivalent to a signal originating from an image antenna below ground, see Figure 4-10.

For ILS the polarization is horizontal, consequently the expression for the radiation pattern is that derived for arrays fed **out-of-phase**:

$$E = 2A\sin\left(\frac{2\pi}{\lambda}H\sin\theta\right)$$

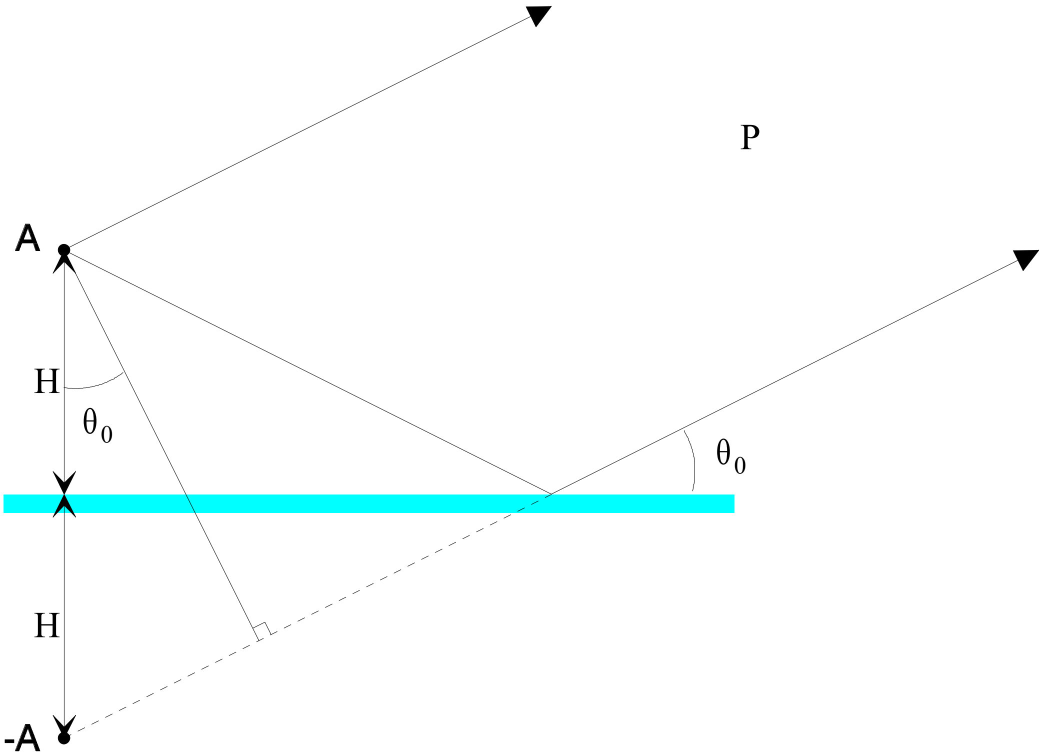


Figure 4-10 Radiation from antenna above ground

In order to create a guidance signal along a specified (3°) glide path angle we need to produce a SBO null in the radiation pattern along the glide path angle.
This is accomplished by feeding SBO to the antenna and adjusting the height **2H** such that the electrical phase delay φ of the reflected signal is equal to **one wavelength** λ.

Figure 4-11 shows the SBO antenna producing a null in the radiation pattern at the Glide Path angle.

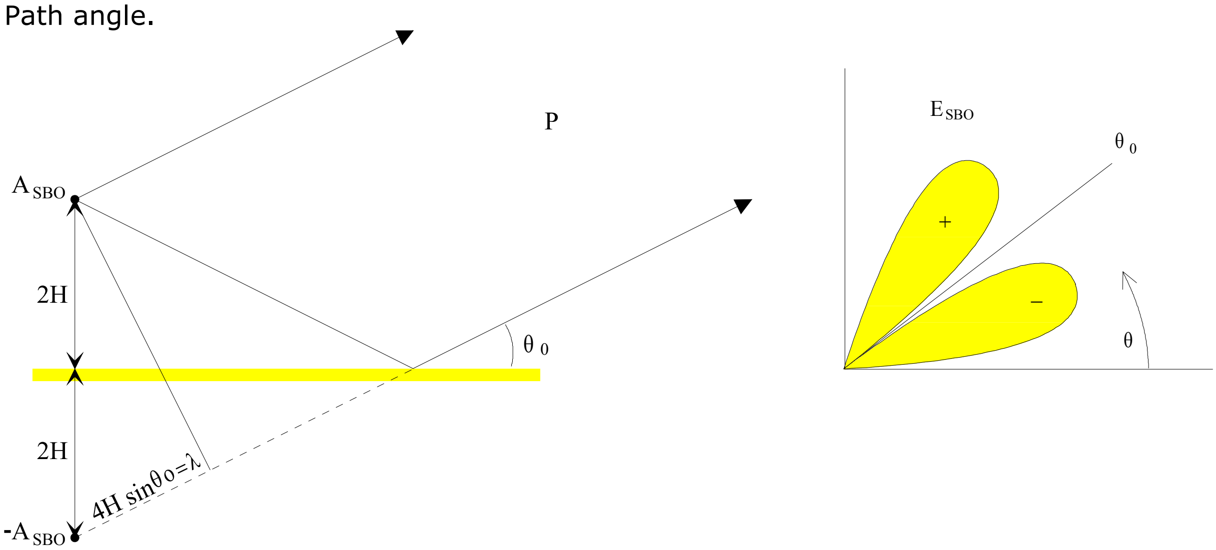


Figure 4-11 Antenna element fed with SBO signal producing a null in the radiation pattern at θo

The CSB signal should produce maximum at 3° so its position will be ½ of the SBO antenna height.
The CSB radiation pattern will be:

$$E_{CSB} = 2A_{CSB} \sin\left(\frac{2\pi}{\lambda} H \sin\theta\right)$$

In order to provide relative position information in the Glide Path region, the total radiation pattern must be predominately **90 Hz above** the Glide Path and **150 Hz below** the Glide Path. This can be accomplished by phasing the CSB and SBO radiation signal 180° out-of -phase.

Now we have a GP antenna array consisting of two antennas placed above ground plane, the lower antenna radiating CSB and the upper antenna at twice the height radiating SBO.
This GP configuration is called a Null Reference system (see Figure 4-12).

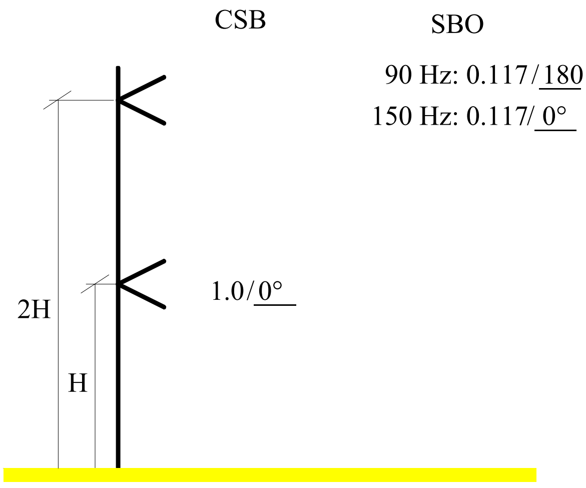


Figure 4-12 Null Reference Antenna System

From Figure 4-11 we define the phase delay from the reflected signal equal to λ.

$$4H\sin\theta_0 = \lambda$$

From this equation we can calculate the lower antenna height (and antenna spacing):

$$H = \frac{\lambda}{4\sin\theta_0}$$

Figure 4-13 shows the CSB and SBO amplitudes (E) versus elevation angle θ.

Note that the CSB has a maximum at θo.

The SBO has two maxima due to the double antenna height.
Note that the SBO amplitude is zero at the Glide Path angle θo.

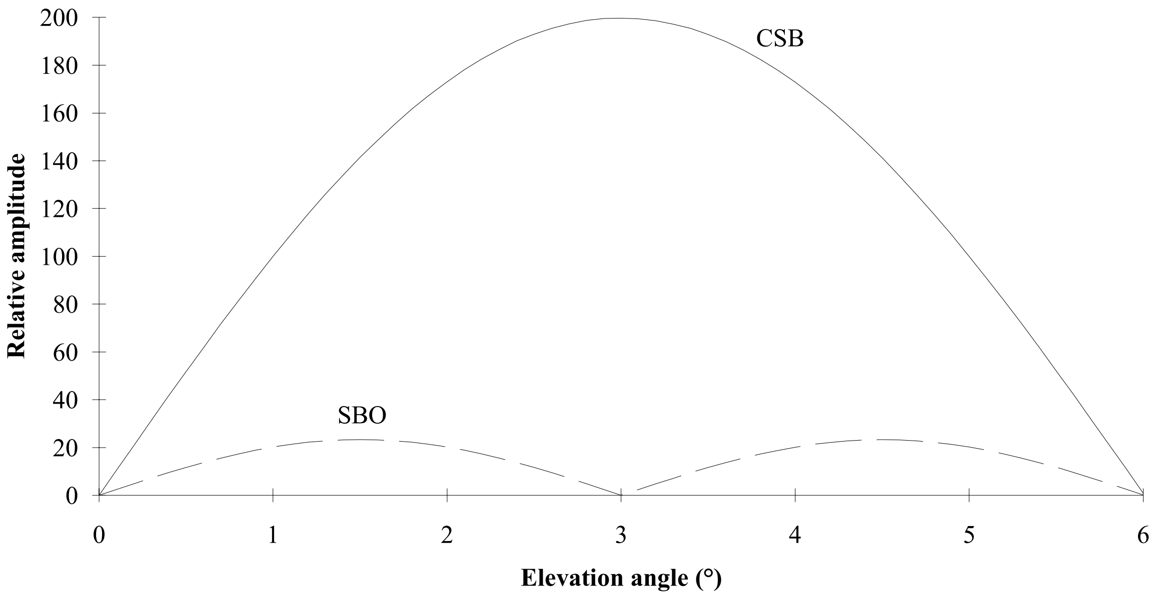


Figure 4-13 CSB and SBO radiation pattern for Null reference Antenna System

5. LOCALIZER ANTENNA SYSTEMS

5.1 GENERAL

5.2 6 ELEMENTS ANTENNA SYSTEM NM 3522
5.2.1 Technical specifications
5.2.2 Example, modulation distribution at 10°
5.2.3 Beam Bend Potential
5.2.4 Example, BBP at 25°

5.3 12 ELEMENTS ANTENNA SYSTEM NM 3523B (SINGLE FREQUENCY)

5.4 12 ELEMENTS ANTENNA SYSTEM NM 3524 (DUAL FREQUENCY)

5.5 24 ELEMENTS ANTENNA SYSTEM NM 3525

5.6 16 ELEMENTS ANTENNA SYSTEM NM 3526

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5 LOCALIZER ANTENNA SYSTEMS

5.1 General

Localizer antenna systems comprise 12, 16 or 24 antennas depending on site topography. The 6 antennas system is not a part of our product range today, but is here used as an example.
Two versions of 12 elements systems are available, one single frequency system and one dual frequency system (with clearance signal).
The 16 and 24 elements system includes a clearance signal.

The feeding of the antenna elements, and their spacing, are optimised to give an SBO radiation pattern with minimum radiation for azimuth angles where large reflecting objects are likely to be located.
The CSB radiation pattern is designed to give the required DDM distribution and field intensity (power density) inside the ±35° sector.

The distribution network feeds the antenna elements with the proper amplitude and phase of the CSB and SBO signals.

The Course Sector Width is adjusted by changing the amplitude of the SBO feeding the ADU (Antenna Distribution Unit).

The Course Line can be adjusted by using a phase shifter inserted at the output of the ADU to one of the antennas.

5.2 6 elements Antenna System NM 3522

Figure 5-1 shows the CSB and SBO distribution amplitudes and phases to the antennas. The distance from each antenna element to origo (centre line) is also given.

The spacing and amplitudes are computer optimised to give radiation patterns of low intensity inside the critical sector 10 - 20° from the course line, where most of the major reflecting objects are located.

The radiation pattern of the array is the sum of the patterns of each antenna element pair. The CSB and SBO patterns of the three element pairs are given in Figure 5-3. With LPDA, the pattern will be according to equations:

$$E_{CSB}(\varphi) = E_{a(CSB)}(\varphi) \cdot E_e(\varphi)$$

$$E_{SBO}(\varphi) = E_{a(SBO)}(\varphi) \cdot E_e(\varphi)$$

where $E_e(\varphi)$ is given in Figure 5-3. The patterns are also given in Figure 5.3. As shown, the LPDA has minimal influence on the resulting patterns inside the ±10° sector, but it drastically reduces the side lobes outside approximately 30°.
This effect is well understood by studying the patterns of the LPDA.

Further comments on the radiation pattern:

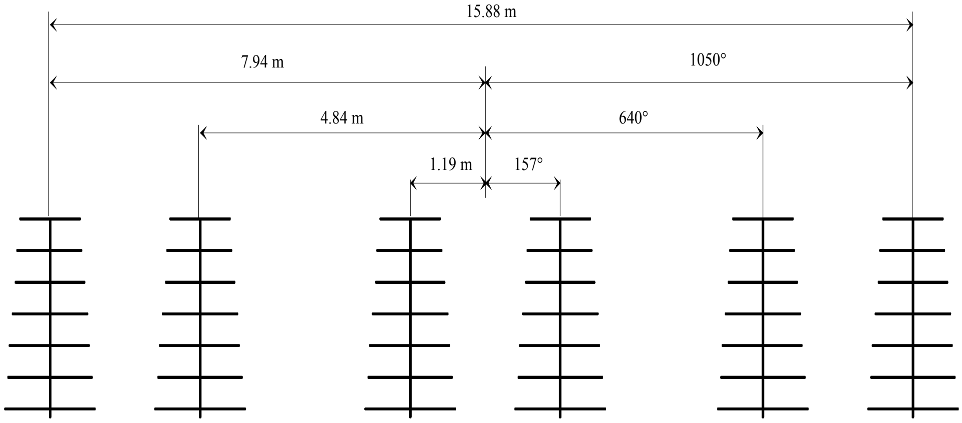
The CSB pattern has a null at 42.5°, which gives an infinite DDM at this angle.
The aircraft ILS receiver will react on this signal by course indication (DDM = 0) and a "flag"-warning. The "flag"-warning results from a too low sum of depth of modulation of the 90 Hz and 150 Hz (SDM).
The pilot should not use the guidance information with a "flag"-warning, and neither should an ILS be used outside the ±35° sector.

The SBO pattern has a null at 64°, which gives a course information (DDM = 0) with no "flag"-warning. This false course has no practical interest as it is well outside the ±35° sector.

Figure 5-4 shows the resulting DDM and modulation distribution in the far field.
Values below 40% modulation are DDM values; above 40% are SDM values.

NOTE: The negative section of the Modulation (%) axis indicates that the resulting modulation component (150 Hz) changes phase polarity.

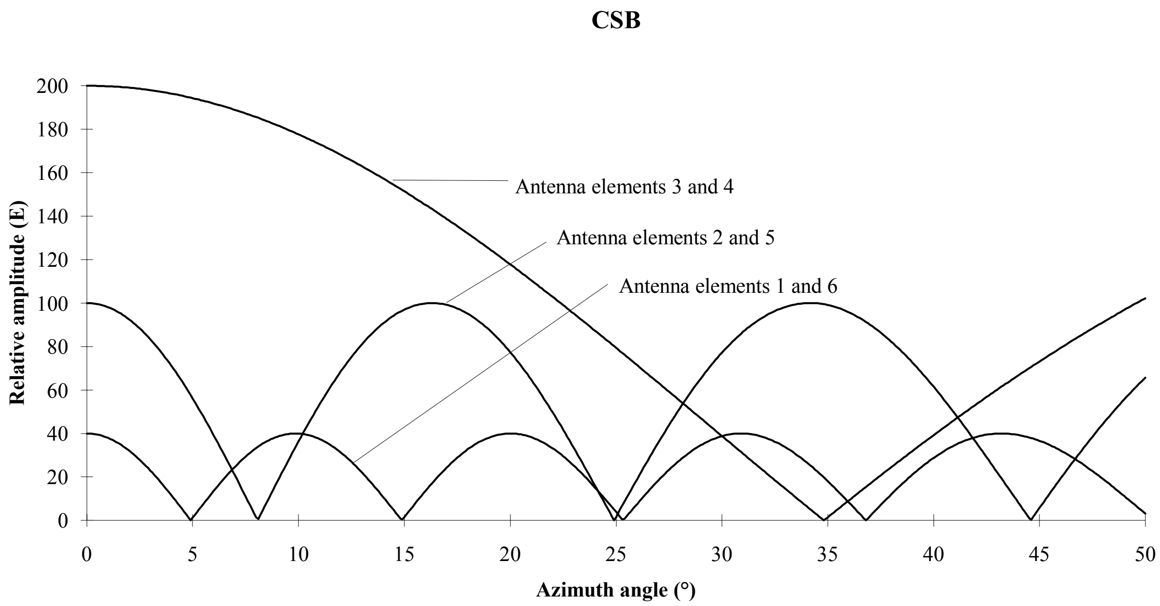
5.2.1 Technical specifications



ANTENNA NO.	1	2	3	4	5	6
CSB AMPLITUDE	20	50	100	100	50	20
CSB PHASE	0	0	0	0	0	0
90 Hz SB AMPLITUDE	8.70	8.70	16.37	16.37	8.70	8.70
90 Hz SB PHASE (°)	90	90	90	-90	-90	-90
150 Hz SB AMPLITUDE	8.70	8.70	16.37	16.37	8.70	8.70
150 Hz SB PHASE (°)	-90	-90	-90	90	90	90

COURSE SECTOR WIDTH: 5°

Figure 5-1 Distribution of CSB and SBO signals



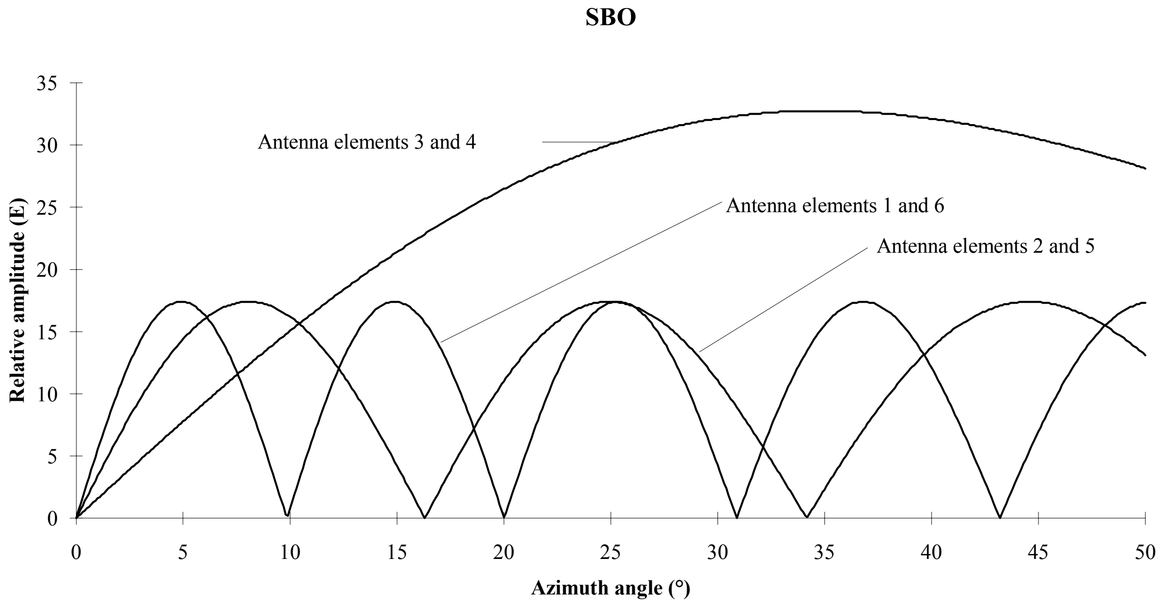
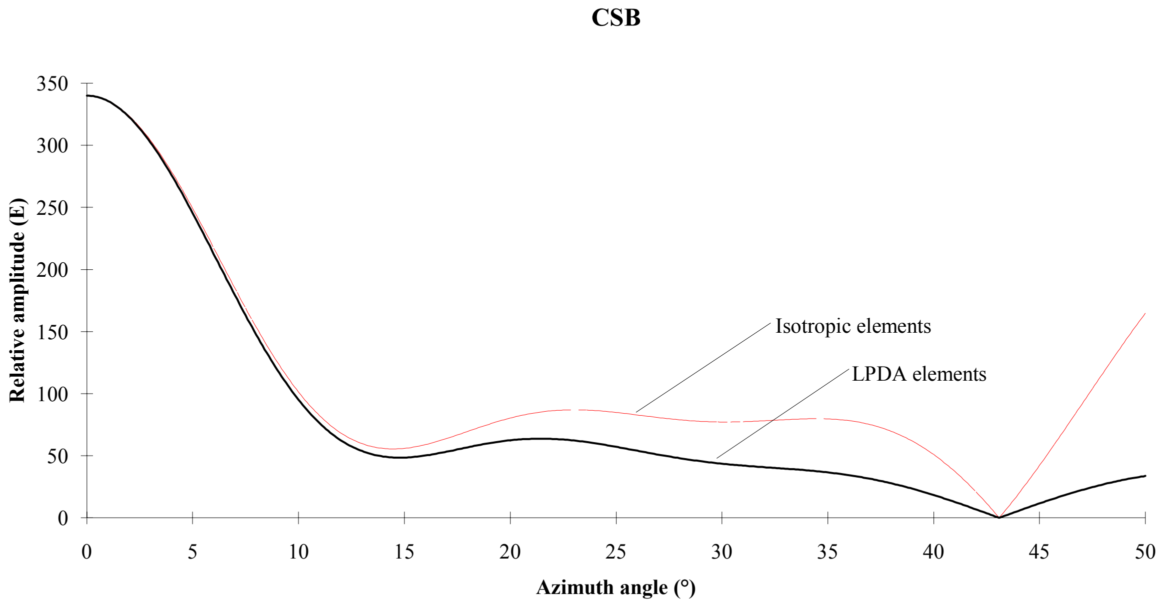


Figure 5-2 CSB and SBO radiation patterns of the three antenna element pairs. (The pattern of the LPDA is not included)



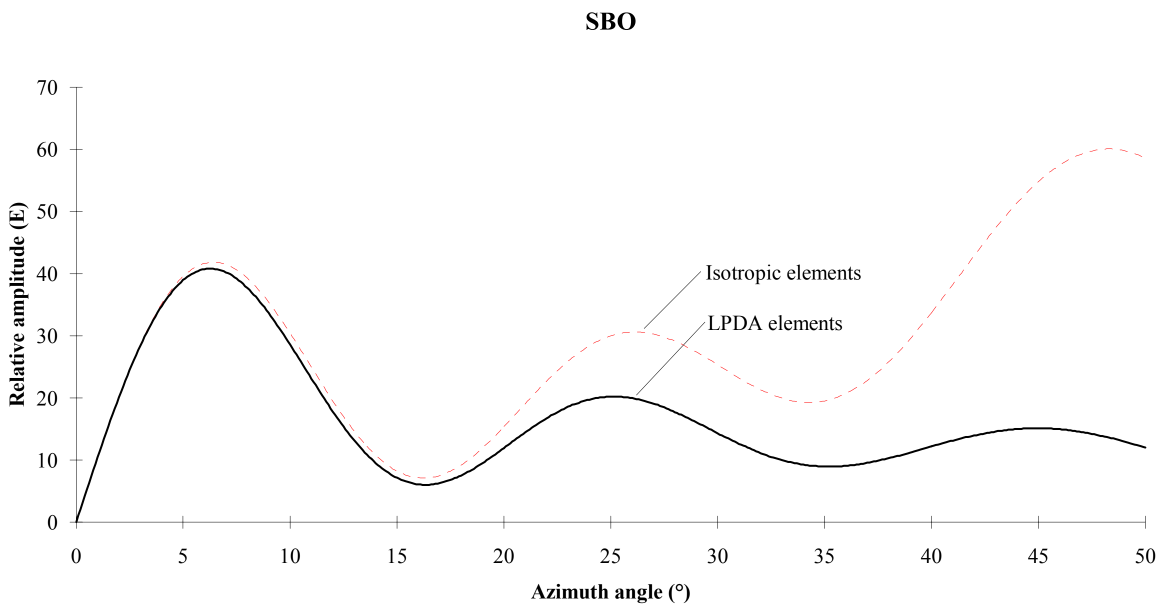


Figure 5-3 CSB and SBO radiation patterns with and without the pattern of the LPDA included. (CS = 5°)

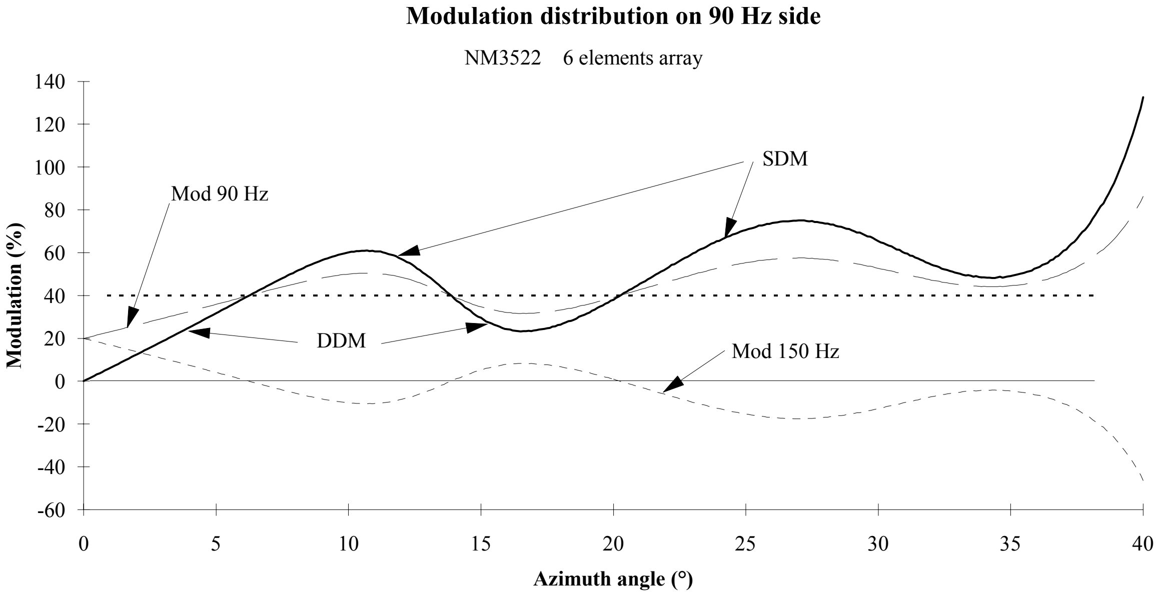


Figure 5-4 Calculated DDM and modulation distribution
(mod 90 Hz, mod 150 Hz, SDM)

5.2.2 Example

Modulation distribution for NM3522 6 elements array at 10° azimuth.

From Figure 5-3 we read the relative amplitudes for CSB and SBO at 10° azimuth:

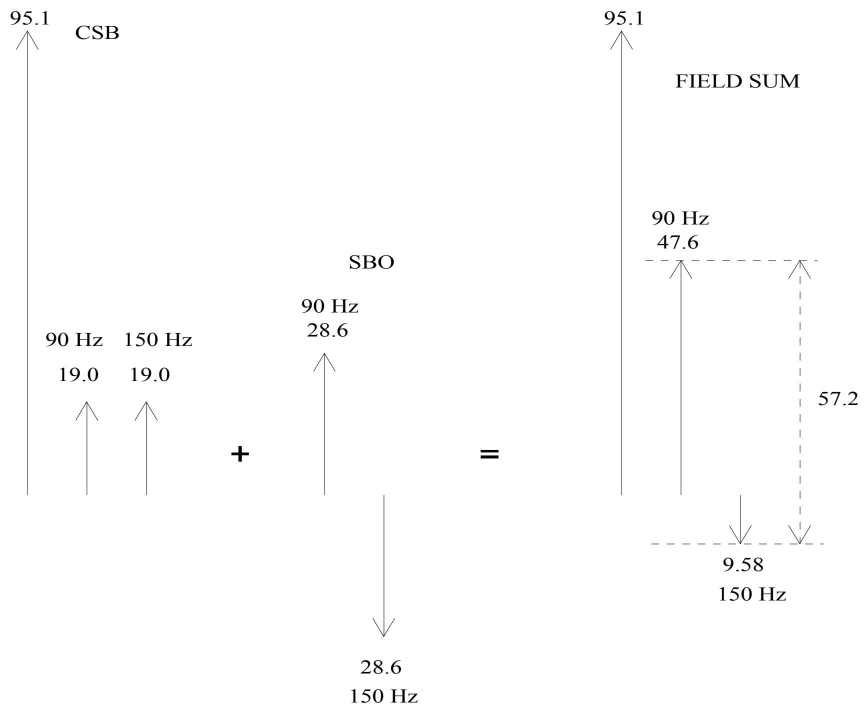
CSB = 95.1
SBO = 28.6

$$\text{MOD}(10^\circ) = \frac{2 \cdot 28.6}{95.1} = \underline{0.6} \quad \text{(SDM)}$$

The CSB modulation components are 0.2 (20%) each, hence the amplitudes are:

$$95.1 \cdot 0.2 = \underline{19.0}$$

In the field CSB and SBO vectors are added together as shown in the figure below:



In the **field sum** the 150 Hz modulation components is 180° out of phase with the 90 Hz because the SBO amplitude is larger than the modulation level of the CSB.

$$MOD_{90} = \frac{47.6}{95.1} = \underline{0.50} \qquad MOD_{150} = \frac{9.58}{95.1} = \underline{0.10}$$

$$SDM = MOD_{90} + MOD_{150} = 0.50 + 0.10 = \underline{\underline{0.60}}$$

5.2.3 Beam Bend Potential

The course structure performance degradation (bends, etc.) is determined by the SBO radiation on the reflecting object and on the reflecting properties of the object.
An object inside the sector 12 - 23° will receive a low radiation intensity.

We define the term **Beam Bend Potential** (**BBP**) which gives the maximum performance degradation on the course if the object reflects all the incidental radiation in the direction to the approaching aircraft, i.e. |R| = 1.

The BBP is equal to the ratio between the SBO signal in the direction to the object and the CSB signal received by the directly radiated signal:

$$\mathrm{BBP}(\varphi) = 2\frac{E_{SBO}(\varphi)}{E_{CSB}(0)}$$

For the 6 elements localizer NM3522 the BBP is:

$$\mathrm{BBP}(\varphi) = 2\frac{E_{SBO}(\varphi)}{340}$$

where φ is the direction to the object. The BBP(φ) is given in Figure 5-5 for a course sector of 5°.

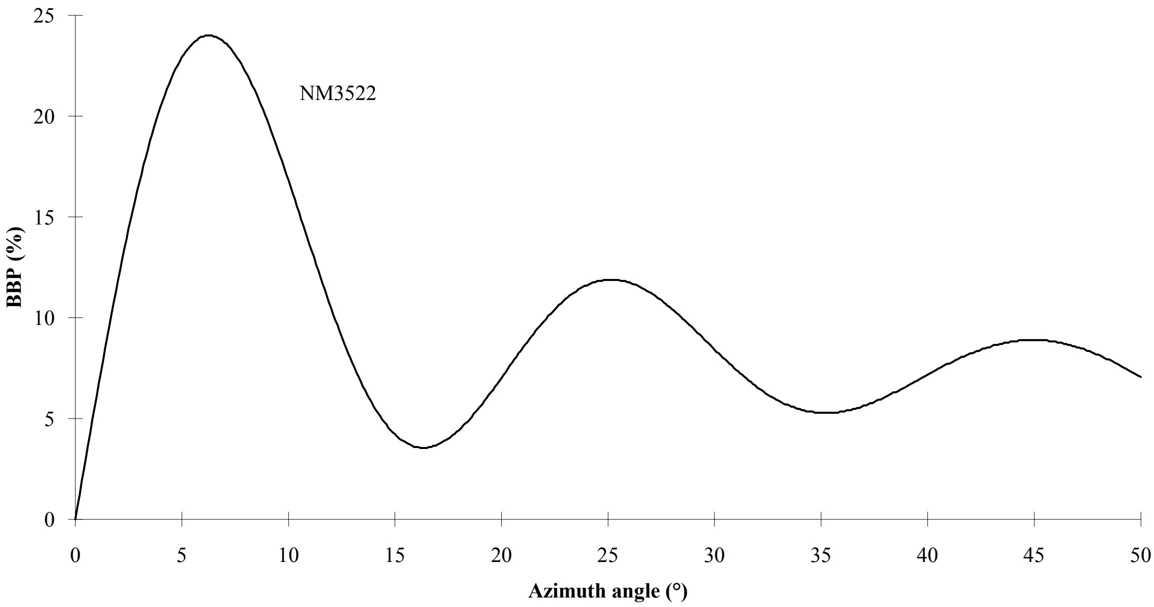


Figure 5-5 BBP(φ) for CS = 5°, φ is the direction to the reflecting object

Example

For the 6 elements antenna array the SBO is 20.2 at φ = 25° (see Figure 5.3).
Calculate BBP at φ = 25°:

$$BBP(25°) = 2\frac{20.2}{340} \cdot 100\% = \underline{\underline{11.9\%}}$$

Calculate maximum reflection factor R_{max}:

The maximum acceptable course bend for a category I localizer is 15μA (1.55% DDM).
For a reflecting object at 25° azimuth the reflection coefficient (R) must be less than:

$$R_{max} = \frac{1.55}{11.9} = \underline{\underline{0.13}}$$

to ensure a bend less than 15μA.

A factor, which is not taken into account in the expression for the BBP is any difference in vertical radiation pattern of the LPDA (Figure 4-9) in the direction to the aircraft (θ = 3°) and in the direction to the reflecting object.
Quite often the vertical angle to buildings etc. is less than 3°, which gives a lower radiation on the objects. This will result in a lower BBP than given by Figure 5.5.

Figure 5-6 shows BBP (course sector 5°) for antenna systems NM3523B, NM3524, NM3525 and NM3526.

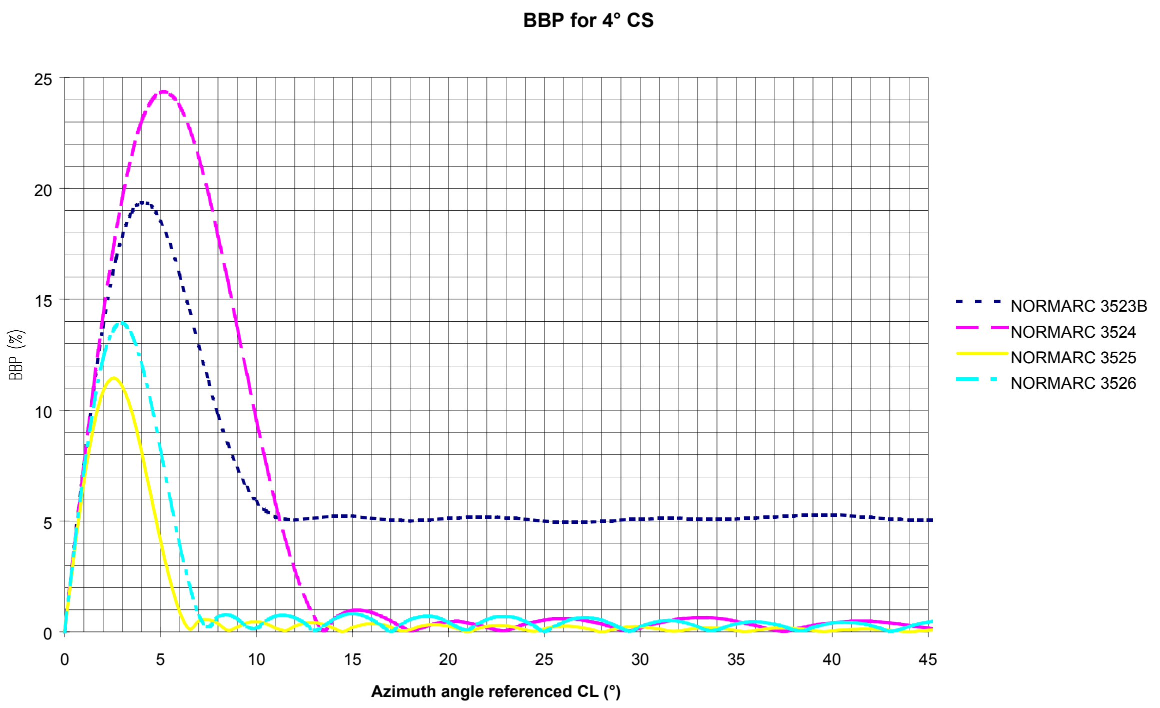


Figure 5-6 Beam Bend Potential - Course Sector 4°

12 ELEMENTS ANTENNA SYSTEM NM 3523B (SINGLE FREQUENCY)

Table 5-1 shows the antenna spacing and phase and amplitude distribution to the antennas.

The spacing and amplitudes are computer optimised to give radiation patterns of low intensity inside the critical sector 10 -30° from the course line, where most of the major reflecting objects are located.

The radiation pattern of the array is the sum of the patterns of each antenna element pair, and is given in Figure 5-7.

Figure 5-8 shows the far field DDM modulation distribution.

Figure 5-9 shows the Beam Bend Potential.

