POLARIZATION

SO FAR IN OUR CONSIDERATION OF WAVES AND ANTENNAS WE HAVE ADOPTED A SCALAR APPROACH.

TO ACCOUNT FOR POLARIZATION, WE HAVE TO TAKE A VECTOR APPROACH, THIS SLIGHTLY COMPLICATES THE ALGEBRA AS WE HAVE TO WORK WITH VECTORS AND MATRICES.

WE NORMALLY CHOOSE TO DEFINE WAVE POLARIZATION BY THE IEEE STANDARD DEFINITION:

"THE LOCUS OF THE E-FIELD DIRECTION (E-VECTOR) DESCRIBED IN TIME AT THE SPACE ORIGIN (Z=0)".

FOR A PLANE WAVE PROPAGATING ALONG A DIRECTION z, THE COMPOUND E-FIELD CAN BE REPRESENTED BY E-FIELD COMPONENTS ALONG x AND y SUCH THAT

$$\underline{E} = E_x \hat{\underline{x}} + E_y \hat{\underline{y}} \quad \text{OR} \quad \underline{E} = \begin{bmatrix} E_x \\ E_y \end{bmatrix}$$

WE CAN WRITE E_x AND E_y AS;

$$E_x = E_1 \exp(j\delta_1)$$

$$E_y = E_2 \exp(j\delta_2)$$

IF $\delta_1 = \delta_2$, THE COMPOUND WAVE WILL BE <u>LINEARLY</u> POLARIZED

IF $\delta_1 - \delta_2 = \pm 90^\circ$, AND $E_1 = E_2$ THE COMPOUND WAVE WILL BE <u>CIRCULARLY</u> POLARIZED

AS A FUNCTION OF TIME, E_x AND E_y CAN BE WRITTEN AS;

$$E_x = E_1 \cos(\omega t + \delta_1)$$

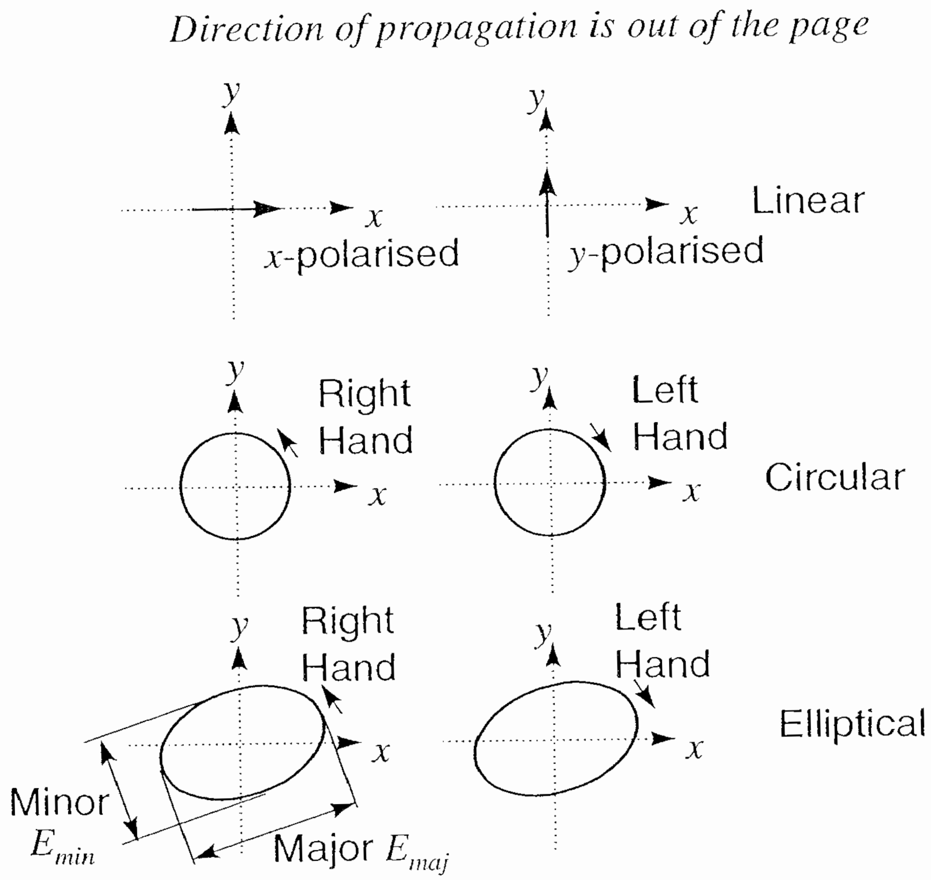
$$E_y = E_2 \cos(\omega t + \delta_2)$$

BY ELIMINATING ωt WE CAN SHOW THAT;

$$\left(\frac{E_x}{E_1}\right)^2 \left(\frac{E_y}{E_2}\right)^2 - 2\,\frac{E_x}{E_1}\,\frac{E_y}{E_2}\cos(\delta_1 - \delta_2) = \sin^2(\delta_1 - \delta_2)$$

THIS IS THE EQUATION OF AN <u>ELLIPSE</u>. WE CAN IN GENERAL DESCRIBE ANY COHERENT POLARIZATION IN TERMS OF AN ELLIPSE.

