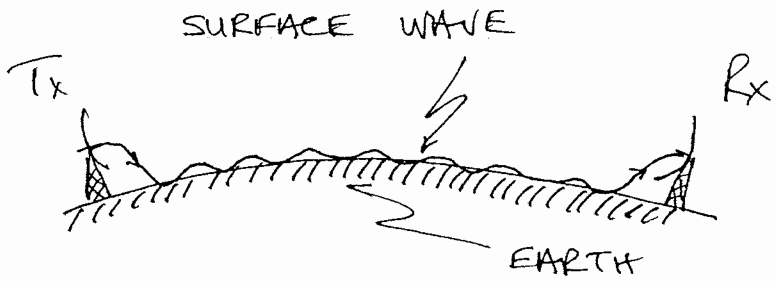
RADIOWAVE PROPAGATION

PROPAGATION CAN BE CLASSIFIED INTO:

* SURFACE WAVE: (SOMETIMES REFERRED TO AS GROUNDWAVE PROPAGATION - WHICH CAN BE CONFUSED WITH GROUND-REFLECTED WAVES, SO WE WON'T USE IT)

  VLF TO MF (3kHz - 3MHz)

  WAVE GUIDED BY SPHERICAL TERRESTRIAL WAVEGUIDE OF EARTH AND THE IONOSPHERE, OR AS A SURFACE WAVE



SURFACE WAVES CAN PROVIDE LARGE COVERAGE

VLF : WORLDWIDE
LF : INTER-CONTINENTAL
MF : COUNTRY WIDE
HF (SURFACE): RESTRICTED.

$$C = W \log_2 \left(1 + S/N\right) \text{ BITS } s^{-1}$$

=> LIMITED BANDWIDTH

SURFACE WAVE THEORIES HAVE BEEN PRESENTED BY

K.A. NORTON 1936-7 PROC. IRE
VOL 24 pp 1367 - 1387
Vol 25 pp 1203 - 1256

J.R WAIT 1957 PROC. IRE
Vol 45 pp 760 - 767

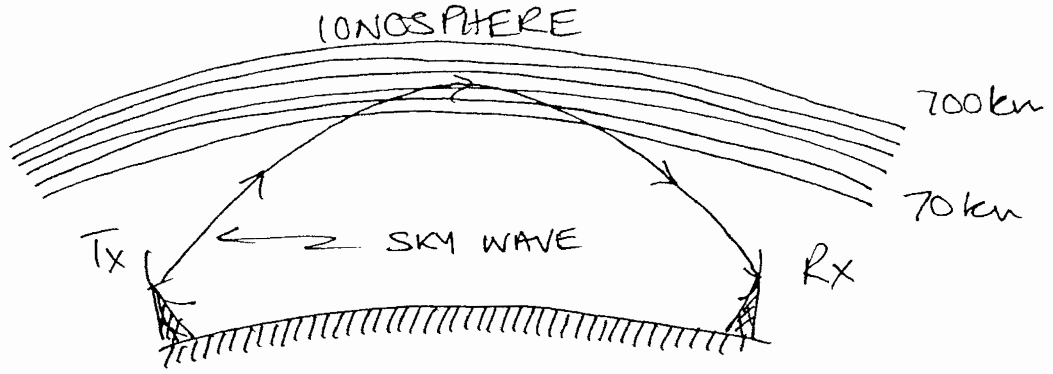
- THEORY IS BEYOND THE SCOPE OF THIS COURSE

THE WAVELENGTHS ARE QUITE LARGE:
$f = 3\,kHz - 3\,MHz \Rightarrow \lambda = 100\,km - 100\,m$

SINCE MOST ANTENNAS HAVE DIMENSIONS IN TERMS OF WAVELENGTHS, IT SHOULD NOT COME AS TOO MUCH OF A SURPRISE TO LEARN THAT SURFACE WAVE ANTENNAS ARE LARGE PHYSICALLY AND SMALL ELECTRICALLY (i.e FRACTIONS OF A WAVELENGTH)

* SKY WAVE: (IONOSPHERIC) WAVE IS LAUNCHED INTO THE ATMOSPHERE, AND DUE TO THE PHYSICAL CONDITIONS OF THE IONOSPHERE, THE WAVE IS REFLECTED / REFRACTED BACK DOWN TO EARTH.

MF - HF (300kHz - 30MHz)



MARCONI'S PROPAGATION EXPERMENTS FROM CORNWALL TO NEWFOUNDLAND - EXPLAINED BY HEAVISIDE, WHO SUGGESTED IDEA OF A REFLECTIVE LAYER IN THE ATMOSPHERE

APPLETON CONFIRMED EXPERIMENTALLY THE EXISTANCE OF THE IONOSPHERE

IONOSPHERE IS STRUCTURED INTO A NUMBER OF "LAYERS" : D1, D2, E, F1, F2 (SEE DIAGRAM ON PAGE 9 OF LECTURE #1)

CRITICAL FREQUENCY : ZENITH LAUNCHED WAVES

MAXIMUM USABLE FREQ: NON-ZENITH ANGLES

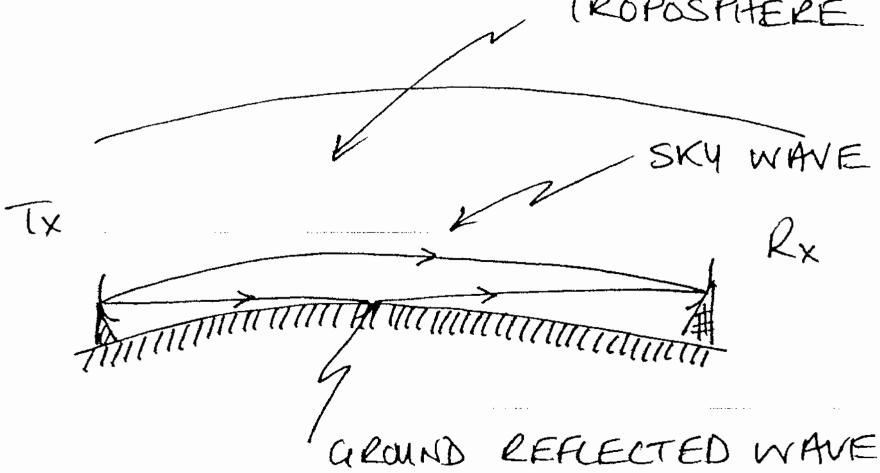
BOTH A FUNCTION OF THE FREE ELECTRON DENSITY