Antenna	Distance m	CSB ampl	CSB phase °	SBO ampl	SBO phase °
1	-16.90	2.40	0	0.90	-90
2	-13.90	8.10	0	2.61	-90
3	-10.90	19.00	0	4.88	-90
4	-7.91	33.50	0	6.72	-90
5	-4.77	54.90	0	7.72	-90
6	-0.95	100.00	0	15.18	-90
7	0.95	100.00	0	15.18	90
8	4.77	54.90	0	7.72	90
9	7.91	33.50	0	6.72	90
10	10.90	19.00	0	4.88	90
11	13.90	8.10	0	2.61	90
12	16.90	2.40	0	0.90	90

Table 5-1 NM 3523B 12 elements Array antenna spacing and signal distribution

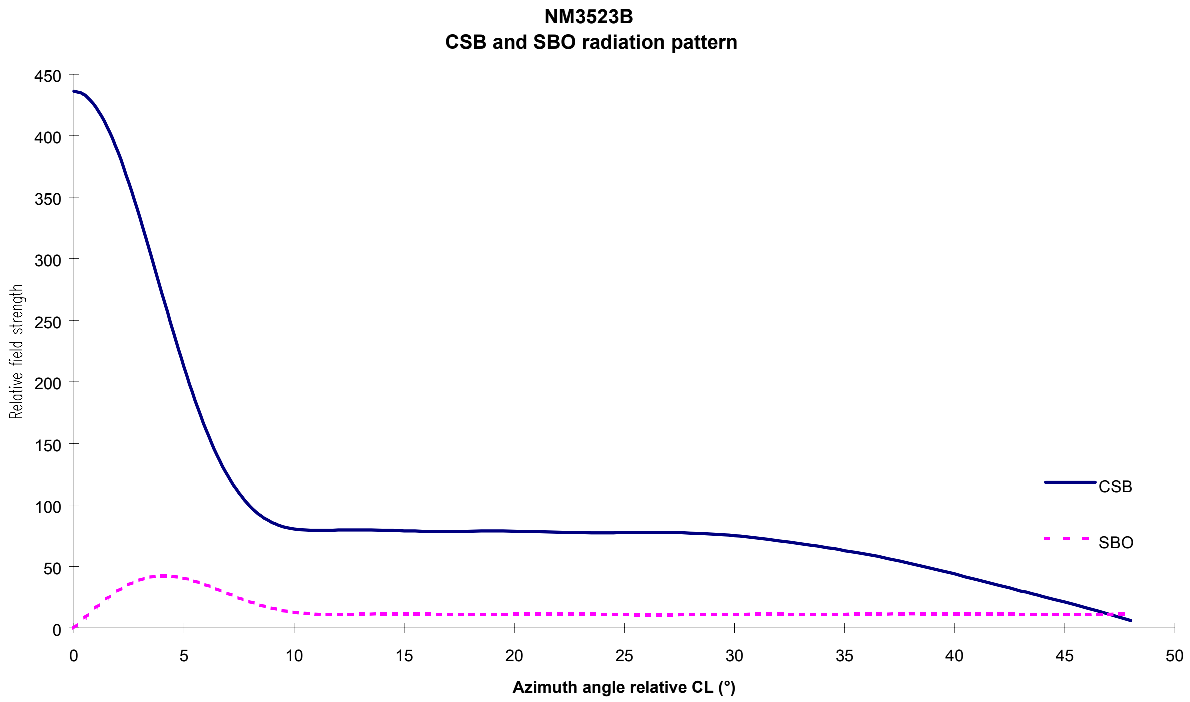


Figure 5-7 CSB and SBO radiation patterns including LPDA

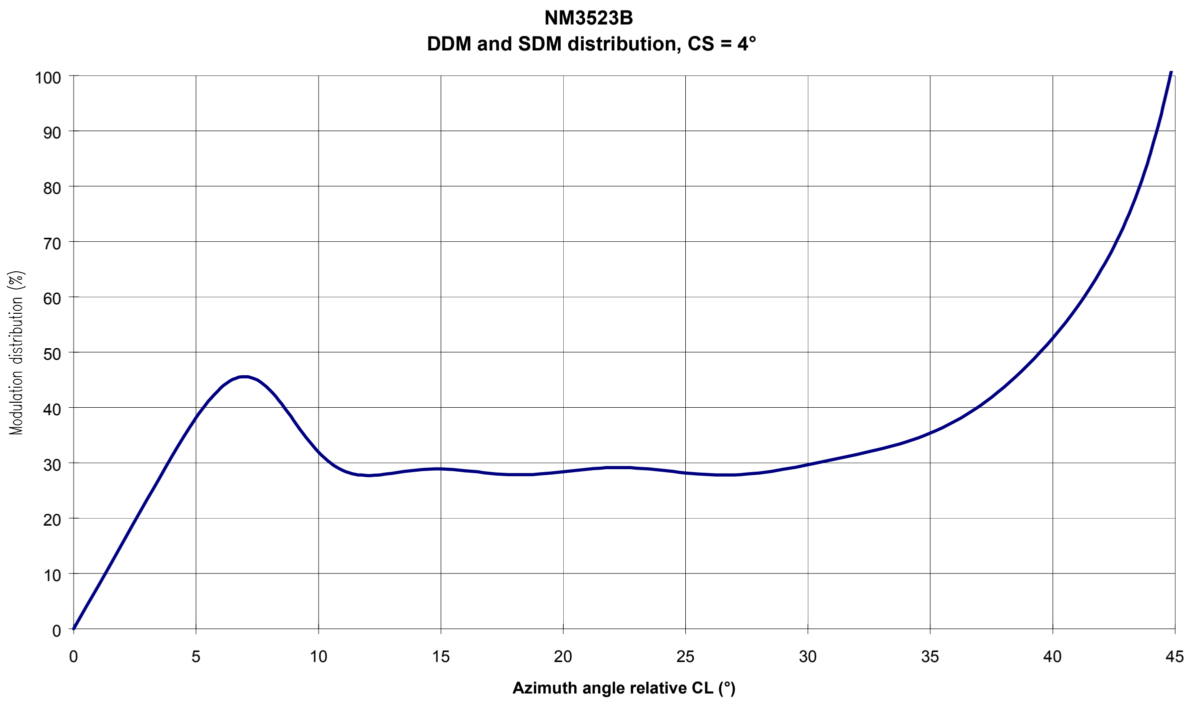


Figure 5-8 DDM distribution

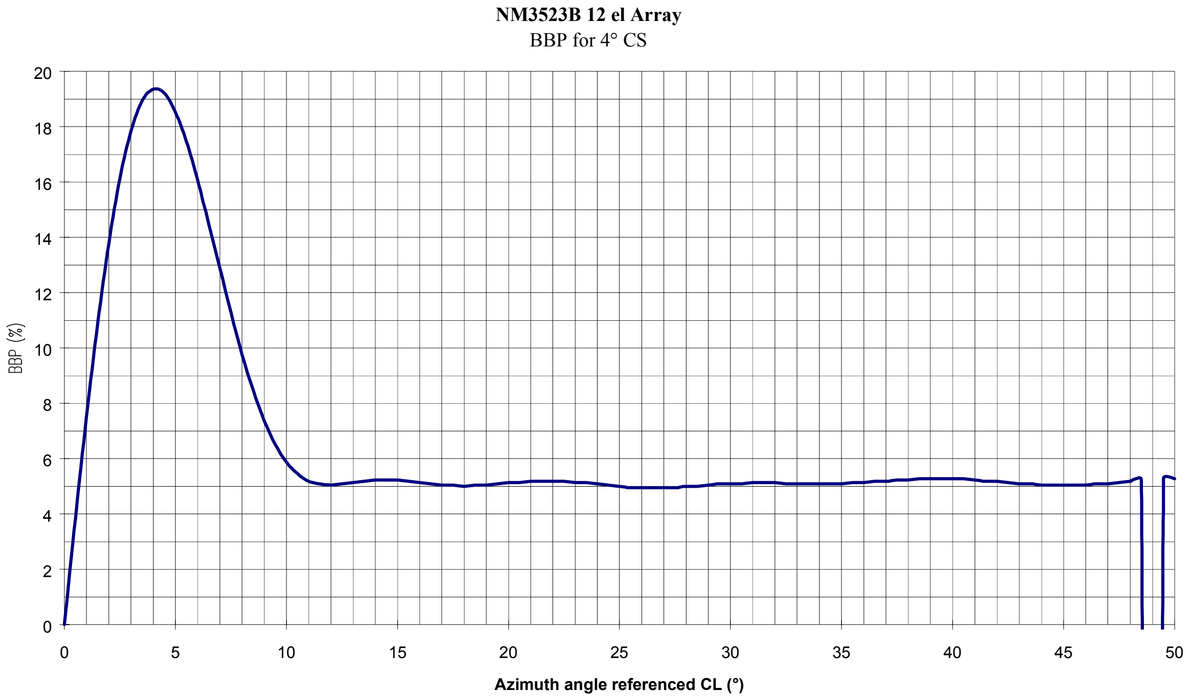


Figure 5-9 Beam Bend Potential for 4.0° Sector Width

The Beam Bend Potential is calculated according to the formula:

$$BBP_{(\%)} = 2\frac{SBO(\varphi)}{CSB_{max}} \cdot 100\%$$

where $CSB_{max} = 436.2$ (maximum relative value at φ =0°).

5.3 12 ELEMENTS ANTENNA SYSTEM NM 3524 (DUAL FREQUENCY)

Table 5-2 shows the CSB and SBO distribution amplitudes and the phases to the antennas.

Figure 5-10 shows the array radiation pattern for CSB and SBO course and clearance signals.

Figure 5-11 shows an example of lobing CSB and SBO from one antenna pair only. SBO magnitude is scaled to CSB magnitude.

The clearance CSB pattern has a null at 42° azimuth.

Figure 5-12 shows the DDM modulation distribution.

Figure 5-13 shows the Beam Bend Potential.

Antenna	Distance m	CSB ampl	CSB phase °	SBO ampl	SBO phase °	CLR CSB ampl	CLR CSB phase °	CLR SBO ampl	CLR SBO phase °
1	-11.22	11.7	0	4.9	-90				
2	-9.18	23.4	0	8.1	-90				
3	-7.14	46.5	0	12.5	-90	20	180		
4	-5.10	69.0	0	13.2	-90	10	180		
5	-3.06	88.1	0	10.1	-90	50	180	11	-90
6	-1.02	100.0	0	3.8	-90	100	0	27	-90
7	1.02	100.0	0	3.8	90	100	0	27	90
8	3.06	88.1	0	10.1	90	50	180	11	90
9	5.10	69.0	0	13.2	90	10	180		
10	7.14	46.5	0	12.5	90	20	180		
11	9.18	23.4	0	8.1	90				
12	11.22	11.7	0	4.9	90				

Table 5-2 NM 3524 12 elements Array antenna spacing and signal distribution

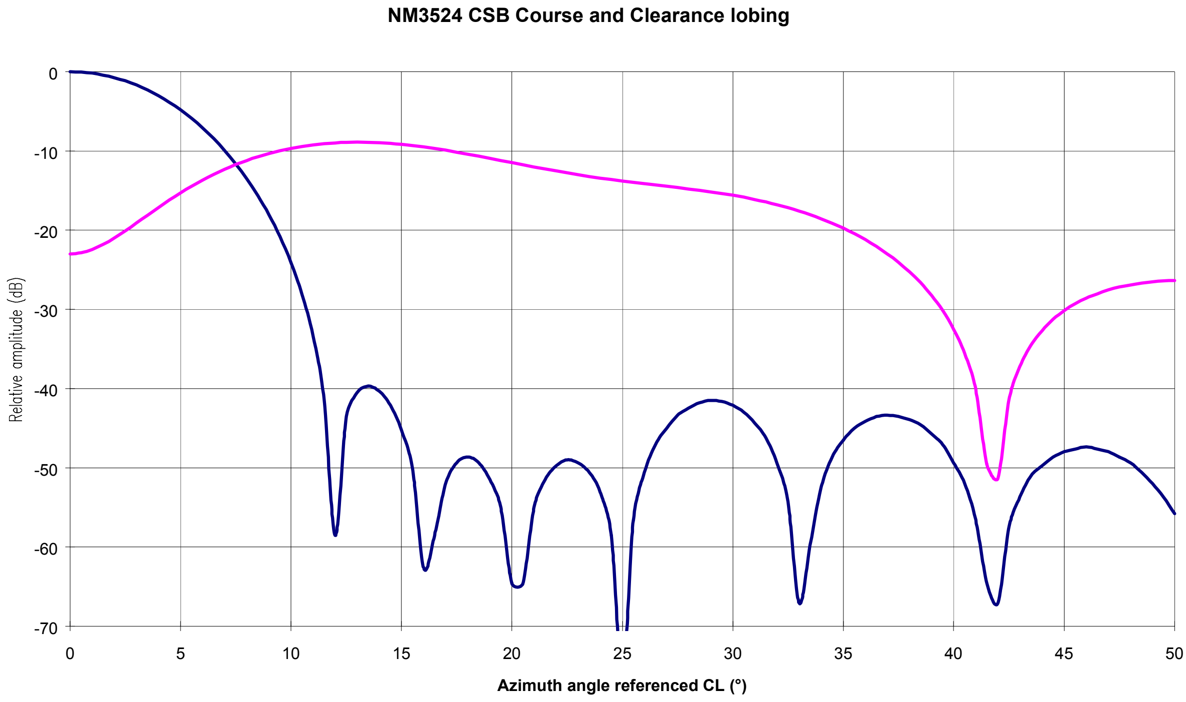


Figure 5-10 Antenna Course and Clearance lobing

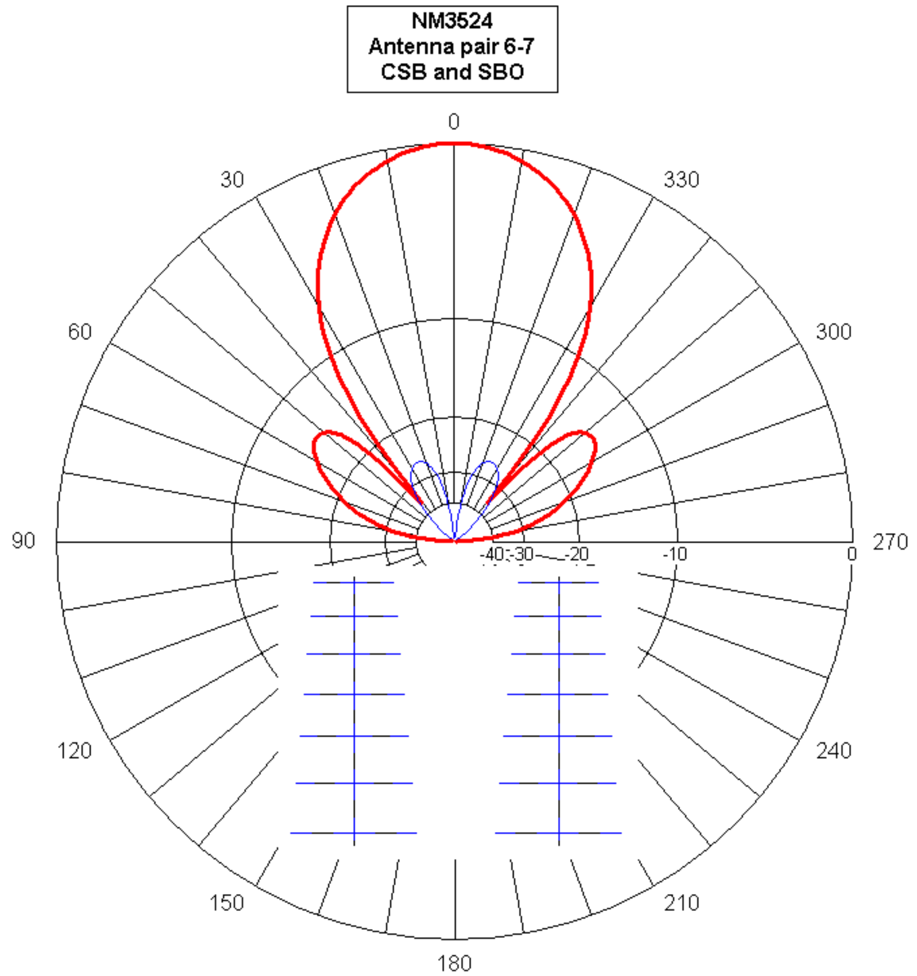


Figure 5-11 Polar diagram of CSB and SBO lobing from one antenna pair

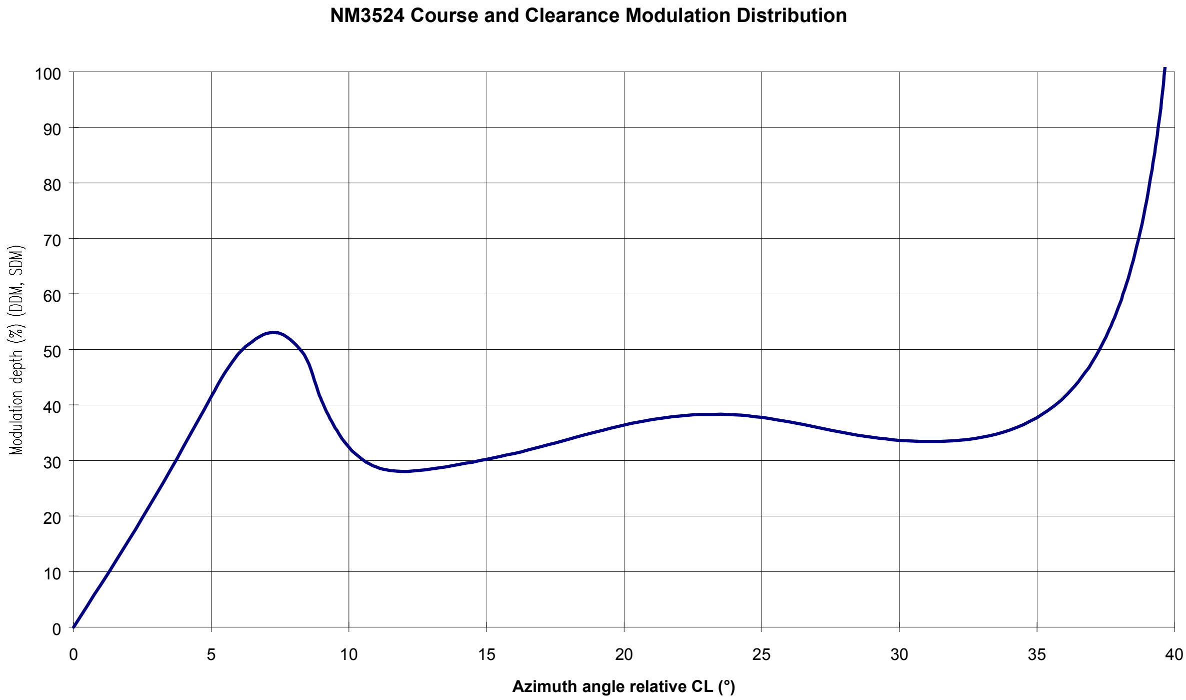


Figure 5-12 DDM distribution

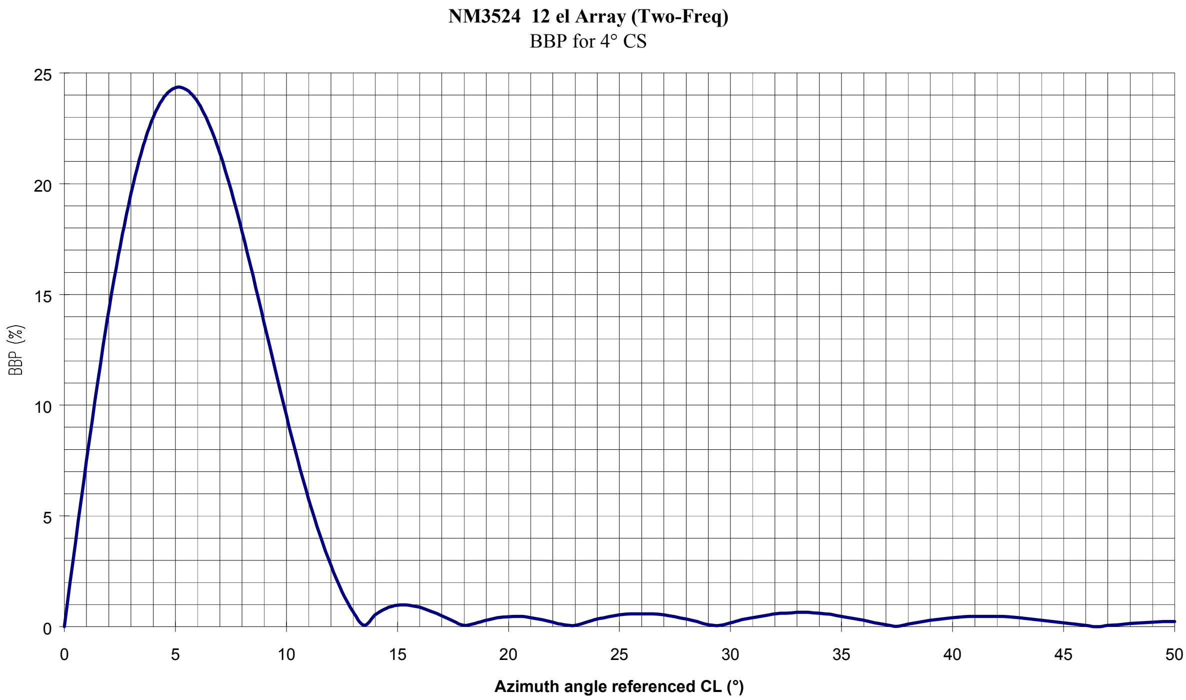


Figure 5-13 Beam Bend Potential

The Beam Bend Potential is calculated according to the formula:

$$\mathrm{BBP}_{(\%)} = 2\frac{\mathrm{SBO}(\varphi)}{\mathrm{CSB}_{max}} \cdot 100\%$$

where $\mathrm{CSB}_{max} = 677.4$ (maximum relative value at φ =0°).

5.4 24 ELEMENTS ANTENNA SYSTEM NM 3525

Table 5-3 shows the CSB and SBO distribution amplitudes and phases to the antennas.

Figure 5-14 shows the array radiation pattern for CSB and SBO course and clearance signals.

Figure 5-15 shows the DDM modulation distribution.

Figure 5-16 shows the Beam Bend Potential.

Antenna	Distance m	CSB ampl	CSB phase °	SBO ampl	SBO phase °	CLR CSB ampl	CLR CSB phase °	CLR SBO ampl	CLR SBO phase °
1	-23.46	12.6	0	2.5	-90				
2	-21.42	14.8	0	2.7	-90				
3	-19.38	22.4	0	3.7	-90				
4	-17.34	31.4	0	4.6	-90				
5	-15.30	41.6	0	5.4	-90				
6	-13.26	52.6	0	5.9	-90				
7	-11.22	63.7	0	6.1	-90				
8	-9.18	74.3	0	5.8	-90				
9	-7.14	83.9	0	5.1	-90	20	180		
10	-5.10	91.6	0	4.0	-90	10	180		
11	-3.06	97.1	0	2.5	-90	50	180	11	-90
12	-1.02	100.0	0	0.9	-90	100	0	27	-90
13	1.02	100.0	0	0.9	90	100	0	27	90
14	3.06	97.1	0	2.5	90	50	180	11	90
15	5.10	91.6	0	4.0	90	10	180		
16	7.14	83.9	0	5.1	90	20	180		
17	9.18	74.3	0	5.8	90				
18	11.22	63.7	0	6.1	90				
19	13.26	52.6	0	5.9	90				
20	15.30	41.6	0	5.4	90				
21	17.34	31.4	0	4.6	90				
22	19.38	22.4	0	3.7	90				
23	21.42	14.8	0	2.7	90				
24	23.46	12.6	0	2.5	90				

Table 5-3 NM 3525 24 elements Array antenna spacing and signal distribution

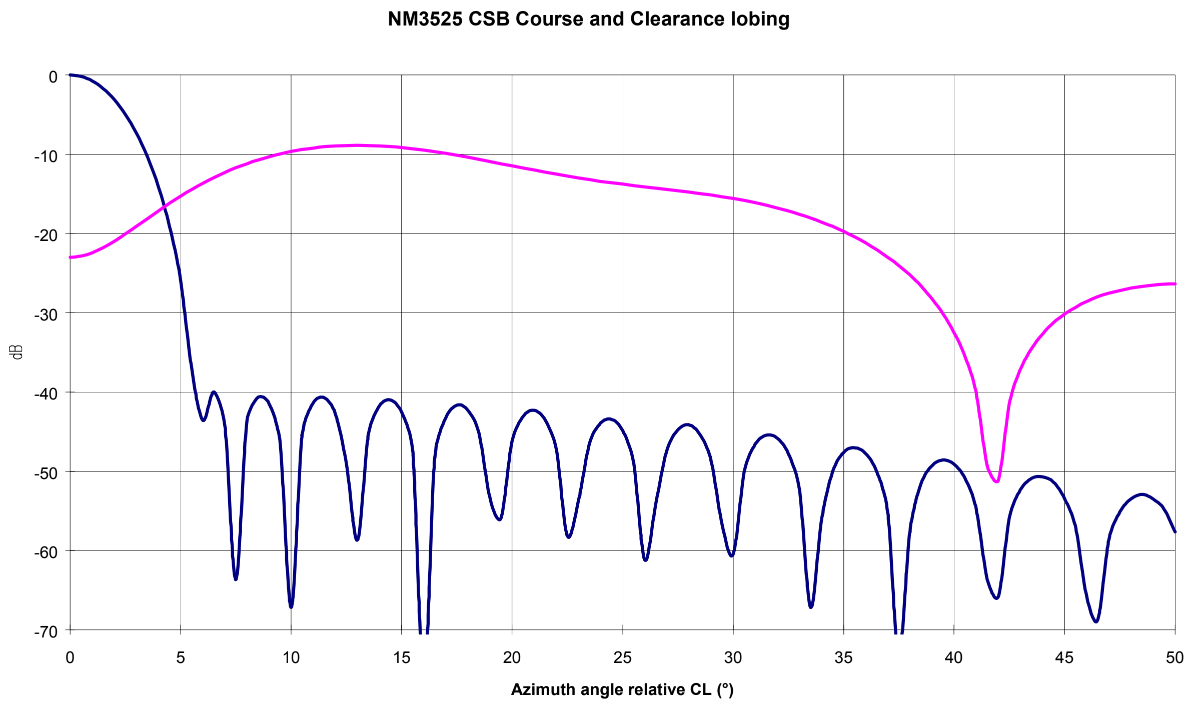


Figure 5-14 Antenna Course and Clearance lobing

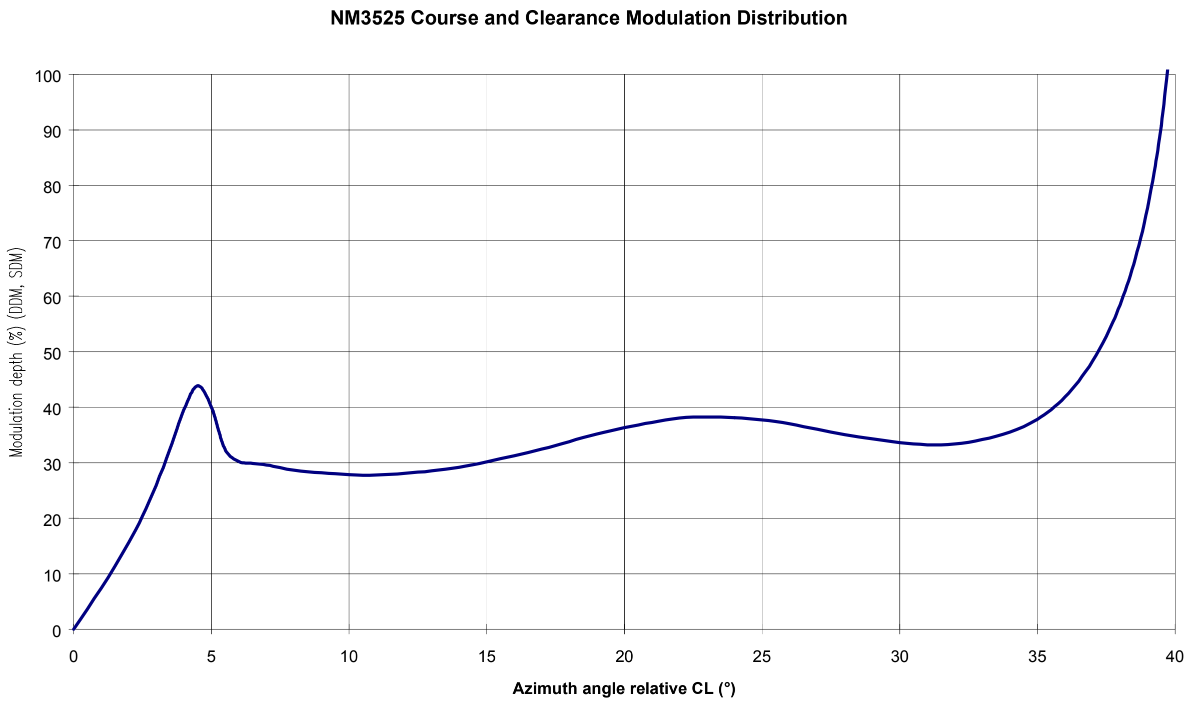


Figure 5-15 DDM modulation distribution

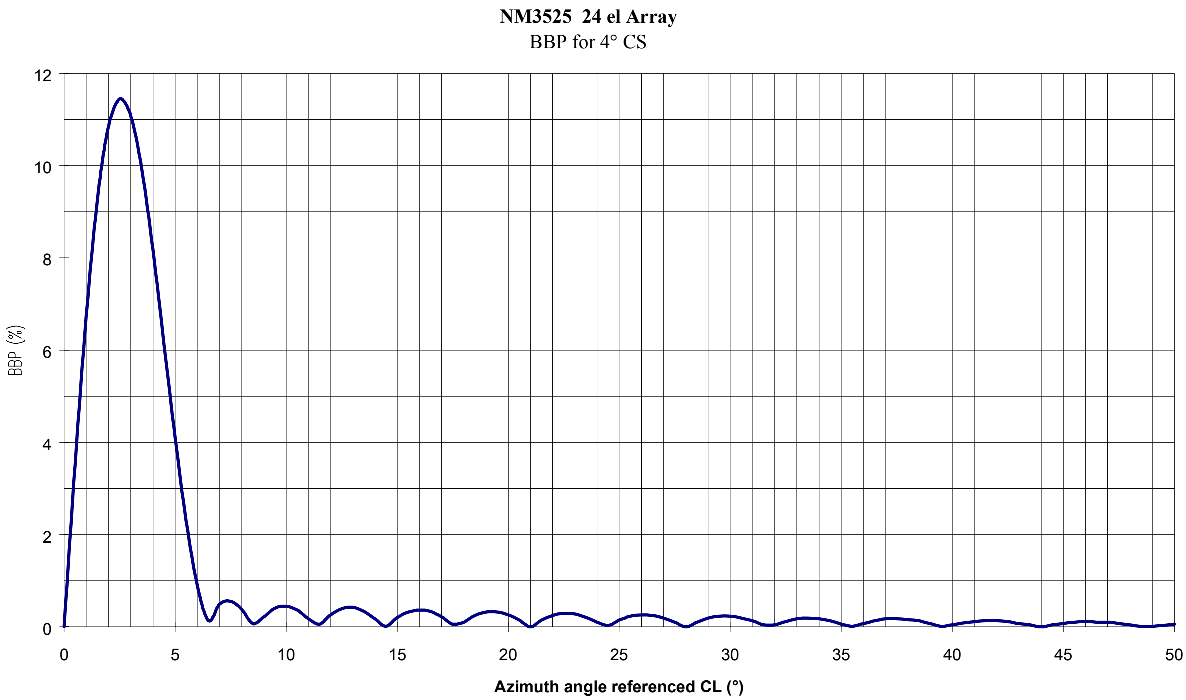


Figure 5-16 Beam Bend Potential

The Beam Bend Potential is calculated according to the formula:

$$BBP_{(\%)} = 2\frac{SBO(\varphi)}{CSB_{max}} \cdot 100\%$$

where $CSB_{max} = 1371.8$ (maximum relative value at φ =0°).

5.5 16 ELEMENTS ANTENNA SYSTEM NM3526

Table 5-4 shows the antenna spacing and phase and amplitude distribution of Course and Clearance signals to the antennas.

Figure 5-17 and Figure 5-18 shows Course CSB and SBO lobing respectively.

Figure 5-19 and Figure 5-20 shows Clearance CSB and SBO lobing respectively.

Figure 5-21 shows modulation distribution (DDM and SDM)

Figure 5-22 shows Beam Bend Potential for a CS = 4°.