③



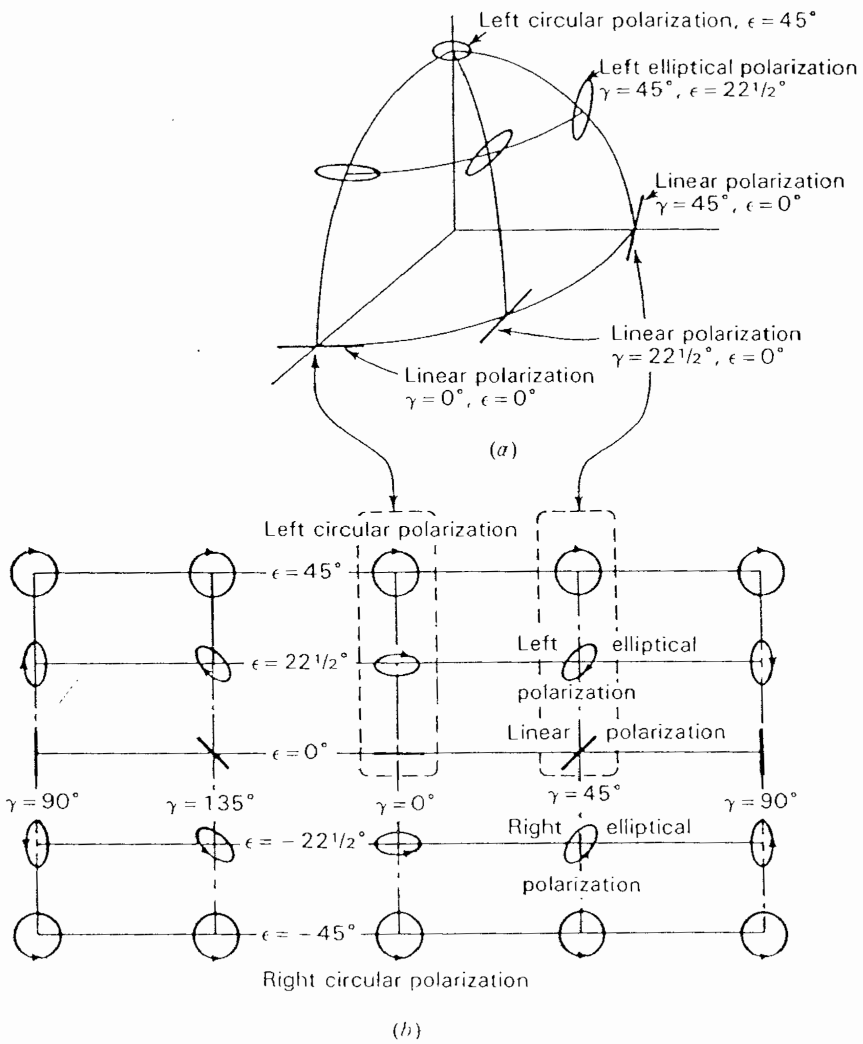


Figure 2-40 (*a*) One octant of Poincaré sphere with polarization states. (*b*) Rectangular projection of Poincaré sphere showing full range of polarization states.

SIZE DOES MATTER

TO AVOID CONFUSION WE WILL STATE SOME DEFINITIONS;

* AN ELECTRICALLY SMALL ANTENNA IS ONE THAT CAN BE BOUNDED BY A SPHERE HAVING A RADIUS EQUAL TO $\lambda/2\pi$

* A PHYSICALLY CONSTRAINED ANTENNA WHICH MAY BE REQUIRED FOR A PAGER ANTENNA FOR EXAMPLE IS NOT NECESSARILY ELECTRICALLY SMALL BUT IS SHAPED SUCH THAT A SIGNIFICANT SIZE REDUCTION CAN BE ACHIEVED.

* A PHYSICALLY SMALL ANTENNA MAY BE NEITHER OF THE ABOVE. IT MAY BE DESCRIBED AS SMALL BECAUSE IT OPERATES AT A HIGH FREQUENCY AND IS CONSEQUENTLY PHYSICALLY SMALL

WIRE ANTENNAS

THE SIMPLEST WIRE ANTENNA POSSIBLE IS THE HERTZIAN DIPOLE OR INFINITESIMAL DIPOLE

THE HERTZIAN DIPOLE CONSISTS OF A STRAIGHT PIECE OF WIRE WHOSE LENGTH L, AND DIAMETER ARE BOTH VERY MUCH LESS THAN λ. THE DIPOLE CARRIES A CURRENT THAT IS UNIFORM ALONG ITS LENGTH.

IF WE PLACE THE DIPOLE ALONG THE Z-AXIS WE CAN FIND THE FIELDS;

$$E_\theta = j Z_0 \frac{kILe^{-jkr}}{4\pi r}\left[1 + \frac{1}{jkr} - \frac{1}{(kr)^2}\right]\sin\theta$$

$$E_r = Z_0 \frac{ILe^{-jkr}}{2\pi r^2}\left[1 + \frac{1}{jkr}\right]\cos\theta$$

$$H_\phi = j \frac{kILe^{-jkr}}{4\pi r}\left[1 + \frac{1}{jkr}\right]\sin\theta$$

$$H_r = 0, \quad H_\theta = 0, \quad E_\phi = 0$$

IN THE FAR-FIELD WE CAN NEGLECT THE $1/r^2$ TERMS AND ANY OTHER HIGH ORDER TERMS ($1/r^2$ GETS SMALL QUICKLY!)

IN THE FAR-FIELD WE HAVE;

$$E_\theta = j Z_0 \frac{k I L e^{-jkr}}{4\pi r} \sin\theta$$

$$H_\phi = j \frac{k I L e^{-jkr}}{4\pi r} \sin\theta$$

$$E_r = 0, \; E_\phi = 0, \; H_r = 0, \; H_\theta = 0$$

WE CAN DEDUCE THE FOLLOWING IMPORTANT POINTS;

* THE ONLY NON-ZERO FIELDS ARE E_θ AND H_ϕ, WHICH ARE ORTHOGONAL TO EACH OTHER EVERY WHERE.