CRITICAL FREQ: $\sqrt{1-\frac{81N}{f^2}} = 0 \Rightarrow f_c = 9\sqrt{N_{MAX}}$

MUF : $MUF = f_c \sec\theta$.

* SPACEWAVE : LINE-OF-SIGHT

VHF - UHF - AND UP



SPACEWAVE PROPAGATION MODIFIED BY;

- REFLECTION : FROM THE GROUND
- REFLECTION : WITHIN THE TROPOSPHERE
- REFRACTION : BY THE TROPOSPHERE
- DIFFRACTION : BY OBSTACLES ALONG THE PROPAGATION PATH
- SCATTERING : FROM RAIN, HYDROMETEORS
- ABSORPTION : ATMOSPHERIC GASES
- ABSORPTION : FROM HYDROMETEORS

- FADING : FAST / SLOW, MULTIPATH

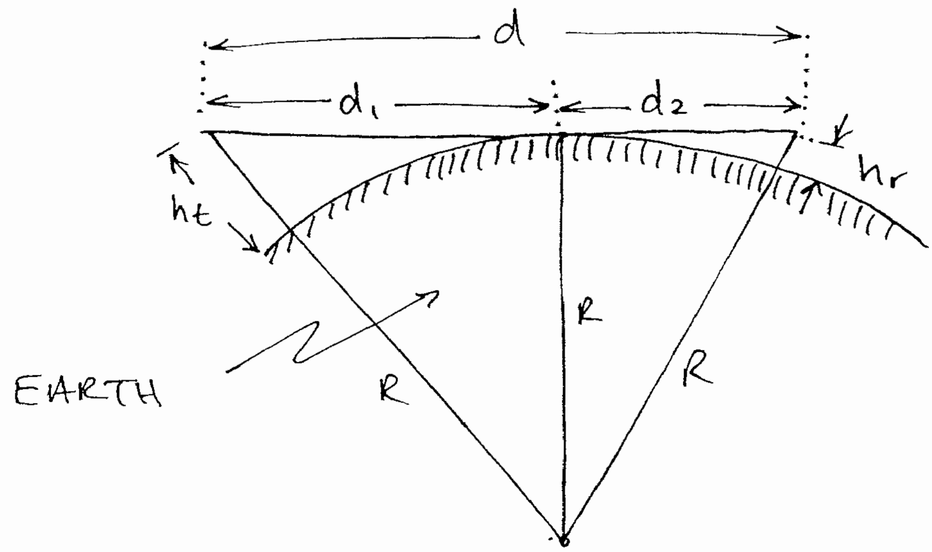
MOST OF THE REMAINDER OF THIS COURSE WILL CONCENTRATE ON SPACEWAVE PROPAGATION

* SCATER PROPAGATION : RAIN SCATTER

SPACE WAVE PROPAGATION:

LINE-OF-SIGHT RANGE

BECAUSE OF EARTH CURVATURE, THE L.O.S RANGE IS LIMITED



FROM BASIC GEOMETRY; $d = d_1 + d_2$

$$d_1^2 = (h_t + R)^2 - R^2$$
$$= h_t^2 + 2h_tR - R^2 \simeq 2h_tR$$

$$d_2^2 = (h_r + R)^2 - R^2$$
$$h_r^2 + 2h_rR - R^2 \simeq 2h_rR$$

$$\Rightarrow \quad d = \sqrt{2R}\left[h_t + h_r\right]^{1/2}$$

$R = 6378$ km (EARTH RADIUS APPROX.)
FOR A "STANDARD" ATMOSPHERE, GIVEN CERTAIN REFRACTIVE CONDITIONS $R = R_E \triangleq 8500$ km.

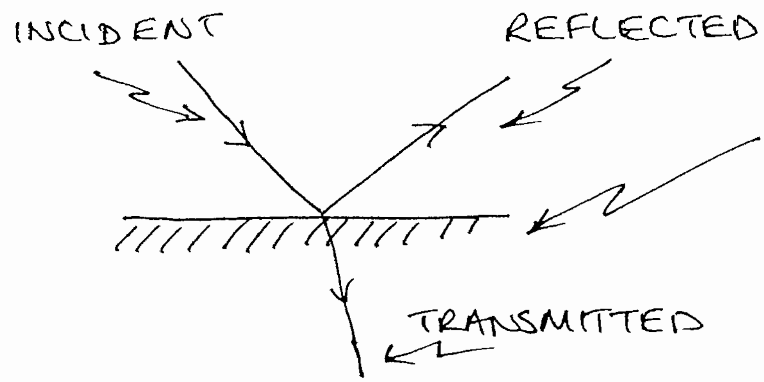
HENCE;

