REVIEW OF LAST LECTURE

* FOR $f \geq 30\,MHz$ (VHF, UHF, SHF & EHF) PROPAGATION REGION IS THE TROPOSPHERE USING LINE-OF-SIGHT

  - CAN'T USE SKY WAVES (FOR > 30MHz, WAVES ESCAPE THE IONOSPHERE)

  - CAN'T USE SURFACE WAVES (RAPID ATTENUATION OF VERY SHORT WAVES)

  - CAN USE SPACE WAVE = DIRECT WAVE + GROUND REFLECTED

NOTE: TO ENSURE SPACE WAVE PROPAGATION, WE POSITION OUR Tx AND Rx ANTENNAS AT LEAST SEVERAL WAVELENGTHS ABOVE THE SURFACE.

* L.O.S PROPAGATION DISTANCES

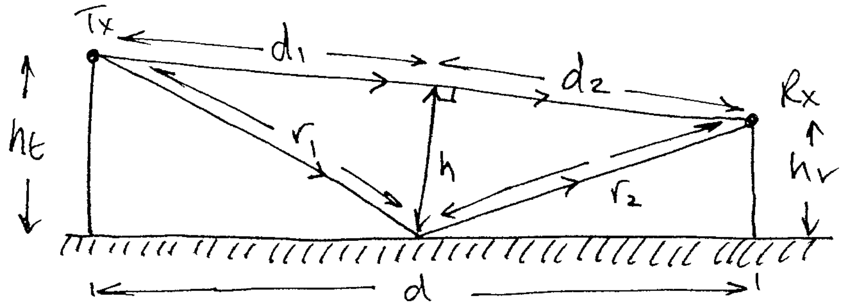
* REFLECTIONS (FOR A SMOOTH SURFACE)

  - BREWSTER ANGLE, WHICH ONLY OCCURS IN THE $\Gamma_{\parallel}$ TERM

  - ARBITRARY POLARIZATION INCIDENT WAVES.

  - COMBINED DIRECT & REFLECTED WAVES
    $P_r \propto \frac{1}{d^4}$

FLAT EARTH REFLECTION: FRESNEL ZONES



$(r_1 + r_2) > (d_1 + d_2)$ WHICH IMPLIES A POSSIBLE PHASE DIFFERENCE.

SINCE THE REFLECTED WAVE IS ASSUMED TO BE;

* VERTICALLY POLARIZED

AND * $|\Gamma_{\parallel}| = 1$, $\arg[\Gamma_{\parallel}] = \pi$

THEN, THE REFLECTED AND DIRECT WAVES ARE IN PHASE IF THE EXCESS PATH LENGTH IS AN ODD MULTIPLE OF $\lambda/2$.