* THE RATIO $E_\theta / H_\phi = Z_0$, SO THE FIELDS ARE IN PHASE AND THE IMPEDANCE IS $Z_0 = 120\pi \, \Omega$

* THE FIELD IS PROPORTIONAL TO $1/r$

* THE FIELD IS ZERO AT $\theta = 0$ AND π.

* E, H AND r FORM AN ORTHOGONAL SET, THE POYNTING VECTOR IS IN THE r- DIRECTION AND CARRIES POWER AWAY FROM THE ORIGIN IN ALL DIRECTIONS

THE RADIATION INTENSITY OF THE HERTZIAN DIPOLE CAN BE FOUND FROM;

$$U = r^2 S \qquad (\mathrm{W\ sr^{-1}})$$

THE TIME-AVERAGED POYNTING VECTOR IS GIVEN BY

$$\underline{S}_{av} = \tfrac{1}{2} E_\theta H_\phi \, \hat{\underline{r}}$$

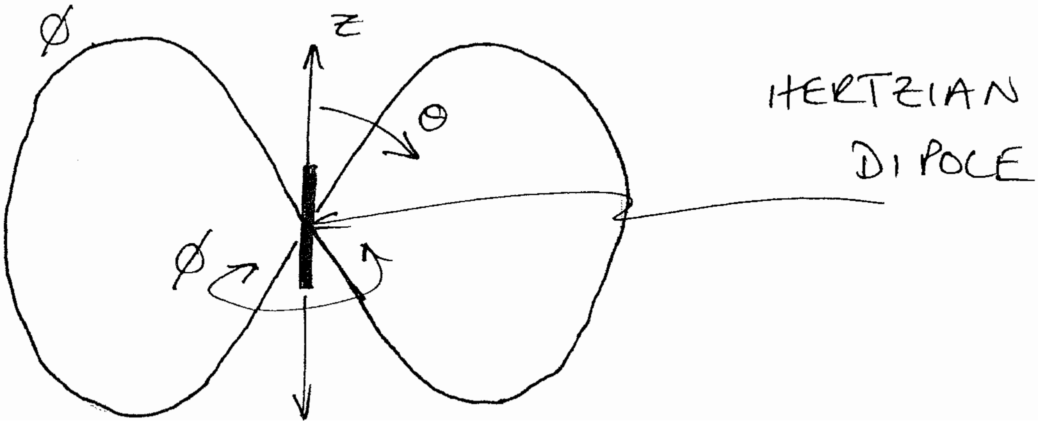
HENCE

$$U = r^2 \times \frac{1}{2} \frac{|E_\theta|^2}{Z_0} = \frac{Z_0}{2} \left[\frac{k I L}{4\pi}\right]^2 \sin^2\theta$$

THUS, THE NORMALIZED RADIATION INTENSITY (THE NORMALIZED POWER PATTERN)

$$P_n = \frac{U}{U|_{MAX}} = \frac{\frac{Z_0}{2}\left[\frac{kIL}{4\pi}\right]^2 \sin^2\theta}{\frac{Z_0}{2}\left[\frac{kIL}{4\pi}\right]^2} = \sin^2\theta .$$

THE RADIATION PATTERN IS UNIFORM FOR ALL ϕ



PRACTICAL DIPOLES

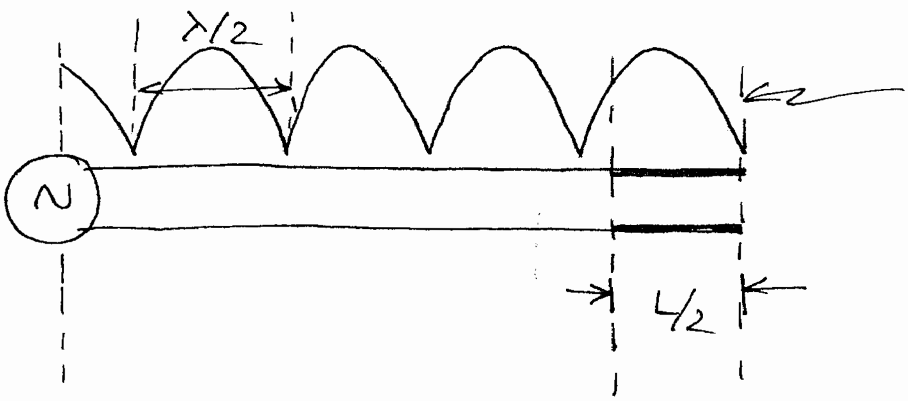
THE HERTZIAN DIPOLE ANALYSIS ASSUMES A UNIFORM CURRENT DISTRIBUTION, THIS IS ONLY THE CASE FOR WHICH THE LENGTH IS SAY $\lesssim \lambda/10$.

IF WE WANT TO OPERATE WITH LONGER LENGTH ANTENNAS (FOR THE HERTZIAN DIPOLE THE RADIATED FIELDS ARE PROPORTIONAL TO LENGTH) WE MUST KNOW ABOUT THE CURRENT DISTRIBUTION ALONG THE ANTENNA, $I(z)$.