$$d = 4120 \left[h_t + h_r \right]^{1/2} \quad [m]$$

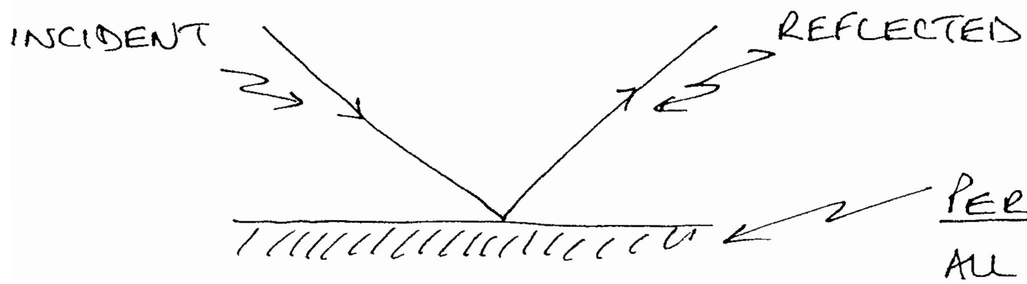
NOTE, THIS EQUATION ASSUMES A SMOOTH PATH BETWEEN THE TRANSMITTER AND RECEIVER, HOWEVER IT IS A REASONABLE FIRST ORDER APPROXIMATION.

REFLECTION

WHEN AN E-M WAVE PROPAGATING IN ONE MEDIUM IS INCIDENT UPON ANOTHER MEDIUM HAVING DIFFERENT DIELECTRIC PROPERTIES, THE WAVE WILL BE PARTIALLY REFLECTED AND PARTIALLY TRANSMITTED



PERFECT DIELECTRIC
NO LOSS OF ENERGY VIA ABSORPTION.



PERFECT CONDUCTOR
ALL ENERGY IS REFLECTED

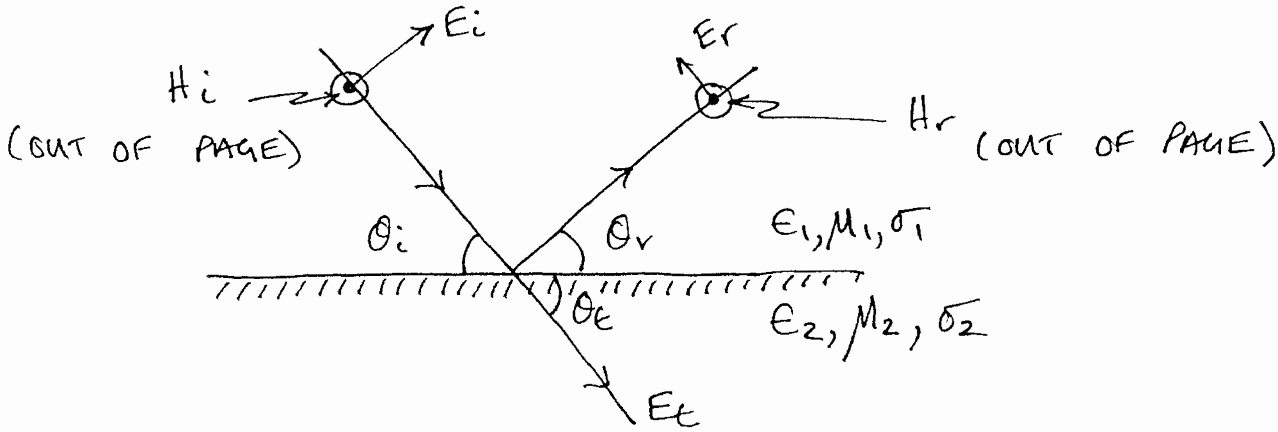
WE CAN RELATE THE INCIDENT AND REFLECTED ELECTRIC FIELDS VIA A

FRESNEL REFLECTION COEFFICIENT

THE FRESNEL REFLECTION COEFFICIENT IS A FUNCTION OF;

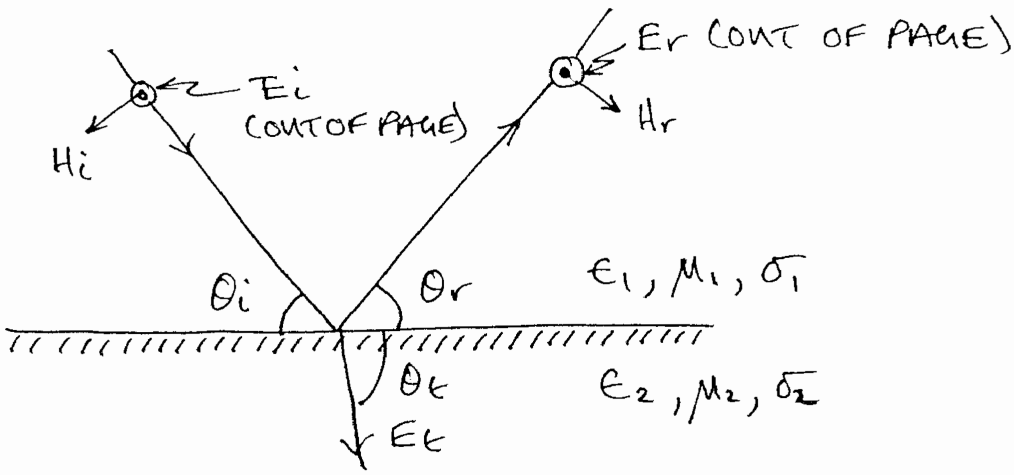
* THE MATERIAL PROPERTIES; CONDUCTIVITY AND PERMITTIVITY.
* INCIDENCE ANGLE
* FREQUENCY
* POLARIZATION

CONSIDER THE FOLLOWING SITUATION;



E- FIELD IN THE PLANE OF INCIDENCE

(VERTICAL POLARIZATION)



E - FIELD NORMAL TO PLANE OF INCIDENCE

(HORIZONTAL POLARIZATION)