EXCESS PATH LOSS, $\Delta = (r_1 + r_2) - (d_1 - d_2)$, HENCE

$$\Delta = \frac{n\lambda}{2} \quad \text{WHERE } n = 1, 3, 5, \ldots$$

$$r_1 = (d_1^2 + h^2)^{1/2}$$

$$r_2 = (d_2^2 + h^2)^{1/2}$$

IF $h \ll d_{1,2}$ WE CAN USE BINOMIAL APPROX. FOR THE SQUARE ROOTS

$$r_1 = d_1\left(1 + h^2/d_1^2\right)^{1/2} \simeq d_1 + \frac{h^2}{2d_1}$$

SIMILARLY,

$$r_2 = d_2\left(1 + h^2/d_2^2\right)^{1/2} \simeq d_2 + \frac{h^2}{2d_2}$$

HENCE $\quad \Delta \simeq \dfrac{h^2}{2}\dfrac{(d_1+d_2)}{d_1 d_2}$

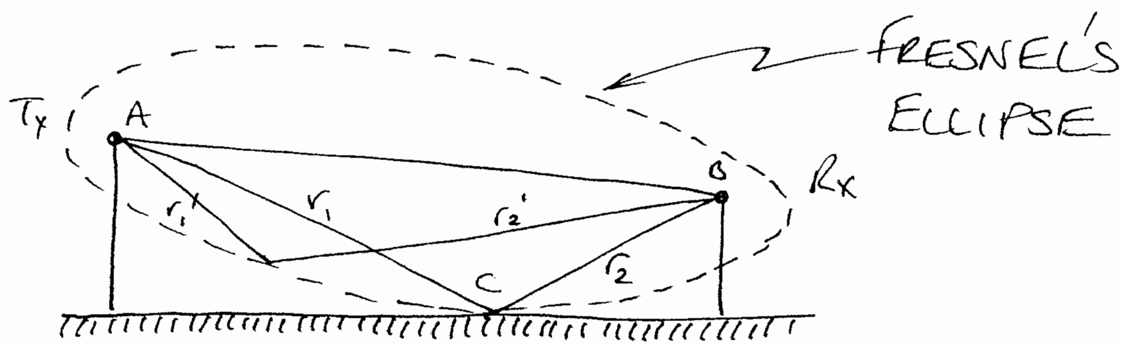
$\Delta = \dfrac{n\lambda}{2}$ FOR INPHASE DIRECT & REFLECTED

SO; $\quad \dfrac{n\lambda}{2} = \dfrac{h^2}{2}\dfrac{(d_1+d_2)}{d_1 d_2} \qquad n = 1, 3, \ldots$

HENCE

$$h = \sqrt{\frac{n\lambda\, d_1 d_2}{d_1+d_2}}$$

SO, AS LONG AS $(r_1 + r_2)$ IS KEPT CONSTANT, THE LOCUS OF THE REFLECTING POINTS IS AN ELLIPSOID WITH THE TRANSMITTER AND RECEIVER ANTENNAS AS THE FOCI, PRODUCING AN IN-PHASE WAVE



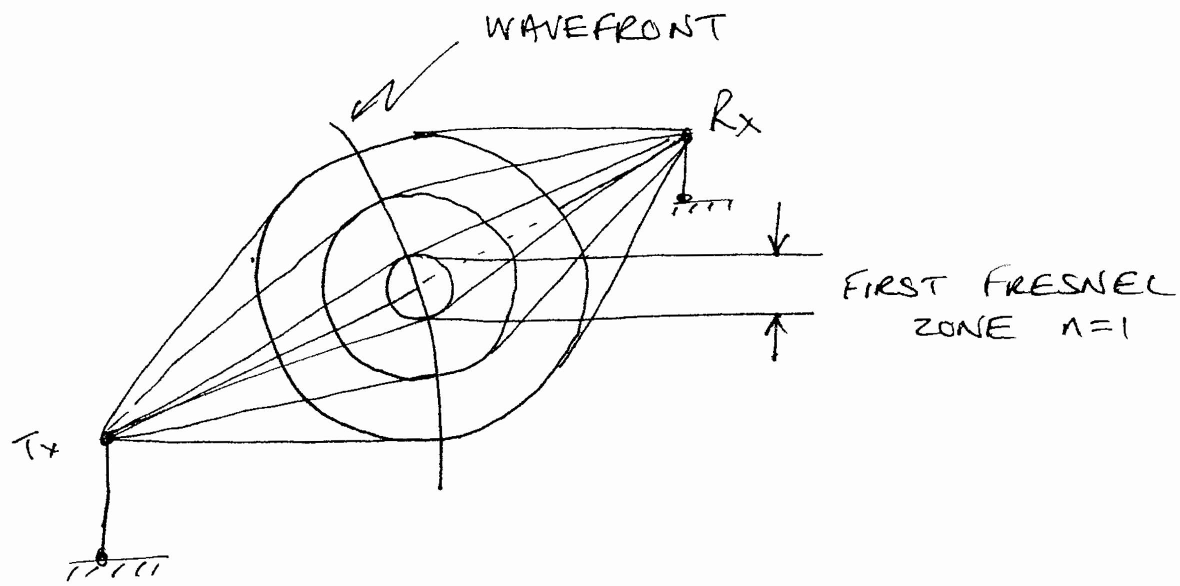
THE EQUATION OF THE ELLIPSE IS;

$$AB + BC = AC + \frac{n\lambda}{2}$$

i.e $$(d_1^2 + h^2)^{1/2} + (d_2^2 + h^2)^{1/2} = d_1 + d_2 + \frac{n\lambda}{2}$$