CURRENT DISTRIBUTION

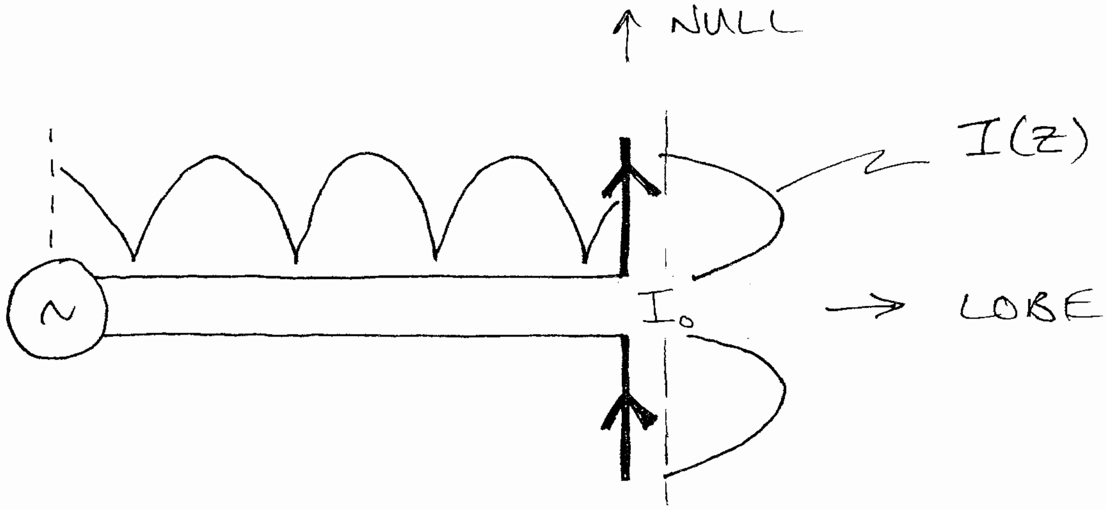
IF WE FEED A TWO WIRE TRANSMISSION LINE WHICH IS O/C AT ONE END WE GET A STANDING WAVE, WITH THE CURRENT EQUAL TO ZERO AT THE O/C END.

THE CURRENT IN THE TWO WIRES FLOWS IN OPPOSITE DIRECTIONS
$\Rightarrow$ VIRTUALLY NO FAR-FIELD RADIATION.



CURRENT DISTRIBUTION OVER THE LENGTH OF THE LINE

IF WE THEN BEND THE WIRES OUTWARD TO FORM A DIPOLE, THE CURRENTS IN THE END SECTION ARE IN THE SAME DIRECTION, SO WE GET RADIATION



THIS RADIATION DOES (DEPENDING ON THE LENGTH) CHANGE THE CURRENT DIST-RIBUTION, BUT FOR $L = \lambda/2$ THE SINUSOIDAL APPROXIMATION IS QUITE A GOOD ONE.

TO MODEL THE CURRENT DISTRIBUTION, WE START WITH STANDARD TRANSMISSION LINE THEORY;

$$I(z) = I_0 \sin\left[k\left(\frac{L}{2} - |z|\right)\right]$$

FOR INFINITESIMALLY THIN WIRE DIPOLE WIRES THIS GIVES EXACT RESULTS, BUT FOR REAL WIRE (THIN COMPARED TO ITS LENGTH) IT IS QUITE GOOD.

FOR LENGTHS $\lambda/10$ TO $\lambda/4$ A LINEAR APPROXIMATION CAN BE USED FOR MOST PURPOSES.

IN GENERAL, TO CALCULATE THE RADIATED FIELD OF A LONGER DIPOLE WE MUST;

* DETERMINE AN EXPRESSION FOR $I(z)$.

* CONSIDER THE LARGE DIPOLE AS BEING COMPRISED OF A LARGE NUMBER OF SMALL ($\ll \lambda$) HERTZIAN DIPOLES, THE CONTRIBUTIONS OF WHICH WE CAN SUM IN THE FAR-FIELD

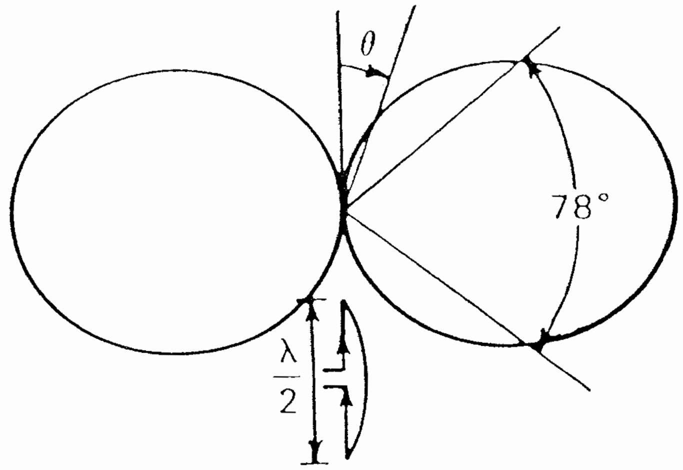
WITHOUT RESORTING TO THIS KIND OF ANALYSIS, WE CAN DEDUCE SOME QUALITATIVE RESULTS;

* A DIPOLE WILL BE OMNIDIRECTIONAL IRRESPECTIVE OF ITS LENGTH (IT IS ROTATIONALLY SYMMETRIC ABOUT ITS AXIS)