A LOSSY DIELECTRIC CAN BE DESCRIBED BY A COMPLEX DIELECTRIC CONSTANT

$$\epsilon^* = \epsilon_0 \epsilon_r - j\,\epsilon'$$

WHERE $\epsilon' = \dfrac{\sigma}{\omega}$,

σ - CONDUCTIVITY $S\,m^{-1}$
$\omega = 2\pi f$ FREQUENCY
$\epsilon_0 = 8.85 \times 10^{-12}\ F\,m^{-1}$
ϵ_r = RELATIVE PERMITTIVITY. (NO-UNITS)

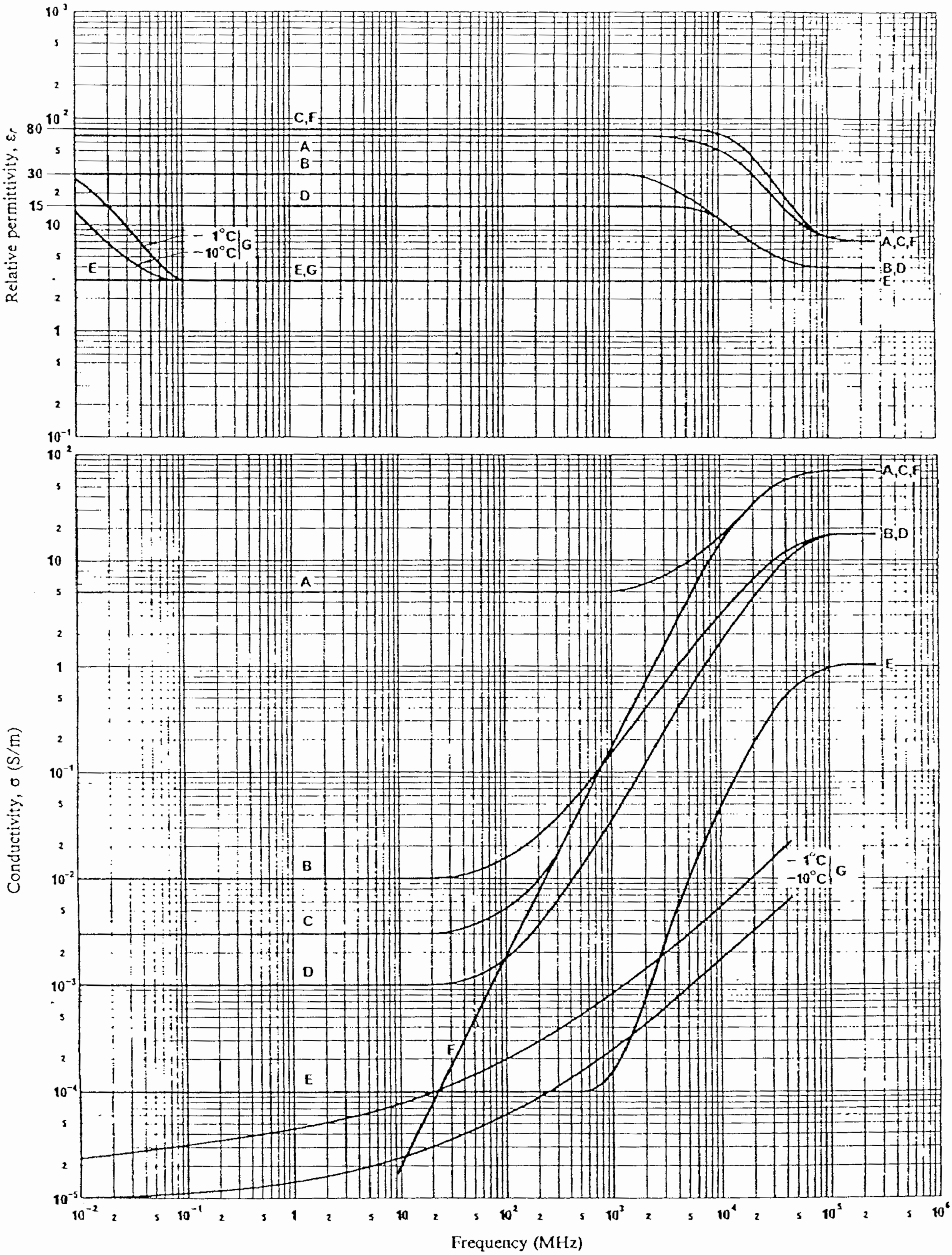
FOR GOOD CONDUCTORS $\left(f < \dfrac{\sigma}{\epsilon_0 \epsilon_r} \right)$, ϵ_r AND σ ARE RELATIVELY INSENSITIVE TO FREQUENCY.

FOR LOSSY DIELECTRICS, ϵ_r IS FAIRLY CONSTANT WITH FREQ. UPTO AROUND 10GHz.

σ CAN BE QUITE SENSITIVE FOR LOSSY DIELECTRICS. (SEE PAGE 9)

Relative permittivity, ε_r, and conductivity, σ, as a function of frequency

(9)



A: sea water (average salinity), 20° C
B: wet ground
C: fresh water, 20° C
D: medium dry ground
E: very dry ground
F: pure water, 20° C
G: ice (fresh water)

FROM:
ITU-R
P527-3

IN EACH CASE WE CAN WRITE;

$$E_r = \Gamma E_i$$

AND

$$E_t = (1+\Gamma) E_i$$

WHERE Γ IS $\Gamma_{\parallel}$ OR $\Gamma_{\perp}$ DEPENDING ON THE POLARIZATION.