FOR ALL PAIRS OF r_1 AND r_2 THERE IS A PAIR OF d_1 AND d_2, WHERE $d_1 + d_2 = d$ = CONSTANT. FOR A GIVEN d, $d_1 d_2$ IS MAXIMIZED IF $d_1 = d_2$

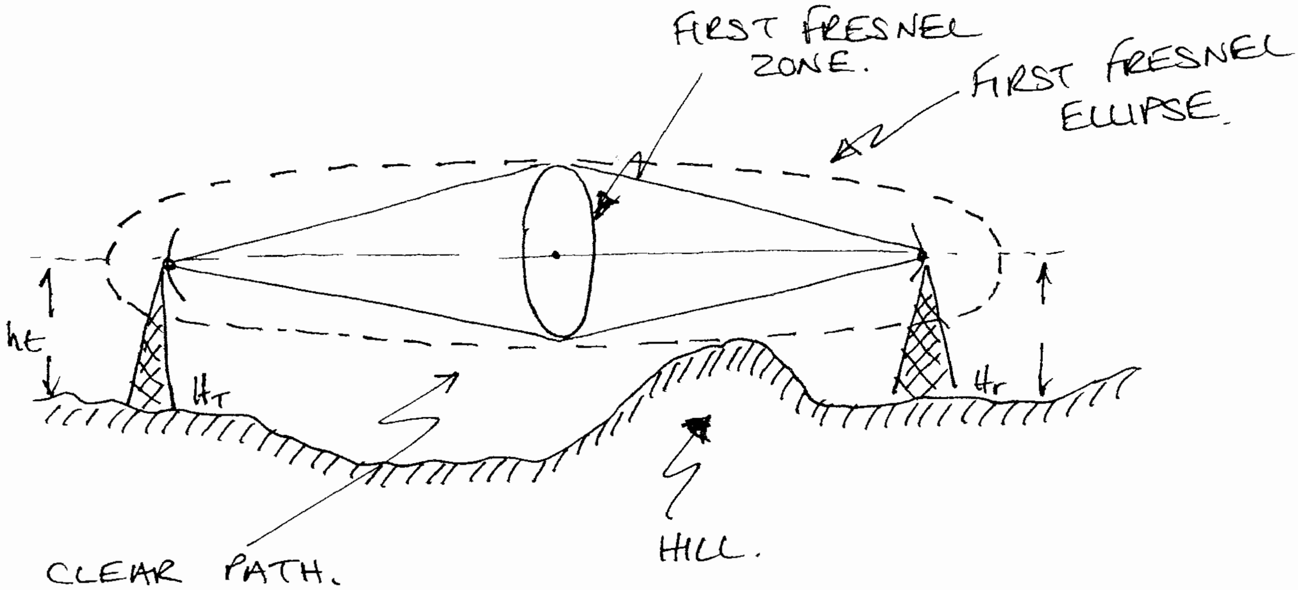
THUS $$h_{MAX} = \sqrt{\tfrac{1}{2} n\lambda d}$$



THE PATH DIFFERENCE BETWEEN SUCCESSIVE <u>FRESNEL ZONES</u> IS λ.