Antenna	Distance m	CSB ampl	CSB phase °	SBO ampl	SBO phase °	CLR CSB ampl	CLR CSB phase °	CLR SBO ampl	CLR SBO phase °
1	-19.23	13.77	0	5.32	-90	3.59	0		
2	-16.09	29.61	0	6.60	-90		180	1.23	90
3	-13.13	50.57	0	8.52	-90	4.52	180	0.99	90
4	-10.34	71.13	0	8.86	-90	8.28	180	1.84	90
5	-7.73	87.64	0	7.86	-90	29.04	180	0.86	-90
6	-5.30	97.46	0	5.82	-90	3.24	180	1.40	-90
7	-3.04	100.00	0	3.38	-90	88.18	180	7.14	-90
8	-0.95	94.42	0	0.99	-90	142.40	0	29.62	-90
9	0.95	94.42	0	0.99	90	142.40	0	29.62	90
10	4.04	100.00	0	3.38	90	88.18	180	7.14	90
11	5.30	97.46	0	5.82	90	3.24	180	1.40	90
12	7.73	87.64	0	7.86	90	29.04	180	0.86	90
13	10.34	71.13	0	8.86	90	8.28	180	1.84	-90
14	13.13	50.57	0	8.52	90	4.52	180	0.99	-90
15	16.09	29.61	0	6.60	90		180	1.23	-90
16	19.23	13.77	0	5.32	90	3.59	0		

Table 5-4 NM3526 16 elements Array. Antenna spacing and signal distribution (CS: 4°)

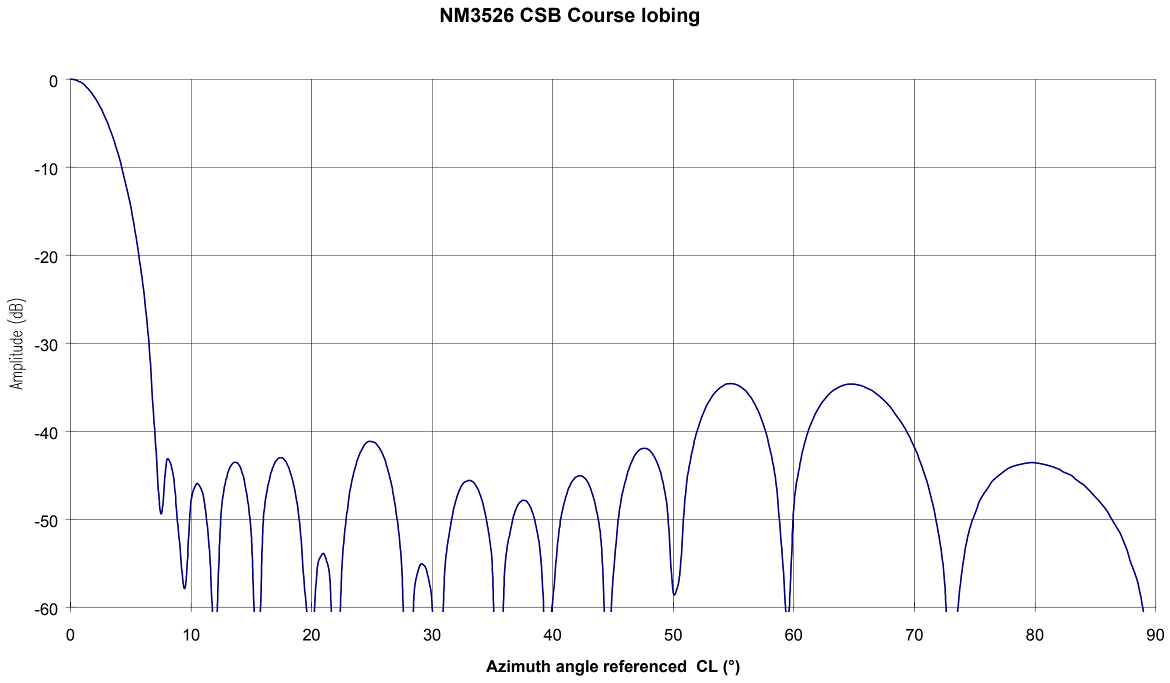


Figure 5-17 CSB Course lobing (dB)

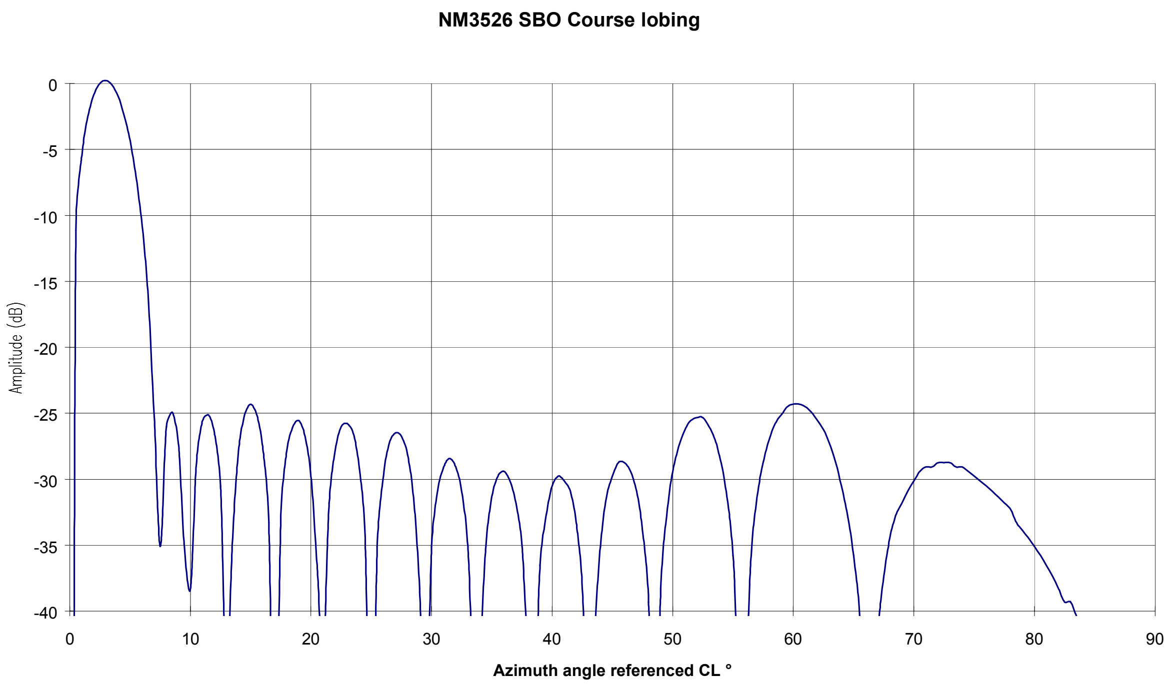


Figure 5-18 SBO Course lobing (dB)

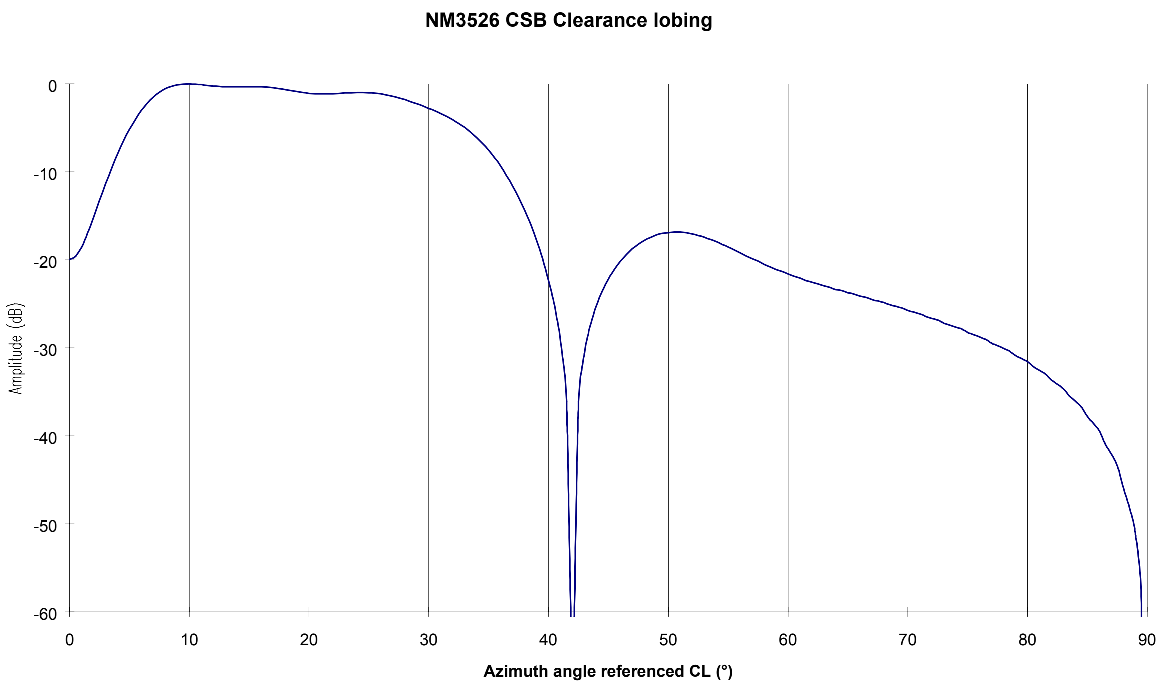


Figure 5-19 CSB Clearance lobing (dB)

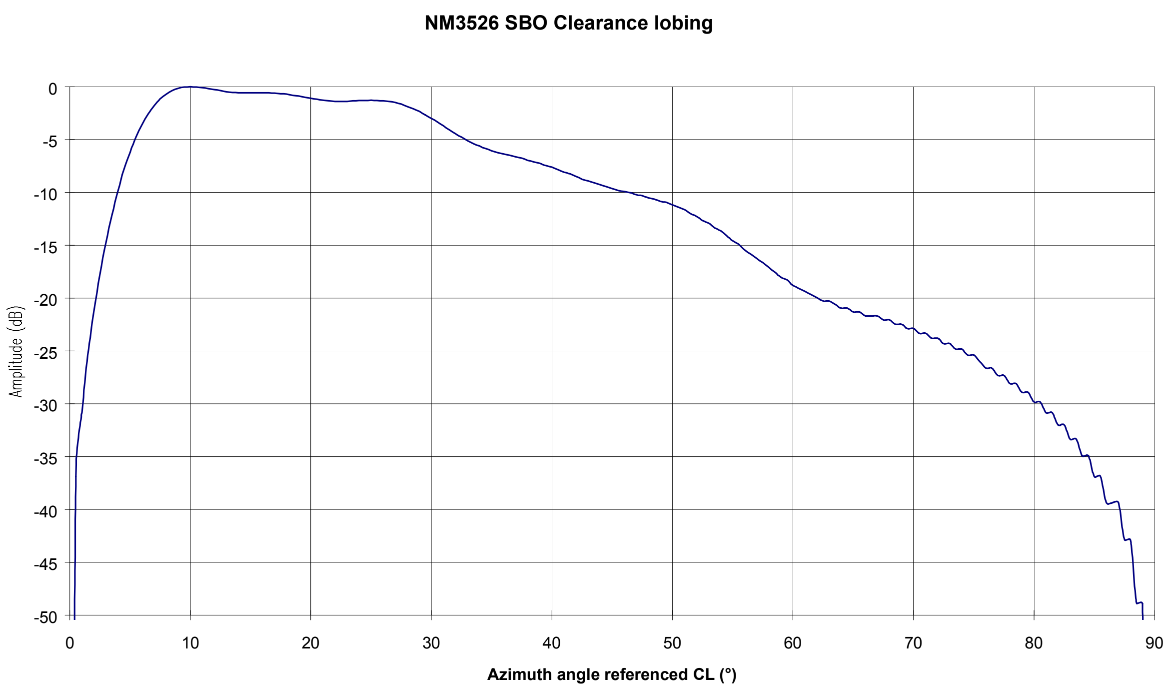


Figure 5-20 SBO Clearance lobing (dB)

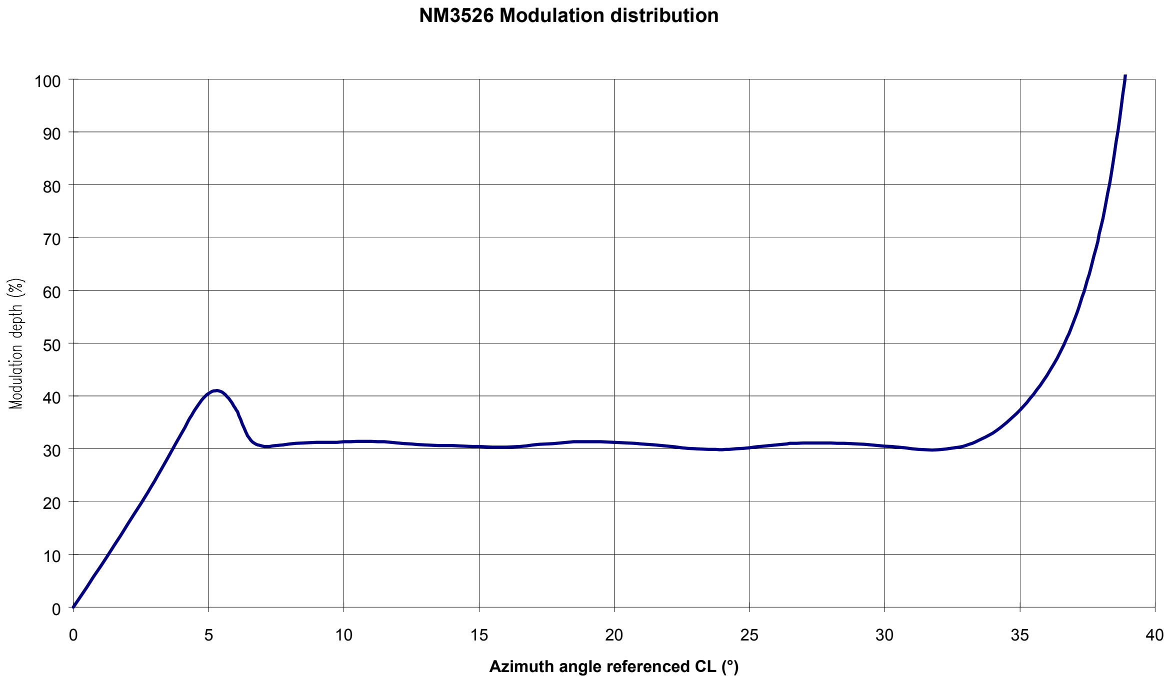


Figure 5-21 Modulation distribution

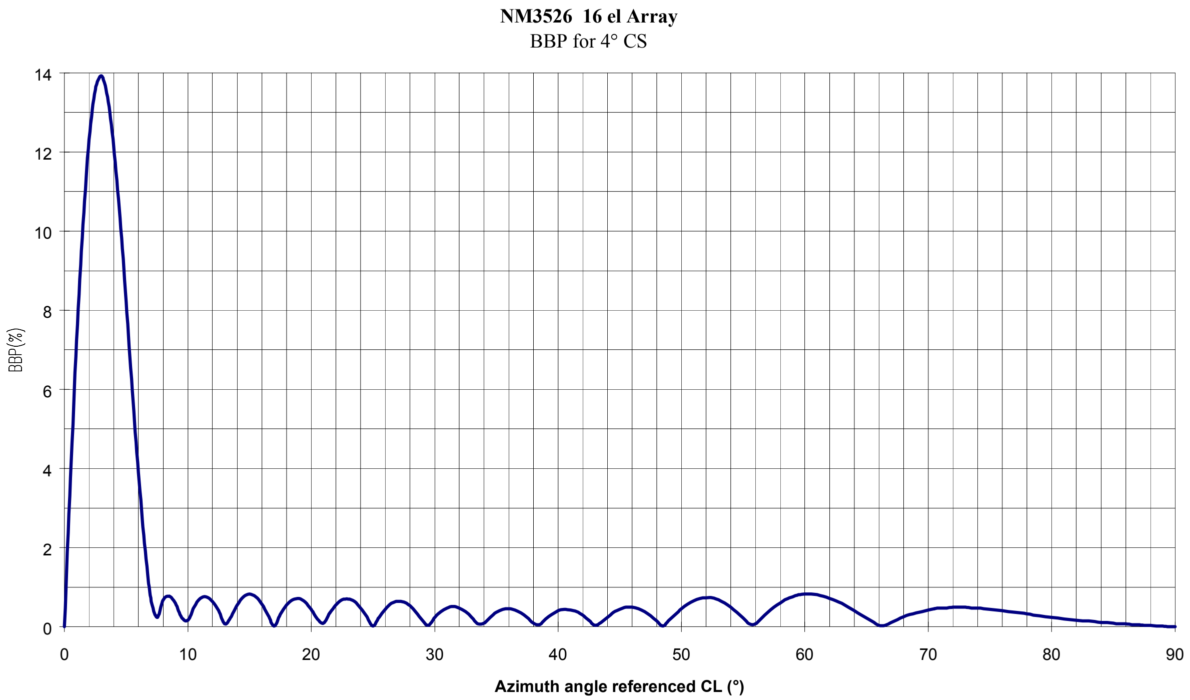


Figure 5-22 Beam Bend Potential

The Beam Bend Potential is calculated according to the formula:

$$BBP_{(\%)} = 2\frac{SBO(\varphi)}{CSB_{max}} \cdot 100\%$$

where $CSB_{max} = 1088.8$ (maximum relative value at φ =0°).

6 GLIDE PATH ANTENNA SYSTEMS

6.1 NULL REFERENCE ANTENNA SYSTEM NM 3543
6.1.2 Principle of Operation
6.1.3 Theoretical considerations
6.1.4 Error analysis Null Reference System

6.2 SIDEBAND REFERENCE ANTENNA SYSTEM NM 3544
6.2.1 Theoretical considerations

6.3 M-ARRAY ANTENNA SYSTEM NM 3545
6.3.1 Theoretical considerations
6.3.2 The Clearance signal

6.4 ANTENNA ELEMENT OFFSET
6.4.1 Null Reference Antenna System
6.4.2 Sideband Reference Antenna System
6.4.3 M-Array Antenna System
6.4.4 Forward Slope and Sideways Slope
6.4.5 Ground current

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6 GLIDE PATH ANTENNAS SYSTEMS

6.1 NULL REFERENCE SYSTEM NM 3543

6.1.1 Principle of operation

The Null Reference system employs two antenna elements, one of which is used to radiate the SBO signal and the other the CSB. The antenna element fed with the SBO signal is located at such a height on the mast that the second null of the vertical radiation pattern occurs at the desired glide path angle θo.

The other antenna element is located on the mast at half the height of the first and is fed with CSB signal. See Figure 6-1. It produces a first lobe pattern that has its maximum at the glide path angle. See Figure 6-2. The pilot is directed onto the correct glide path by information given by the difference in depth of modulation of the 90 and 150 Hz tones.

$$\mathrm{DDM} = m_{150} - m_{90} = 2 \cdot \frac{E_{SBO}}{E_{CSB}} \cdot \cos\phi$$

where

m_{90} = 90 Hz component modulation depth

m_{150} = 150 Hz component modulation depth

E_{SBO} = amplitude of the SBO signal

E_{CSB} = amplitude of the CSB signal

ϕ = RF phase angle between E_{SBO} and E_{CSB}

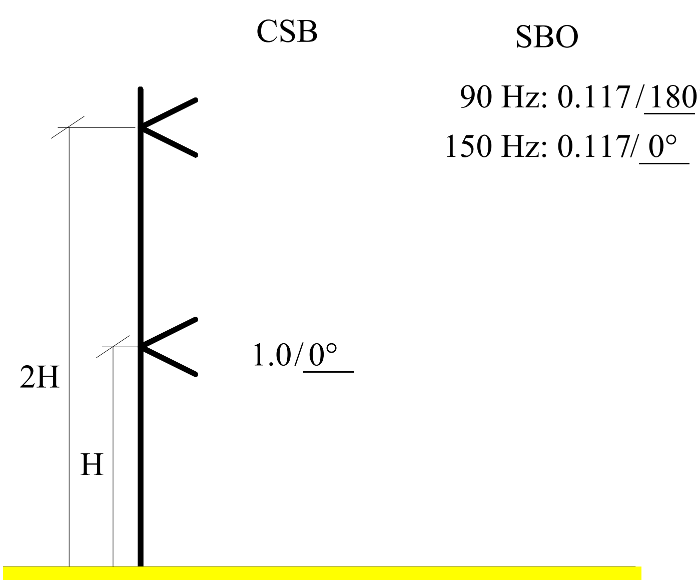

Figure 6-1 Null Reference Antenna Configuration

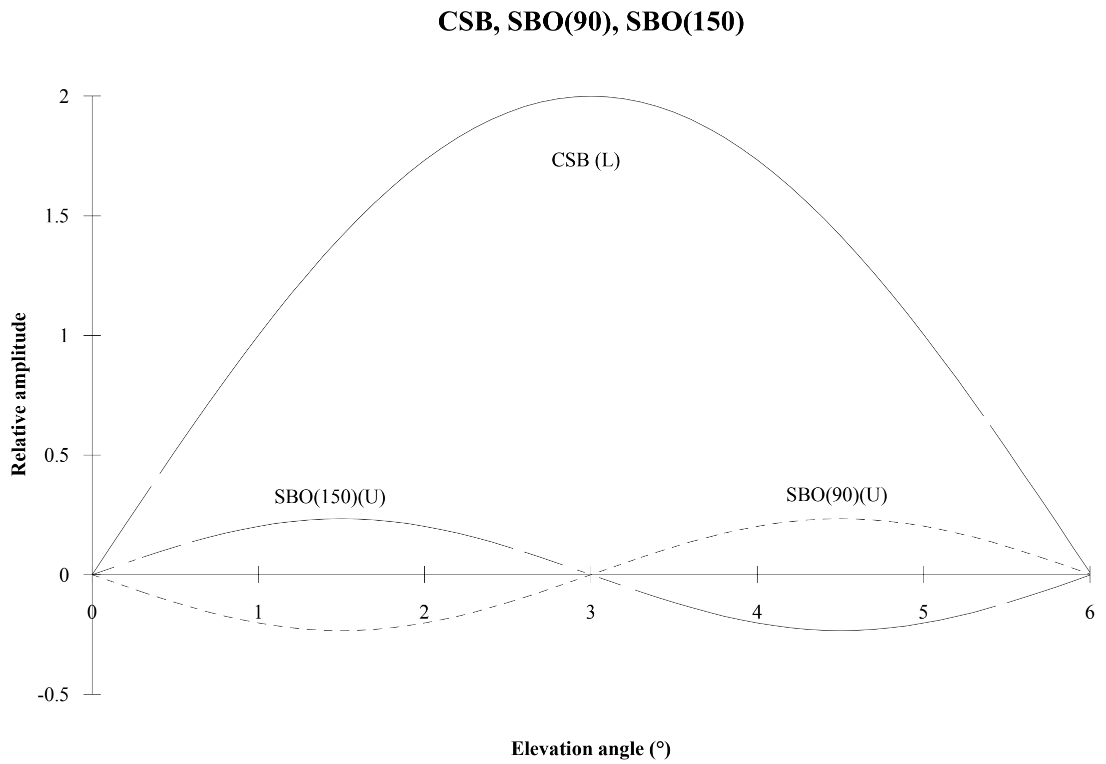

Figure 6-2 CSB and SBO lobe patterns for Null Reference antenna system

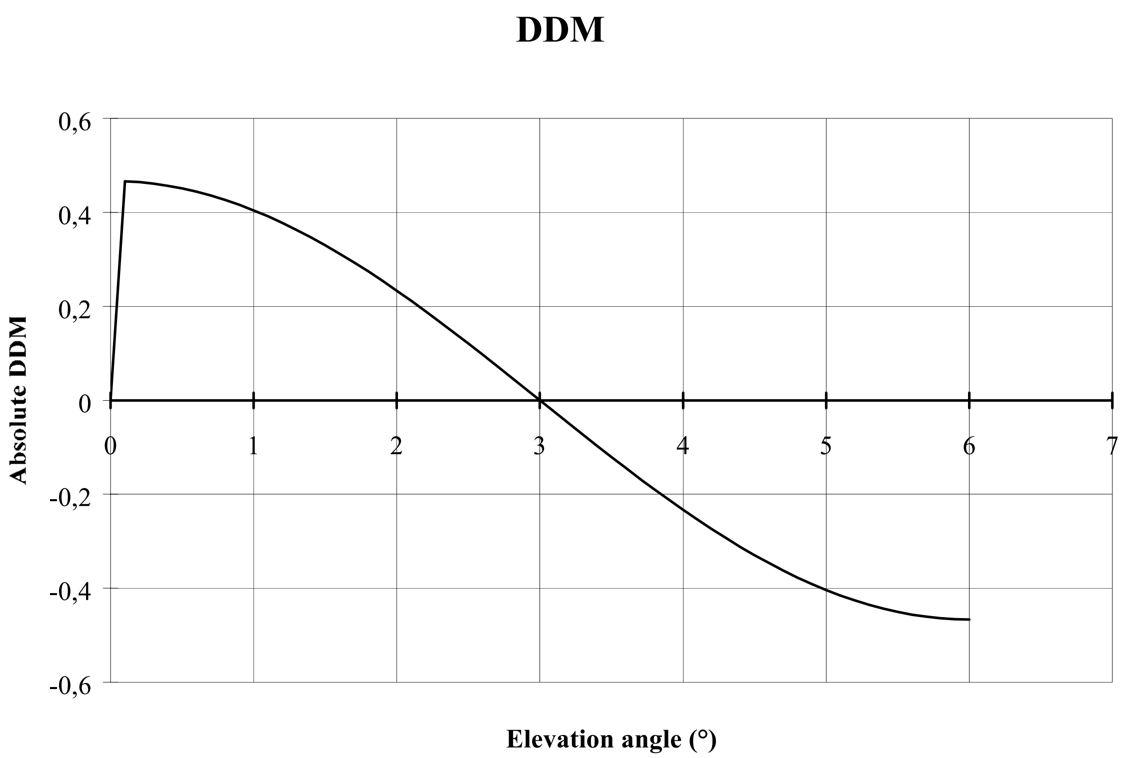

Figure 6-3 ***DDM v.s. elevation angle θ.***

6.1.2 Theoretical considerations

The CSB and SBO radiation patterns are shown in Figure 6-2.
At the glide path angle, the SBO radiation pattern has a null and hence DDM = 0. Below the glide path angle (θo), the SBO signal has the 150 Hz components in phase with the CSB signal; the SBO radiation pattern will give a fly-up signal below θo.

Above θo, the SBO radiation gives a fly-down signal as the SBO signal has the 90 Hz sideband in phase with the CSB signal.

By using the expression for the radiation pattern, as derived in general antenna theory, the CSB and SBO patterns are given by:

$$E_{CSB}(\theta) = 2A_{CSB} \cdot \sin(\frac{2\pi}{\lambda} \cdot H \cdot \sin\theta)$$

$$E_{SBO}(\theta) = 2A_{SBO} \cdot \sin(\frac{2\pi}{\lambda} \cdot 2H \cdot \sin\theta)$$

By introducing

$$H = \frac{\lambda}{4 \cdot \sin\theta o}$$

the expressions are

$$E_{CSB}(\theta) = 2A_{CSB} \cdot \sin(\frac{\pi}{2} \cdot \frac{\sin\theta}{\sin\theta o})$$

$$E_{SBO}(\theta) = 2A_{SBO} \cdot \sin(\pi \cdot \frac{\sin\theta}{\sin\theta o})$$

The DDM is given by

$$DDM = 2 \cdot \frac{E_{SBO}(\theta)}{E_{CSB}(\theta)}$$

To obtain the required sector width of $\pm 0.12\theta o$ for DDM = 0.0875, the amplitude A_{CSB} and A_{SBO} must have a ratio given by

$$0.0875 = 2 \cdot \frac{E_{SBO}(\theta o - 0.12\theta o)}{E_{CSB}(\theta o - 0.12\theta o)}$$

$$\frac{A_{SBO}}{A_{CSB}} = 0.0437 \cdot \frac{\sin(\pi \cdot \frac{\sin .88\theta o}{\sin\theta o})}{\sin(\frac{\pi}{2} \cdot \frac{\sin 0.88\theta o}{\sin\theta o})}$$

and since $\sin\theta o \approx \theta o$

$$\frac{A_{SBO}}{A_{CSB}} \approx 0.0437 \cdot \frac{\sin(\frac{\pi}{2} \cdot 0.88)}{\sin(\pi \cdot 0.88)} = \underline{\underline{0.117}}$$

Figure 6-4 shows the DDM v.s. elevation angle.

Figure 6-5 shows the feed signal for Null-Reference system expressed as vectors:

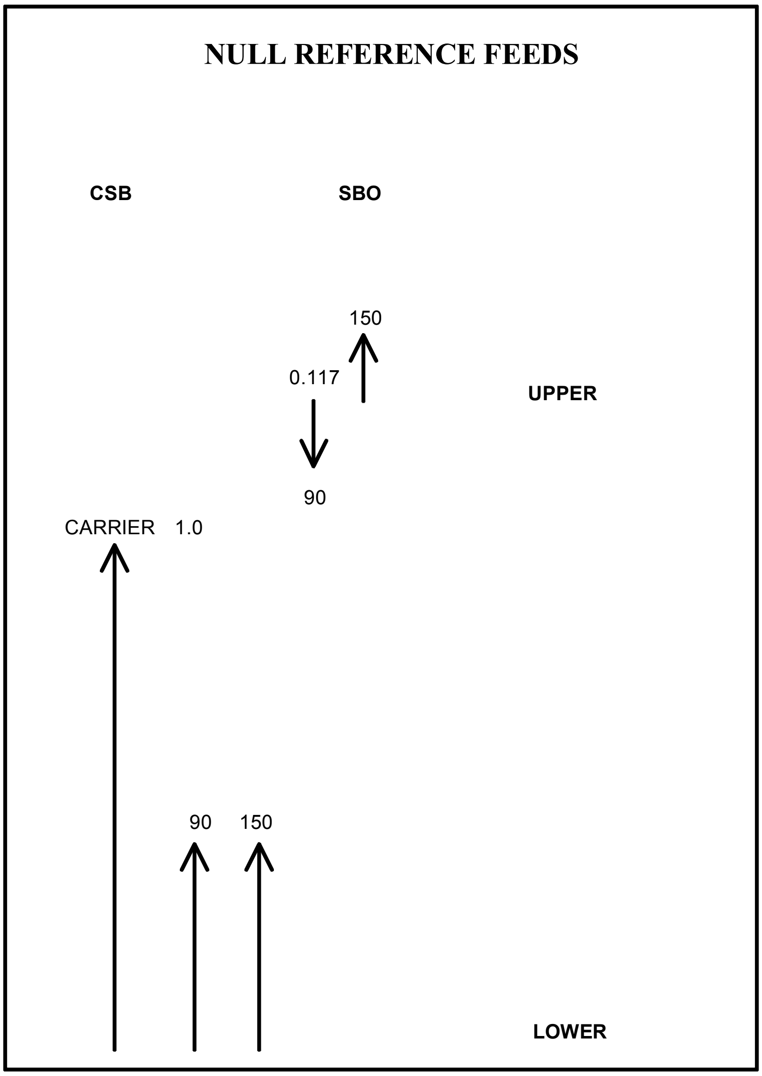

Figure 6-5 Vector representation of Null-Reference feed signals

The CSB is fed to the lower antenna only with phase zero and amplitude 1.
The SBO is fed to the upper antenna with the 150 Hz sideband in-phase (0°) with the CSB and amplitude 0.117 referenced to the carrier of the CSB.

6.1.3 ERROR ANALYSIS NULL REFERENCE SYSTEM

The glide path angle depends on the following factors:

* The height of the upper antenna above the ground.
* The average slope of the ground in the approach sector.
* The DDM-balance of the transmitter.

The glide path angle θo is given by

$$\sin(\theta o + \alpha) = \frac{\lambda}{4H}$$

where α is the average slope of the ground, α is **positive for a down-slope.** H is half the height of the upper antenna above the reflecting ground plane.

In practice, only H could change during the seasons due to changing reflection properties of the ground (from a dry sand soil to a wet ground, or a snow layer). If the height H is varying 30 cm, the glide path angle will change by approximately 0.24°, which is just above the Cat. I alarm limit.
The RF phase between the SBO and CSB signals (ϕ) has only effect on the sector width, accordingly the formula

$$DDM = \frac{2E_{SBO}}{E_{CSB}} \cdot \cos\phi$$

However, ϕ is not critical. A 20° phase error will only increase the sector width by 6%. The Cat.I alarm limit is about 30%.
Also the amplitude ratio between the SBO and CSB signals will have effect on the sector width only. A 2 dB change will change the width by about 30%.

6.2 SIDEBAND REFERENCE SYSTEM NM 3544

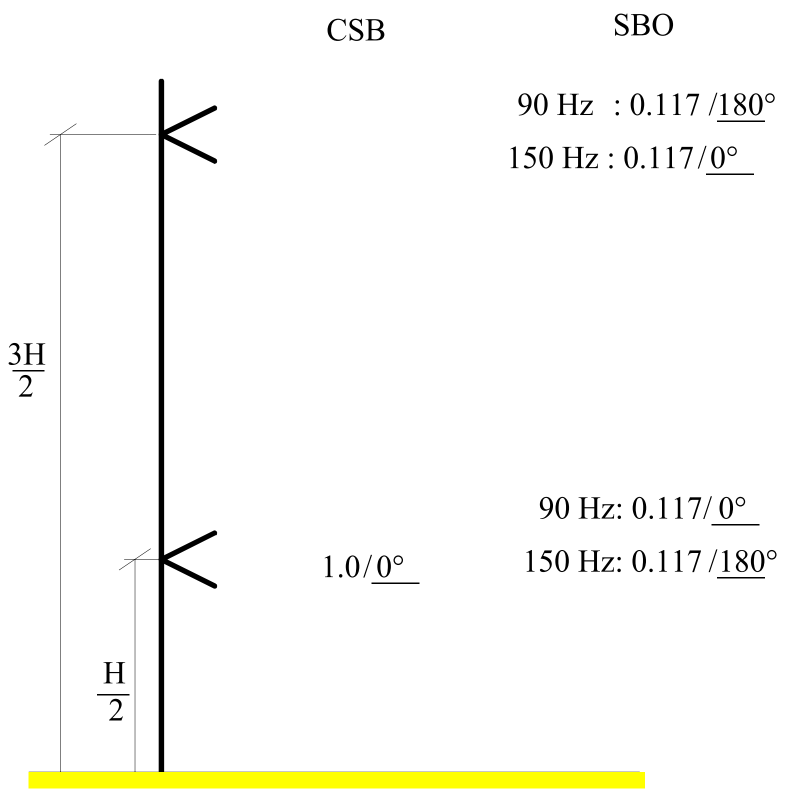

Figure 6-6 Sideband Reference Antenna Configuration

6.2.1 Theoretical considerations

Figure 6-6 shows the antenna heights and feeding configuration.

The CSB and SBO radiation patterns are shown in Figure 6-7. Only the lower antenna element radiates the CSB signal. At the glide path angle, the SBO radiations from the two elements are of identical amplitude but 180° out of phase.
Below the glide path angle θo, the radiation from the upper element dominates. As this SBO signal has the 150 Hz sideband in phase with the CSB signal, the SBO radiation pattern will give a fly-up signal below θo.
Above θo, the SBO radiation from the lower element dominates and gives a fly-down signal as this SBO signal has the 90 Hz sideband in phase with the CSB signal.

By using the expression for the radiation pattern, the CSB and SBO patterns are given by:

$$E_{CSB}(\theta) = 2A_{CSB} \cdot \sin(\frac{2\pi}{\lambda} \cdot 0.5H \cdot \sin\theta)$$

$$E_{SBO}(\theta) = -2A_{SBO} \cdot \sin(\frac{2\pi}{\lambda} \cdot 0.5H \cdot \sin\theta) + 2A_{SBO} \cdot \sin(\frac{2\pi}{\lambda} \cdot 1.5H \cdot \sin\theta)$$

By introducing $H = \frac{\lambda}{4 \cdot \sin\theta o}$

the expressions are $E_{CSB}(\theta) = -2A_{CSB} \cdot \sin(\frac{\pi}{4} \cdot \frac{\sin\theta}{\sin\theta o})$

$$E_{SBO}(\theta) = -2A_{SBO} \cdot \sin(\frac{\pi}{4} \cdot \frac{\sin\theta}{\sin\theta o}) + \sin(\frac{3\pi}{4} \cdot \frac{\sin\theta}{\sin\theta o})$$

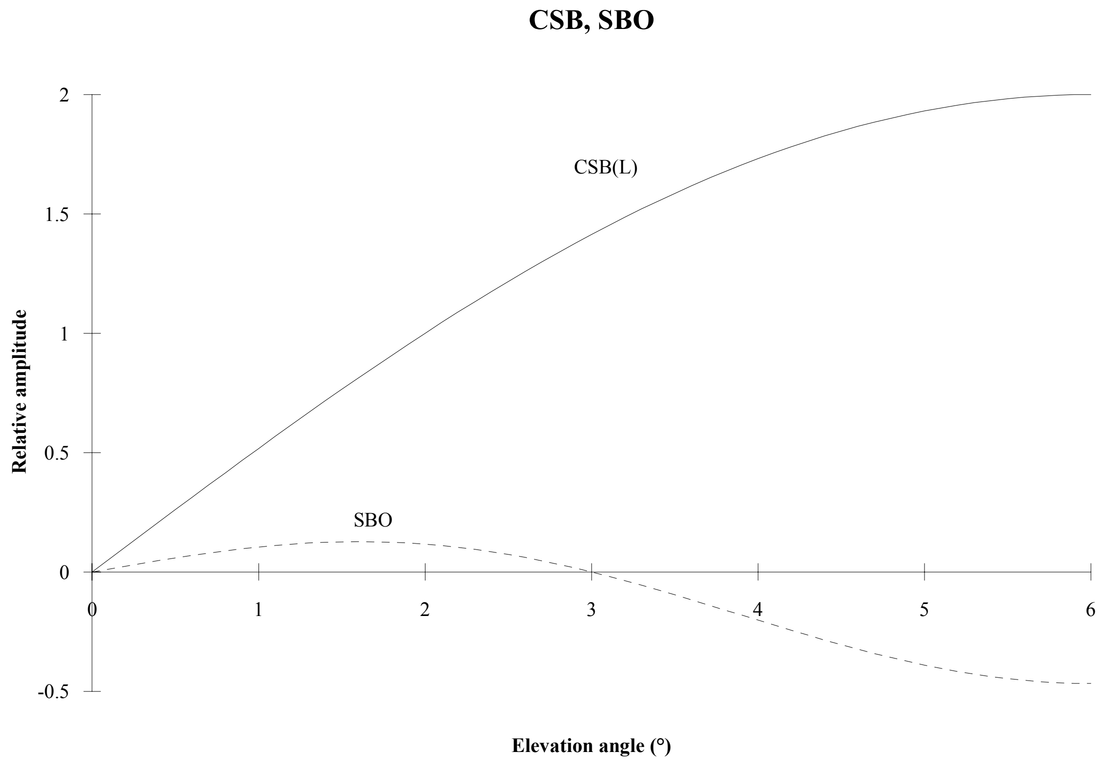

Figure 6-7 CSB and SBO lobe pattern for Sideband Reference Antenna system

The DDM is given by:

$$DDM = 2 \cdot \frac{E_{SBO}(\theta)}{E_{CSB}(\theta)}$$

To obtain the required sector width of ± 0.12θo for DDM = 0.0875, the amplitude $\mathbf{A_{CSB}}$ and $\mathbf{A_{SBO}}$ must have a ratio given by:

$$0.0875 = 2 \cdot \frac{E_{SBO}(\theta o - 0.12\theta o)}{E_{CSB}(\theta o - 0.12\theta o)}$$

$$\frac{A_{SBO}}{A_{CSB}} = 0.0437 \cdot \frac{\sin(\frac{\pi}{4} \cdot \frac{\sin(0.88\theta o)}{\sin\theta o})}{\sin(\frac{\pi}{4} \cdot \frac{\sin(0.88\theta o)}{\sin\theta o}) - \sin(\frac{3\pi}{4} \cdot \frac{\sin(0.88\theta o)}{\sin\theta o})}$$

and since $\sin\theta o \approx \theta o$

$$\frac{A_{SBO}}{A_{CSB}} \approx 0.0437 \cdot \frac{\sin(\frac{\pi}{4} \cdot 0.88)}{\sin(\frac{\pi}{4} \cdot 0.88) - \sin(\frac{3\pi}{4} \cdot 0.88)} = \underline{\underline{0.117}}$$

Figure 6-8 shows the radiation pattern for lower and upper antenna CSB and SBO distribution (upper diagram) and Figure 6-9 shows the resultant DDM distribution.