USING MAXWELL'S EQUATIONS TO DESCRIBE THE BOUNDARY CONDITIONS BETWEEN TWO DIELECTRICS, ALONG WITH THE LAWS OF REFLECTION ($\theta_i = \theta_r$) AND REFRACTION ($\frac{\sin\theta_i}{\sin\theta_r} = n$) (SNELL'S LAW), WE CAN WRITE;

$$\Gamma_{\parallel} = \frac{E_r}{E_i} = \frac{\eta_2 \sin\theta_t - \eta_1 \sin\theta_i}{\eta_2 \sin\theta_t + \eta_1 \sin\theta_i}$$

E-FIELD IN PLANE OF INCIDENCE

$$\Gamma_{\perp} = \frac{E_r}{E_i} = \frac{\eta_2 \sin\theta_i - \eta_1 \sin\theta_t}{\eta_2 \sin\theta_i + \eta_1 \sin\theta_t}$$

FOR THE CASE WHERE THE FIRST MEDIUM IS FREE SPACE AND $\mu_1 = \mu_2$ THESE CAN BE SIMPLIFIED.

$$\eta_{1,2} = \sqrt{\frac{\mu_{1,2}}{\epsilon_{1,2}}}$$ $\leftarrow$ THE INTRINSIC IMPEDANCE OF THE MEDIUM

SIMPLIFYING WE CAN OBTAIN;

$$\Gamma_{\parallel} = \frac{-\epsilon_r^* \sin\theta_i + \sqrt{\epsilon_r^* - \cos^2\theta_i}}{\epsilon_r^* \sin\theta_i + \sqrt{\epsilon_r^* - \cos^2\theta_i}}$$

AND

$$\Gamma_{\perp} = \frac{\sin\theta_i - \sqrt{\epsilon_r^* - \cos^2\theta_i}}{\sin\theta_i + \sqrt{\epsilon_r^* - \cos^2\theta_i}}$$

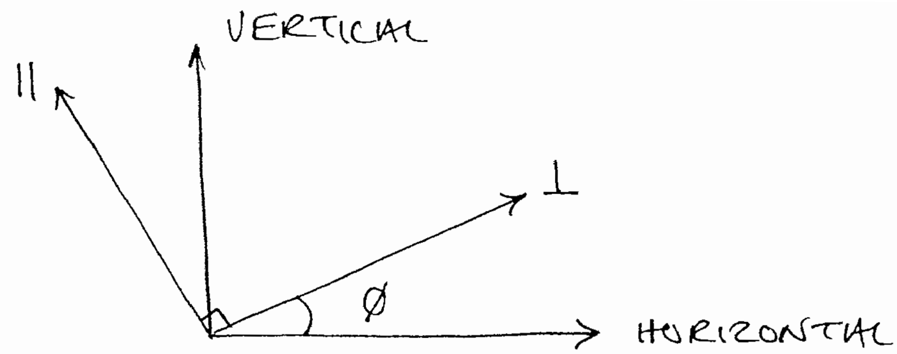
WHERE ϵ_r^* IS THE COMPLEX DIELECTRIC CONSTANT OF MEDIUM #2. HENCE;

$$\underbrace{\epsilon_r^*}_{} = \underbrace{\epsilon_r}_{\text{PERMITTIVITY OF MEDIUM \#2}} - j\frac{\sigma}{\omega\epsilon_0} \leftarrow \text{CONDUCTIVITY OF MEDIUM \#2}$$

HENCE, FOR A GIVEN MATERIAL (σ, ϵ_r) AND FREQUENCY WE CAN COMPUTE $\Gamma_{\parallel}$ AND $\Gamma_{\perp}$

ANY COHERENTLY POLARIZED WAVE CAN BE DECOMPOSED INTO TWO ORTHOGONAL WAVES FOR EXAMPLE CIRCULAR POLARIZATION CAN BE DECOMPOSED INTO A UNIT HORIZONTAL WAVE AND A UNIT VERTICAL WAVE PLUS A $\pi/2$ PHASE SHIFT.

IN THE GENERAL CASE THE WAVE INCIDENT MAY NOT HAVE EITHER E_i OR H_i NORMAL TO THE DIELECTRIC. IN THIS CAN WE MUST ROTATE OUR COORDINATES SUCH THAT THIS IS SO...



WE CAN RELATE THE INCIDENT AND REFLECTED ELECTRIC FIELDS IN THIS CASE BY;

$$\begin{bmatrix} E_H \\ E_V \end{bmatrix}_{REFL.} = [R]^T [\Gamma] [R] \begin{bmatrix} E_H \\ E_V \end{bmatrix}_{INCIDENT}$$

WHERE;