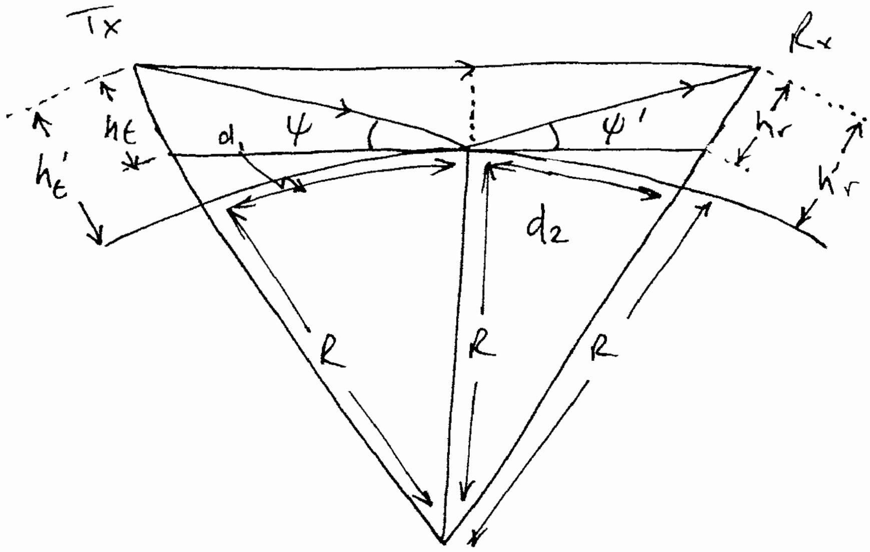
> FOR MOST DIRECTIONAL ANTENNAS, WHEN EMPLOYED AT THE TRANSMITTER AND RECEIVER MORE THAN 90% OF THE RADIATED ENERGY IS CONTAINED WITHIN THE FIRST FRESNEL ZONE ($n=1$)

TO HAVE A CLEAR PROPAGATION PATH; NO OBSTRUCTION SHOULD OCCUR IN THE FIRST FRESNEL ZONE;



REFLECTION FROM A CURVED EARTH

CONSIDER THE FOLLOWING DIAGRAM;



FROM OUR EQUATION FOR L.O.S PROPAGATION, WE CAN WRITE;

$$h_t = h_t' - \frac{d_1^2}{2R} \quad - (1)$$

AND

$$h_r = h_r' - \frac{d_2^2}{2R} \quad - (2)$$

AT THE POINT OF REFLECTION ON THE EARTH, WE HAVE;

$$\psi = \psi'$$

ALSO WHEN THE DISTANCES ARE LARGE COMPARED TO THE ANTENNA HEIGHTS, THE ANGLES $\psi = \psi' \simeq h_t/d_1$ or h_r/d_2 ($\sin\theta = \theta$, IN RADIANS FOR SMALL ANGLES)

HENCE, WE CAN WRITE;

$$\frac{h_t}{h_r} = \frac{d_1}{d_2}. \quad - (3)$$

ALSO OBVIOUSLY WE HAVE $d_1 + d_2 = d$ $-$ (4).

FROM EQ^{N}s (1), (2), (3) AND (4) WE CAN SOLVE FOR THE FOUR UNKNOWNS, h_t, h_r (THE EFFECTIVE HEIGHTS) AND d_1 AND d_2 THE DISTANCE TO THE POINT OF REFLECTION

FOR EXAMPLE:

FIND THE POINT OF REFLECTION ON A CURVED EARTH BETWEEN TWO ANTENNAS OF HEIGHTS $h_t' = 400m$ AND $h_r' = 100m$ AND AT A DISTANCE $d = 100km$ APART, $R = 8500km$

IF WE USE HEIGHTS IN "m" AND DISTANCES IN "km" $\times 10^3$

$$h_t = 400 - d_1^2/(2 \times 8.5)$$

AND;

FROM (4)

$$h_r = 100 - (100 - d_1)^2/(2 \times 8.5)$$

IF WE DIVIDE h_t BY h_r WE HAVE

FROM (3)

$$\frac{h_t}{h_r} = \frac{400 - d_1^2/17}{100 - (10000 - 200d_1 + d_1^2)/17} = \frac{d_1}{100 - d_1}$$