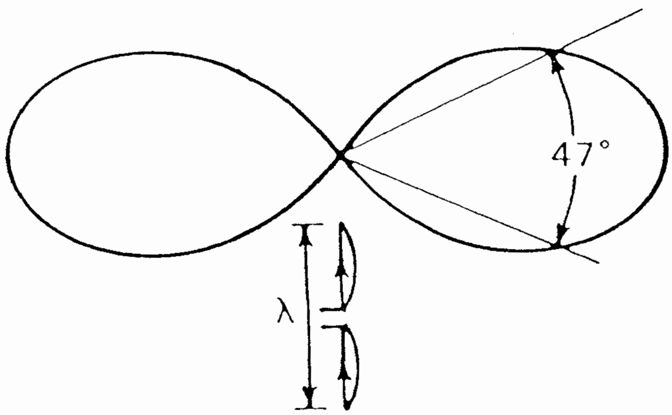
* THE CURRENT ALWAYS POINTS DIRECTLY TOWARDS OR AWAY FROM ALL POINTS ON THE AXIS OF THE DIPOLE - SO NO RADIATION IS PRODUCED, HENCE A NULL OCCURS AT ALL POINTS

FAR-FIELD RADIATION PATTERNS

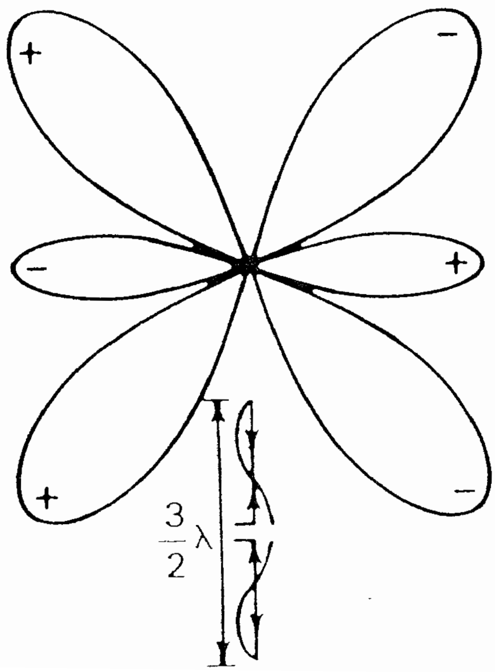
(a)



(b)

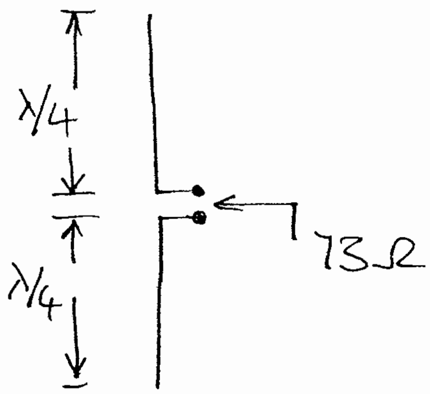


(c)



HALF-WAVE DI-POLE

THE HALF-WAVE DIPOLE IS A WELL CHARACTERIZED AND EFFICIENT ANTENNA



AT VHF AND ABOVE DIMENSIONS ARE CONVENIENT,

CURRENT DISTRIBUTION IS SINUSOIDAL

THE DIRECTIVITY OF A HALF-WAVE DIPOLE IS 2.15 dBi

A VERTICALLY ORIENTED DIPOLE GENERATE[S] A VERTICALLY POLARIZED SIGNAL, A HORIZONTALLY ORIENTED DI-POLE GENERATE[S] A HORIZONTALLY POLARIZED SIGNAL

THE HALF-WAVE DIPOLE IS OFTEN USED AS A REFERENCE ANTENNA.
- THE ADVANTAGE OF THIS IS THAT IT CAN BE CONSTRUCTED AND MEASURED WHEREAS AN ISOTROPIC RADIATOR CANNOT.