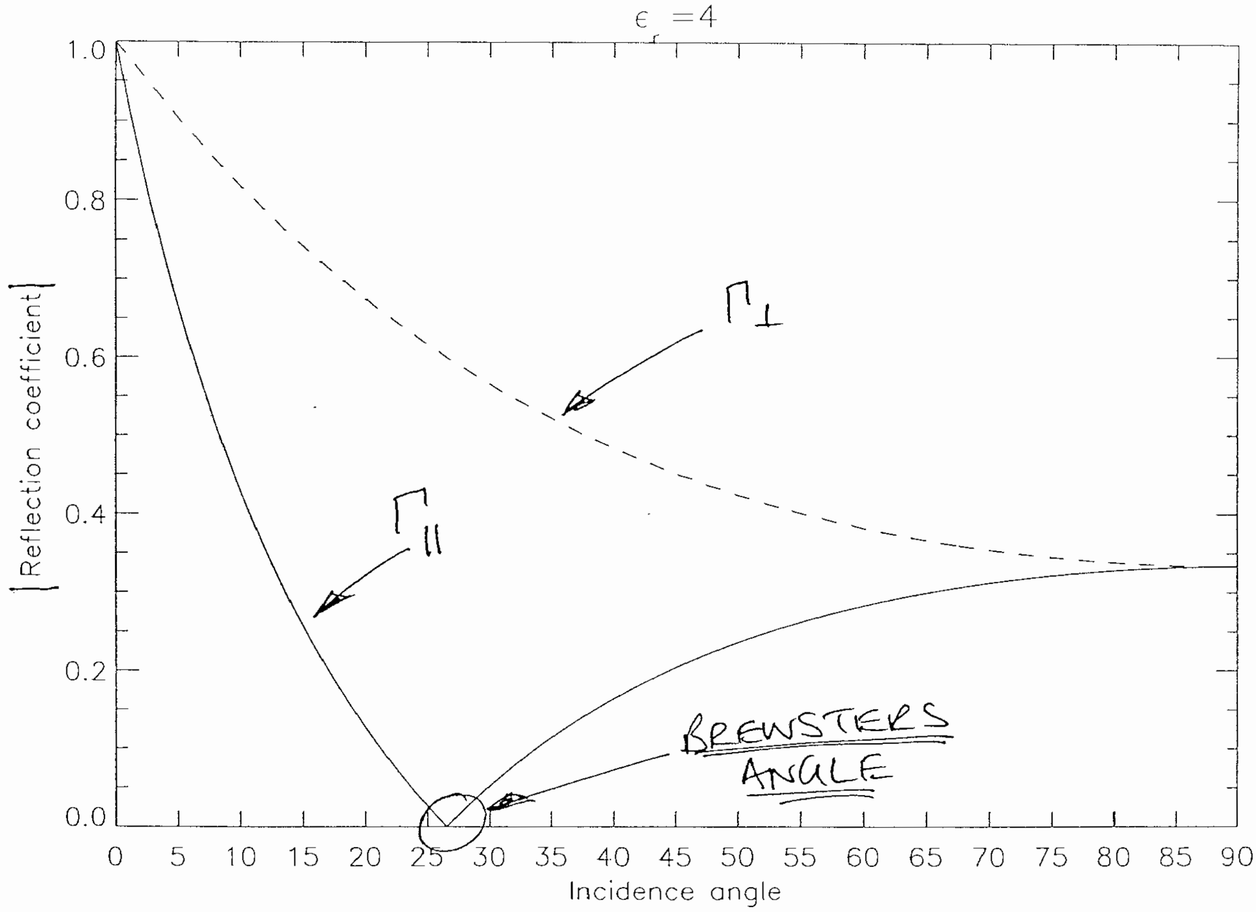
$$[R] = \begin{bmatrix} \cos\phi & \sin\phi \\ -\sin\phi & \cos\phi \end{bmatrix}$$

ROTATION MATRIX

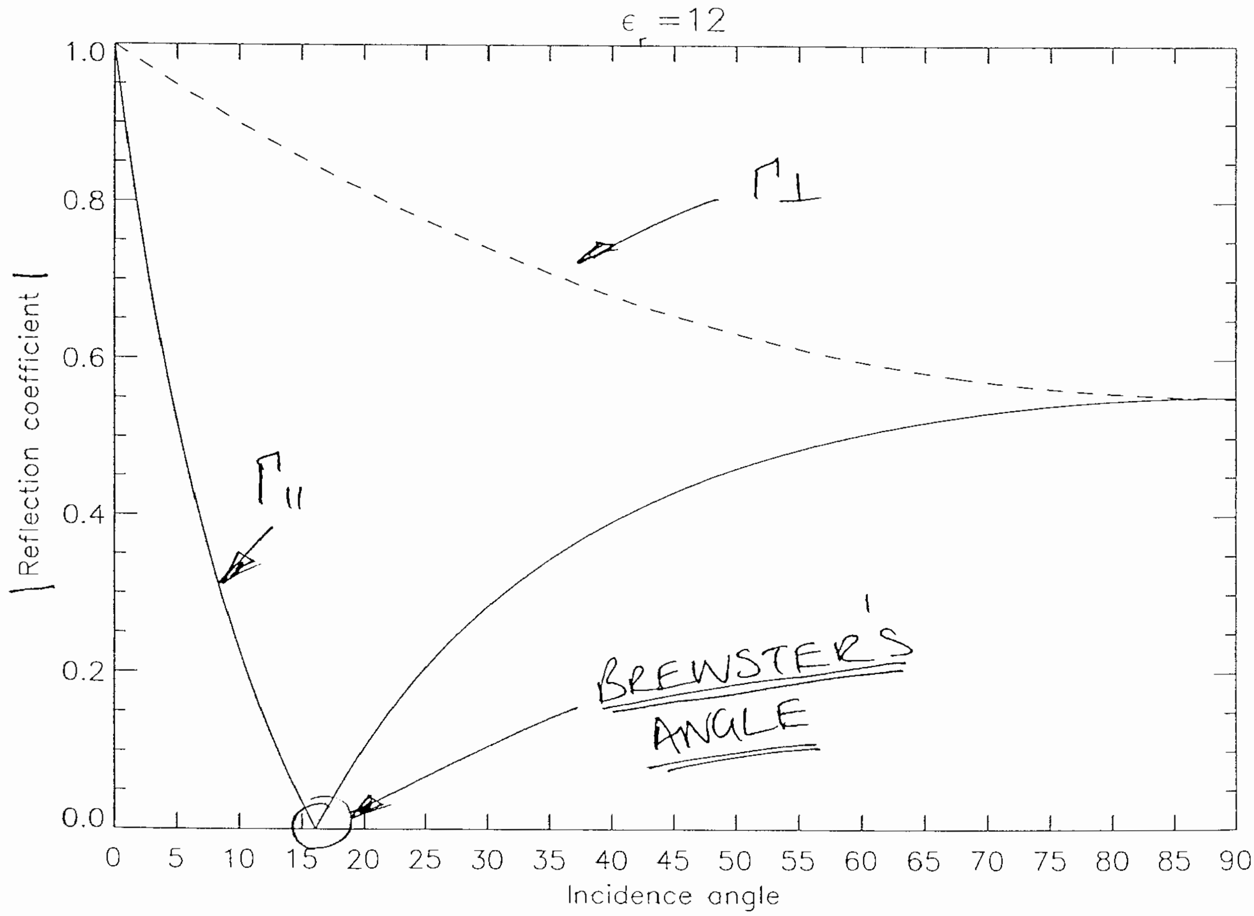
$$[\Gamma] = \begin{bmatrix} \Gamma_{\perp} & 0 \\ 0 & \Gamma_{\parallel} \end{bmatrix}$$