HENCE WE CAN WRITE THIS AS;

$$d_1^3 - 150d_1^2 + 750d_1 + 340{,}000 = 0$$

THE THREE SOLUTIONS ARE;

$$d_1 \cong 120.25,\ \cong 70.09,\ \cong -40.34\,km$$

OF THESE, THE ONLY VALID SOLUTION IS $d_1 = 70.09\,km$

SUBSTITUTING $d_1 = 70.1$ km INTO THE EQUATIONS FOR h_t AND h_r WE OBTAIN;

$$h_t = 110.9 \text{ m} \quad \text{AND} \quad h_r = 47.4 \text{ m},$$

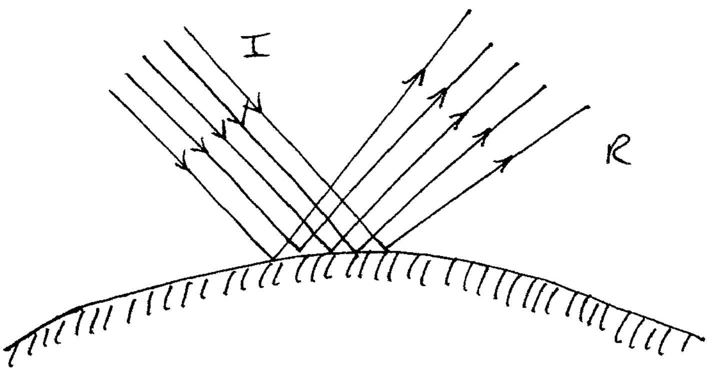
WHICH WE CAN SUBSTITUTE INTO OUR EQUATIONS FOR THE ELECTRIC FIELD;

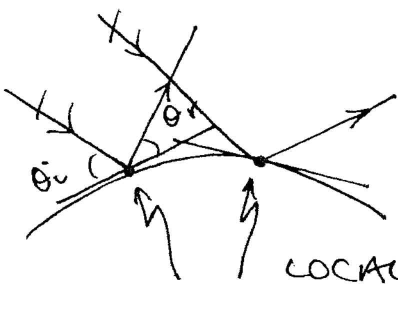
$$|E| = \left| \frac{2E_0 d_0}{d} \sin\left(\frac{2\pi h_t h_r}{\lambda d}\right) \right|$$ TO OBTAIN

THE ELECTRIC FIELD AT 100 km OVER A CURVED EARTH.

DIVERGENCE OF REFLECTED WAVES

THE REFLECTION OF AN INCIDENT WAVE BY A CURVED SURFACE, PRODUCES AN AMOUNT OF DIVERGENCE – AS IN GEOMETRIC OPTICS





LOCAL TANGENTIAL PLANES

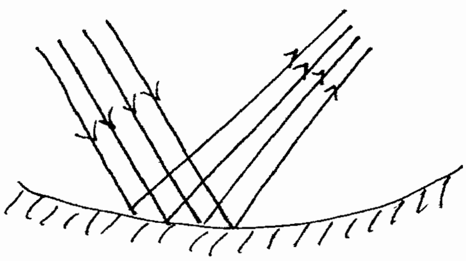
THE EFFECT OF DIVERGENCE CAN BE INCORPORATED INTO THE REFLECTION BY AN EXPRESSION CALLED THE "DIVERGENCE FACTOR", D. GIVEN BY;

$$D \cong \left[1 + \frac{2d_1d_2}{R_c(h_t+h_r)} \right]^{-1/2}$$

IF THE CURVATURE IS NEGATIVE, THAT IS R_c (NORMALLY THE EARTH RADIUS) IS NEGATIVE, THEN $D > 1$ WHICH CAUSES CONVERGENCE (OR FOCUSSING)