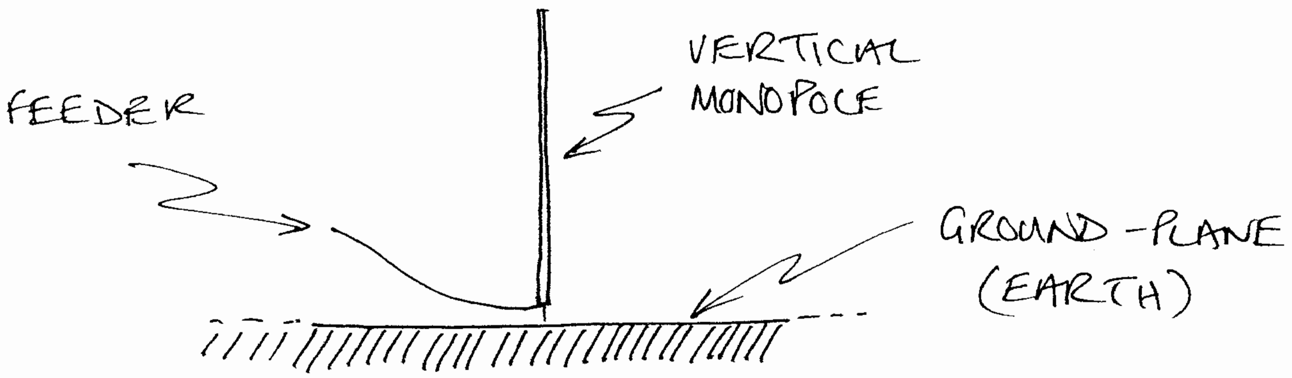
$$0 \text{ dBd} = 2.15 \text{ dBi}$$

dB w.r.t. DIPOLE

MONOPOLE ANTENNAS

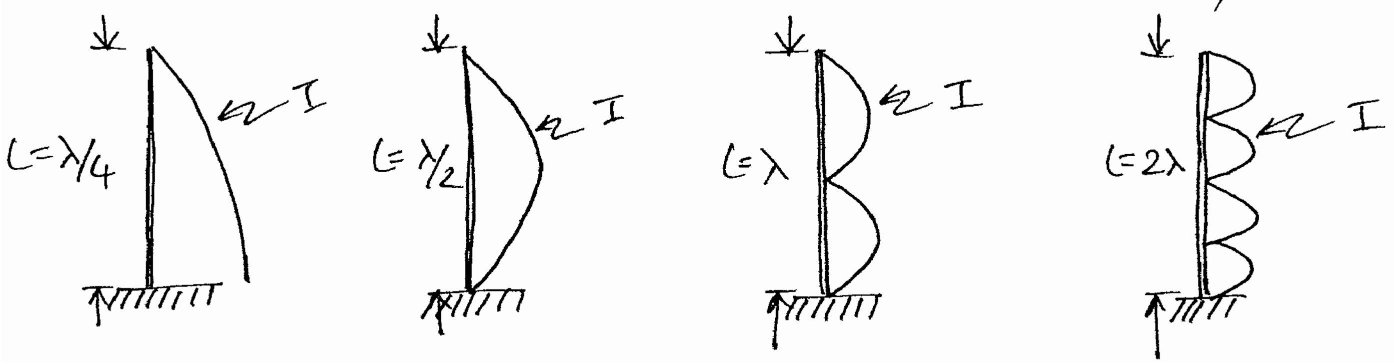
IT IS USUAL TO MOUNT DI-POLES WELL-ABOVE THE GROUND. THE MONOPOLE HOWEVER IS NOT REQUIRED TO BE ELEVATED.

AT LOW-FREQUENCIES WHERE THEY ARE COMMONLY USED, IT CAN BE FED A SMALL DISTANCE ABOVE THE EARTH WHICH ACTS AN INFINITE GROUND PLANE

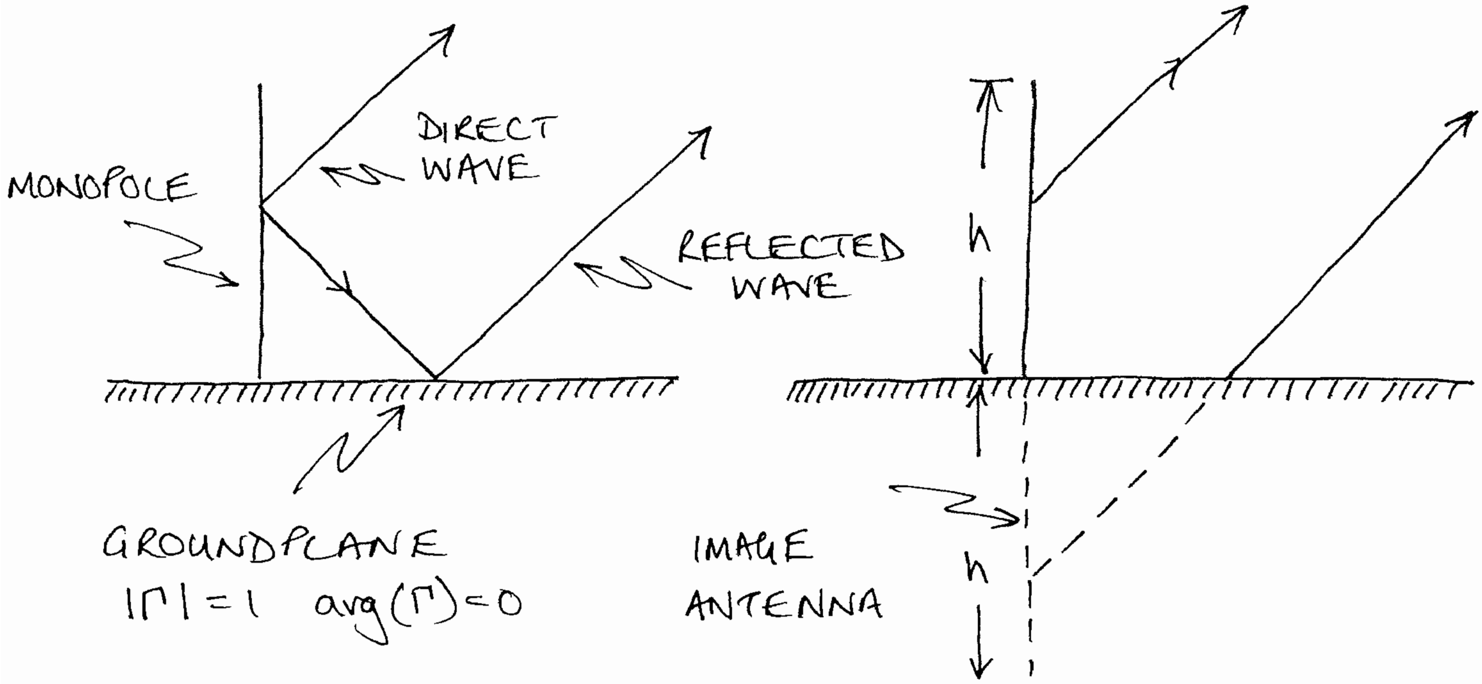


THE EARTH CAUSES A REFLECTION OF AN IMPINGING WAVES VIA AN ASSOCIATED COMPLEX-VALUED REFLECTION COEFFICIENT (DENOTED Γ - MORE ON THIS LATER ON)

LIKE DI-POLES, MONOPOLES CAN BE USED WITH VARIOUS WIRE LENGTHS;



WE CAN USE THE METHOD OF IMAGES TO LOOK AT THE BEHAVIOUR OF THE MONOPOLE



FROM THIS WE CAN SEE THAT WE EFFECTIVELY HAVE A DIPOLE OF LENGTH 2h RADIATING INTO THE HALF-SPHERE ABOVE THE GROUND PLANE.