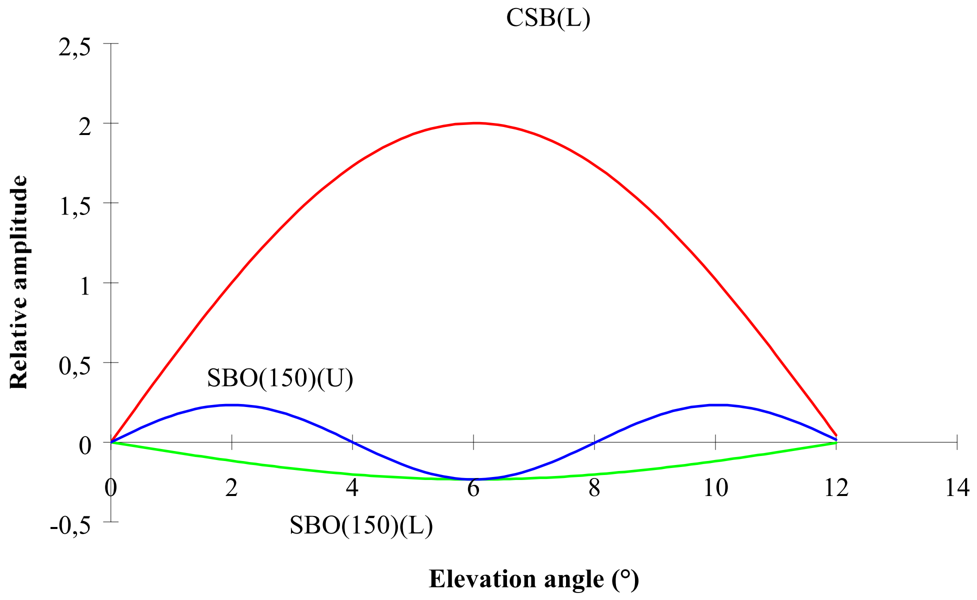

Figure 6-8 CSB and SBO element radiation pattern for Sideband Reference system

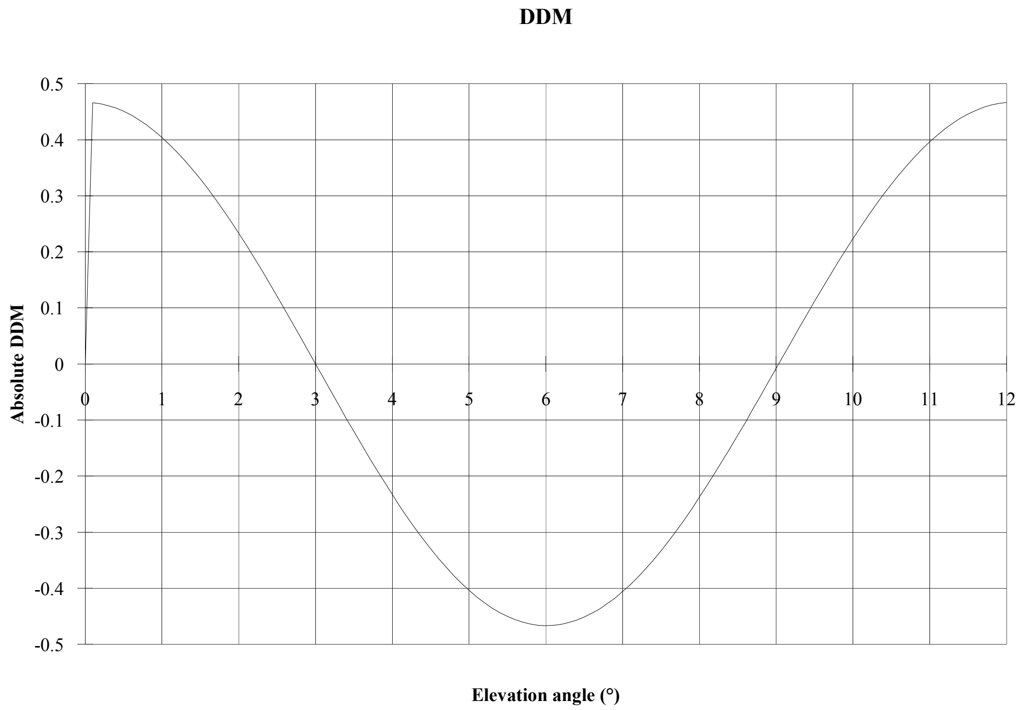

Figure 6-9 The DDM distribution with normal feeding

Figure 6-10 shows the feed signals of Sideband Reference system expressed as vectors:

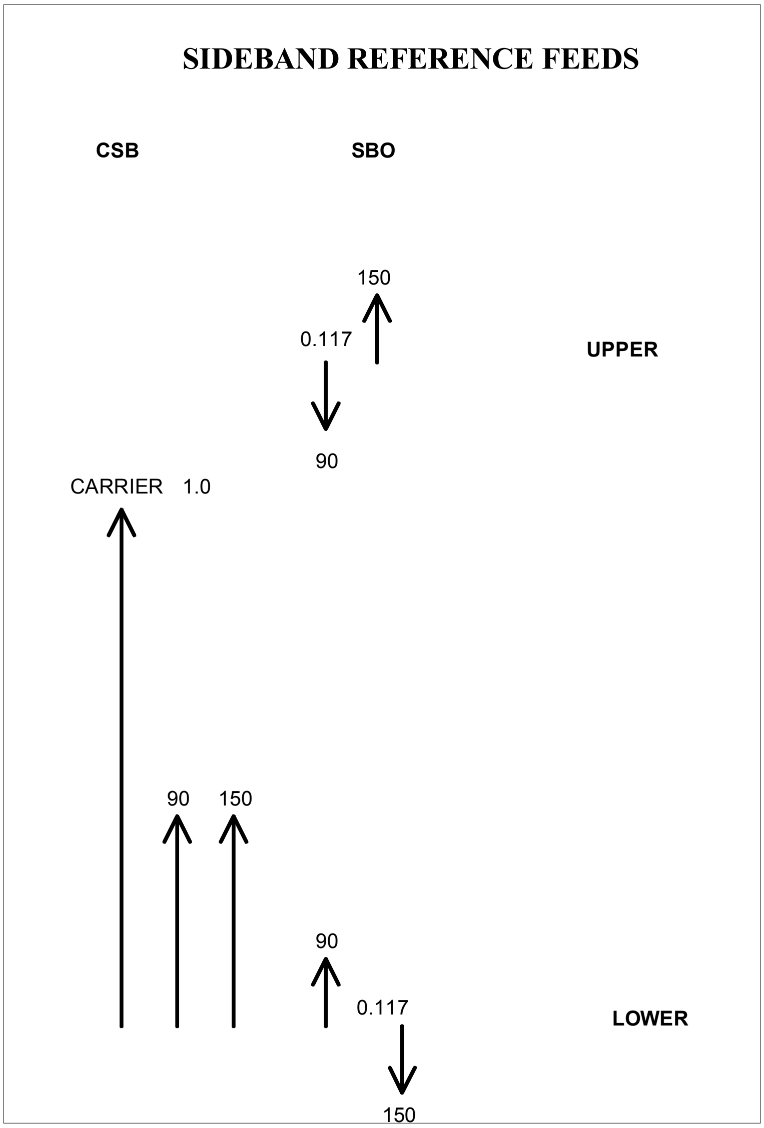

Figure 6-10 Vector representation of Sideband Reference feed signals

The CSB is fed to the lower antenna only with phase zero and amplitude 1.

The SBO is fed to lower and upper antenna with amplitude 0.117 referenced to the carrier of the CSB.
The upper antenna 150 Hz sideband is in-phase (0°) with the CSB.
The lower antenna 150 Hz sideband is out-of-phase (180°) with the CSB.

6.3 M-ARRAY ANTENNA SYSTEM NM 3545

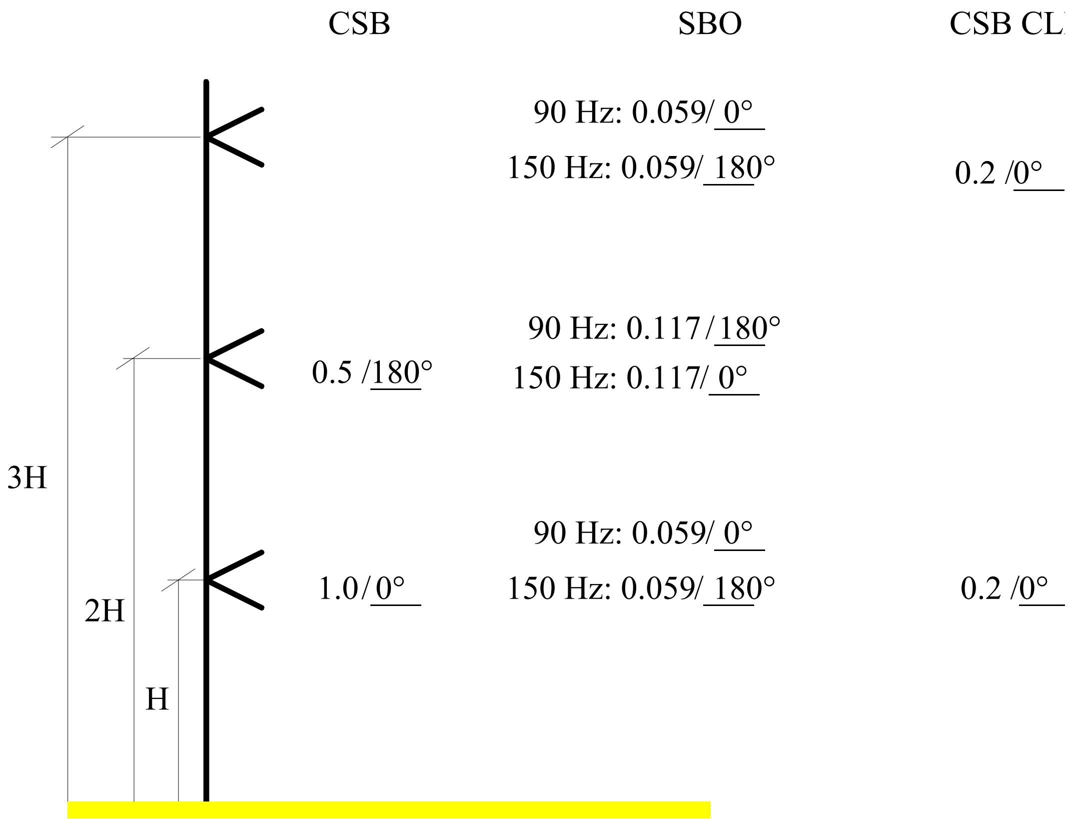

Figure 6-11 M-array Antenna Configuration

6.3.1 Theoretical considerations

Figure 6-11 shows the antenna heights and feeding configuration.

The CSB and SBO radiation patterns are shown in Figure 6-14. Only the lower and middle antenna elements radiate the CSB signal.

At the glide path angle θo, the SBO radiation from the middle element is zero, and from the upper and lower elements the radiations are of identical amplitude but 180° out-of-phase giving a null in the composite SBO radiation pattern.

By using the expression for the radiation pattern the CSB and SBO patterns are given by:

$$E_{CSB}(\theta) = 2A_{CSB}(\sin(\frac{2\pi}{\lambda} \cdot H \cdot \sin\theta) - 0.5\sin(\frac{2\pi}{\lambda} \cdot 2H \cdot \sin\theta))$$

$$E_{SBO}(\theta) = 2A_{SBO}(0.5\sin(\frac{2\pi}{\lambda} \cdot H \cdot \sin\theta) - \sin(\frac{2\pi}{\lambda} \cdot 2H \cdot \sin\theta) + 0.5\sin(\frac{2\pi}{\lambda} \cdot 3H \cdot \sin\theta))$$

By introducing

$$H = \frac{\lambda}{4\sin\theta o}$$

and sinθ =θ, sinθo = θo which is a good approximation for small angles, the radiation patterns can be expressed as

$$E_{CSB}(\theta) = 2A_{CSB}(\sin(\frac{\pi}{2} \cdot \frac{\theta}{\theta o}) - 0.5\sin(\pi \cdot \frac{\theta}{\theta o}))$$

$$E_{SBO}(\theta) = 2A_{SBO}(0.5\sin(\frac{\pi}{2} \cdot \frac{\theta}{\theta o}) - \sin(\pi \cdot \frac{\theta}{\theta o}) + 0.5\sin(\frac{3\pi}{2} \cdot \frac{\theta}{\theta o}))$$

Figure 6-12 shows the CSB element patterns.

Figure 6-13 shows the SBO element patterns.

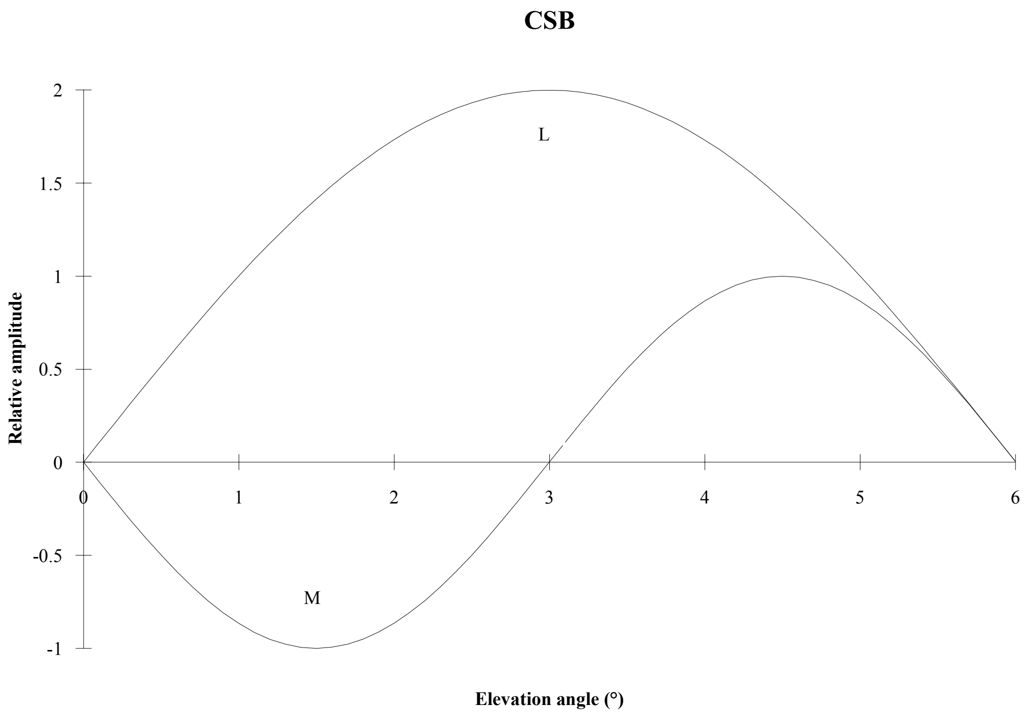

Figure 6-12 CSB element patterns

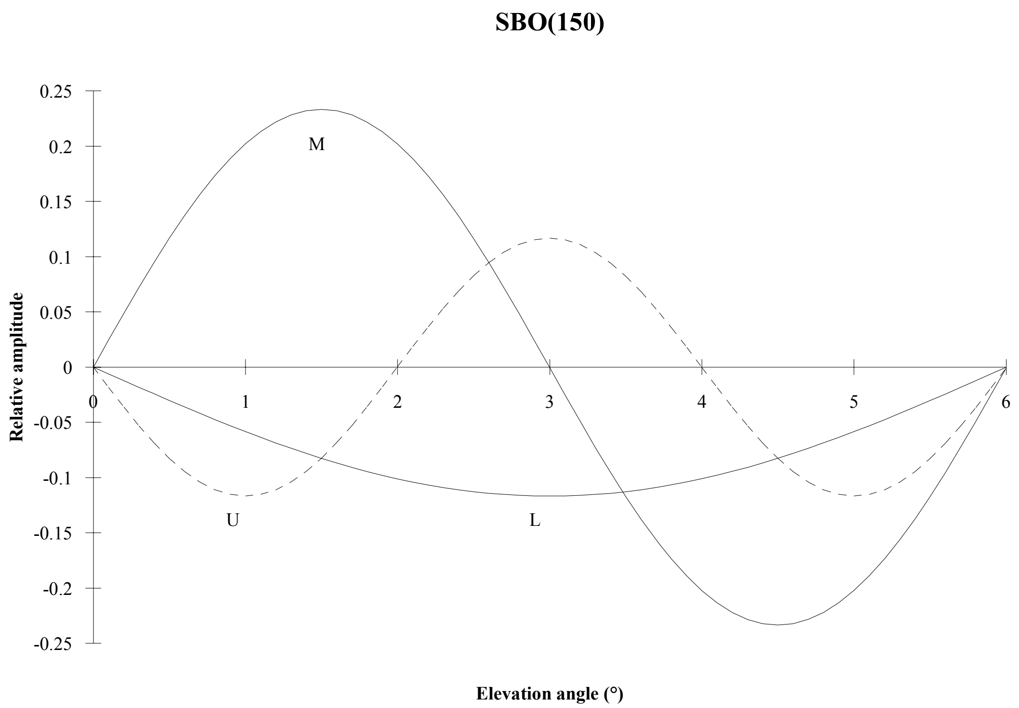

Figure 6-13 SBO element patterns.

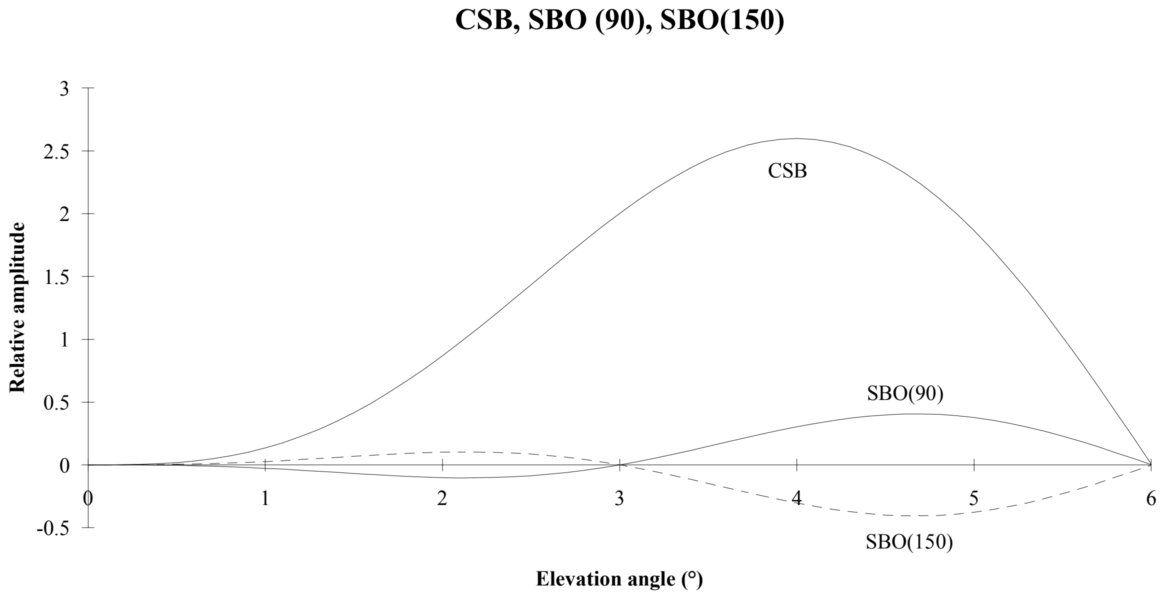

Figure 6-14 CSB and SBO radiation pattern for M-array System

The DDM is given by:

$$DDM = 2 \cdot \frac{E_{SBO}(\theta)}{E_{CSB}(\theta)}$$

To obtain the required sector width of ± 0.12θo for DDM = 0.0875, the amplitude $\mathbf{A_{CSB}}$ and $\mathbf{A_{SBO}}$ must have a ratio given by:

$$0.0875 = 2 \cdot \frac{E_{SBO}(\theta o - 0.12\theta o)}{E_{CSB}(\theta o - 0.12\theta o)}$$

$$\frac{A_{SBO}}{A_{CSB}} = 0.0437 \cdot \frac{\sin(\frac{\pi}{4} \cdot \frac{\sin(0.88\theta o)}{\sin\theta o})}{\sin(\frac{\pi}{4} \cdot \frac{\sin(0.88\theta o)}{\sin\theta o}) - \sin(\frac{3\pi}{4} \cdot \frac{\sin(0.88\theta o)}{\sin\theta o})}$$

and since $\sin\theta o \approx \theta o$

$$\frac{A_{SBO}}{A_{CSB}} \approx 0.0437 \cdot \frac{\sin(\frac{\pi}{4} \cdot 0.88)}{\sin(\frac{\pi}{4} \cdot 0.88) - \sin(\frac{3\pi}{4} \cdot 0.88)} = \underline{\underline{0.117}}$$

Figure 6-15 shows the DDM distribution v.s. glide path angle.

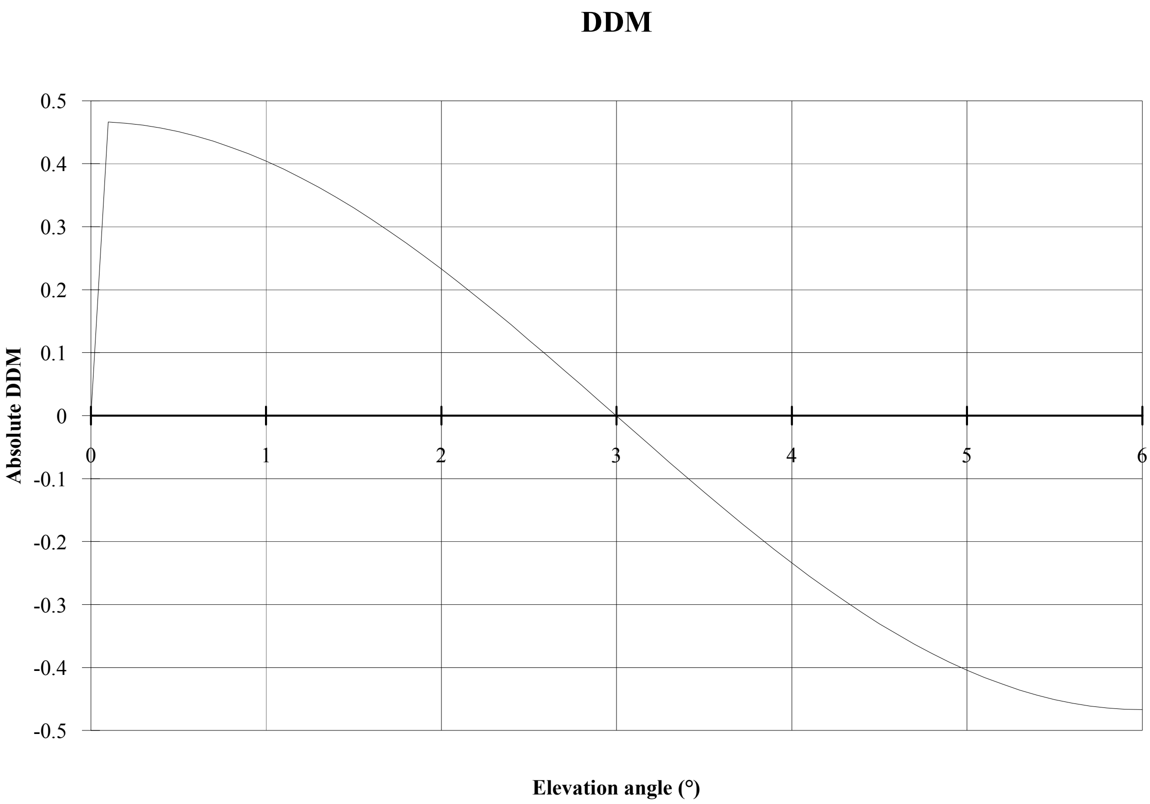

Figure 6-15 DDM distribution.

Figure 6-16 shows the feed signals for M-Array system expressed as vectors:

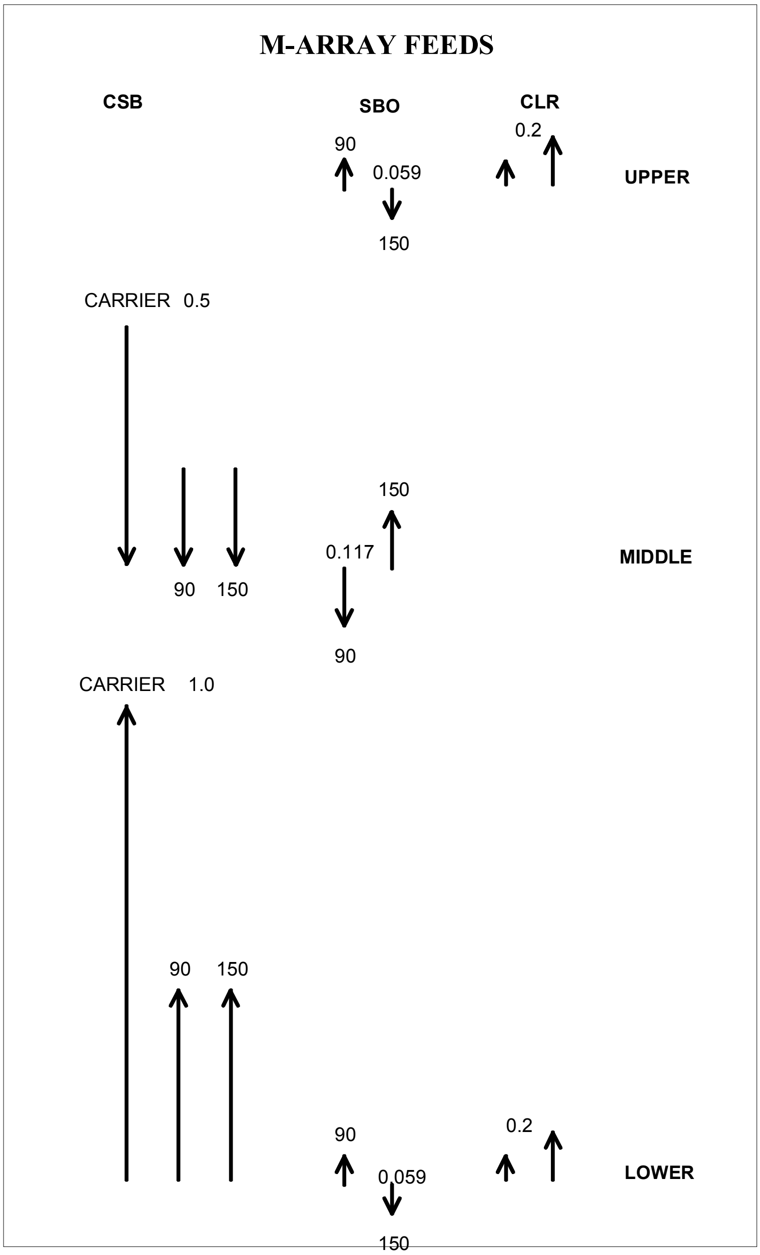

Figure 6-16 Vector representation of M-Array feed signals

The CSB is referenced to the lower antenna with amplitude 1 and zero phases. The CSB to middle antenna is one half (-6dB) and the phase is180°.
The SBO to middle antenna is 0.117 referenced to the Carrier of the CSB to lower antenna, and the phase is zero for the 150 Hz components.
The SBO to upper and lower antenna is one half (-6dB) of the SBO to middle antenna and the phase is 180°.
The clearance signal (CLR CSB) is fed to upper and lower antennas only. The amplitudes are equal, and phase between lower and upper feed is zero.

6.3.2 The Clearance signal

For low elevation angles, the CSB radiation intensity is too low to give the required field strength.

To overcome this problem, a separate transmitter generating a "fly-up" signal is used to create a strong signal below 1.5° angle.

The carrier frequency of the CLR signal is nominally 15 kHz below the Course carrier frequency.

The modulation depth is 20% 90 Hz and 60% 150 Hz i.e. 343 μA "fly-up".

The aircraft receiver's detector is capturing the stronger of the two carriers (CSB and CLR) thus suppressing the weakest signal by approximately the square of the ratio between the CSB and CLR carrier levels.

The CLR signal is fed to the **Lower** and **Upper** antenna elements, which result in a radiation, pattern having a null at the Glide Path Angle θo.

The radiation pattern is

$$E_{CLR} = 2A_{CLR}(\sin\frac{\pi}{2}\cdot\frac{\theta}{\theta o} + \sin\frac{3\pi}{2}\cdot\frac{\theta}{\theta o})$$

$$A_{CLR} = 0.2A_{CSB}$$

Figure 6-17 shows the CLR element patterns and the resultant CLR signal.

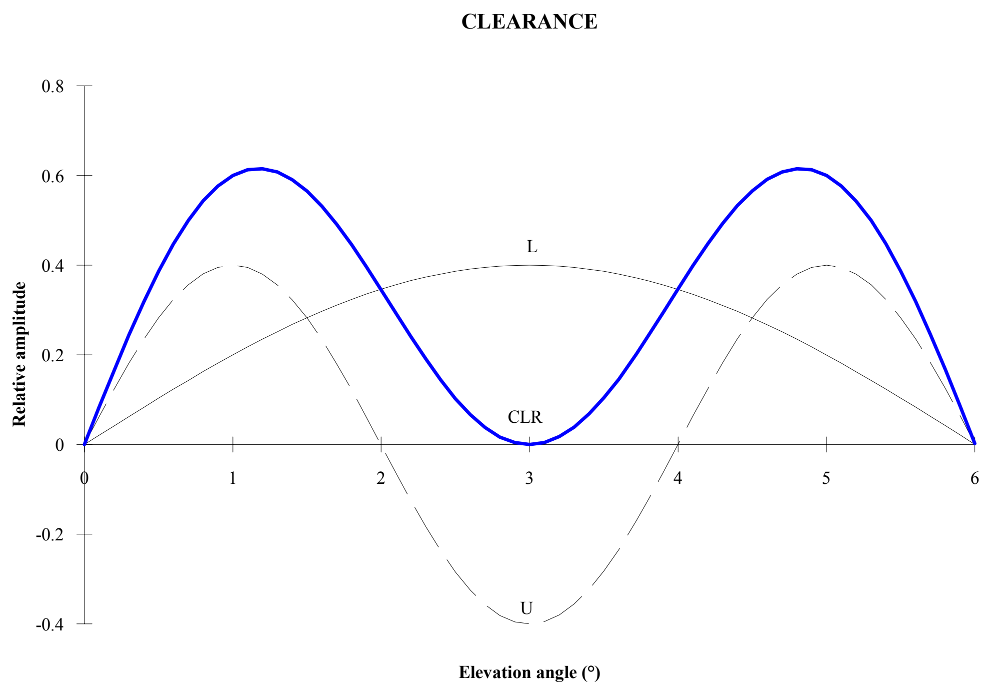

Figure 6-17 M-Array Clearance Far Field Radiation Pattern

6.4 ANTENNA ELEMENT OFFSET

Since the glide path antenna is of the order of 10 m high, it cannot be sited on or close to the runway surface. Typically it is located 120 m to the side of the runway and opposite the required touchdown point.

This amount of antenna offset has only a small effect on the signal quality. The most noticeable effect is that the locus of zero DDM is no longer an exactly straight line but has a hyperbolic bend or "flare" over the final few hundred meters.

To compensate for this effect the antenna elements are offset. This offset is such that the distance from each of the elements to the centreline of the runway adjacent to the mast is the same.
To calculate the offset, use Figure 6-18, which gives the offset equal to:

$$\text{Offset} = \frac{h_2^2 - h_1^2}{2d} = \frac{4H^2 - H^2}{2d} = \frac{3H^2}{2d}$$

where d = distance from the base of the antenna mast to the centre line
h1 = height of lower antenna element (H)
h2 = height of upper antenna element (2H)

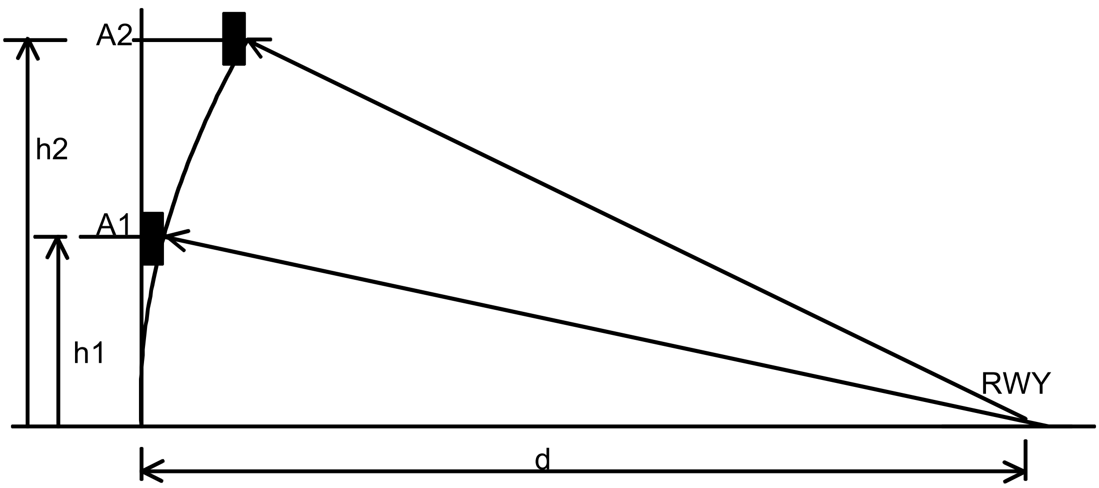

Figure 6-18 Geometric illustration of antenna element offset

Taking into account the **sideways slope (SSL)** of the reflection plane between the runway and GP mast the offset value should be modified by the factor S:

$$S = H \cdot \sin(SSL)$$

which is subtracted from the offset value calculated for a perfect horizontal plane:

$$\text{Offset A1} = 1.5\frac{H^2}{d} - S$$

SSL is defined as **positive** when there is a **downward** slope from the centreline to the GP mast.

6.4.1 Null Reference Antenna System

$$\text{Offset A1} = 1.5\frac{H^2}{d} - S$$

6.4.2 Sideband Reference Antenna System

$$\frac{(1.5H)^2 - (0.5H)^2}{2d} = \frac{H^2}{d}$$

$$\text{Offset A1} = \frac{H^2}{d} - S$$

6.4.3 M-Array Antenna System

$$\frac{(3H)^2 - (2H)^2}{2d} = 2.5 \cdot \frac{H^2}{d} \quad \text{for the upper}$$

$$\frac{H^2 - (2H)^2}{2d} = -1.5 \cdot \frac{H^2}{d} \quad \text{for the lower}$$

$$\text{Offset A3} = 2.5 \cdot \frac{H^2}{d} - S$$

$$\text{Offset A1} = -1.5 \cdot \frac{H^2}{d} + S$$

where $S = H \cdot \sin(SSL)$

6.4.4 Forward Slope and Sideways Slope

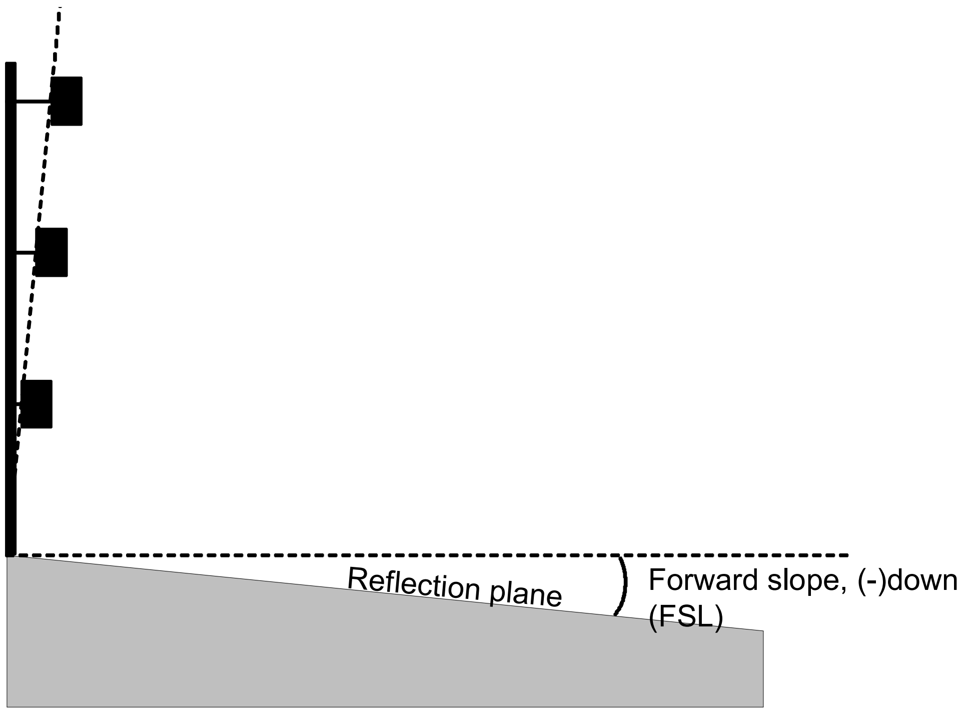

Figure 6-19 Definition of Forward Slope (FSL)

Forward slope: The average forward slope (FSL) of the Beam Forming Area in front of the GP antenna mast.

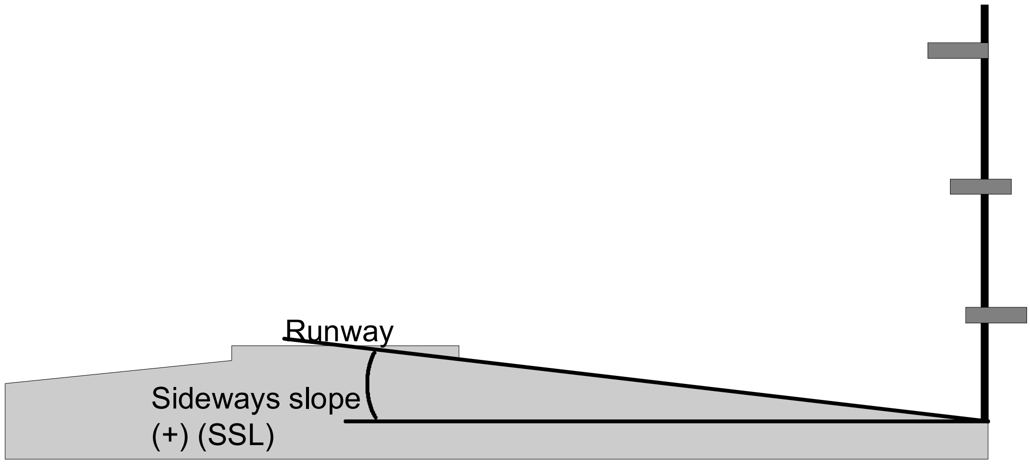

Figure 6-20 Definition of Sideways Slope (SSL)

Sideways slope: The average sideways (cross-) slope (SSL) of the Beam Forming Area in front of the GP antenna mast.