IF WE WANTED TO CONSIDER TRANSMISSION THE $[\Gamma]$ MATRIX COULD BE REPLACED BY;

$$[T] = \begin{bmatrix} (1+\Gamma_{\perp}) & 0 \\ 0 & (1+\Gamma_{\parallel}) \end{bmatrix}$$



$\epsilon_r = 4$
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
Incidence angle
|Reflection coefficient|
$\Gamma_\perp$
$\Gamma_{\parallel}$
BREWSTERS ANGLE



$\epsilon_r = 12$
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
Incidence angle
|Reflection coefficient|
$\Gamma_\perp$
$\Gamma_{\parallel}$
BREWSTER'S ANGLE

BREWSTER'S ANGLE

THE BREWSTER ANGLE IS THE ANGLE AT WHICH NO REFLECTION OCCURS IN THE MEDIUM OF ORIGIN.

THE BREWSTER ANGLE OCCURS WHEN

$$\Gamma_{\parallel} = 0 \Rightarrow -\epsilon_r^* \sin\theta_i + \sqrt{\epsilon_r^* - \cos^2\theta_i} = 0$$

$$\epsilon_r^* \sin\theta_i = \sqrt{\epsilon_r^* - \cos^2\theta_i}$$

$$\epsilon_r^{*2} \sin^2\theta_i = \epsilon_r^* - \cos^2\theta_i$$

$$\epsilon_r^{*2} \sin^2\theta_i + \cos^2\theta_i = \epsilon_r^*$$

SINCE $\sin^2\theta + \cos^2\theta \equiv 1$

$$\epsilon_r^{*2} \sin^2\theta_i + \epsilon_r^{*2} \cos^2\theta_i + (1 - \epsilon_r^{*2}) \cos^2\theta_i = \epsilon_r^*$$

WHICH REDUCES TO

$$\cos\theta_i = \sqrt{\frac{(\epsilon_r^{*2} - \epsilon_r^*)}{(\epsilon_r^{*2} - 1)}}$$

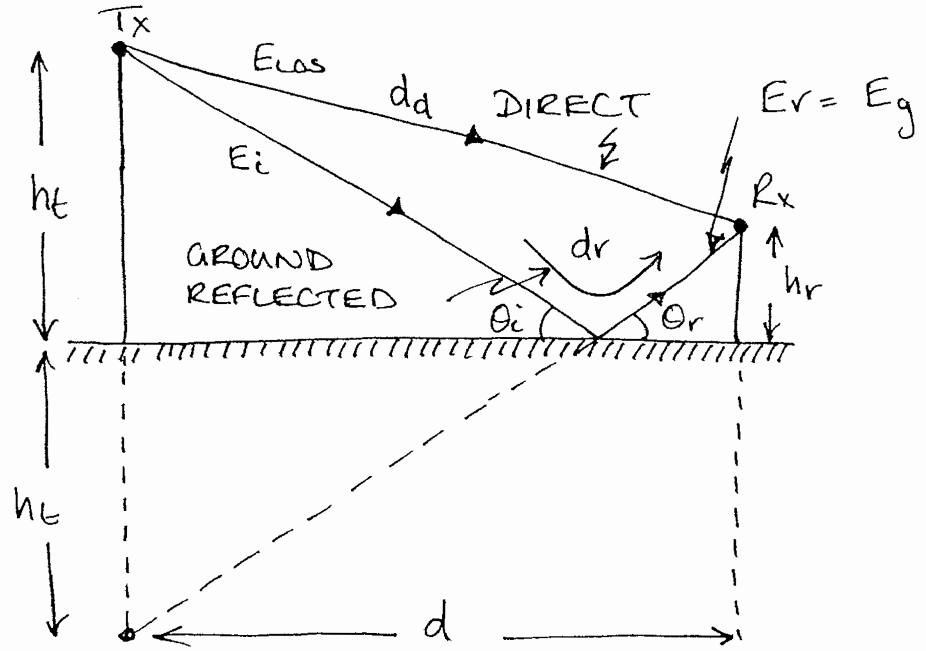
THUS FOR $\epsilon_r^* = 4 + j0 \quad \theta_i \simeq 63.4^\circ$

$\epsilon_r^* = 12 + j0 \quad \theta_i \simeq 16.1^\circ$

RECALLING WHAT WE SAID ABOUT PERFECT CONDUCTORS EARLIER WE CAN NOW SEE THAT;

$$\Gamma_{\parallel} = 1 \quad \text{AND} \quad \Gamma_{\perp} = -1 \quad \text{(REGARDLESS OF THE INCIDENT ANGLE)}$$

FLAT EARTH REFLECTION



CONSIDER THE DIAGRAM ABOVE:

(DIRECT WAVE) $\quad d_d = \sqrt{d^2 + (h_t - h_r)^2}$

(REFL. WAVE) $\quad d_r = \sqrt{d^2 + (h_t + h_r)^2}$

THE EXCESS PATH LENGTH $= d_r - d_d$

USING THE BINOMIAL APPROXIMATION FOR THE SQU. RE ROOT WE OBTAIN.

$$d_d \cong d\left[1 + \frac{1}{2}\left(\frac{h_t - h_r}{d}\right)^2\right]$$

AND

$$d_r \cong d\left[1 + \frac{1}{2}\left(\frac{h_t + h_r}{d}\right)^2\right]$$

HENCE $d_r - d_d \cong \dfrac{2 h_t h_r}{d.} = \Delta$

SINCE THE TWO PATHS DIFFER THE PHASE OF THE DIRECT AND REFLECTED WAVES MAY DIFFER. THE PHASE LAG ϕ,

$$\phi = \frac{\Delta \omega_c}{c} = \frac{2\pi\Delta}{\lambda} \quad \text{[RADIANS]}$$

$$= \frac{4\pi h_t h_r}{\lambda d} \quad \text{[RADIANS]}$$

IF E_0 IS THE ELECTRIC FIELD AT SOME REFERENCE DISTANCE d_0 THEN FOR SOME DISTANCE $d > d_0$ THEN THE E-FIELD IS;

$$E(d,t) = \frac{E_0 d_0}{d} \cos\left[\omega_c(t - d/c)\right]$$

THE L.O.S E-FIELD COMPONENT IS THEREFORE;

$$E_{LOS}(d_d, t) = \frac{E_o d_o}{d_d} \cos[\omega_c (t - d_d/c)]$$

SIMILARLY THE REFLECTED WAVE CAN BE EXPRESSED AS; (INCLUDING THE FRESNEL REFLECTION COEFFICIENT)

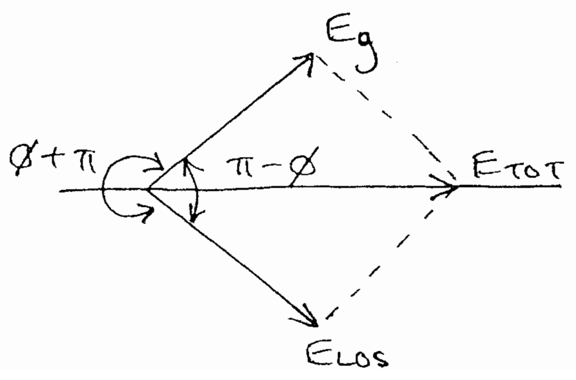
$$E_g(d_r, t) = \Gamma \left[\frac{E_o d_o}{d_r} \cos[\omega_c (t - d_r/c)] \right]$$

SINCE THE WAVE IS REFLECTED $\theta_i = \theta_r$, AND $E_g = \Gamma E_i$ (ALSO $E_t = (1+\Gamma) E_i$

IF WE ASSUME VERTICAL POLARIZATION $\Gamma = -1$ (HENCE $E_t = 0$). THEN;

$$|E_{TOT}| = |E_{LOS} + E_g|$$

FOR LARGE DISTANCES THE EXCESS PATH LOSS BECOMES SMALL. E_g AND E_{LOS} ARE ALMOST IDENTICAL, DIFFERING ONLY IN PHASE.



FROM THIS WE CAN WRITE;

$$|E_{TOT}| = \left| 2 \frac{E_o d_o}{d} \cos\left(\frac{\pi - \phi}{2}\right) \right|$$

RECALL: $\phi = \frac{4\pi h_t h_r}{\lambda d}$

$$|E_{TOT}| = \left| 2 \frac{E_o d_o}{d} \sin\left(\frac{2\pi h_t h_r}{\lambda d}\right) \right|$$

WRITING THIS AS A POWER, $(P = |E|^2)$
WE HAVE;

TOTAL RECEIVED POWER
DIRECT & REFLECTED

$$P_{TOT} = 4P_r \sin^2 (2\pi h_t h_r / \lambda d)$$

FOR $d \gg h$ $(\sin\theta \cong \theta)$, $d \simeq d_r \simeq d_d$

$$P_{TOT} = 4P_r \left[\frac{2\pi h_t h_r}{\lambda d}\right]^2$$

FROM OUR LINK BUDGET EQUATIONS WE CAN NOW WRITE;

$$P_{TOT} = P_t G_t G_r \frac{h_t^2 h_r^2}{d^4}$$

NOTE $P_{TOT} \propto \frac{1}{d^4}$. FOR REFLECTED WAVES AND DIRECT WAVES

COMPARED WITH THE FREE-SPACE CASE OF

$$P_r \propto \frac{1}{d^2}.$$

SUMMARY

* L.O.S PROPAGATION DISTANCE

* REFLECTION – BREWSTER'S ANGLE

* REFLECTION FROM A FLAT EARTH.

  - AT THE RECEIVER $d_r > d_d$ SO THE TWO SIGNALS ARRIVE OUT OF PHASE.

  - THE REFLECTED WAVE E_r IS π OUT OF PHASE WITH INCIDENT WAVE E_{LOS}

  - IF THE PATH DIFFERENCE IS AN ODD MULTIPLE OF $\lambda/2$ THEY ARE IN PHASE i.e

$$\Delta = d_r - d_d = \frac{n\lambda}{2} \qquad n = 1, 3, 5, \ldots$$

  - IF THE SIGNALS ARE IN PHASE THE RECEIVED SIGNAL POWER INCREASES OTHERWISE IT IS DECREASED, IN WHICH CASE

$$P_{TOT} \propto \frac{1}{d^4}$$

  - THIS IS THE TOPIC OF FRESNEL ZONES WHICH WE WILL LOOK AT NEXT LECTURE.