* FIELD STRENGTHS ARE THE SAME AS FOR A DIPOLE OF 2h WITH THE SAME FEED CURRENT.

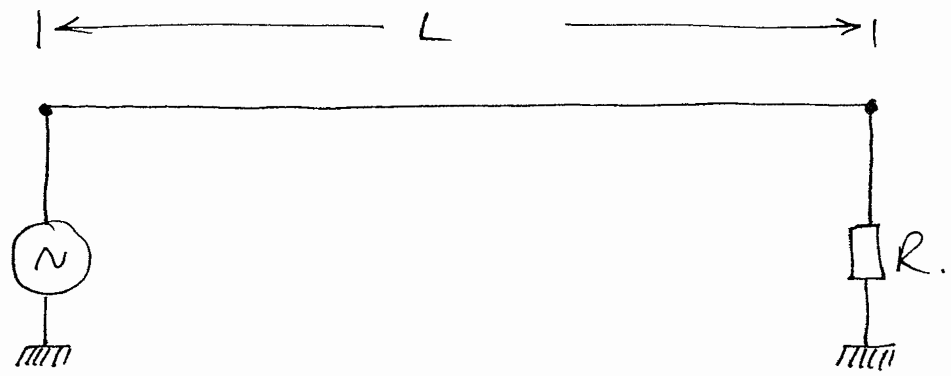
* RADIATION PATTERN IS HALF THAT OF A DIPOLE

* TOTAL POWER RADIATED IS HALF THAT OF A DIPOLE

* HENCE, RADIATION RESISTANCE IS HALF THAT OF A DIPOLE

HORIZONTAL WIRE ANTENNAS

CONSIDER A HORIZONTAL WIRE REMOTE FROM THE GROUND;



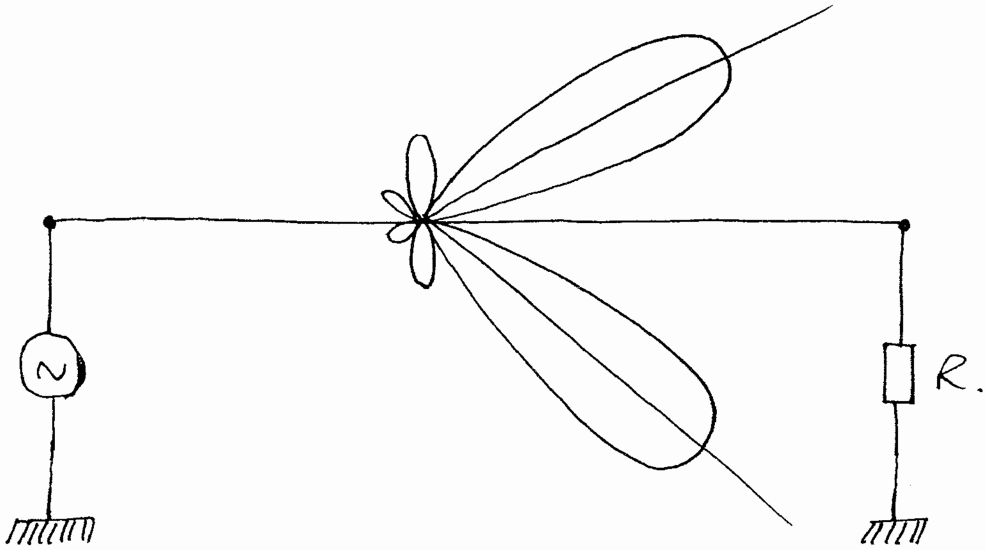
THIS STRUCTURE WHEN CORRECTLY TERMINATED (BY R) SUPPORTS A TRAVELLING WAVE – AND IS CALLED A NON-RESONANT ANTENNA.

SUCH AN ANTENNA HAS A UNIFORM CURRENT DISTRIBUTION, BUT DOES HAVE A PROGRESSIVE PHASE LAG OF β RADIANS PER UNIT LENGTH.

THIS PHASE LAG CAUSES SMALL DOUBLETS (HERTZIAN DIPOLES) TO APPEAR PLACED END-TO-END ALONG THE WIRE.

THE RADIATION PATTERN CAN BE DETERMINED BY SUMMING THE DOUBLET FIELDS END-TO-END TAKING PROPER ACCOUNT OF THEIR PHASE

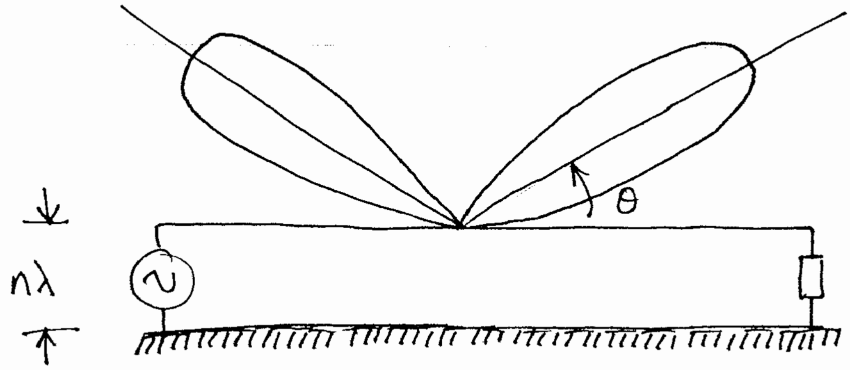
A TYPICAL RADIATION PATTERN MIGHT LOOK LIKE THIS;



IF THE WIRE IS CLOSE TO THE GROUND, THE RADIATION IS REFLECTED UPWARDS. AGAIN WE CAN USE THE METHOD OF IMAGES. IF THE ANTENNA IS AT A HEIGHT $n\lambda$ ABOVE THE SURFACE, WHICH NOW HAS A PHASE REVERSAL OF $180°$ ($|\Gamma| = 1$ $\arg(\Gamma) = 180°$).