6.4.5 Ground current

The H-field from each antenna element is inducing ground currents in front of the glide Path antenna system.
These currents are generating the signals, which we have previously modelled as image antenna signals.
The ground currents can be decomposed into CSB and SBO currents.

Figure 6-21 shows SBO ground currents for Null Reference, Sideband Reference and M-Array antenna systems.
The 0 dB reference level is equivalent to a ground current level which will cause a bend of maximum 4μA if the ground plane ended at this distance from the GP.

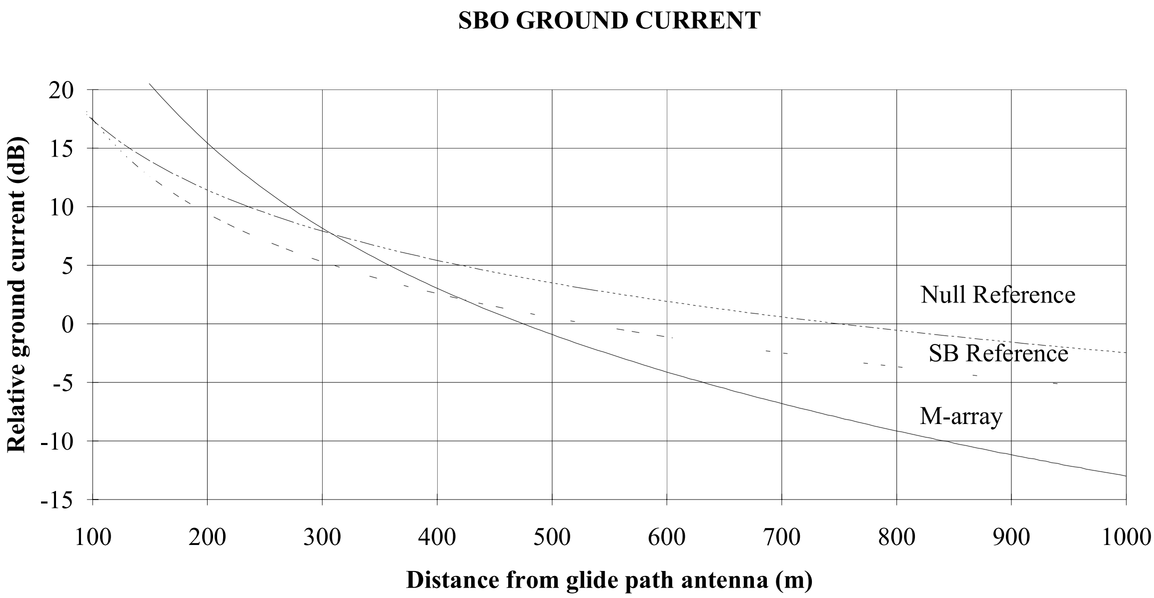

Figure 6-21 Relative SBO ground current referenced to the critical level 0 dB

7. MONITORING

7.1 LOCALIZER MONITORING
7.1.1 General
7.1.2 Principal description of Monitor Network Signal processing

7.2 GLIDE PATH MONITORING
7.2.1 Integral Monitoring.

7.3 GLIDE PATH NEAR FIELD MONITORING
7.3.1 Theoretical analysis
7.3.2 Null Reference Antenna System NF monitor considerations
7.3.3 Sideband Reference Antenna System NF monitor considerations
7.3.4 M/Array Antenna system NF monitor considerations

Null Reference Array DDM contours	(2 pages)
Sideband Reference Array DDM contours	(2 pages)
Sideband Reference Array SBO contours	(2 pages)
M/array DDM contours	(2 pages)
M-Array SBO Field contours	(2 pages)

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7 MONITORING

7.1 Localizer Monitoring

7.1.1 General

To ensure correct operation of the localizer, it is monitored in three different ways. A **near field** antenna monitors the **course line**, which is located about 50 to 200 m in front of the antenna system.

The **course line** is also monitored by an **integral monitor**. This is obtained by sampling the signal in each antenna element and combining them in-phase in a monitor network to simulate the far field course line.

An azimuth angle equal to the course sector to the right of the course line is also simulated in the monitor network. Hence, the **course sector width** and **displacement sensitivity** can be monitored.

7.1.2 Principal description of Monitor Network Signal processing

The Six Elements Monitor Network MO416 will be used as an example of signal throughput description.
The network has an input for each return signal from the antenna.
In-phase power splitters provide two paths from each input:
One path is for the course line combiner and the second path for the course sector combiner. Figure 7-1.

For the course line, all signal paths from the antenna elements to the CL output of the network must be of equal electrical length.
All course line paths within the network are made equal, and all monitoring cables between antenna and network must have the same electrical length.

To simulate a given **course sector width** the signal from each antenna must be given a phase shift θ, depending on the element offset from the course line. This phase shift, relative to a fictious antenna element on the course line is

$$\theta_n = a_n \sin \frac{CS}{2}$$

where a_n is the element offset (in electrical degrees), see Figure 7-1.

This phase shift has been taken care of by 50Ω delay lines laid out on the micro strip board, using element no. 1 as reference.

Since these delays will be exact for one course sector width and one frequency only, a phase shifter is added to cover a range of sector widths over the localizer band.

Offset	El. degrees
a1	1050
a2	640
a3	157
a4	157
a5	640
a6	1050

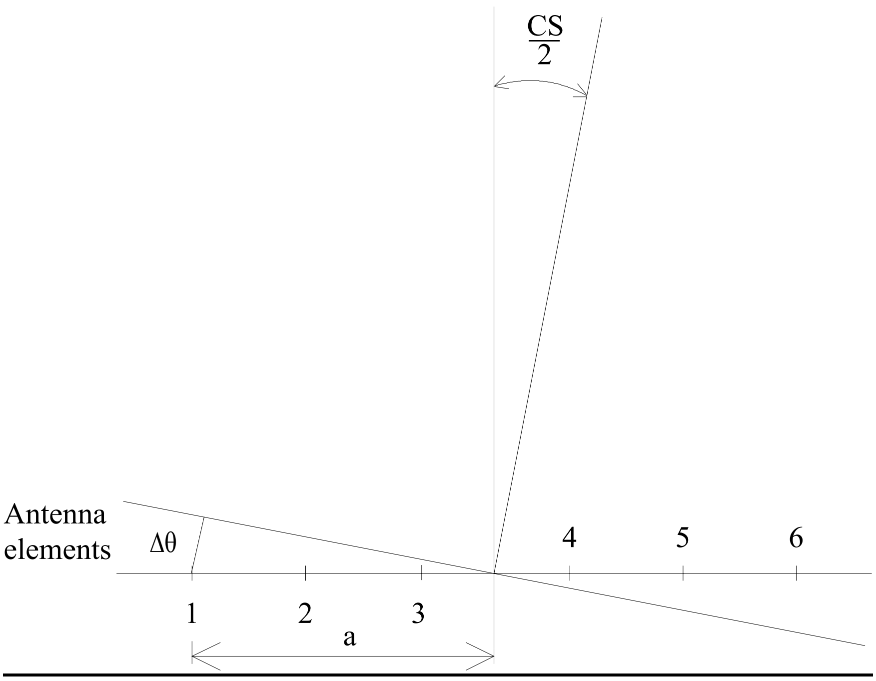


Figure 7-1 Simulation of Course Sector Monitor

The only adjustable components in the monitor network are the two-phase shifters PH1 and PH2, for **course line** and **course sector** respectively.
These must be adjusted on site following completion of the localizer antenna system trimming.
Phase PH1 is adjusted to give 0% DDM (difference in depth of modulation) and PH2 is adjusted to give 15.5% DDM in the monitor receiver.

7.2 GLIDE PATH MONITORING

7.2.1 Integral monitoring

The signals from the pickup probes, which are proportional to the radiated signals from the antenna elements, are fed through the equal length monitor cables to the Monitor Network.
The far field Glide Path Angle, the lower Sector Width and the Clearance (if applicable) are simulated in the network by combination of the signals.

In order to simulate a specific monitor point in the far field we monitor the signal from each antenna with correct level and phase and then combine the signals into one output signal.

To obtain the correct signal level we calculate for the angle of interest (f.ex. 2.3°) the relative level according to the formula:

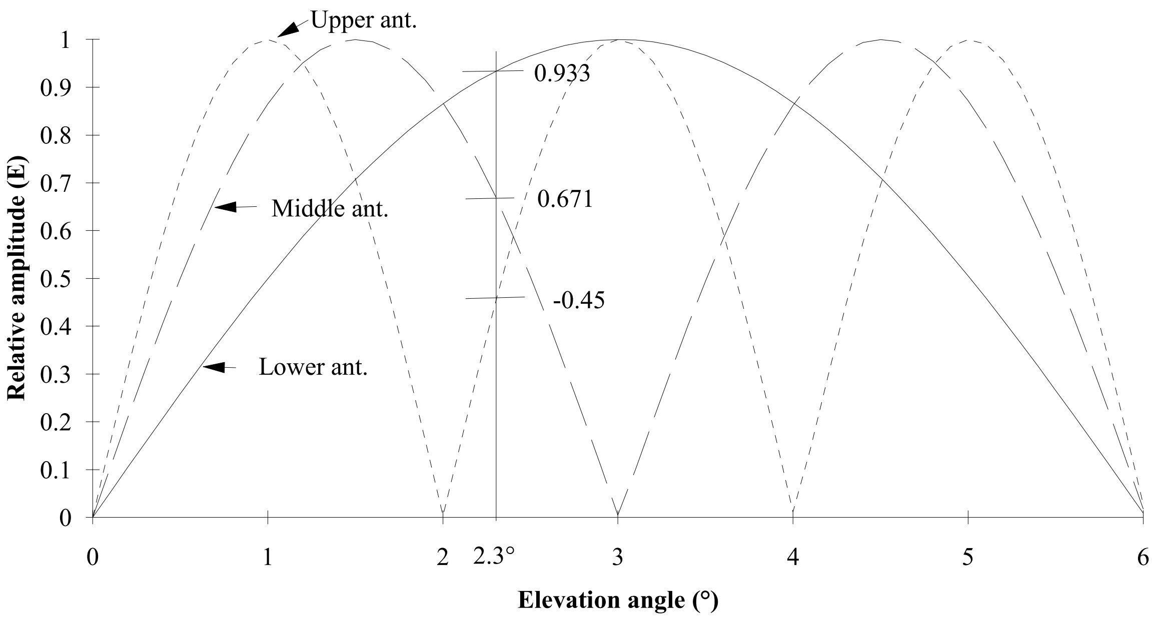
$$E_a = \sin(\frac{2\pi}{\lambda} H_a \sin\theta)$$

where H_a is the antenna height.

For frequency 332 MHz and Lower Antenna height 4.31 m, the following signal levels for θ = 2.3° will be:

$E_L = 0.933$ (0 dB), 0° phase
$E_M = 0.671$ (-2.9 dB), 0° phase
$E_U = -0.450$ (-6.3 dB), 180° phase

The diagram below shows the lobing for each antenna in the M-Array system according to the formula give above:



The monitor network should include the above given attenuation values for Middle Antenna (2.9 dB) and Upper Antenna (6.3 dB) referenced to Lower Antenna (0 dB). The signal path must also include a delay of 180° for Upper Antenna return signal.

7.3 GLIDE PATH NEAR FIELD MONITORING

7.3.1 Theoretical analysis

The near field monitor measures variations of the radiated signals, which may result from alterations in the condition of the ground near to the antenna system or mechanical misalignment of the antenna elements.

The distance to the monitor antenna is so short that there will be a large phase error caused by difference between the path lengths to the antenna elements.
This phase error will result in large variations of the DDM along the 3° path, depending on the distance for the radiating antenna elements.
The phase error between one antenna and its image antenna will be calculated in the following, based on Figure 7-3.

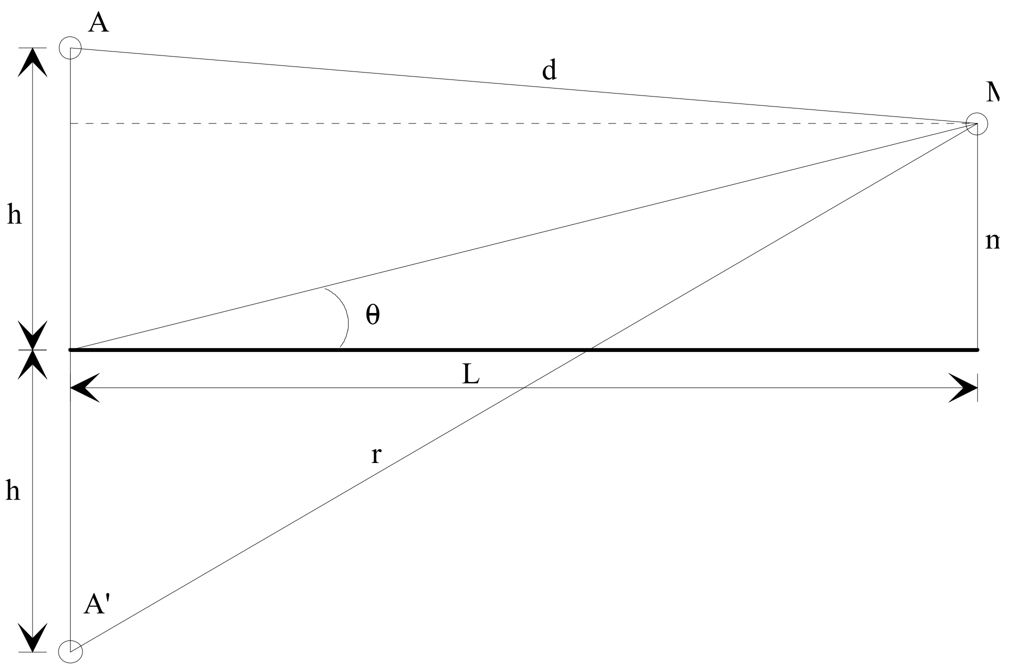


Figure 7-2 Path lengths from an Antenna element A and it's Image A'

to a Monitor point M

The monitor antenna height **m** expressed by distance **L** and elevation angle θ is:

$$m = L \tan \theta$$

The electrical distance of the direct signal Φ_d is:

$$\Phi_d = \sqrt{L^2 + (h-m)^2} \cdot \frac{2\pi}{\lambda}$$

In the expression of Φ_r, a 180° phase shift caused by the ground reflection, must be included.

The electrical distance of the reflected signal r is:

$$\Phi_r = \sqrt{L^2 + (h+m)^2} \cdot \frac{2\pi}{\lambda} + \pi$$

The phase of the total received signal at the monitor point M will be as shown in Figure 7-3.

$$\Phi_M = \frac{\Phi_r + \Phi_d}{2}$$

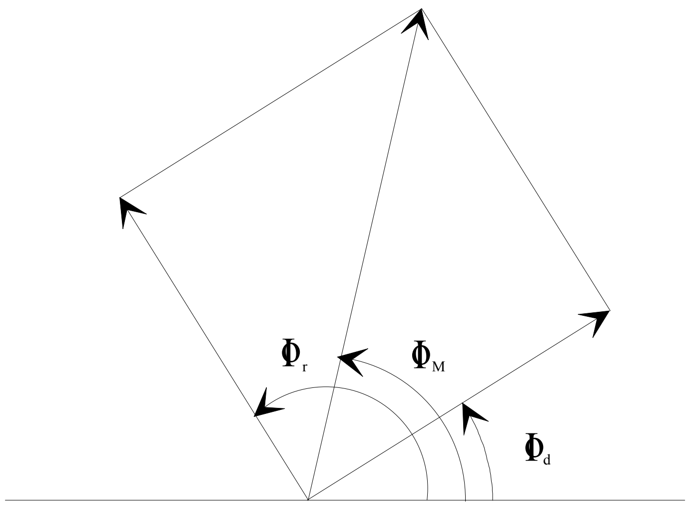
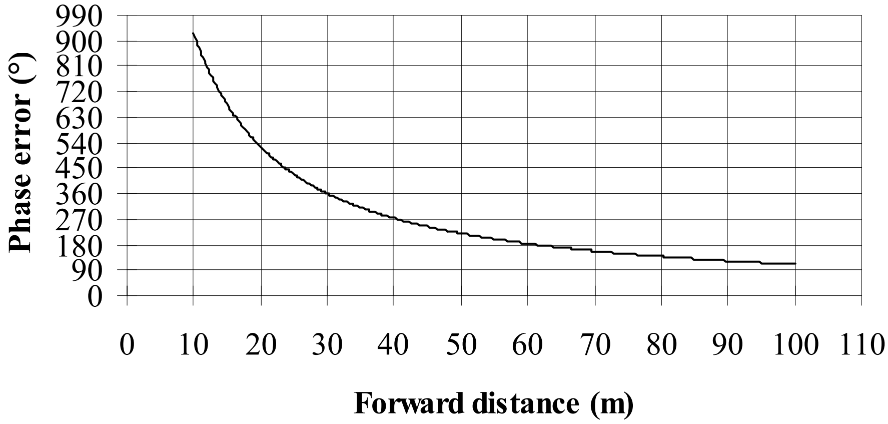


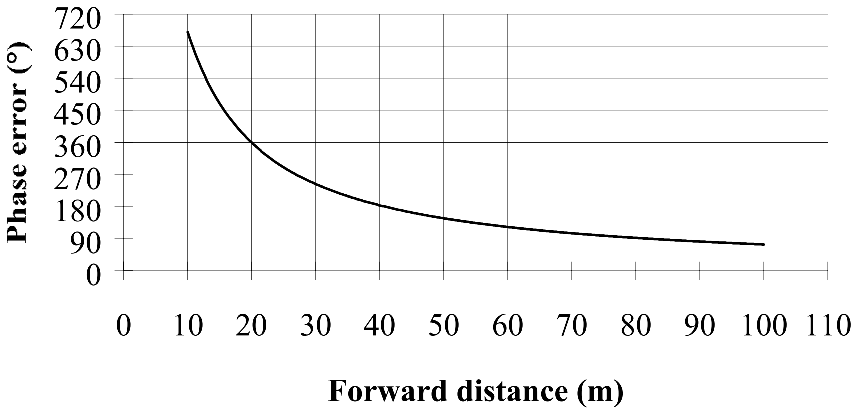
Figure 7-3 The formation of the Phase of the total signal at M

The phase error $\Phi_{MU} - \Phi_{ML}$ as a function of the distance L from the antenna system is shown in Figure 7-4 for θ = 3°.

Null Reference System



Sideband Reference System



M-Array System

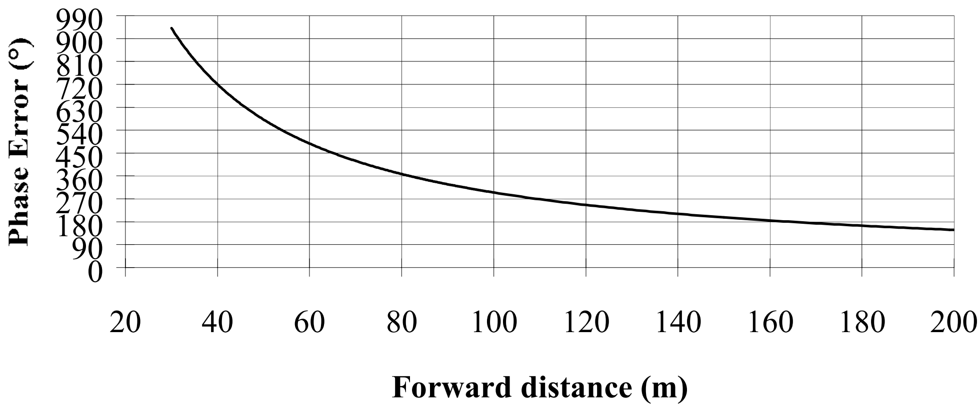


Figure 7-4 The phase error vs. the distance to the antenna system for Null Reference, Sideband Reference and M-Array antenna systems

7.3.2 Null Reference Antenna System Near Field Monitor considerations

To monitor the glide path angle, the phase error should be 0° or 360°. However, none of the distances are convenient.
For a nearly 0° phase error the distance must be more than 500 m which gives a very high monitor antenna.
For 360° phase error, the distance is 30 m. This very short distance results in a 16° elevation angle to the ground reflected signal from the upper antenna element.
The ground reflection coefficient could be as small as 0.6 for this reflected signal which will give an unacceptable error.

The monitor position chosen is given by **180°** phase error. For this phase error, the monitor antenna must be located at approximately **62 m** to obtain a DDM = 0.

The correlation between the guidance signal received at the monitor position and in the far field, for different errors in the antenna system, is good. However, due to the 180° phase error the sense is opposite.
The DDM distribution around the monitor point is given in Figure 7-5.

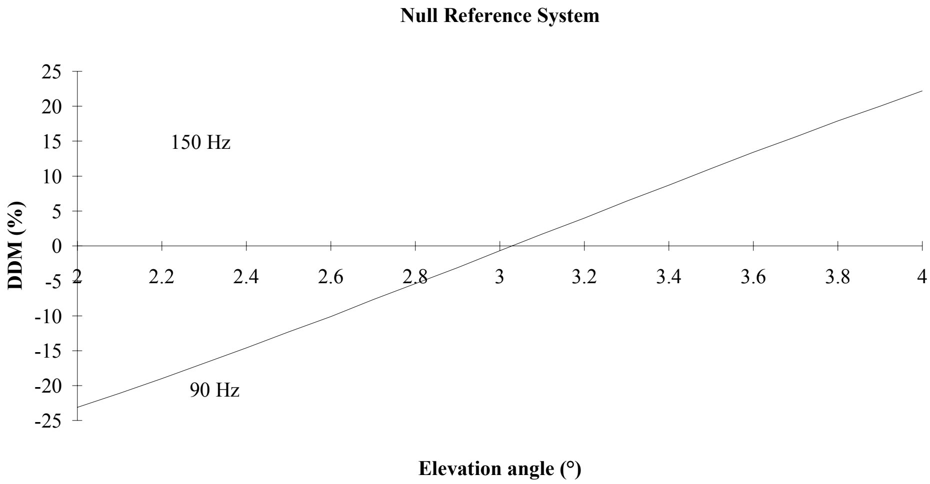


Figure 7-5 DDM distribution at 62 m from the antenna system

7.3.3 Sideband Reference Antenna System Near Field Monitor considerations

To monitor the glide path angle, the phase error should be 0° of 360°. However, none of the distances are convenient.
For a nearly 0 phase error, the distance must be more than 500 m which gives a very high monitor antenna.
For 360° phase error the distance is 21 m. This very short distance results in a 20° elevation angel to the ground reflected signal from the upper antenna element.
The ground reflection coefficient could be as small as 0.6 for this reflected signal which will give an unacceptable error.

The monitor position chosen is given by **180°** phase error. For this phase error, the monitor antenna must be located at approximately **41 m** and at 2θ (6°) to obtain a DDM = 0.

The correlation between the guidance signal received at the monitor position and in the far field, for different errors in the antenna system, is good.
However, above and below the monitor position there is a **flydown** signal.
The DDM distribution around the monitor position is given in Figure 7-6.

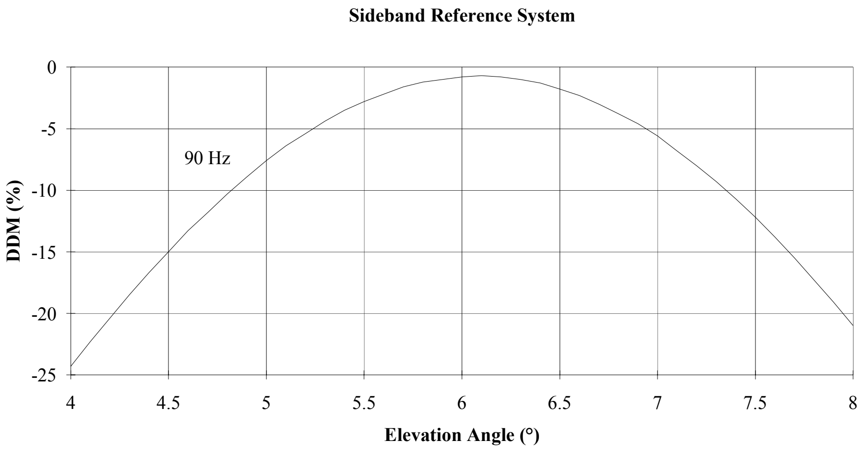


Figure 7-6 DDM distribution at 42 m and 6° elevation

As shown in the figure, the DDM is not exactly zero at 6°, but 0.8%. The reason is significant difference in signal attenuation from the two elements at this short distance.
To summarize, Table 7-1 shows the monitor alarm conditions for different errors in the transmitter and antenna distribution system.

	Far Field		Near Field
Parameter	GP alarm	SW alarm	41.2 m GP alarm
SBO/CSB ratio		2.0 dB	
SBO/CSB phase		41°	
Au/Al ratio	2.0 dB	2.5 dB	2.0 dB
Au/Al phase	30°	45°	40°
Wet snow layer	30 cm	>50 cm	40 cm

Table 7-1 Monitor alarm conditions, Sideband Reference System.

(3° ±0.22° and 0.72° ±0.18°)

7.3.4 M-Array Antenna System Near Field Monitor considerations

To monitor the glide path angle, the phase error should be 0° or 360°. For a nearly 0° phase error, the distance must be more than 1000 m which gives a very high monitor antenna. For **360°** phase error, the distance is approximately **82 m**.

The monitor position used by NORMARC is given by a **360°** phase error.
The correlation between the guidance signal received at the monitor position and the far field, for different errors in the antenna system, is good.
The DDM distribution around the monitor point is given in Figure 7-7 .

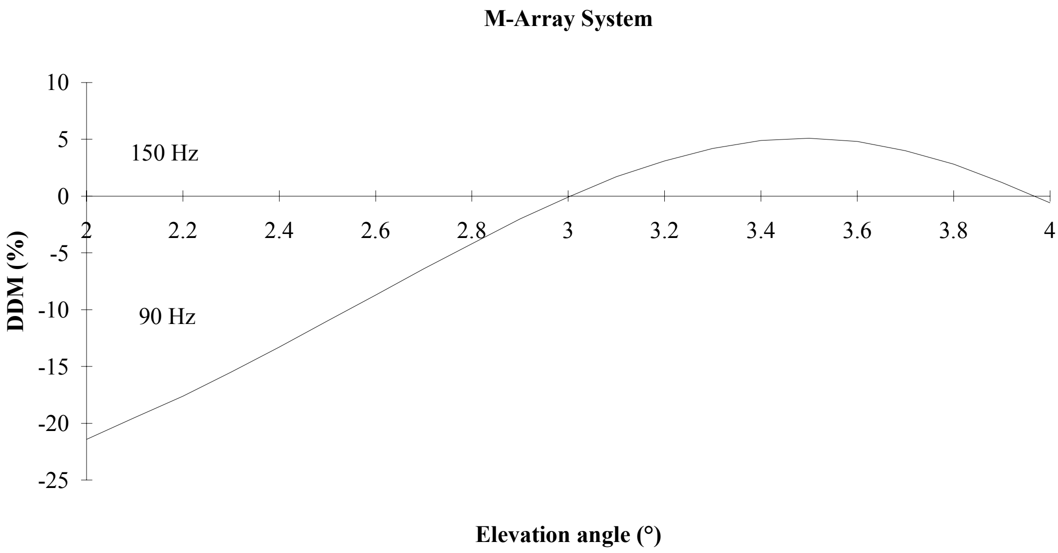


Figure 7-7 DDM distribution at 82 m from the antenna system

Table 7-2 shows the monitor alarm conditions for different errors in the transmitter and antenna system.

Parameter	GP alarm	SW alarm	Low Clearance
SBO/CSB ratio		±2.0 dB	
SBO/CSB phase		±40°	
Au/Am ratio	±2.5 dB		
Au/Am phase	±57°		
Al/Am ratio	±3.5 dB	±0.8 dB	±0.6 dB
Al/Am phase	±57°	±20°	±15°
Wet snow layer	60 cm		

Table 7-2 Monitor alarm conditions, M-Array System

8. FLIGHT INSPECTION

8.1 REQUIREMENTS AND TOLERANCES

8.2 MULTIPATH ANALYSIS

8.3 MONITOR ALARM LIMITS

Reprints from Doc. 8071 Volume II

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8 FLIGHT INSPECTION

Adequate monitoring, ground testing and maintenance, on a routine and continuing basis, should be normal means of ensuring that the ILS signal-in-space performs within the specified tolerances, and that the operational integrity and serviceability of the ILS facility is maintained. The purpose of the flight inspection should be to:

* Confirm the correctness of the setting of essential signal-in-space parameters, and determine the operational safety and acceptability of the ILS installation.

* Periodically correlate signal patterns observed in flight and from the ground.

The flight-testing is sufficiently extensive to determine the effects, which the ground environment will have on the facility performance.
The most common effect is reflections of the radiated signal (multipath), which give “bends”, or "scalloping" on the course line or glide path structure. See Figure 8-1.
Another effect of the environment is shadowing of the radiated signal, which will give a reduction in the signal strength in certain sectors.

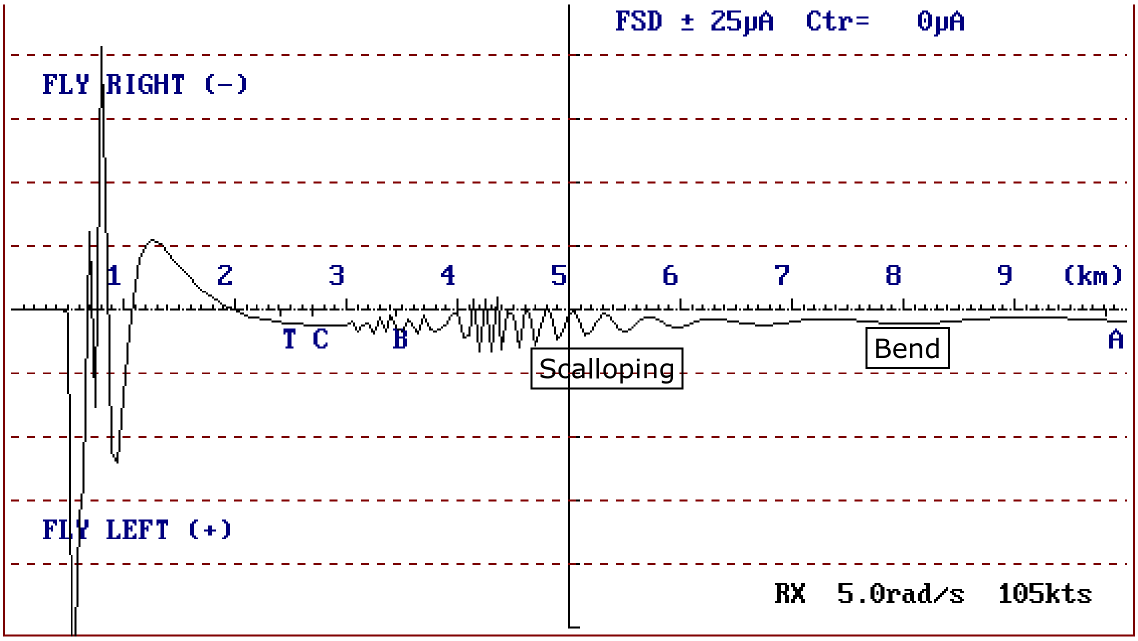


Figure 8-1 Roughness, scalloping and bend on the course structure

8.1 Requirements and tolerances

The requirements and tolerances for flight inspection are given in the ICAO Document 8071, volume II. A summary of the requirements is reproduced on the following pages.

8.2 Multipath analysis

The airborne receiver receives both the direct radiated, and the reflected signals.
The RF phase between the signals is given by the difference in path lengths and the phase of the reflection coefficient. As the aircraft flies along a flight path the difference in path lengths varies which gives a change of the RF phase difference. This results in a variation in DDM of the received signal.

The DDM can be calculated in the following way:

$$\mathrm{DDM} = \frac{2E_{SBO}}{E_{CSB}} \cos\gamma$$

where:

$$E_{SBO} = E_{SBO}(\mathrm{direct}) + E_{SBO}(\mathrm{reflected})$$
$$E_{CSB} = E_{CSB}(\mathrm{direct}) + E_{CSB}(\mathrm{reflected})$$
$$\gamma = \text{RF phase between } E_{SBO} \text{ and } E_{CSB}$$

The path structure is mainly of interest at the course line or glide path angle where $E_{SBO}(\mathrm{direct}) = 0$.The reflected signal is given by the radiation in the direction of the reflecting object (φ') and the reflection coefficient ρ.
Hence,

$$\mathrm{DDM} = \frac{2\rho E_{SBO}(\varphi')}{E_{CSB}(0) + \rho E_{CSB}(\varphi')} \cdot \cos\gamma$$

As $E_{CSB}(0)$ is the maximum or near the maximum radiation, and ρ is in the order of 0.1 $E_{CSB}(0) >> \rho E_{CSB}(\varphi')$.

Hence,

$$\mathrm{DDM} = \frac{2\rho E_{SBO}(\varphi')}{E_{CSB}(0)} \cdot \cos\gamma$$

where γ is the phase between the reflected SBO signal and the directly radiated CSB signal. The phase γ may vary several periods along the flight path, which results in a variation of DDM through positive and negative values.

The DDM structure, as measured along a flight path (CL or GP) is given on a flight recording. An example is shown in Figure 8-2.

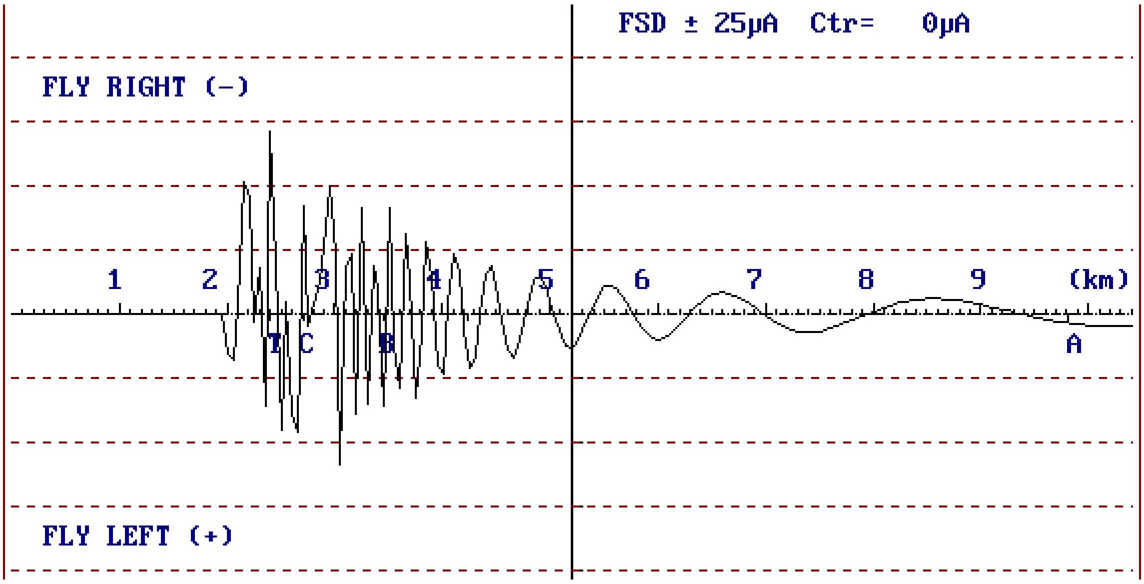


Figure 8-2 DDM structure

The bend period gives information on the direction to the reflecting object. Based upon some trigonometric calculations, the direction to the reflecting object is given by:

$$\cos\beta = 1 - \frac{\lambda}{\Lambda}$$

and

$$\frac{\Lambda}{\lambda} = \frac{1}{1-\cos\beta}$$

where λ is the **electrical** wave length in meters,
and Λ is the **bend** wavelength in meters.

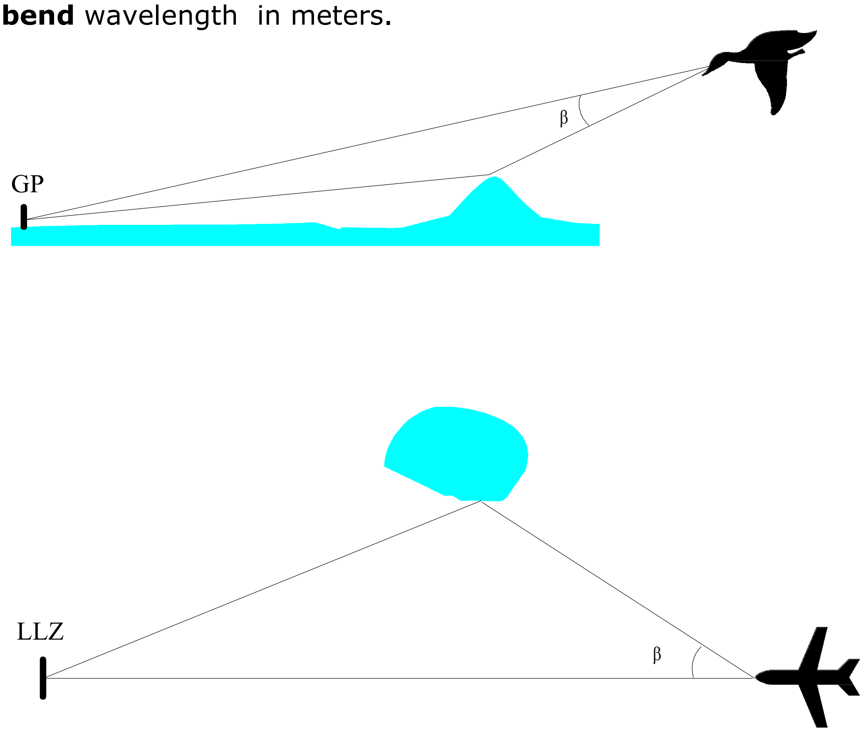


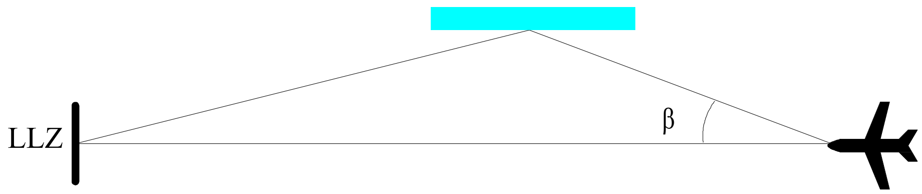
Figure 8-3 The angle β to the reflecting object

As shown in Figure 8-3 the angle β varies along the flight path. The angle is maximum when the aircraft passes the object and the bend wavelength is at a minimum.
This information is of help in analysing a flight record with significant bends.

By using the equation for cosβ (above) for different sections of a flight path, distances which give several values for β, the reflecting object can in most cases be pinpointed by the crossing point of the lines from the aircraft to the object.

On a flight recording of the DDM structure the peak amplitudes will be attenuated as a function of the aircraft's ground speed according to the formula:

$$\text{Attenuation:} \quad \alpha = \frac{1}{\sqrt{1+896(1-\cos\beta)^2}}$$



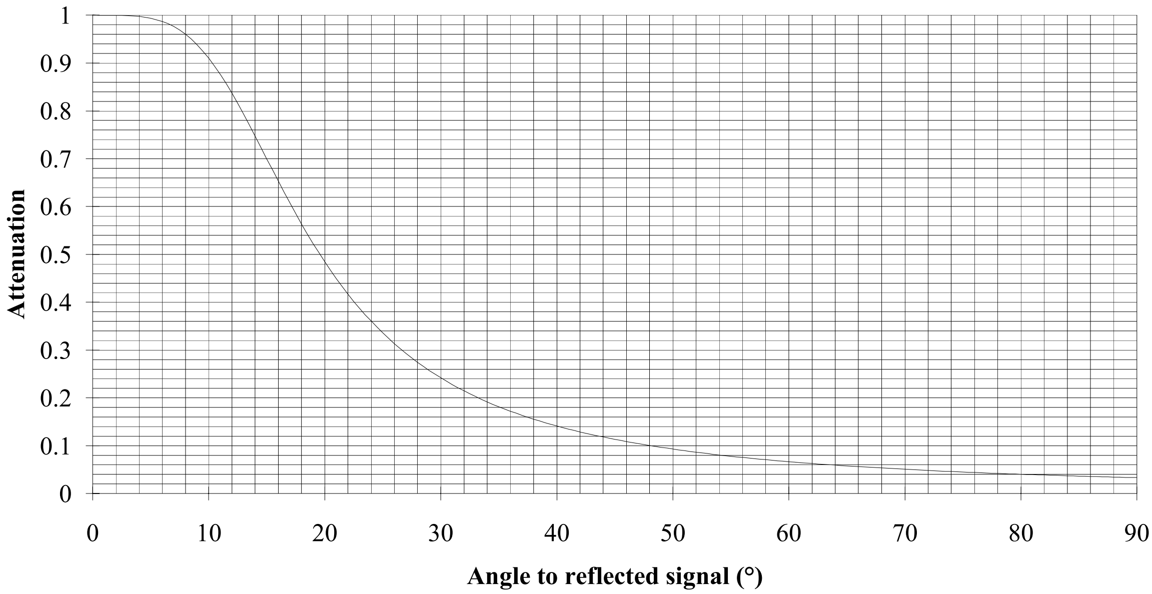


Figure 8-4 Attenuation of localizer beam bends caused by the aircraft ground speed of 105 knots

8.3 MONITOR ALARM LIMITS

Interpreted from Manual of Testing of Radio Navigation Aids, Volume II.

LOCALIZER

Displacement Sensitivity DS = 0.145% DDM/meter at ILS Reference Datum.

CL alarm Cat I: $\pm 10.5\text{m} \cdot 0.145 = \pm 1.52\%\text{DDM} = \pm 14.7\mu\text{A}$

CL alarm Cat II: $\pm 7.5\text{m} \cdot 0.145 = \pm 1.09\%\text{DDM} = \pm 10.5\mu\text{A}$

CL alarm Cat III: $\pm 6.0\text{m} \cdot 0.145 = \pm 0.87\%\text{DDM} = \pm 8.4\mu\text{A}$

DS alarm Cat I, II: $\pm 17\% := \pm 2.64\%\text{DDM} = \pm 25.5\mu\text{A}$

DS alarm Cat III: $\pm 10\% := \pm 1.55\%\text{DDM} = \pm 15\mu\text{A}$

GLIDE PATH

CL alarm Cat I, II, III: $\frac{75\mu\text{A}}{0.36°} \cdot \pm 0.075\theta = \pm 46.9\mu\text{A}$

DS alarm Cat I: $\frac{75\mu\text{A}}{0.36°} \cdot \pm 0.0375\theta = \pm 23.4\mu\text{A}$

DS alarm Cat II, III: 25% of 8.75% DDM = $\pm 2.19\% DDM = \pm 18.7 \mu A$

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9. EXERCISES

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9 EXERCISES

1. LLZ
   Course Sector width CS= 5.5°
   At azimuth angle φ the DDM = 13.2%
   Calculate angle φ (°).

2. LLZ
   CS = 4°. Calculate DDM at 2° azimuth

   a) With no phasing error

   b) With 30° SBO/CSB phasing error

3. LLZ
   At Φ = 1° (azimuth) the SBO and CSB relative amplitudes are 0.26 and 10 respectively.
   Calculate DDM and CS.

4. LLZ
   CS = 4.5°. Calculate DDM 1.8° to the left of CL seen from the aircraft. (DDM in %, μA)

5. LLZ
   CS = 4.5°. At 0.6° azimuth to the left seen from the aircraft calculate

   a) DDM

   b) m_{90}, m_{150} (modulation depth)

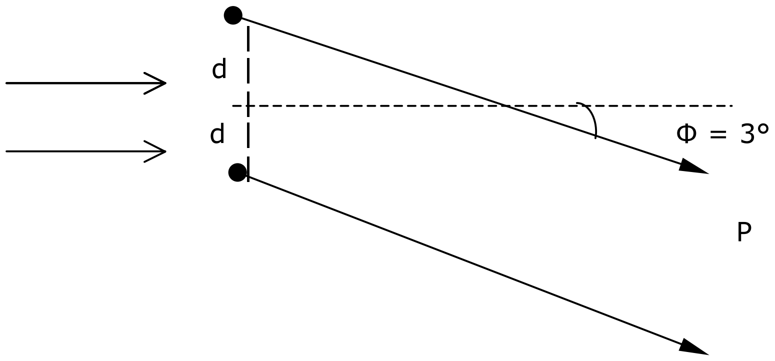
6. In front of a LLZ the DDM is 10.0% 2° from the CL.
   Calculate CS.

7. GP
   Glide path angle (GPA = 3°). The sector width (SW) is 0.75°. At SW/2 points DDM is 75µA. Calculate DDM at 0.36° below GPA (Annex 10 half sector width).

8. GP
   GPA = 3°. SW = 0.72°. GPA alarm limits 0.14°.
   Calculate DDM alarm limit.

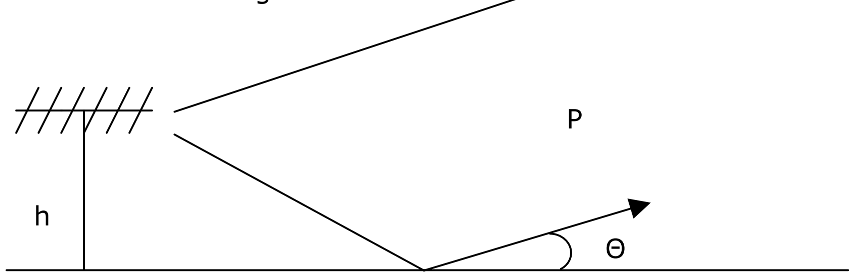
9. One antenna pair only from a LLZ array is radiating:
f= 110.3MHz d = 1.19m

CSB	SBO
10∟0°	1.6∟-90°
10∟0°	1.6∟+90°



Calculate DDM in point P (far field) at 3° azimuth.

10. LZZ above the ground.



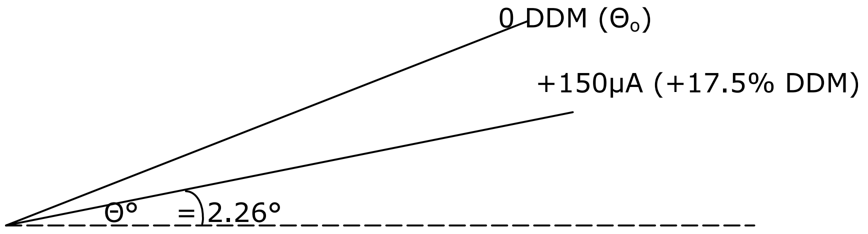
λ = 2.73m
θ = 3°

a) If antenna height (h) is increased from 2m to 3m what is the net increase in field strength (dB) in point P (far field)?

b) Increase (h) further from 3m to 4m. Calculate increased field strength.

11. GP
$\Theta_o = 3°$
At 0.12 Θ_o below path DDM is 60µA.
Calculate the sector width (SW).

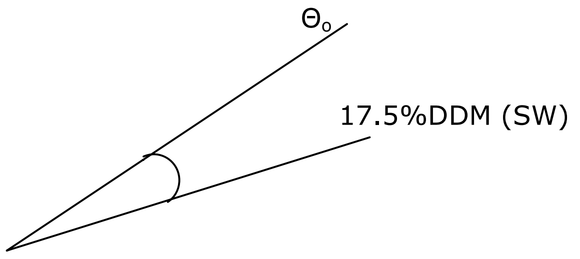
12. NULL REF GP



At 2.26° elevation DDM is + 17.5%.
A phase error of 27° is introduced between SBO and CSB.

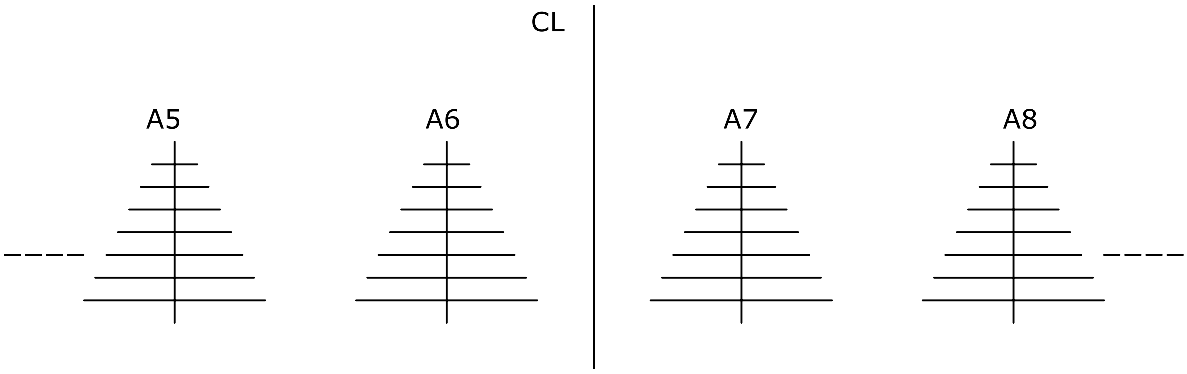
a) Calculate new DDM at Θ = 2.26°.

b) What is the effect of the de-phasing at Θ_o?



c) Calculate the modulation depth m_{90}, m_{150} at SW = 17.5% DDM.

13. NORMARC 3523



CSB	10∟0°	18∟0°		18∟0°	10∟0°
SBO_{90}	1.03∟90°	2.33∟90°		2.33∟-90°	1.03∟-90°
SBO_{150}	1.03∟-90°	2.33∟-90°		2.33∟90°	1.03∟90°

Calculate DDM in A5, A6, A7 and A8.

a) With normal radiation.
b) With 90°-stub in SBO.

14. For a localizer with CS= 5° what is the DDM and SDM at

a) 0° (CL)

b) 2.5° azimuth.

c) 5.0° azimuth.

15.

a) Calculate the SBO power for a localizer having a carrier power of 10W.

b) What is the CSB power?

16. NULL-REF GP

GPA: Θo = 3°

f = 332.3MHz

SBO = 0.117 (A_{SBO})

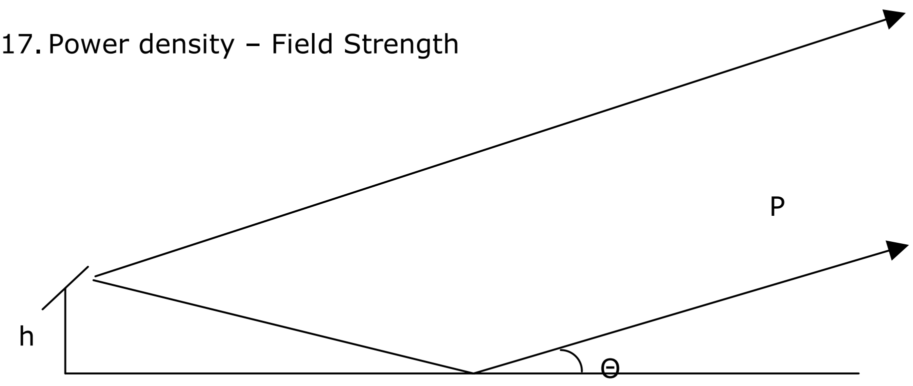
CSB = 1 (A_{CSB})

a) Calculate antenna height (spacing).

b) Calculate SBO and CSB relative amplitudes at θ = 2.6° (elevation).

c) Calculate DDM at Θ = 2.6° (μA, % DDM).

17. Power density – Field Strength



From a λ/2 dipole antenna 1 watt is transmitted at frequency 329 MHz. Distance to receiver (aircraft) is 25 Nm.

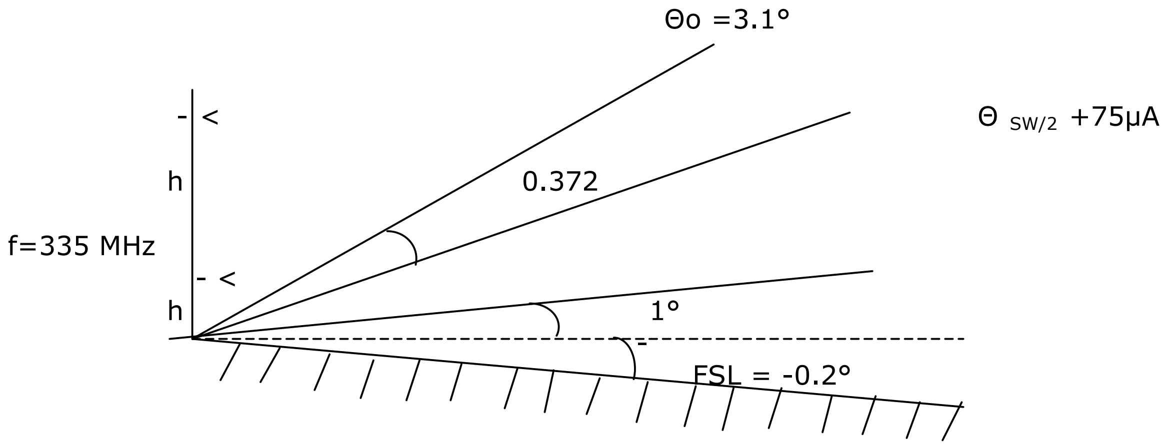
Antenna height: h = 1m

El. Angle: Θ = 3°

Tx antenna gain: 1.64 (ref isotropic antenna)

Calculate power density (watts/m²) and field strength (volts/m) in point P (receiver position).

18. NULL REF.



a) Calculate antenna spacing h

b) Calculate SBO/CSB (voltage ratio)

c) Calculate CDI (µA) at θ = 1.0° elevation.

APPENDIX A

Coaxial cable.

All cables used by NORMARC ILS have 50Ω impedance. Table A - 1 shows the characteristics of different cables.

Type	Colour	Dielectric	Dielectric constant	Phase velocity	Attenuation/100 m 110 MHz (dB)	330 MHz (dB)	Phase stability (ppm/°C)
RG-142	Brown	PTEE	2.1	0.69	12	25	appr. 90
RG-214	Black	PE	2.3	0.66	7	13	appr. 200*
RG-223	Black	PE	2.3	0.66	16	29	appr.400
RG-402	Copper	PTEE	2.1	0.69	12	25	appr. 30
CF ¼"	Black	PE-foam	1.5	0.82	4.6	8.3	appr. 30
CF ½"	Black	PE-foam	1.5	0.82	2.5	5.0	appr. 30

Table A - 1 Characteristics of coaxial cables

*) With artificial ageing, the stability will be increased to approximately 100 ppm/°.

The phase stability β (ppm/°C) gives information of the change of electrical length with temperature.
In several parts of the ILS system a good phase tracking between cables is important. If the changes of the lengths are different, it could result in phase errors, which are not acceptable.

The larger the ppm/°C, the higher the probability of having cables with a different ppm/°C, and the more critical it is to have the cables in the same temperature environment.

The phase variation with temperature and the length of the cable is given by:

$$\alpha = \beta \cdot T \frac{L}{\lambda} \cdot 360 \cdot 10^{-6} (\text{degrees})$$

where
β = stability given in ppm/°C
T = temperature change in °C
L = cable length in meters
λ = wave length in the cable (meters)

As an example, consider two 20 m long CF ¼" cables operating at 330 MHz. A 10° difference in the temperature of the cables will give a phase difference α:

$$\alpha = 30 \cdot 10 \frac{20}{0.75} \cdot 360 \cdot 10^{-6} = \underline{\underline{2.9^\circ}}$$

The relationship between phase velocity (v) and dielectric constant (ε) is:

$$v = \frac{1}{\sqrt{\varepsilon}}$$

Example.

Find the mechanical length (L) of a CF ¼" cable equivalent to 1° phase delay at 330 MHz.

$$\lambda_{(cable)} = \frac{300}{f(MHz)} \cdot \frac{1}{\sqrt{\varepsilon}} \quad (m)$$

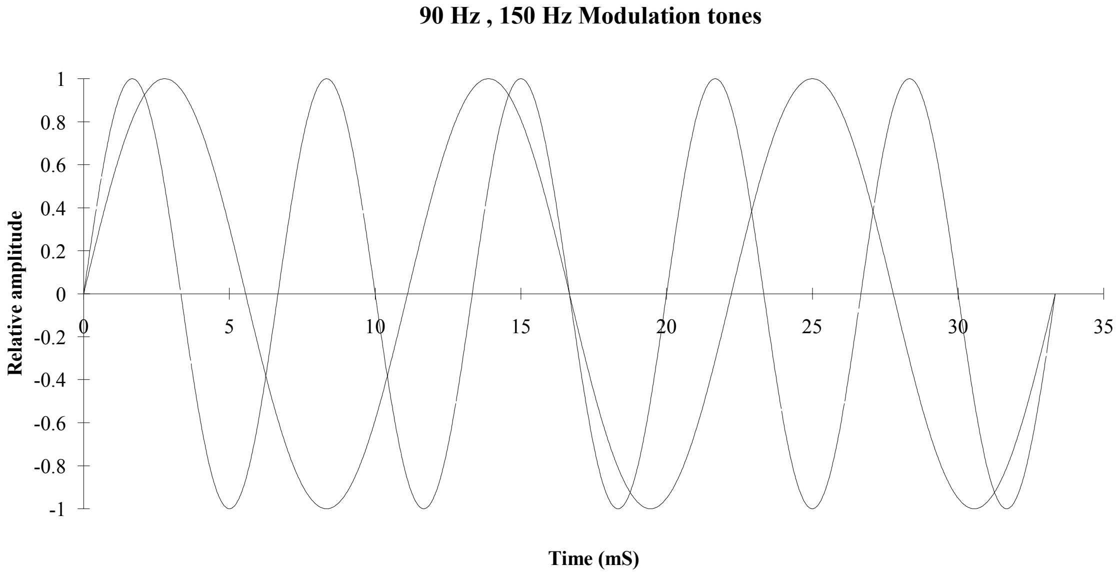
$$\lambda_{(cable)} = \frac{300}{330} \cdot \frac{1}{\sqrt{1.5}} = \underline{0.74m}$$

$$L = \frac{0.74 \cdot 1000(mm)}{360°} = \underline{\underline{2.06mm/°}}$$

	110.1 MHz		332.0 MHz	
Cable	mm/°	°/cm	mm/°	°/cm
CF ¼" / CF ½"	6.18	1.62	2.05	4.88
RG-142 / 402	5.22	1.91	1.73	5.77
RG-214 / 223	4.99	2.00	1.66	6.04

Table A - 2 Phase delay for different cables

APPENDIX B



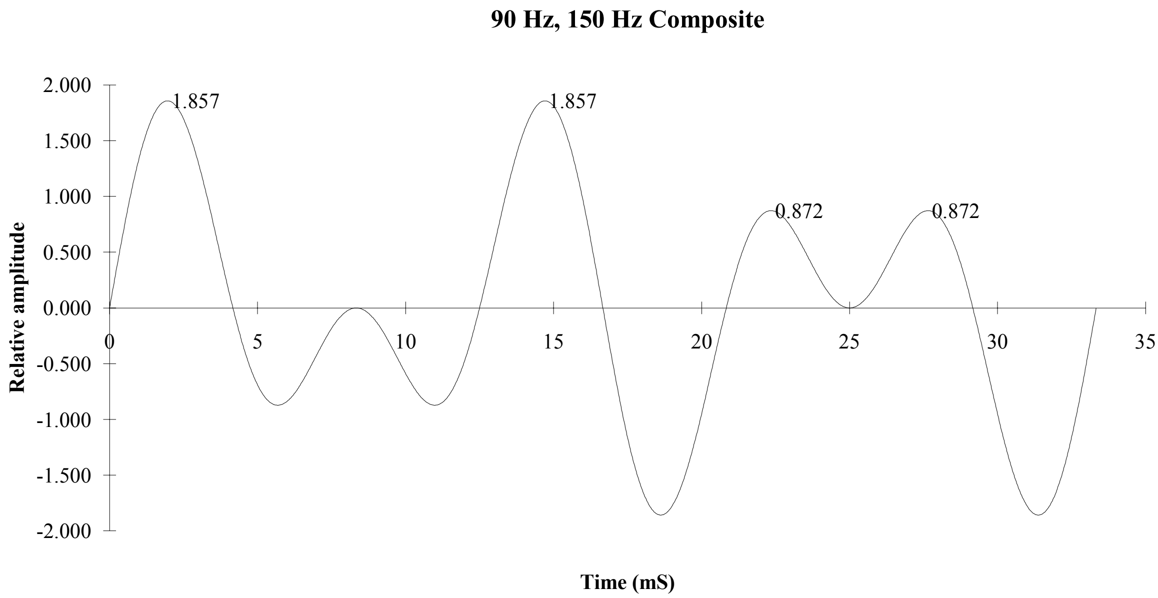
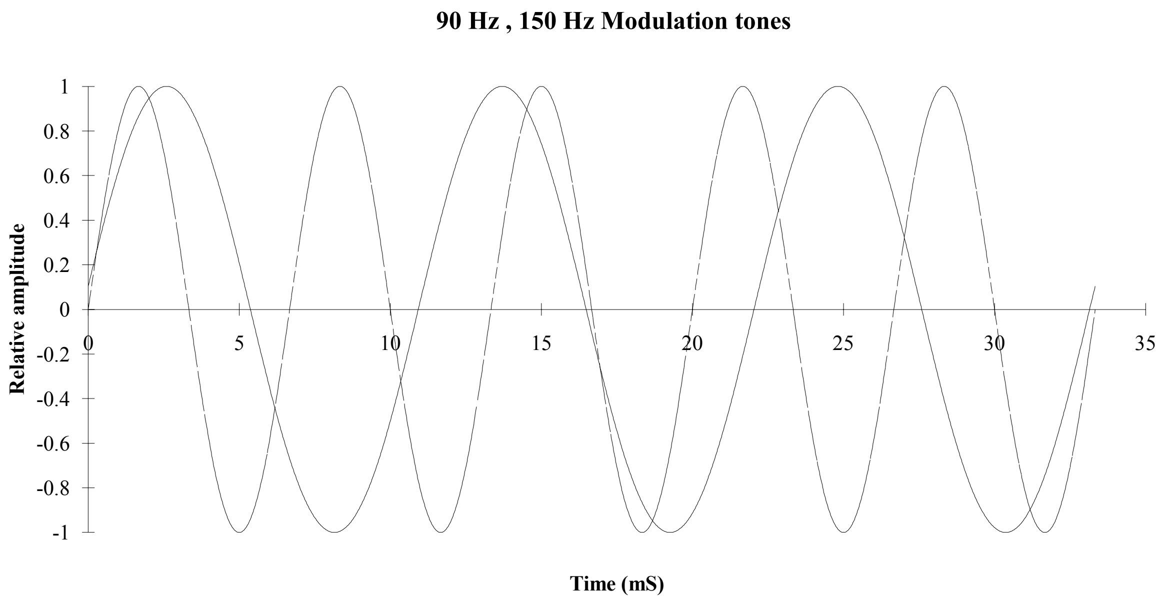


Figure B - 1 Perfect 90 Hz and 150 Hz modulation tones and envelope, zero phase start point.



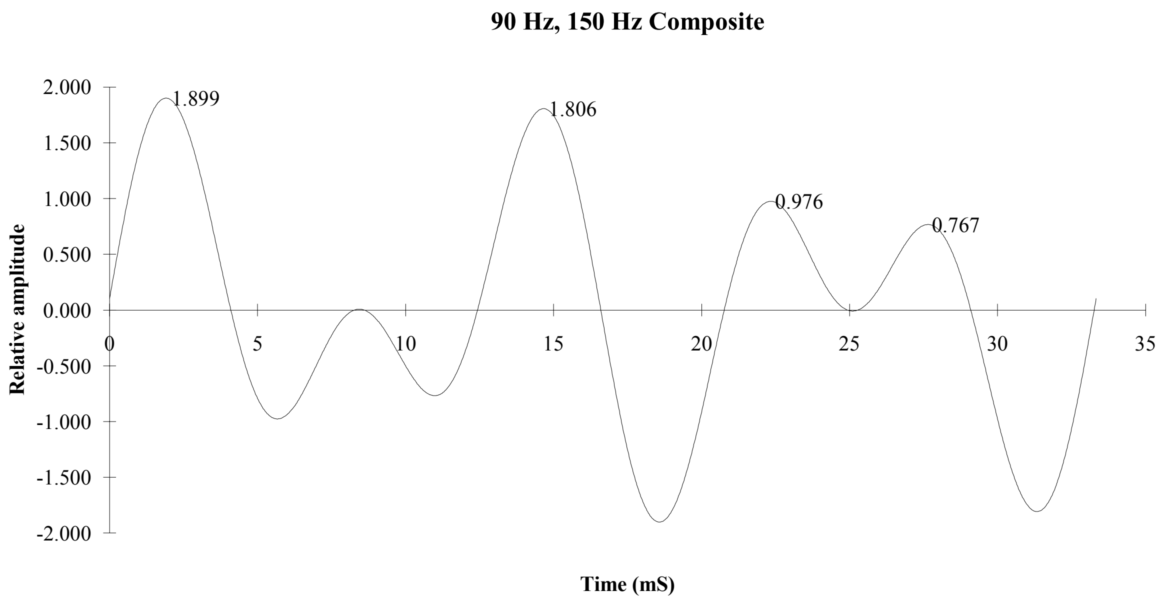


Figure B - 2 +10° phase error (90 Hz) in reference to 150 Hz, and the resulting envelope

APPENDIX C

The M-array Family.

To obtain a null in the SBO pattern at θ_0 no more nulls inside $2\theta_0$ and a correct DDM curve, the three antenna elements must be at H, 2H and 3H.

For the standard M-array, the radiation patterns have the form

$$E_{SBO} = K(0.5\sin\Psi - \sin 2\Psi + 0.5\sin 3\Psi), \Psi = \frac{\pi}{2}\frac{\sin\theta}{\sin\theta_0}$$

Using trigonometric identity this can be arranged as

$$E_{SBO} = \sin 2\Psi(\cos\Psi - 1)$$

This is exactly the SBO pattern for a Null Reference system multiplied by a modified term

$$\mathrm{G}(\Psi) = \cos\Psi - 1$$

Similarly for the CSB pattern

$$E_{CSB} = \sin\Psi(\cos\Psi - 1)$$

Then since

$$\mathrm{DDM} = \frac{2\mathrm{E_{SBO}}}{\mathrm{E_{CSB}}} = -\frac{2\mathrm{K}\sin 2\Psi}{\sin\Psi}$$

$$DDM = -4K\cos\Psi = -0.468\cos\left(\frac{\pi}{2}\frac{\sin\theta}{\sin\theta_0}\right)$$

(To obtain the correct sensitivity, K = 0.117).

This shows that provided SBO and CSB radiation patterns are multiplied by the same factor G then DDM is exactly the same as for the Null Reference at all angles.

The factor G increases the field at high angles and reduces the field at low angles to give the characteristic M-array scooping.

Other possible arrays can be derived by an alternative choice of G. For example G = 1 for Null Reference and $\mathrm{G} = \frac{1}{(\sqrt{2}\cos(0.54\Psi)}$ for Sideband Reference.

For a 3-element array the form of the factor G is $\mathrm{G} = \mathrm{x}\cos\Psi - 1$ where x can have any value provided G does not go to zero for any elevation angle below 6°.

The SBO radiation pattern then has

$$E_{SBO} = K \sin 2\Psi \left(x \cos\varphi - 1 \right)$$

$$= K\left(0.5x \sin\Psi - \sin 2\Psi + 0.5 \sin 3\Psi \right)$$

similarly

$$E_{CSB} = K(\sin\Psi - 0.5x \sin 2\Psi)$$

Factor G can be designed to give low radiation just above the ground and hence minimize the induced ground currents at a specified distance from the array.

By choosing

$$G = 1.17e^{j37°} \cos\Psi - 1$$

the induced ground currents from the upper and lower antenna elements just cancel the induced ground current from the middle antenna at 390λ from the array.

The Modified M-array is a system designed with a SBO ground current null at 390λ (350 m) from the array.

Figure C- 1 shows the normalized SBO ground current for Modified M-array along with the Null Reference and M-Array for comparison.

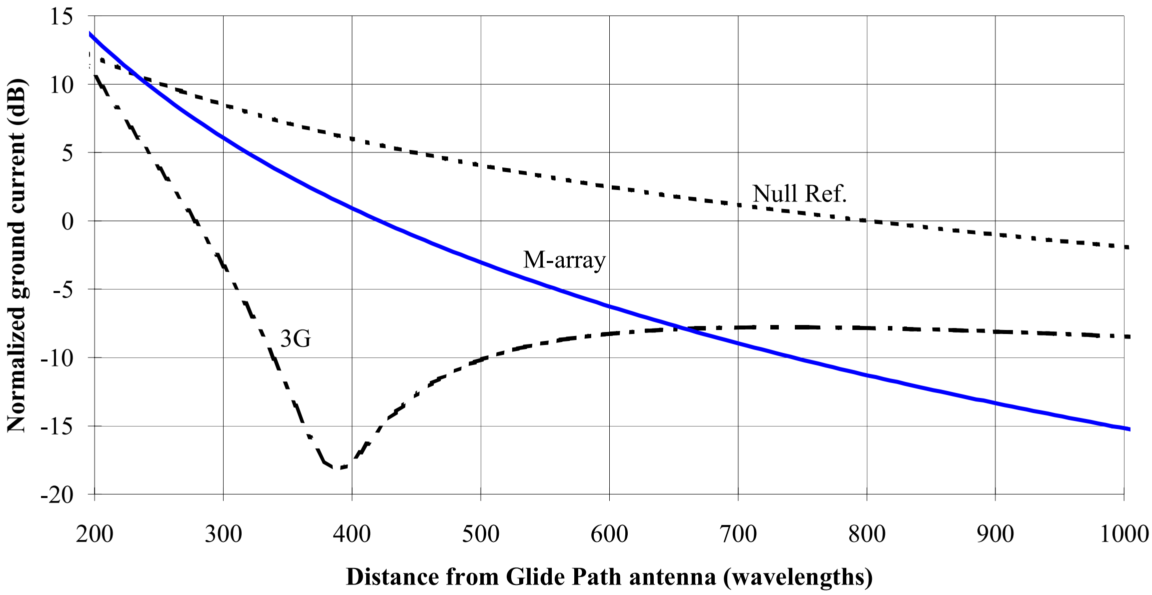


Figure C- 1 SBO ground current distribution

ICAO Annex 10 (Partial)

CHAPTER 3. SPECIFICATIONS FOR RADIO NAVIGATION AIDS

Note.— Specifications concerning the siting and construction of equipment and installations on operational areas aimed at reducing the hazard to aircraft to a minimum are contained in Annex 14, Chapter 8.

3.1 Specification for ILS

3.1.1 Definitions

Angular displacement sensitivity. The ratio of measured DDM to the corresponding angular displacement from the appropriate reference line.

Back course sector. The course sector which is situated on the opposite side of the localizer from the runway.

Course line. The locus of points nearest to the runway centre line in any horizontal plane at which the DDM is zero.

Course sector. A sector in a horizontal plane containing the course line and limited by the loci of points nearest to the course line at which the DDM is 0.155.

DDM — Difference in depth of modulation. The percentage modulation depth of the larger signal minus the percentage modulation depth of the smaller signal, divided by 100.

Displacement sensitivity (localizer). The ratio of measured DDM to the corresponding lateral displacement from the appropriate reference line.

Facility Performance Category I — ILS. An ILS which provides guidance information from the coverage limit of the ILS to the point at which the localizer course line intersects the ILS glide path at a height of 60 m (200 ft) or less above the horizontal plane containing the threshold.

Note.— This definition is not intended to preclude the use of Facility Performance Category I — ILS below the height of 60 m (200 ft), with visual reference where the quality of the guidance provided permits, and where satisfactory operational procedures have been established.

Facility Performance Category II — ILS. An ILS which provides guidance information from the coverage limit of the ILS to the point at which the localizer course line intersects the ILS glide path at a height of 15 m (50 ft) or less above the shorizontal plane containing the threshold.

Facility Performance Category III — ILS. An ILS which, with the aid of ancillary equipment where necessary, provides guidance information from the coverage limit of the facility to, and along, the surface of the runway.

Front course sector. The course sector which is situated on the same side of the localizer as the runway.

Half course sector. The sector, in a horizontal plane containing the course line and limited by the loci of points nearest to the course line at which the DDM is 0.0775.

Half ILS glide path sector. The sector in the vertical plane containing the ILS glide path and limited by the loci of points nearest to the glide path at which the DDM is 0.0875.

ILS continuity of service. That quality which relates to the rarity of radiated signal interruptions. The level of continuity of service of the localizer or the glide path is expressed in terms of the probability of not losing the radiated guidance signals.

ILS glide path. That locus of points in the vertical plane containing the runway centre line at which the DDM is zero, which, of all such loci, is the closest to the horizontal plane.

ILS glide path angle. The angle between a straight line which represents the mean of the ILS glide path and the horizontal.

ILS glide path sector. The sector in the vertical plane containing the ILS glide path and limited by the loci of points nearest to the glide path at which the DDM is 0.175.

Note.— The ILS glide path sector is located in the vertical plane containing the runway centre line, and is divided by the radiated glide path in two parts called upper sector and lower sector, referring respectively to the sectors above and below the glide path.

ILS integrity. That quality which relates to the trust which can be placed in the correctness of the information supplied by the facility. The level of integrity of the localizer or the glide path is expressed in terms of the probability of not radiating false guidance signals.

ILS Point "A". A point on the ILS glide path measured along the extended runway centre line in the approach direction a distance of 7.5 km (4 NM) from the threshold.

ILS Point "B". A point on the ILS glide path measured along the extended runway centre line in the approach direction a distance of 1 050 m (3 500 ft) from the threshold.

ILS Point "C". A point through which the downward extended straight portion of the nominal ILS glide path passes at a height of 30 m (100 ft) above the horizontal plane containing the threshold.

ILS Point "D". A point 4 m (12 ft) above the runway centre line and 900 m (3 000 ft) from the threshold in the direction of the localizer.

ILS Point "E". A point 4 m (12 ft) above the runway centre line and 600 m (2 000 ft) from the stop end of the runway in the direction of the threshold.

Note.— See Attachment C, Figure C-1.

ILS reference datum (Point "T"). A point at a specified height located above the intersection of the runway centre line and the threshold and through which the downward extended straight portion of the ILS glide path passes.

Two-frequency glide path system. An ILS glide path in which coverage is achieved by the use of two independent radiation field patterns spaced on separate carrier frequencies within the particular glide path channel.

Two-frequency localizer system. A localizer system in which coverage is achieved by the use of two independent radiation field patterns spaced on separate carrier frequencies within the particular localizer VHF channel.