THE PATH DIFFERENCE IS $2(n\lambda)\cos\theta$.

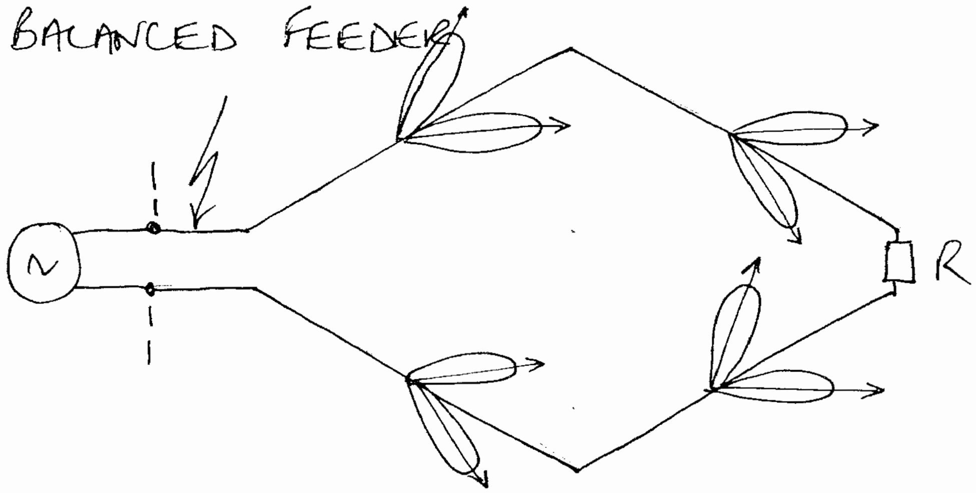
BOTH LOBES ARE DIRECTED UPWARDS.



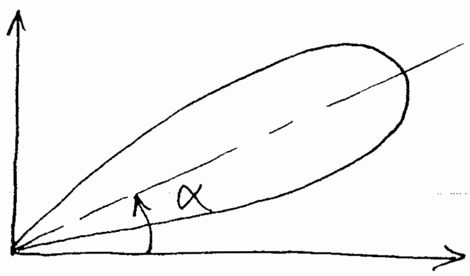
$n = 1/2$

RHOMBIC ANTENNA

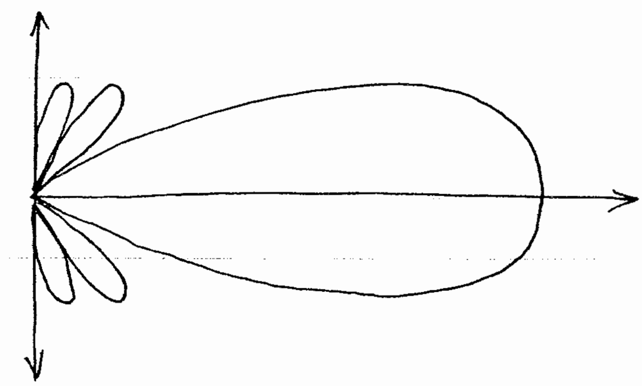
THE RHOMBIC ANTENNA CONSISTS OF FOUR LENGTHS OF WIRE ORIENTED HORIZONTALLY TO FORM A RHOMBUS (SUPRISE!)



THE OVERALL PATTERN TYPICALLY LOOKS LIKE;



VERTICAL PATTERN



HORIZONTAL PATTERN

OPTIMUM PERFORMANCE DETERMINATION IS QUITE COMPLICATED. PERFORMANCE IS DICTATED BY THE HEIGHT, THE LENGTH OF EACH SECTION AND THE TILT ANGLE OF THE INDIVIDUAL LOBES

TYPICAL PARAMETERS ARE;

HEIGHT $h = \lambda$
LENGTH OF WIRE SECTION $L = 6\lambda$
BEAM ELEVATION $\alpha = 14.5^{\circ}$

THIS TYPE OF ANTENNA IS OFTEN USED TO DIRECTING RADIATION AT HF (3-30MHz) INTO THE IONOSPHERE.

THE CHARACTERISTIC IMPEDANCE $Z_0 = 600 - 800\Omega$ GAIN IS TYPICALLY 15dB, AND BANDWIDTH IS SEVERAL MHz. (THE LARGE BANDWIDTH IS DUE TO THE FACT THAT IT IS A NON-RESONANT ANTENNA UNLIKE THE DIPOLE)

THE RHOMBIC ANTENNA HAS;

* WIDE BANDWIDTH COMPARED TO A $\lambda/2$ DIPOLE

* LOW-EFFICIENCY COMPARED TO RESONANT ANTENNAS SUCH AS A YAGI (≈50% POWER GOES INTO MATCHED LOAD)

* HIGH SIDELOBES

* LOW CONSTRUCTION COSTS COMPARED TO OTHER LONG WAVELENGTH ANTENNAS.
  - HOWEVER THEY CAN STILL REQUIRE A HUGE SITE.