3.1.2 Basic requirements

3.1.2.1 The ILS shall comprise the following basic components:

a) VHF localizer equipment, associated monitor system, remote control and indicator equipment;

b) UHF glide path equipment, associated monitor system, remote control and indicator equipment;

c) VHF marker beacons, associated monitor systems, remote control and indicator equipment, except as provided in 3.1.7.6.6 below.

3.1.2.1.1 Facility Performance Categories I, II and III — ILS shall provide indications at designated remote control points of the operational status of all ILS ground system components.

Note 1.— It is intended that the air traffic services unit involved in the control of aircraft on the final approach be one of the designated control points receiving, without delay, information on the operational status of the ILS as derived from the monitors.

Note 2.— It is intended that the air traffic system is likely to call for additional provisions which may be found essential for the attainment of full operational Category III capability, e.g. to provide additional lateral and longitudinal guidance during the landing roll-out, and taxiing, and to ensure enhancement of the integrity and reliability of the system.

3.1.2.2 The ILS shall be constructed and adjusted so that, at a specified distance from the threshold, similar instrumental indications in the aircraft represent similar displacements from the course line or ILS glide path as appropriate, irrespective of the particular ground installation in use.

3.1.2.3 The localizer and glide path components specified in 3.1.2.1 a) and b) above which form part of a Facility Performance Category I — ILS shall comply at least with the Standards in 3.1.3 and 3.1.5 below respectively, excepting those in which application to Facility Performance Category II — ILS is prescribed.

3.1.2.4 The localizer and glide path components specified in 3.1.2.1 a) and b) above which form part of a Facility Performance Category II — ILS shall comply with the Standards applicable to these components in a Facility Performance Category I — ILS, as supplemented or amended by the Standards in 3.1.3 and 3.1.5 below in which application to Facility Performance Category II — ILS is prescribed.

3.1.2.5 The localizer and glide path components and other ancillary equipment specified in 3.1.2.1.1 above, which form part of a Facility Performance Category III — ILS, shall otherwise comply with the Standards applicable to these components in Facility Performance Categories I and II — ILS, except as supplemented by the Standards in 3.1.3 and 3.1.5 below in which application to Facility Performance Category III — ILS is prescribed.

3.1.2.6 To ensure an adequate level of safety, the ILS shall be so designed and maintained that the probability of operation within the performance requirements specified is of a high value, consistent with the category of operational performance concerned.

Note.— The specifications for Facility Performance Categories II and III — ILS are intended to achieve the highest degree of system integrity, reliability and stability of operation under the most adverse environmental conditions to be encountered. Guidance material to achieve this objective in Categories II and III operations is given in 2.8 of Attachment C.

3.1.2.7 At those locations where two separate ILS facilities serve opposite ends of a single runway, an interlock shall ensure that only the localizer serving the approach direction in use shall radiate, except where the localizer in operational use is Facility Performance Category I — ILS and no operationally harmful interference results.

3.1.2.7.1 **Recommendation.—** *At those locations where two separate ILS facilities serve opposite ends of a single runway and where a Facility Performance Category I — ILS is to be used for auto-coupled approaches and landings in visual conditions an interlock should ensure that only the localizer serving the approach direction in use radiates, providing the other localizer is not required for simultaneous operational use.*

Note.— If both localizers radiate there is a possibility of interference to the localizer signals in the threshold region. Additional guidance material is contained in 2.1.9 and 2.13 of Attachment C.

3.1.2.7.2 At locations where ILS facilities serving opposite ends of the same runway or different runways at the same airport use the same paired frequencies, an interlock shall ensure that only one facility shall radiate at a time. When switching from one ILS facility to another, radiation from both shall be suppressed for not less than 20 seconds.

Note.— Additional guidance material on the operation of localizers on the same frequency channel is contained in 2.1.9 of Attachment C and Volume V, Chapter 4.

3.1.3 VHF localizer and associated monitor

Introduction. The specifications of this 3.1.3 cover ILS localizers providing either positive guidance information over 360 degrees of azimuth, or providing such guidance only within a specified portion of the front coverage (see 3.1.3.7.4 below). Where ILS localizers providing positive guidance information in a limited sector are installed, information from some suitably located navigation aid, together with appropriate procedures, will generally be required to ensure that any misleading guidance information outside the sector is not operationally significant.

3.1.3.1 *General*

3.1.3.1.1 The radiation from the localizer antenna system shall produce a composite field pattern which is amplitude modulated by a 90 Hz and a 150 Hz tone. The radiation field pattern shall produce a course sector with one tone predominating on one side of the course and with the other tone predominating on the opposite side.

3.1.3.1.2 When an observer faces the localizer from the approach end of a runway, the depth of modulation of the radio frequency carrier due to the 150 Hz tone shall predominate on his right hand and that due to the 90 Hz tone shall predominate on his left hand.

3.1.3.1.3 All horizontal angles employed in specifying the localizer field patterns shall originate from the centre of the localizer antenna system which provides the signals used in the front course sector.

3.1.3.2 *Radio frequency*

3.1.3.2.1 The localizer shall operate in the band 108 MHz to 111.975 MHz. Where a single radio frequency carrier is used, the frequency tolerance shall not exceed plus or minus 0.005 per cent. Where two radio frequency carriers are used, the frequency tolerance shall not exceed 0.002 per cent and the nominal band occupied by the carriers shall be symmetrical about the assigned frequency. With all tolerances applied, the frequency separation between the carriers shall not be less than 5 kHz nor more than 14 kHz.

3.1.3.2.2 The emission from the localizer shall be horizontally polarized. The vertically polarized component of the radiation on the course line shall not exceed that which corresponds to a DDM error of 0.016 when an aircraft is positioned on the course line and is in a roll attitude of 20 degrees from the horizontal.

3.1.3.2.2.1 For Facility Performance Category II localizers, the vertically polarized component of the radiation on the course line shall not exceed that which corresponds to a DDM error of 0.008 when an aircraft is positioned on the course line and is in a roll attitude of 20 degrees from the horizontal.

3.1.3.2.2.2 For Facility Performance Category III localizers, the vertically polarized component of the radiation within a sector bounded by 0.02 DDM either side of the course line shall not exceed that which corresponds to a DDM error of 0.005 when an aircraft is in a roll attitude of 20 degrees from the horizontal.

3.1.3.2.3 For Facility Performance Category III localizers, signals emanating from the transmitter shall contain no components which result in an apparent course line fluctuation of more than 0.005 DDM peak to peak in the frequency band 0.01 Hz to 10 Hz.

3.1.3.3 *Coverage*

3.1.3.3.1 The localizer shall provide signals sufficient to allow satisfactory operation of a typical aircraft installation within the localizer and glide path coverage sectors. The localizer coverage sector shall extend from the centre of the localizer antenna system to distances of:

46.3 km (25 NM) within plus or minus 10 degrees from the front course line;

31.5 km (17 NM) between 10 degrees and 35 degrees from the front course line;

18.5 km (10 NM) outside of plus or minus 35 degrees if coverage is provided;

except that, where topographical features dictate or operational requirements permit, the limits may be reduced to 33.3 km (18 NM) within the plus or minus 10-degree sector and 18.5 km (10 NM) within the remainder of the coverage when alternative navigational facilities provide satisfactory coverage within the intermediate approach area. The localizer signals shall be receivable at the distances specified at and above a height of 600 m (2 000 ft) above the elevation of the threshold, or 300 m (1 000 ft) above the elevation of the highest point within the intermediate and final approach areas, whichever is the higher. Such signals shall be receivable, to the distances specified, up to a surface extending outward from the localizer antenna and inclined at 7 degrees above the horizontal.

Note.— Guidance material on localizer coverage is given in 2.1.11 of Attachment C.

3.1.3.3.2 In all parts of the coverage volume specified in 3.1.3.3.1 above, other than as specified in 3.1.3.3.2.1, 3.1.3.3.2.2 and 3.1.3.3.2.3 below, the field strength shall be not less than 40 microvolts per metre (minus 114 dBW/m^2).

Note.— This minimum field strength is required to permit satisfactory operational usage of ILS localizer facilities.

3.1.3.3.2.1 For Facility Performance Category I localizers, the minimum field strength on the ILS glide path and within the localizer course sector from a distance of 18.5 km (10 NM) to a height of 60 m (200 ft) above the horizontal plane containing the threshold shall be not less than 90 microvolts per metre (minus 107 dBW/m^2).

3.1.3.3.2.2 For Facility Performance Category II localizers, the minimum field strength on the ILS glide path and within the localizer course sector shall be not less than 100 microvolts per metre (minus 106 dBW/m^2) at a distance of 18.5 km (10 NM) increasing to not less than 200 microvolts per metre (minus 100 dBW/m^2) at a height of 15 m (50 ft) above the horizontal plane containing the threshold.

3.1.3.3.2.3 For Facility Performance Category III localizers, the minimum field strength on the ILS glide path and within the localizer course sector shall be not less than 100 microvolts per metre (minus 106 dBW/m^2) at a distance of 18.5 km (10 NM), increasing to not less than 200 microvolts per metre (minus 100 dBW/m^2) at 6 m (20 ft) above the horizontal plane containing the threshold. From this point to a further point 4 m (12 ft) above the runway centre line, and 300 m (1 000 ft) from the threshold in the direction of the localizer, and thereafter at a height of 4 m (12 ft) along the length of the runway in the direction of the localizer, the field strength shall be not less than 100 microvolts per metre (minus 106 dBW/m^2).

Note.— The field strengths given in 3.1.3.3.2.2 and 3.1.3.3.2.3 above are necessary to provide the signal-to-noise ratio required for improved integrity.

3.1.3.3.3 **Recommendation.—** *Above 7 degrees, the signals should be reduced to as low a value as practicable.*

Note 1.— The requirements in 3.1.3.3.1, 3.1.3.3.2.1, 3.1.3.3.2.2 and 3.1.3.3.2.3 above are based on the assumption that the aircraft is heading directly toward the facility.

Note 2.— Guidance material on significant airborne receiver parameters is given in 2.2.2 and 2.2.4 of Attachment C.

3.1.3.3.4 When coverage is achieved by a localizer using two radio frequency carriers, one carrier providing a radiation field pattern in the front course sector and the other providing a radiation field pattern outside that sector, the ratio of the two carrier signal strengths in space within the front course sector to the coverage limits specified at 3.1.3.3.1 above shall not be less than 10 dB.

Note.— Guidance material on localizers achieving coverage with two radio frequency carriers is given in the Note to 3.1.3.11.2 below and in 2.7 of Attachment C.

3.1.3.3.5 **Recommendation.—** *For Facility Performance Category III localizers, the ratio of the two carrier signal strengths in space within the front course sector should not be less than 16 dB.*

3.1.3.4 *Course structure*

3.1.3.4.1 For Facility Performance Category I localizers, bends in the course line shall not have amplitudes which exceed the following:

Zone	*Amplitude (DDM) (95% probability)*
Outer limit of coverage to ILS Point "A"	0.031
ILS Point "A" to ILS Point "B"	0.031 at ILS Point "A" decreasing at a linear rate to 0.015 at ILS Point "B"
ILS Point "B" to ILS Point "C"	0.015

3.1.3.4.2 For Facility Performance Categories II and III localizers, bends in the course line shall not have amplitudes which exceed the following:

Zone	*Amplitude (DDM) (95% probability)*
Outer limit of coverage to ILS Point "A"	0.031
ILS Point "A" to ILS Point "B"	0.031 at ILS Point "A" decreasing at a linear rate to 0.005 at ILS Point "B"
ILS Point "B" to the ILS reference datum	0.005

and, for Category III only:

ILS reference datum to ILS Point "D"	0.005
ILS Point "D" to ILS Point "E"	0.005 at ILS Point "D" increasing at a linear rate to 0.010 at ILS Point "E"

Note 1.— The amplitudes referred to in 3.1.3.4.1 and 3.1.3.4.2 above are the DDMs due to bends as realized on the mean course line, when correctly adjusted.

Note 2.— Guidance material relevant to the localizer course structure is given in 2.1.4, 2.1.6 and 2.1.7 of Attachment C.

3.1.3.5 *Carrier modulation*

3.1.3.5.1 The nominal depth of modulation of the radio frequency carrier due to each of the 90 Hz and 150 Hz tones shall be 20 per cent along the course line.

3.1.3.5.2 The depth of modulation of the radio frequency carrier due to each of the 90 Hz and 150 Hz tones shall be within the limits of 18 and 22 per cent.

3.1.3.5.3 The following tolerances shall be applied to the frequencies of the modulating tones:

a) the modulating tones shall be 90 Hz and 150 Hz within plus or minus 2.5 per cent;

b) the modulating tones shall be 90 Hz and 150 Hz within plus or minus 1.5 per cent for Facility Performance Category II installations;

c) the modulating tones shall be 90 Hz and 150 Hz within plus or minus 1 per cent for Facility Performance Category III installations;

d) the total harmonic content of the 90 Hz tone shall not exceed 10 per cent; additionally, for Facility Performance Category III localizers, the second harmonic of the 90 Hz tone shall not exceed 5 per cent;

e) the total harmonic content of the 150 Hz tone shall not exceed 10 per cent.

3.1.3.5.3.1 **Recommendation.—** *For Facility Performance Category I — ILS, the modulating tones should be 90 Hz and 150 Hz within plus or minus 1.5 per cent where practicable.*

3.1.3.5.3.2 For Facility Performance Category III localizers, the depth of amplitude modulation of the radio frequency carrier at the power supply frequency or its harmonics, or by other unwanted components, shall not exceed 0.5 per cent. Harmonics of the supply, or other unwanted noise components that may intermodulate with the 90 Hz and 150 Hz navigational tones or their harmonics to produce fluctuations in the course line, shall not exceed 0.05 per cent modulation depth of the radio frequency carrier.

3.1.3.5.3.3 The modulation tones shall be phase-locked so that within the half course sector, the demodulated 90 Hz and 150 Hz wave forms pass through zero in the same direction within:

a) for Facility Performance Categories I and II localizers: 20 degrees; and

b) for Facility Performance Category III localizers: 10 degrees,

of phase relative to the 150 Hz component, every half cycle of the combined 90 Hz and 150 Hz wave form.

Note 1.— The definition of phase relationship in this manner is not intended to imply a requirement to measure the phase within the half course sector.

Note 2.— Guidance material relative to such measurement is given at Figure C-6 of Attachment C.

3.1.3.5.3.4 With two-frequency localizer systems, 3.1.3.5.3.3 above shall apply to each carrier. In addition, the 90 Hz modulating tone of one carrier shall be phase-locked to the 90 Hz modulating tone of the other carrier so that the demodulated wave forms pass through zero in the same direction within:

a) for Categories I and II localizers: 20 degrees; and

b) for Category III localizers: 10 degrees,

of phase relative to 90 Hz. Similarly, the 150 Hz tones of the two carriers shall be phase-locked so that the demodulated wave forms pass through zero in the same direction within:

1) for Categories I and II localizers: 20 degrees; and

2) for Category III localizers: 10 degrees,

of phase relative to 150 Hz.

3.1.3.5.3.5 Alternative two-frequency localizer systems that employ audio phasing different from the normal inphase conditions described in 3.1.3.5.3.4 above shall be permitted. In this alternative system, the 90 Hz to 90 Hz phasing and the 150 Hz to 150 Hz phasing shall be adjusted to their nominal values to within limits equivalent to those stated in 3.1.3.5.3.4 above.

Note.— This is to ensure correct airborne receiver operation in the region away from the course line where the two carrier signal strengths are approximately equal.

3.1.3.5.3.6 **Recommendation.—** *The sum of the modulation depths of the radio frequency carrier due to the 90 Hz and 150 Hz tones should not exceed 60 per cent or be less than 30 per cent within the required coverage.*

3.1.3.5.3.6.1 For equipment first installed after 1 January 2000, the sum of the modulation depths of the radio frequency carrier due to the 90 Hz and 150 Hz tones shall not exceed 60 per cent or be less than 30 per cent within the required coverage.

Note 1.— If the sum of the modulation depths is greater than 60 per cent for Facility Performance Category I localizers, the nominal displacement sensitivity may be adjusted as provided for in 3.1.3.7.1 to achieve the above modulation limit.

Note 2.— For two-frequency systems, the standard for maximum sum of modulation depths does not apply at or near azimuths where the course and clearance carrier signal levels are equal in amplitude (i.e. at azimuths where both transmitting systems have a significant contribution to the total modulation depth).

Note 3.— The standard for minimum sum of modulation depths is based on the malfunctioning alarm level being set as high as 30 per cent as stated in 2.3.3 of Attachment C.

3.1.3.5.3.7 When utilizing a localizer for radiotelephone communications, the sum of the modulation depths of the radio frequency carrier due to the 90 Hz and 150 Hz tones shall not exceed 65 per cent within 10 degrees of the course line and shall not exceed 78 per cent at any other point around the localizer.

3.1.3.5.4 **Recommendation.—** *Undesired frequency and phase modulation on ILS localizer radio frequency carriers that can affect the displayed DDM values in localizer receivers should be minimized to the extent practical.*

Note.— Relevant guidance material is given in 2.15 of Attachment C.

3.1.3.6 *Course alignment accuracy*

3.1.3.6.1 The mean course line shall be adjusted and maintained within limits equivalent to the following displacements from the runway centre line at the ILS reference datum:

a) for Facility Performance Category I localizers: plus or minus 10.5 m (35 ft), or the linear equivalent of 0.015 DDM, whichever is less;

b) for Facility Performance Category II localizers: plus or minus 7.5 m (25 ft);

c) for Facility Performance Category III localizers: plus or minus 3 m (10 ft).

3.1.3.6.2 **Recommendation.—** *For Facility Performance Category II localizers, the mean course line should be adjusted and maintained within limits equivalent to plus or minus 4.5 m (15 ft) displacement from runway centre line at the ILS reference datum.*

Note 1.— It is intended that Facility Performance Categories II and III installations be adjusted and maintained so that the limits specified in 3.1.3.6.1 and 3.1.3.6.2 above are reached on very rare occasions. It is further intended that design and operation of the total ILS ground system be of sufficient integrity to accomplish this aim.

Note 2.— It is intended that new Category II installations are to meet the requirements of 3.1.3.6.2 above.

Note 3.— Guidance material on measurement of localizer course alignment is given in 2.1.4 of Attachment C.

3.1.3.7 *Displacement sensitivity*

3.1.3.7.1 The nominal displacement sensitivity within the half course sector at the ILS reference datum shall be 0.00145 DDM/m (0.00044 DDM/ft) except that for Category I localizers, where the specified nominal displacement sensitivity cannot be met, the displacement sensitivity shall be adjusted as near as possible to that value. For Facility Performance Category I localizers on runway codes 1 and 2, the nominal displacement sensitivity shall be achieved at the ILS Point "B". The maximum course sector angle shall not exceed 6 degrees.

Note.— Runway codes 1 and 2 are defined in Annex 14.

3.1.3.7.2 The lateral displacement sensitivity shall be adjusted and maintained within the limits of plus or minus:

a) 17 per cent of the nominal value for Facility Performance Categories I and II;

b) 10 per cent of the nominal value for Facility Performance Category III.

3.1.3.7.3 **Recommendation.—** *For Facility Performance Category II — ILS, displacement sensitivity should be adjusted and maintained within the limits of plus or minus 10 per cent where practicable.*

Note 1.— The figures given in 3.1.3.7.1, 3.1.3.7.2 and 3.1.3.7.3 above are based upon a nominal sector width of 210 m (700 ft) at the appropriate point, i.e. ILS Point "B" on runway codes 1 and 2, and the ILS reference datum on other runways.

Note 2.— Guidance material on the alignment and displacement sensitivity of localizers using two radio frequency carriers is given in 2.7 of Attachment C.

Note 3.— Guidance material on measurement of localizer displacement sensitivity is given in 2.9 of Attachment C.

3.1.3.7.4 The increase of DDM shall be substantially linear with respect to angular displacement from the front course line (where DDM is zero) up to an angle on either side of the front course line where the DDM is 0.180. From that angle to plus or minus 10 degrees, the DDM shall not be less than 0.180. From plus or minus 10 degrees to plus or minus 35 degrees, the DDM shall not be less than 0.155. Where coverage is required outside of the plus or minus 35 degrees sector, the DDM in the area of the coverage, except in the back course sector, shall not be less than 0.155.

Note 1.— The linearity of change of DDM with respect to angular displacement is particularly important in the neighbourhood of the course line.

Note 2.— The above DDM in the 10-35 degree sector is to be considered a minimum requirement for the use of ILS as a landing aid. Wherever practicable a higher DDM, e.g. 0.180, is advantageous to assist high speed aircraft to execute large angle intercepts at operationally desirable distances provided that limits on modulation percentage given in 3.1.3.5.3.6 are met.

Note 3.— Wherever practicable, the localizer capture level of automatic flight control systems is to be set at or below 0.175 DDM in order to prevent false localizer captures.

3.1.3.8 *Voice*

3.1.3.8.1 Facility Performance Categories I and II localizers may provide a ground-to-air radiotelephone communication channel to be operated simultaneously with the navigation and identification signals, provided that such operation shall not interfere in any way with the basic localizer function.

3.1.3.8.2 Category III localizers shall not provide such a channel, except where extreme care has been taken in the design and operation of the facility to ensure that there is no possibility of interference with the navigational guidance.

3.1.3.8.3 If the channel is provided, it shall conform with the following Standards:

3.1.3.8.3.1 The channel shall be on the same radio frequency carrier or carriers as used for the localizer function, and the radiation shall be horizontally polarized. Where two carriers are modulated with speech, the relative phases of the modulations on the two carriers shall be such as to avoid the occurrence of nulls within the coverage of the localizer.

3.1.3.8.3.2 The peak modulation depth of the carrier or carriers due to the radiotelephone communications shall not exceed 50 per cent but shall be adjusted so that:

a) the ratio of peak modulation depth due to the radiotelephone communications to that due to the identification signal is approximately 9:1;

b) the sum of modulation components due to use of the radiotelephone channel, navigational signals and identification signals shall not exceed 95 per cent.

3.1.3.8.3.3 The audio frequency characteristics of the radiotelephone channel shall be flat to within 3 dB relative to the level at 1 000 Hz over the range 300 Hz to 3 000 Hz.

3.1.3.9 *Identification*

3.1.3.9.1 The localizer shall provide for the simultaneous transmission of an identification signal, specific to the runway and approach direction, on the same radio frequency carrier or carriers as used for the localizer function. The transmission of the identification signal shall not interfere in any way with the basic localizer function.

3.1.3.9.2 The identification signal shall be produced by Class A2A modulation of the radio frequency carrier or carriers using a modulation tone of 1 020 Hz within plus or minus 50 Hz. The depth of modulation shall be between the limits of 5 and 15 per cent except that, where a radiotelephone communication channel is provided, the depth of modulation shall be adjusted so that the ratio of peak modulation depth due to radiotelephone communications to that due to the identification signal modulation is approximately 9:1 (see 3.1.3.8.3.2 above). The emissions carrying the identification signal shall be horizontally polarized. Where two carriers are modulated with identification signals, the relative phase of the modulations shall be such as to avoid the occurrence of nulls within the coverage of the localizer.

3.1.3.9.3 The identification signal shall employ the International Morse Code and consist of two or three letters. It may be preceded by the International Morse Code signal of the letter "I", followed by a short pause where it is necessary to distinguish the ILS facility from other navigational facilities in the immediate area.

3.1.3.9.4 The identification signal shall be transmitted by dots and dashes at a speed corresponding to approximately seven words per minute, and shall be repeated at approximately equal intervals, not less than six times per minute, at all times during which the localizer is available for operational use. When the transmissions of the localizer are not available for operational use, as, for example, after removal of navigational components, or during maintenance or test transmissions, the identification signal shall be suppressed. The dots shall have a duration of 0.1 second to 0.160 second. The dash duration shall be typically three times the duration of a dot. The interval between dots and/or dashes shall be equal to that of one dot plus or minus 10 per cent. The interval between letters shall not be less than the duration of three dots.

3.1.3.10 *Siting*

3.1.3.10.1 The localizer antenna system shall be located on the extension of the centre line of the runway at the stop end, and the equipment shall be adjusted so that the course lines will be in a vertical plane containing the centre line of the runway served. The antenna system shall have the minimum height necessary to satisfy the coverage requirements laid down in 3.1.3.3 above, and the distance from the stop end of the runway shall be consistent with safe obstruction clearance practices.

3.1.3.11 *Monitoring*

3.1.3.11.1 The automatic monitor system shall provide a warning to the designated control points and cause one of the following to occur, within the period specified in 3.1.3.11.3.1 below, if any of the conditions stated in 3.1.3.11.2 below persists:

a) radiation to cease;

b) removal of the navigation and identification components from the carrier;

c) reversion to a lower category in the case of Facility Performance Categories II and III localizers where the reversion requirement exists.

Note.— It is intended that the alternative of reversion offered in 3.1.3.11.1 above may be used only if:

1) the safety of the reversion procedure has been substantiated; and

2) the means of providing information to the pilot on the change of category has adequate integrity.

3.1.3.11.2 The conditions requiring initiation of monitor action shall be the following:

a) for Facility Performance Category I localizers, a shift of the mean course line from the runway centre line equivalent to more than 10.5 m (35 ft), or the linear equivalent to 0.015 DDM, whichever is less, at the ILS reference datum;

b) for Facility Performance Category II localizers, a shift of the mean course line from the runway centre line equivalent to more than 7.5 m (25 ft) at the ILS reference datum;

c) for Facility Performance Category III localizers, a shift of the mean course line from the runway centre line equivalent to more than 6 m (20 ft) at the ILS reference datum;

d) in the case of localizers in which the basic functions are provided by the use of a single-frequency system, a reduction of power output to less than 50 per cent of normal, provided the localizer continues to meet the requirements of 3.1.3.3, 3.1.3.4 and 3.1.3.5 above;

e) in the case of localizers in which the basic functions are provided by the use of a two-frequency system, a reduction of power output for either carrier to less than 80 per cent of normal, except that a greater reduction to between 80 per cent and 50 per cent of normal may be permitted, provided the localizer continues to meet the requirements of 3.1.3.3, 3.1.3.4 and 3.1.3.5 above;

Note.— It is important to recognize that a frequency change resulting in a loss of the frequency difference specified in 3.1.3.2.1 above may produce a hazardous condition. This problem is of greater operational significance for Categories II and III installations. As necessary, this problem can be dealt with through special monitoring provisions or highly reliable circuitry.

f) change of displacement sensitivity to a value differing by more than 17 per cent from the nominal value for the localizer facility.

Note.— In selecting the power reduction figure to be employed in monitoring referred to in 3.1.3.11.2 e) above, particular attention is directed to vertical and horizontal lobe structure (vertical lobing due to different antenna heights) of the combined radiation systems when two carriers are employed. Large changes in the power ratio between carriers may result in low clearance areas and false courses in the off-course areas to the limits of the vertical coverage requirements specified in 3.1.3.3.1 above.

3.1.3.11.2.1 **Recommendation.—** *In the case of localizers in which the basic functions are provided by the use of a two-frequency system, the conditions requiring initiation of monitor action should include the case when the DDM in the required coverage beyond plus or minus 10 degrees from the front course line, except in the back course sector, decreases below 0.155.*

3.1.3.11.3 The total period of radiation, including period(s) of zero radiation, outside the performance limits specified in a), b), c), d), e) and f) of 3.1.3.11.2 above shall be as short as practicable, consistent with the need for avoiding interruptions of the navigation service provided by the localizer.

3.1.3.11.3.1 The total period referred to under 3.1.3.11.3 above shall not exceed under any circumstances:

10 seconds for Category I localizers;

5 seconds for Category II localizers;

2 seconds for Category III localizers.

Note 1.— The total time periods specified are never-to-be-exceeded limits and are intended to protect aircraft in the final stages of approach against prolonged or repeated periods of localizer guidance outside the monitor limits. For this reason, they include not only the initial period of outside tolerance operation but also the total of any or all periods of outside tolerance radiation including period(s) of zero radiation, which might occur during action to restore service, for example, in the course of consecutive monitor functioning and consequent change-over(s) to localizer equipment(s) or elements thereof.

Note 2.— From an operational point of view, the intention is that no guidance outside the monitor limits be radiated after the time periods given, and that no further attempts be made to restore service until a period in the order of 20 seconds has elapsed.

3.1.3.11.3.2 **Recommendation.—** *Where practicable, the total period under 3.1.3.11.3.1 above should be reduced so as not to exceed two seconds for Category II localizers and one second for Category III localizers.*

3.1.3.11.4 Design and operation of the monitor system shall be consistent with the requirement that navigation guidance and identification will be removed and a warning provided at the designated remote control points in the event of failure of the monitor system itself.

Note.— Guidance material on the design and operation of monitor systems is given in 2.1.8 of Attachment C.

3.1.3.11.5 Any erroneous navigation signals on the carrier occurring during removal of navigation and identification components in accordance with 3.1.3.11.1 b) above shall be suppressed within the total periods allowed in 3.1.3.11.3.1 above.

Note.— To prevent hazardous fluctuations in the radiated signal, localizers employing mechanical modulation equipment may require suppression of navigation components during modulator rundown.

3.1.3.12 *Integrity and continuity of service requirements*

3.1.3.12.1 The probability of not radiating false guidance signals shall not be less than $1 - 0.5 \times 10^{-9}$ in any one landing for Facility Performance Categories II and III localizers.

3.1.3.12.2 **Recommendation.—** *The probability of not radiating false guidance signals should not be less than $1 - 1.0 \times 10^{-7}$ in any one landing for Facility Performance Category I localizers.*

3.1.3.12.3 The probability of not losing the radiated guidance signal shall be greater than:

a) $1 - 2 \times 10^{-6}$ in any period of 15 seconds for Facility Performance Category II localizers (equivalent to 2 000 hours mean time between outages).

$1 - 2 \times 10^{-6}$ in any period of 30 seconds for Facility Performance Category III localizers (equivalent to 4 000 hours mean time between outages).

3.1.3.12.4 **Recommendation.—** *The probability of not losing the radiated guidance signal should exceed $1 - 4 \times 10^{-6}$ in any period of 15 seconds for Facility Performance Category I localizers (equivalent to 1 000 hours mean time between outages).*

Note.— Guidance material on integrity and continuity of service is given in 2.8 of Attachment C.

3.1.4 Interference immunity performance for ILS localizer receiving systems

3.1.4.1 After 1 January 1998, the ILS localizer receiving system shall provide adequate immunity to interference from two signal, third-order intermodulation products caused by VHF FM broadcast signals having levels in accordance with the following:

$$2N_1 + N_2 + 72 \leq 0$$

for VHF FM sound broadcasting signals in the range 107.7 – 108.0 MHz

and

$$2N_1 + N_2 + 3\left(24 - 20\ \log\frac{\Delta f}{0.4}\right) \leq 0$$

for VHF FM sound broadcasting signals below 107.7 MHz,

where the frequencies of the two VHF FM sound broadcasting signals produce, within the receiver, a two signal, third-order intermodulation product on the desired ILS localizer frequency.

N_1 and N_2 are the levels (dBm) of the two VHF FM sound broadcasting signals at the ILS localizer receiver input. Neither level shall exceed the desensitization criteria set forth in 3.1.4.2 below.

$\Delta f = 108.1 - f_1$, where f_1 is the frequency of N_1, the VHF FM sound broadcasting signal closer to 108.1 MHz.

3.1.4.2 After 1 January 1998, the ILS localizer receiving system shall not be desensitized in the presence of VHF FM broadcast signals having levels in accordance with the following table:

Frequency (MHz)	*Maximum level of unwanted signal at receiver input (dBm)*
88-102	+15
104	+10
106	+5
107.9	−10

Note 1.— The relationship is linear between adjacent points designated by the above frequencies.

Note 2.— Guidance material on immunity criteria to be used for the performance quoted in 3.1.4.1 and 3.1.4.2 above is contained in Attachment C, 2.2.9.

3.1.4.3 After 1 January 1995, all new installations of airborne ILS localizer receiving systems shall meet the provisions of 3.1.4.1 and 3.1.4.2 above.

3.1.4.4 **Recommendation.—** *Airborne ILS localizer receiving systems meeting the immunity performance standards of 3.1.4.1 and 3.1.4.2 above should be placed into operation at the earliest possible date.*

3.1.5 UHF glide path equipment and associated monitor

Note.— θ is used in this paragraph to denote the nominal glide path angle.

3.1.5.1 *General*

3.1.5.1.1 The radiation from the UHF glide path antenna system shall produce a composite field pattern which is amplitude modulated by a 90 Hz and a 150 Hz tone. The pattern shall be arranged to provide a straight line descent path in the vertical plane containing the centre line of the runway, with the 150 Hz tone predominating below the path and the 90 Hz tone predominating above the path to at least an angle equal to 1.75 θ.

3.1.5.1.2 **Recommendation.—** *The UHF glide path equipment should be capable of adjustment to produce a radiated glide path from 2 to 4 degrees with respect to the horizontal.*

3.1.5.1.2.1 **Recommendation.—** *The ILS glide path angle should be 3 degrees. ILS glide path angles in excess of 3 degrees should not be used except where alternative means of satisfying obstruction clearance requirements are impracticable.*

3.1.5.1.2.2 The glide path angle shall be adjusted and maintained within:

a) 0.075 θ from θ for Facility Performance Categories I and II — ILS glide paths;

b) 0.04 θ from θ for Facility Performance Category III — ILS glide paths.

Note 1.— Guidance material on adjustment and maintenance of glide path angles is given in 2.4 of Attachment C.

Note 2.— Guidance material on ILS glide path curvature, alignment and siting, relevant to the selection of the height of the ILS reference datum is given in 2.4 of Attachment C and Figure C-5.

3.1.5.1.3 The downward extended straight portion of the ILS glide path shall pass through the ILS reference datum at a height ensuring safe guidance over obstructions and also safe and efficient use of the runway served.

3.1.5.1.4 The height of the ILS reference datum for Facility Performance Categories II and III — ILS shall be 15 m (50 ft). A tolerance of plus 3 m (10 ft) is permitted.

3.1.5.1.5 **Recommendation.—** *The height of the ILS reference datum for Facility Performance Category I — ILS should be 15 m (50 ft). A tolerance of plus 3 m (10 ft) is permitted.*

Note 1.— In arriving at the above height values for the ILS reference datum, a maximum vertical distance of 5.8 m (19 ft) between the path of the aircraft glide path antenna and the path of the lowest part of the wheels at the threshold was assumed. For aircraft exceeding this criterion, appropriate steps may have to be taken either to maintain adequate clearance at threshold or to adjust the permitted operating minima.

Note 2.— Appropriate guidance material is given in 2.4 of Attachment C.

3.1.5.1.6 **Recommendation.—** *The height of the ILS reference datum for Facility Performance Category I — ILS used on short precision approach runway codes 1 and 2 should be 12 m (40 ft). A tolerance of plus 6 m (20 ft) is permitted.*

3.1.5.2 *Radio frequency*

3.1.5.2.1 The glide path equipment shall operate in the band 328.6 MHz to 335.4 MHz. Where a single radio frequency carrier is used, the frequency tolerance shall not exceed 0.005 per cent. Where two carrier glide path systems are used, the frequency tolerance shall not exceed 0.002 per cent and the nominal band occupied by the carriers shall be symmetrical about the assigned frequency. With all tolerances applied, the frequency separation between the carriers shall not be less than 4 kHz nor more than 32 kHz.

3.1.5.2.2 The emission from the glide path equipment shall be horizontally polarized.

3.1.5.2.3 For Facility Performance Category III — ILS glide path equipment, signals emanating from the transmitter shall contain no components which result in apparent glide path fluctuations of more than 0.02 DDM peak to peak in the frequency band 0.01 Hz to 10 Hz.

3.1.5.3 *Coverage*

3.1.5.3.1 The glide path equipment shall provide signals sufficient to allow satisfactory operation of a typical aircraft installation in sectors of 8 degrees in azimuth on each side of the centre line of the ILS glide path, to a distance of at least 18.5 km (10 NM) up to 1.75 θ and down to 0.45 θ above the horizontal or to such lower angle, down to 0.30 θ, as required to safeguard the promulgated glide path intercept procedure.

3.1.5.3.2 In order to provide the coverage for glide path performance specified in 3.1.5.3.1 above, the minimum field strength within this coverage sector shall be 400 microvolts per metre (minus 95 dBW/m^2). For Facility Performance Category I glide paths, this field strength shall be provided down to a height of 30 m (100 ft) above the horizontal plane containing the threshold. For Facility Performance Categories II and III glide paths, this field strength shall be provided down to a height of 15 m (50 ft) above the horizontal plane containing the threshold.

Note 1.— The requirements in the foregoing paragraphs are based on the assumption that the aircraft is heading directly toward the facility.

Note 2.— Guidance material on significant airborne receiver parameters is given in 2.2.5 of Attachment C.

Note 3.— Material concerning reduction in coverage outside 8 degrees on each side of the centre line of the ILS glide path appears in 2.4 of Attachment C.

3.1.5.4 *ILS glide path structure*

3.1.5.4.1 For Facility Performance Category I — ILS glide paths, bends in the glide path shall not have amplitudes which exceed the following:

Zone	*Amplitude (DDM) (95% probability)*
Outer limit of coverage to ILS Point "C"	0.035

3.1.5.4.2 For Facility Performance Categories II and III — ILS glide paths, bends in the glide path shall not have amplitudes which exceed the following:

Zone	*Amplitude (DDM) (95% probability)*
Outer limit of coverage to ILS Point "A"	0.035
ILS Point "A" to ILS Point "B"	0.035 at ILS Point "A" decreasing at a linear rate to 0.023 at ILS Point "B"
ILS Point "B" to the ILS reference datum	0.023

Note 1.— The amplitudes referred to in 3.1.5.4.1 and 3.1.5.4.2 above are the DDMs due to bends as realized on the mean ILS glide path correctly adjusted.

Note 2.— In regions of the approach where ILS glide path curvature is significant, bend amplitudes are calculated from the mean curved path, and not the downward extended straight line.

Note 3.— Guidance material relevant to the ILS glide path course structure is given in 2.1.5 of Attachment C.

3.1.5.5 *Carrier modulation*

3.1.5.5.1 The nominal depth of modulation of the radio frequency carrier due to each of the 90 Hz and 150 Hz tones shall be 40 per cent along the ILS glide path. The depth of modulation shall not deviate outside the limits of 37.5 per cent to 42.5 per cent.

3.1.5.5.2 The following tolerances shall be applied to the frequencies of the modulating tones:

a) the modulating tones shall be 90 Hz and 150 Hz within 2.5 per cent for Facility Performance Category I — ILS;

b) the modulating tones shall be 90 Hz and 150 Hz within 1.5 per cent for Facility Performance Category II — ILS;

c) the modulating tones shall be 90 Hz and 150 Hz within 1 per cent for Facility Performance Category III — ILS;

d) the total harmonic content of the 90 Hz tone shall not exceed 10 per cent: additionally, for Facility Performance Category III equipment, the second harmonic of the 90 Hz tone shall not exceed 5 per cent;

e) the total harmonic content of the 150 Hz tone shall not exceed 10 per cent.

3.1.5.5.2.1 **Recommendation.—** *For Facility Performance Category I — ILS, the modulating tones should be 90 Hz and 150 Hz within plus or minus 1.5 per cent where practicable.*

3.1.5.5.2.2 For Facility Performance Category III glide path equipment, the depth of amplitude modulation of the radio frequency carrier at the power supply frequency or harmonics, or at other noise frequencies, shall not exceed 1 per cent.

3.1.5.5.3 The modulation shall be phase-locked so that within the ILS half glide path sector, the demodulated 90 Hz and 150 Hz wave forms pass through zero in the same direction within:

a) for Facility Performance Categories I and II — ILS glide paths: 20 degrees;

b) for Facility Performance Category III — ILS glide paths: 10 degrees,

of phase relative to the 150 Hz component, every half cycle of the combined 90 Hz and 150 Hz wave form.

Note 1.— The definition of phase relationship in this manner is not intended to imply a requirement for measurement of phase within the ILS half glide path sector.

Note 2.— Guidance material relating to such measures is given at Figure C-6 of Attachment C.

3.1.5.5.3.1 With two-frequency glide path systems, 3.1.5.5.3 above shall apply to each carrier. In addition, the 90 Hz modulating tone of one carrier shall be phase-locked to the 90 Hz modulating tone of the other carrier so that the demodulated wave forms pass through zero in the same direction within:

a) for Categories I and II — ILS glide paths: 20 degrees;

b) for Category III — ILS glide paths: 10 degrees,

of phase relative to 90 Hz. Similarly, the 150 Hz tones of the two carriers shall be phase-locked so that the demodulated wave forms pass through zero in the same direction, within:

1) for Categories I and II — ILS glide paths: 20 degrees;

2) for Category III — ILS glide paths: 10 degrees,

of phase relative to 150 Hz.

3.1.5.5.3.2 Alternative two-frequency glide path systems that employ audio phasing different from the normal inphase condition described in 3.1.5.5.3.1 above shall be permitted. In these alternative systems, the 90 Hz to 90 Hz phasing and the 150 Hz to 150 Hz phasing shall be adjusted to their nominal values to within limits equivalent to those stated in 3.1.5.5.3.1 above.

Note.— This is to ensure correct airborne receiver operation within the glide path sector where the two carrier signal strengths are approximately equal.

3.1.5.5.4 **Recommendation.—** *Undesired frequency and phase modulation on ILS glide path radio frequency carriers that can affect the displayed DDM values in glide path receivers should be minimized to the extent practical.*

Note.— Relevant guidance material is given in 2.15 of Attachment C.

3.1.5.6 *Displacement sensitivity*

3.1.5.6.1 For Facility Performance Category I — ILS glide paths, the nominal angular displacement sensitivity shall correspond to a DDM of 0.0875 at angular displacements above and below the glide path between 0.07 θ and 0.14 θ.

Note.— The above is not intended to preclude glide path systems which inherently have asymmetrical upper and lower sectors.

3.1.5.6.2 **Recommendation.—** *For Facility Performance Category I — ILS glide paths, the nominal angular displacement sensitivity should correspond to a DDM of 0.0875 at an angular displacement below the glide path of 0.12 θ with a tolerance of plus or minus 0.02 θ. The upper and lower sectors should be as symmetrical as practicable within the limits specified in 3.1.5.6.1 above.*

3.1.5.6.3 For Facility Performance Category II — ILS glide paths, the angular displacement sensitivity shall be as symmetrical as practicable. The nominal angular displacement sensitivity shall correspond to a DDM of 0.0875 at an angular displacement of:

a) 0.12 θ below path with a tolerance of plus or minus 0.02 θ;

b) 0.12 θ above path with a tolerance of plus 0.02 θ and minus 0.05 θ.

3.1.5.6.4 For Facility Performance Category III — ILS glide paths, the nominal angular displacement sensitivity shall correspond to a DDM of 0.0875 at angular displacements above and below the glide path of 0.12 θ with a tolerance of plus or minus 0.02 θ.

3.1.5.6.5 The DDM below the ILS glide path shall increase smoothly for decreasing angle until a value of 0.22 DDM is reached. This value shall be achieved at an angle not less than 0.30 θ above the horizontal. However, if it is achieved at an angle above 0.45 θ, the DDM value shall not be less than 0.22 at least down to 0.45 θ or to such lower angle, down to 0.30 θ, as required to safeguard the promulgated glide path intercept procedure.

Note.— The limits of glide path equipment adjustment are pictorially represented in Figure C-11 of Attachment C.

3.1.5.6.6 For Facility Performance Category I — ILS glide paths, the angular displacement sensitivity shall be adjusted and maintained within plus or minus 25 per cent of the nominal value selected.

3.1.5.6.7 For Facility Performance Category II — ILS glide paths, the angular displacement sensitivity shall be adjusted and maintained within plus or minus 20 per cent of the nominal value selected.

3.1.5.6.8 For Facility Performance Category III — ILS glide paths, the angular displacement sensitivity shall be adjusted and maintained within plus or minus 15 per cent of the nominal value selected.

Note.— Explanatory material on ILS glide path adjustment and maintenance values appears at 2.1.5 of Attachment C.

3.1.5.7 *Monitoring*

3.1.5.7.1 The automatic monitor system shall provide a warning to the designated control points and cause radiation to cease within the periods specified in 3.1.5.7.3.1 below if any of the following conditions persist:

a) shift of the mean ILS glide path angle equivalent to more than minus 0.075 θ to plus 1.10 θ from θ;

b) in the case of ILS glide paths in which the basic functions are provided by the use of a single-frequency system, a reduction of power output to less than 50 per cent, provided the glide path continues to meet the requirements of 3.1.5.3, 3.1.5.4 and 3.1.5.5 above;

c) in the case of ILS glide paths in which the basic functions are provided by the use of two-frequency systems, a reduction of power output for either carrier to less than 80 per cent of normal, except that a greater reduction to between 80 per cent and 50 per cent of normal may be permitted, provided the glide path continues to meet the requirements of 3.1.5.3, 3.1.5.4 and 3.1.5.5 above;

Note.— It is important to recognize that a frequency change resulting in a loss of the frequency difference specified in 3.1.5.2.1 above may produce a hazardous condition. This problem is of greater operational significance for Categories II and III installations. As necessary, this problem can be dealt with through special monitoring provisions or highly reliable circuitry.

d) for Facility Performance Category I — ILS glide paths, a change of the angle between the glide path and the line below the glide path (150 Hz predominating) at which a DDM of 0.0875 is realized by more than plus or minus 0.0375 θ;

e) for Facility Performance Categories II and III — ILS glide paths, a change of displacement sensitivity to a value differing by more than 25 per cent from the nominal value;

f) lowering of the line beneath the ILS glide path at which a DDM of 0.0875 is realized to less than 0.7475 θ from horizontal;

g) a reduction of DDM to less than 0.175 within the specified coverage below the glide path sector.

Note 1.— The value of 0.7475 θ from horizontal is intended to ensure adequate obstacle clearance. This value was derived from other parameters of the glide path and monitor specification. Since the measuring accuracy to four significant figures is not intended, the value of 0.75 θ may be used as a monitor limit for this purpose. Guidance on obstacle clearance criteria is given in PANS-OPS (Doc 8168).

Note 2.— Subparagraphs f) and g) are not intended to establish a requirement for a separate monitor to protect against deviation of the lower limits of the half sector below 0.7475 θ from horizontal.

Note 3.— At glide path facilities where the selected nominal angular displacement sensitivity corresponds to an angle below the ILS glide path which is close to or at the maximum limits specified in 3.1.5.6 above, it may be necessary to adjust the monitor operating limits to protect against sector deviations below 0.7475 θ from horizontal.

Note 4.— Guidance material relating to the condition described in g) appears in 2.4.13 of Attachment C.

3.1.5.7.2 **Recommendation.—** *Monitoring of the ILS glide path characteristics to smaller tolerances should be arranged in those cases where operational penalties would otherwise exist.*

3.1.5.7.3 The total period of radiation, including period(s) of zero radiation, outside the performance limits specified in a), b), c), d), e) and f) of 3.1.5.7.1 above shall be as short as practicable, consistent with the need for avoiding interruptions of the navigation service provided by the ILS glide path.

3.1.5.7.3.1 The total period referred to under 3.1.5.7.3 above shall not exceed under any circumstances:

6 seconds for Category I — ILS glide paths;

2 seconds for Categories II and III — ILS glide paths.

Note 1.— The total time periods specified are never-to-be-exceeded limits and are intended to protect aircraft in the final stages of approach against prolonged or repeated periods of ILS glide path guidance outside the monitor limits. For this reason, they include not only the initial period of outside tolerance operation but also the total of any or all periods of *outside tolerance radiation, including period(s) of zero radiation, which might occur during action to restore service, for example, in the course of consecutive monitor functioning and consequent changeover(s) to glide path equipment(s) or elements thereof.*

Note 2.— From an operational point of view, the intention is that no guidance outside the monitor limits be radiated after the time periods given, and that no further attempts be made to restore service until a period in the order of 20 seconds has elapsed.

3.1.5.7.3.2 **Recommendation.—** *Where practicable, the total period specified under 3.1.5.7.3.1 above for Categories II and III — ILS glide paths should not exceed 1 second.*

3.1.5.7.4 Design and operation of the monitor system shall be consistent with the requirement that radiation shall cease and a warning shall be provided at the designated remote control points in the event of failure of the monitor system itself.

Note.— Guidance material on the design and operation of monitor systems is given in 2.1.8 of Attachment C.

3.1.5.8 *Integrity and continuity of service requirements*

3.1.5.8.1 The probability of not radiating false guidance signals shall not be less than $1 - 0.5 \times 10^{-9}$ in any one landing for Facility Performance Categories II and III glide paths.

3.1.5.8.2 **Recommendation.—** *The probability of not radiating false guidance signals should not be less than $1 - 1.0 \times 10^{-7}$ in any one landing for Facility Performance Category I glide paths.*

3.1.5.8.3 The probability of not losing the radiated guidance signal shall be greater than $1 - 2 \times 10^{-6}$ in any period of 15 seconds for Facility Performance Categories II and III glide paths (equivalent to 2 000 hours mean time between outages).

3.1.5.8.4 **Recommendation.—** *The probability of not losing the radiated guidance signal should exceed $1 - 4 \times 10^{-6}$ in any period of 15 seconds for Facility Performance Category I glide paths (equivalent to 1 000 hours mean time between outages).*

Note.— Guidance material on integrity and continuity of service is given in 2.8 of Attachment C.

3.1.6 Localizer and glide path frequency pairing

3.1.6.1 The pairing of the runway localizer and glide path transmitter frequencies of an instrument landing system shall be taken from the following list in accordance with the provisions of Volume V, Chapter 4, 4.2:

Localizer (MHz)	*Glide path (MHz)*
108.1	334.7
108.15	334.55
108.3	334.1
108.35	333.95
108.5	329.9
108.55	329.75
108.7	330.5
108.75	330.35
108.9	329.3
108.95	329.15
109.1	331.4
109.15	331.25
109.3	332.0
109.35	331.85
109.5	332.6
109.55	332.45
109.7	333.2
109.75	333.05
109.9	333.8
109.95	333.65
110.1	334.4
110.15	334.25
110.3	335.0
110.35	334.85
110.5	329.6
110.55	329.45
110.7	330.2
110.75	330.05
110.9	330.8
110.95	330.65
111.1	331.7
111.15	331.55
111.3	332.3
111.35	332.15
111.5	332.9
111.55	332.75
111.7	333.5
111.75	333.35
111.9	331.1
111.95	330.95

3.1.6.1.1 In those regions where the requirements for runway localizer and glide path transmitter frequencies of an instrument landing system do not justify more than 20 pairs, they shall be selected sequentially, as required, from the following list:

Sequence number	*Localizer (MHz)*	*Glide path (MHz)*
1	110.3	335.0
2	109.9	333.8
3	109.5	332.6
4	110.1	334.4
5	109.7	333.2

Sequence number	*Localizer (MHz)*	*Glide path (MHz)*
6	109.3	332.0
7	109.1	331.4
8	110.9	330.8
9	110.7	330.2
10	110.5	329.6
11	108.1	334.7
12	108.3	334.1
13	108.5	329.9
14	108.7	330.5
15	108.9	329.3
16	111.1	331.7
17	111.3	332.3
18	111.5	332.9
19	111.7	333.5
20	111.9	331.1

3.1.6.2 Where existing ILS localizers meeting national requirements are operating on frequencies ending in even tenths of a megahertz, they shall be re-assigned frequencies, conforming with 3.1.6.1 or 3.1.6.1.1 above as soon as practicable and may continue operating on their present assignments only until this re-assignment can be effected.

3.1.6.3 Existing ILS localizers in the international service operating on frequencies ending in odd tenths of a megahertz shall not be assigned new frequencies ending in odd tenths plus one twentieth of a megahertz except where, by regional agreement, general use may be made of any of the channels listed in 3.1.6.1 above (see Volume V, Chapter 4, 4.2).

3.1.7 VHF marker beacons

3.1.7.1 *General*

a) There shall be two marker beacons in each installation except as provided in 3.1.7.6.6 below. A third marker beacon may be added whenever, in the opinion of the Competent Authority, an additional beacon is required because of operational procedures at a particular site.

b) The marker beacons shall conform to the requirements prescribed in this 3.1.7. When the installation comprises only two marker beacons, the requirements applicable to the middle marker and to the outer marker shall be complied with.

c) The marker beacons shall produce radiation patterns to indicate predetermined distance from the threshold along the ILS glide path.

3.1.7.1.1 When a marker beacon is used in conjunction with the back course of a localizer, it shall conform with the marker beacon characteristics specified in 3.1.7.

3.1.7.1.2 Identification signals of marker beacons used in conjunction with the back course of a localizer shall be clearly distinguishable from the inner, middle and outer marker beacon identifications, as prescribed in 3.1.7.5.1 below.

3.1.7.2 *Radio frequency*

3.1.7.2.1 The marker beacons shall operate at 75 MHz with a frequency tolerance of plus or minus 0.01 per cent and shall utilize horizontal polarization. As from 1 January 1985 all newly installed marker beacons shall have a frequency tolerance of plus or minus 0.005 per cent. After 1 January 1990 this provision applies for all marker beacons.

3.1.7.2.2 **Recommendation.—** *Marker beacons should operate with a frequency tolerance of plus or minus 0.005 per cent.*

3.1.7.3 *Coverage*

3.1.7.3.1 The marker beacon system shall be adjusted to provide coverage over the following distances, measured on the ILS glide path and localizer course line:

a) inner marker (where installed): 150 m plus or minus 50 m (500 ft plus or minus 160 ft);

b) *middle marker:* 300 m plus or minus 100 m (1 000 ft plus or minus 325 ft);

c) *outer marker:* 600 m plus or minus 200 m (2 000 ft plus or minus 650 ft).

3.1.7.3.2 The field strength at the limits of coverage specified in 3.1.7.3.1 above shall be 1.5 millivolts per metre (82 dBW/m^2). In addition, the field strength within the coverage area shall rise to at least 3.0 millivolts per metre (76 dBW/m^2).

Note 1.— In the design of the ground antenna, it is advisable to ensure that an adequate rate of change of field strength is provided at the edges of coverage. It is also advisable to ensure that aircraft within the localizer course sector will receive visual indication.

Note 2.— Satisfactory operation of a typical airborne marker installation will be obtained if the sensitivity is so *adjusted that visual indication will be obtained when the field strength is 1.5 millivolts per metre (82 dBW/m²).*

3.1.7.4 *Modulation*

3.1.7.4.1 The modulation frequencies shall be as follows:

a) *inner marker (when installed):* 3 000 Hz;

b) *middle marker:* 1 300 Hz;

c) *outer marker:* 400 Hz.

The frequency tolerance of the above frequencies shall be plus or minus 2.5 per cent, and the total harmonic content of each of the frequencies shall not exceed 15 per cent.

3.1.7.4.2 The depth of modulation of the markers shall be 95 per cent plus or minus 4 per cent.

3.1.7.5 *Identification*

3.1.7.5.1 The carrier energy shall not be interrupted. The audio frequency modulation shall be keyed as follows:

a) *inner marker (when installed):* 6 dots per second continuously;

b) *middle marker:* a continuous series of alternate dots and dashes, the dashes keyed at the rate of 2 dashes per second, and the dots at the rate of 6 dots per second;

c) *outer marker:* 2 dashes per second continuously.

These keying rates shall be maintained to within plus or minus 15 per cent.

3.1.7.6 *Siting*

3.1.7.6.1 The inner marker, when installed, shall be located so as to indicate in low visibility conditions the imminence of arrival at the runway threshold.

3.1.7.6.1.1 **Recommendation.—** *If the radiation pattern is vertical, the inner marker, when installed, should be located between 75 m (250 ft) and 450 m (1 500 ft) from the threshold and at not more than 30 m (100 ft) from the extended centre line of the runway.*

Note 1.— It is intended that the inner marker pattern should intercept the downward extended straight portion of the nominal ILS glide path at the lowest decision height applicable in Category II operations.

Note 2.— Care must be exercised in siting the inner marker to avoid interference between the inner and middle markers. Details regarding the siting of inner markers are contained in 2.10 of Attachment C.

3.1.7.6.1.2 **Recommendation.—** *If the radiation pattern is other than vertical, the equipment should be located so as to produce a field within the course sector and ILS glide path sector that is substantially similar to that produced by an antenna radiating a vertical pattern and located as prescribed in 3.1.7.6.1.1 above.*

3.1.7.6.2 The middle marker shall be located so as to indicate the imminence, in low visibility conditions, of visual approach guidance.

3.1.7.6.2.1 **Recommendation.—** *If the radiation pattern is vertical, the middle marker should be located 1 050 m (3 500 ft) plus or minus 150 m (500 ft), from the landing threshold at the approach end of the runway and at not more than 75 m (250 ft) from the extended centre line of the runway.*

Note.— See 2.2.2 of Attachment A regarding the siting of inner and middle marker beacons.

3.1.7.6.2.2 **Recommendation.—** *If the radiation pattern is other than vertical, the equipment should be located so as to produce a field within the course sector and ILS glide path sector that is substantially similar to that produced by an antenna radiating a vertical pattern and located as prescribed in 3.1.7.6.2.1 above.*

3.1.7.6.3 The outer marker shall be located so as to provide height, distance and equipment functioning checks to aircraft on intermediate and final approach.

3.1.7.6.3.1 **Recommendation.—** *The outer marker should be located 7.2 km (3.9 NM) from the threshold except that, where for topographical or operational reasons this distance is not practicable, the outer marker may be located between 6.5 and 11.1 km (3.5 and 6 NM) from the threshold.*

3.1.7.6.4 **Recommendation.—** *If the radiation pattern is vertical, the outer marker should be not more than 75 m (250 ft) from the extended centre line of the runway. If the radiation pattern is other than vertical, the equipment should be located so as to produce a field within the course sector and ILS glide path sector that is substantially similar to that produced by an antenna radiating a vertical pattern.*

3.1.7.6.5 The positions of marker beacons, or where applicable, the equivalent distance(s) indicated by the DME when used as an alternative to part or all of the marker beacon component of the ILS, shall be published in accordance with the provisions of Annex 15.

3.1.7.6.6 Where the provision of VHF marker beacons is impracticable, a suitably located DME, together with associated monitor system and remote control and indicator equipment shall be an acceptable alternative to part or all of the marker beacon component of the ILS.

Note.— Guidance material relative to the use of DME as an alternative to the marker beacon component of the ILS is contained in Attachment C, 2.11.

3.1.7.6.6.1 When so used, the DME shall provide distance information operationally equivalent to that furnished by marker beacon(s).

3.1.7.6.6.2 When used as an alternative for the middle marker, the DME shall be frequency paired with the ILS localizer and sited so as to minimize the error in distance information.

3.1.7.6.6.3 The DME in 3.1.7.6.6 above shall conform to the specification in 3.5 below.

3.1.7.7 *Monitoring*

3.1.7.7.1 Suitable equipment shall provide signals for the operation of an automatic monitor. The monitor shall transmit a warning to a control point if either of the following conditions arise:

a) failure of the modulation or keying;

b) reduction of power output to less than 50 per cent of normal.

3.1.7.7.2 **Recommendation.—** *For each marker beacon, suitable monitoring equipment should be provided which will indicate at the appropriate location a decrease of the modulation depth below 50 per cent.*

Note.— Provisions for the recording and retention of radar data are contained in Annex 11, Chapter 6.

3.2 Specification for precision approach radar system

Note.— Slant distances are used throughout this specification.

3.2.1 The precision approach radar system shall comprise the following elements:

3.2.1.1 The precision approach radar element (PAR).

3.2.1.2 The surveillance radar element (SRE).

3.2.2 When the PAR only is used, the installation shall be identified by the term PAR or precision approach radar and not by the term "precision approach radar system".

3.2.3 The precision approach radar element (PAR)

3.2.3.1 *Coverage*

3.2.3.1.1 The PAR shall be capable of detecting and indicating the position of an aircraft of 15 m^2 echoing area or larger, which is within a space bounded by a 20-degree azimuth sector and a 7-degree elevation sector, to a distance of at least 16.7 km (9 NM) from its respective antenna.

Note.— For guidance in determining the significance of the echoing areas of aircraft, the following table is included:

private flyer (single-engined): 5 to 10 m^2;

small twin-engined aircraft: from 15 m^2;

medium twin-engined aircraft: from 25 m^2;

four-engined aircraft: from 50 to 100 m^2.

3.2.3.2 *Siting*

3.2.3.2.1 The PAR shall be sited and adjusted so that it gives complete coverage of a sector with its apex at a point 150 m (500 ft) from the touchdown in the direction of the stop end of the runway and extending plus or minus 5 degrees about the runway centre line in azimuth and from minus 1 degree to plus 6 degrees in elevation.

Note 1.— 3.2.3.2.1 above can be met by siting the equipment with a set-back from the touchdown, in the direction of the stop end of the runway, of 915 m (3 000 ft) or more, for an offset of 120 m (400 ft) from the runway centre line, or of 1 200 m (4 000 ft) or more, for an offset of 185 m (600 ft) when the equipment is aligned to scan plus or minus 10 degrees about the centre line of the runway. Alternatively, if the equipment is aligned to scan 15 degrees to one side and 5 degrees to the other side of the centre line of the runway, then the minimum set-back can be reduced to 685 m (2 250 ft) and 915 m (3 000 ft) for offsets of 120 m (400 ft) and 185 m (600 ft) respectively.

Note 2.— Diagrams illustrating the siting of PAR are given in Attachment C (Figures C-14 to C-17 inclusive).

3.2.3.3 *Accuracy*

3.2.3.3.1 *Azimuth accuracy.* Azimuth information shall be displayed in such a manner that left-right deviation from the on-course line shall be easily observable. The maximum

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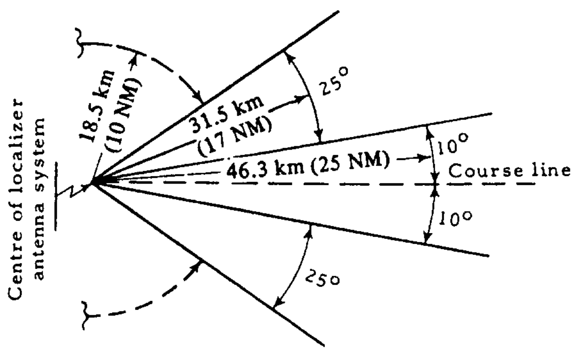
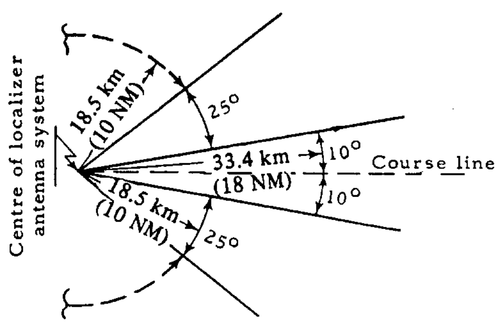
2.5 Diagrams (Figures C-7 to C-12 illustrate certain of the standards contained in Chapter 3)

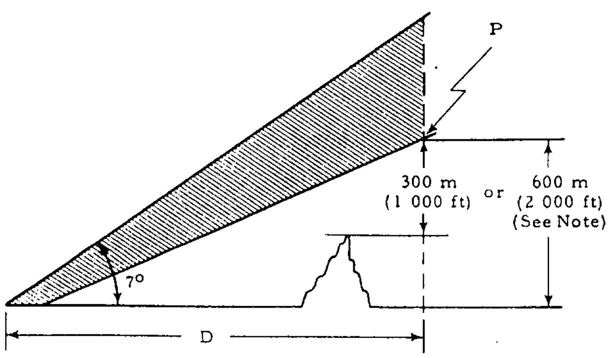


When topographical features dictate or operational requirements and alternative navigation facilities permit, the following coverage may be provided:



Note.— If coverage as prescribed in Chapter 3, 3.1.3.3.1 is required outside the plus or minus 35-degree sector, this is provided to 18.5 km (10 NM), as indicated by the broken arc above.

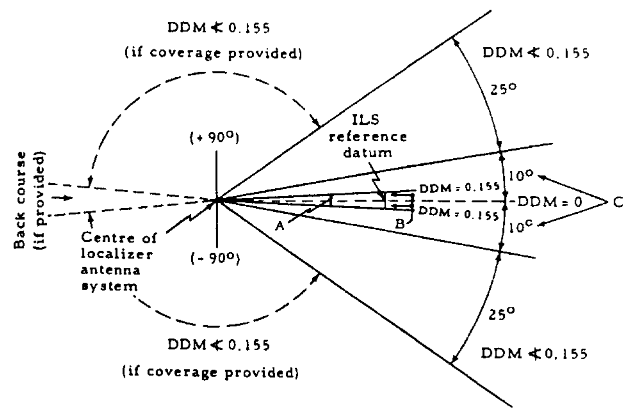
Figure C-7. Localizer coverage with respect to azimuth



D = Distances and azimuths specified in 3. 1. 3. 3. 1

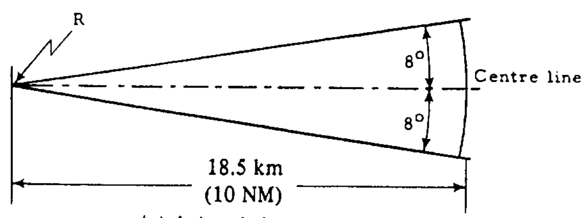
Note.—The point P is either 600 metres (2 000 feet) above the elevation of the threshold, or 300 metres (1 000 feet) above the elevation of the highest point within the intermediate and final approach areas, whichever is the higher.

Figure C-8. Localizer coverage with respect to elevation

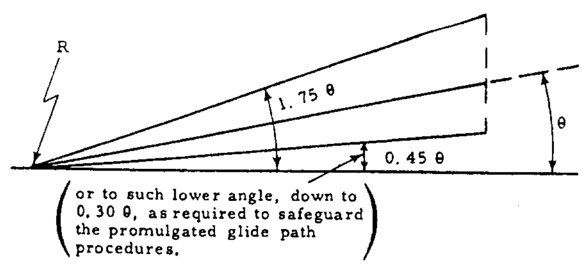


A - Course sector ≯ 6 degrees
B - Displacement sensitivity = 0. 00145 DDM/metre (0. 00044 DDM/foot) at the ILS reference datum
C - DDM increases linearly from zero to value of 0. 180, and then ≮ 0. 180

Figure C-9. Difference in depth of modulation and displacement sensitivity



(a) Azimuthal cover



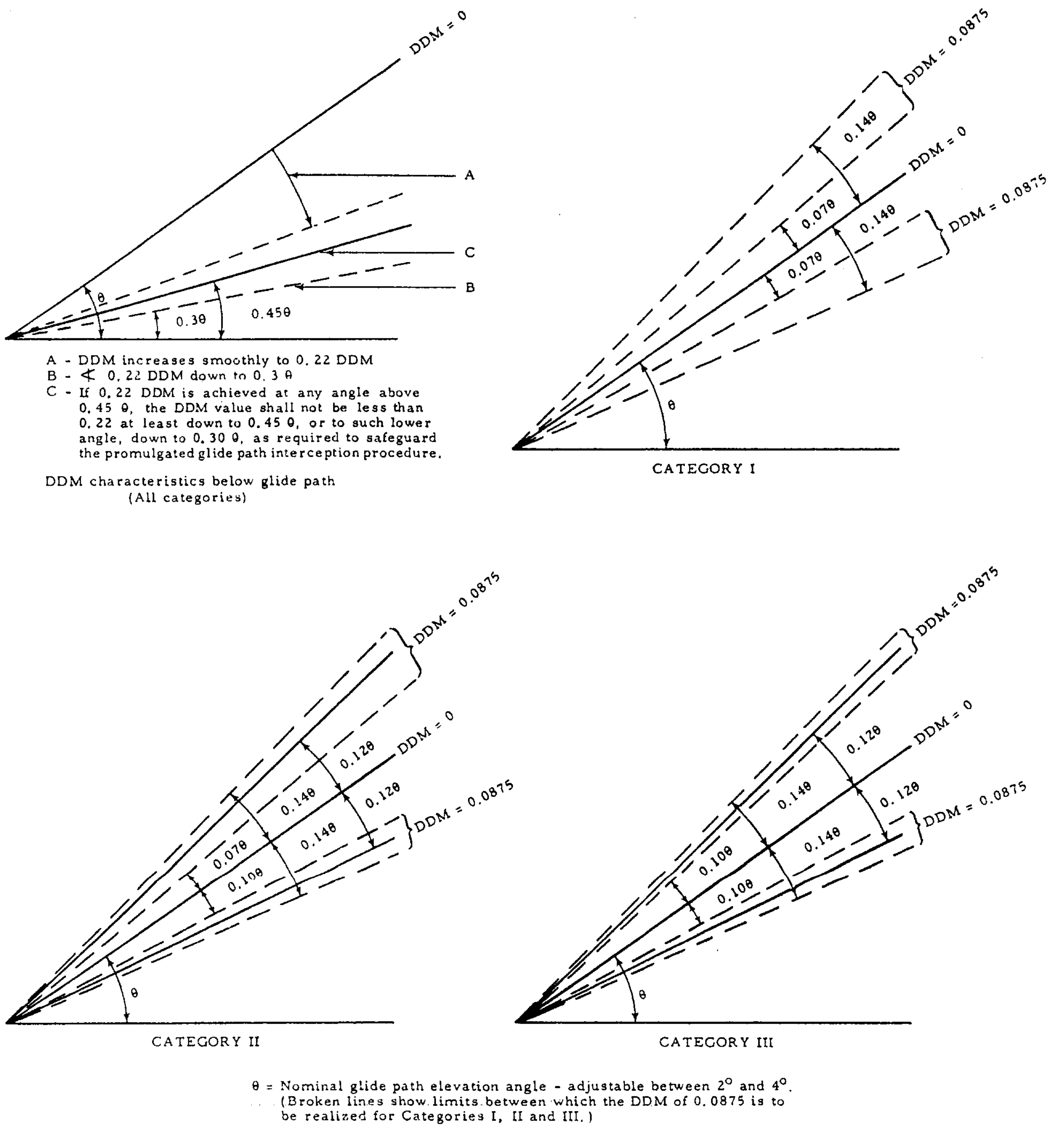
or to such lower angle, down to 0. 30 θ, as required to safeguard the promulgated glide path procedures.

(b) Elevation cover

R = Point at which the downward-extended straight portion of the ILS glide path intersects the runway centre line.

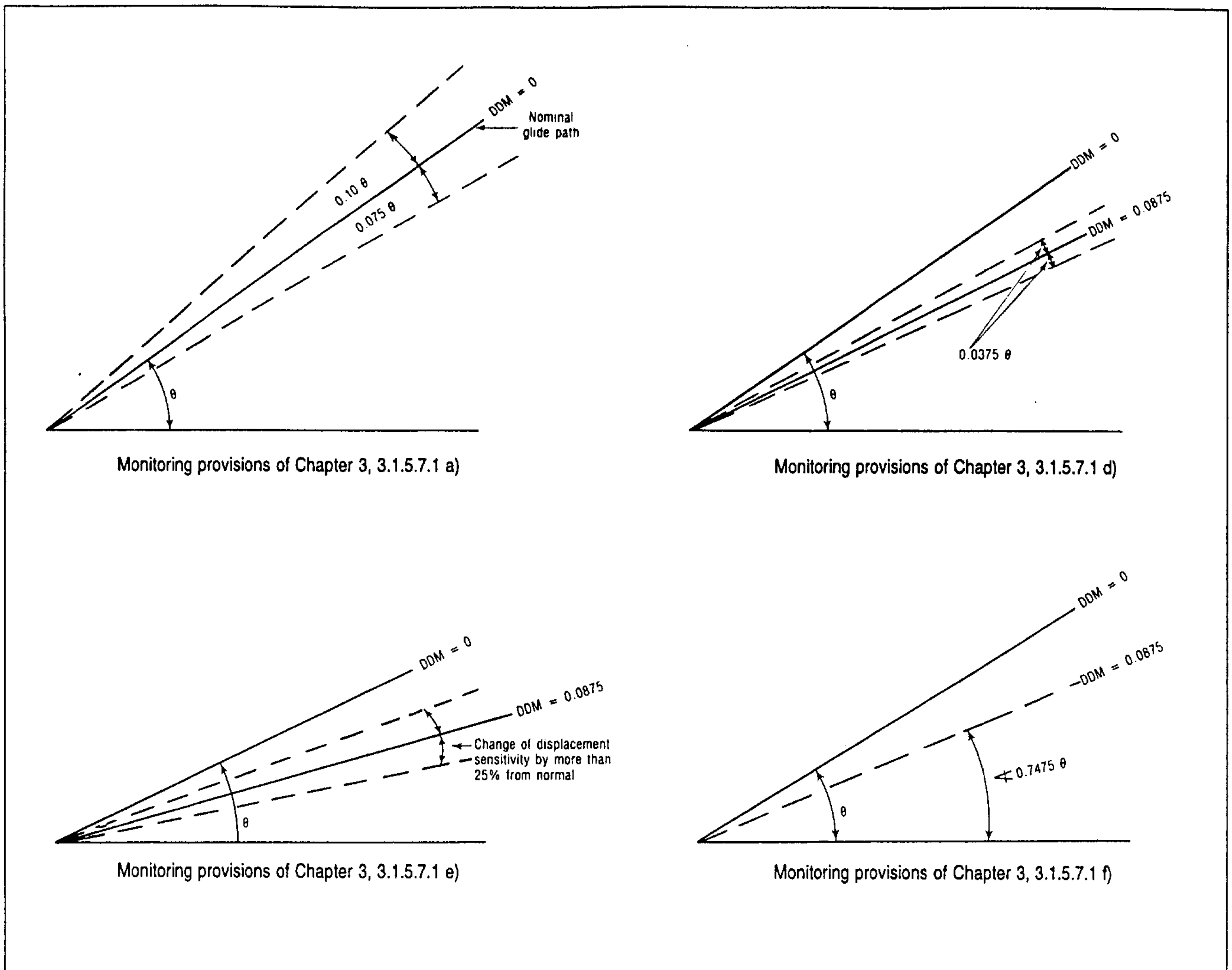
θ = (ILS) glide path angle adjustable between 2° and 4°.

Figure C-10. Glide path coverage



Note.— Figure C-11 depicts the tolerances for the radiated space pattern specified in Chapter 3, 3.1.5.6; however, this space pattern should not be interpreted as being representative of any one particular ground equipment. In this connection, it should be noted that there are several known types of ILS glide path ground equipment having different characteristics but which can satisfy the requirements of Chapter 3, 3.1.5.6. Therefore, wherever there is a requirement to know the tolerances applicable to a specific equipment, reference should be made to the manufacturer's technical data rather than the ICAO systems specification.

Figure C-11. Glide path — difference in depth of modulation



Note.— The broken lines represent the permissible limits of deviation before monitoring action is required.

Figure C-12. Glide path monitoring provisions