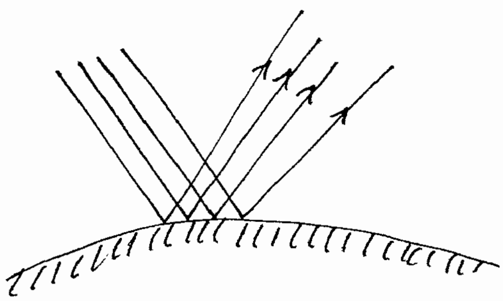
THAT IS;

<u>CONVERGENCE</u>



$D > 1$

<u>DIVERGENCE</u>



$D < 1$

SURFACES: ROUGH AND SMOOTH

FLAT SURFACES THAT HAVE DIMENSIONS MUCH LARGER THAN ONE WAVELENGTH CAN BE MODELLED AS REFLECTIVE SURFACES.

[IF THIS IS NOT THE CASE WE HAVE TO APPLY CORRECT SCATTERING THEORY – THIS IS PRETTY HAIRY STUFF SO WE WILL IGNORE IT FOR THE TIME BEING ...]

WE HAVE SEEN THAT THE REFLECTION COEFFICIENT, Γ IS DEPENDENT ON;

- THE DIELECTRIC PROPERTIES OF THE SURFACE: ϵ_r, σ.
- INCIDENCE ANGLE
- SURFACE CURVATURE

AND

- THE SURFACE ROUGHNESS.

SO FAR WE HAVN'T SAID ANYTHING ABOUT THE SURFACE TEXTURE – WE'VE ASSUMED IT TO BE PERFECTLY SMOOTH.

THE ROUGHNESS OF A SURFACE OFTEN LEADS TO PROPAGATION EFFECTS DIFFERENT TO THOSE THAT WE HAVE LOOKED AT SO FAR.

WE CAN BREAK DOWN THE REFLECTION INTO TWO COMPONENTS. (IN GENERAL THE REFLECTED FIELD WILL HAVE BOTH COMPONENTS).

THE TWO COMPONENTS;

* SPECULAR
* DIFFUSE.

THE SPECULAR COMPONENT IS THE ONE THAT WE HAVE DEALT WITH SO FAR.

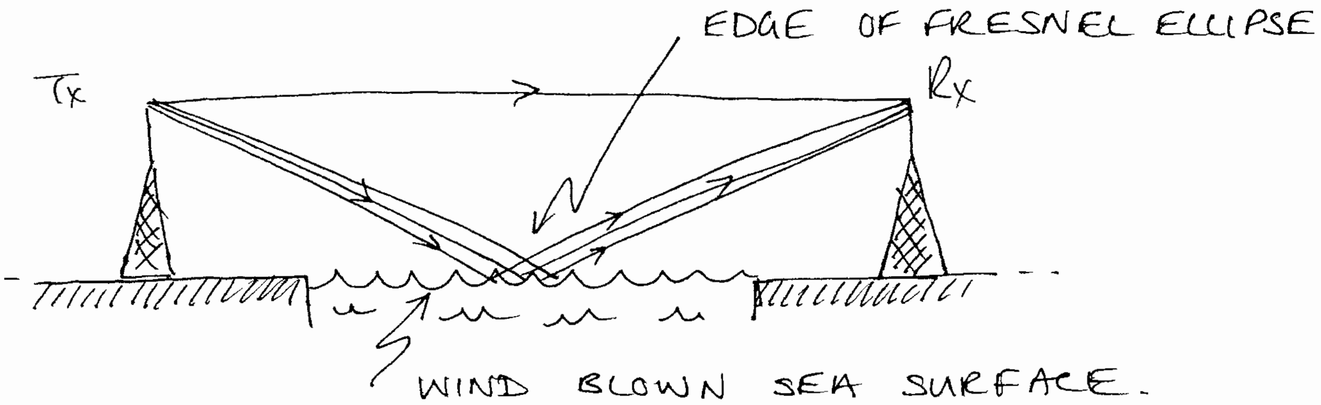
SPECULAR REFLECTION

THE SCATTERED ENERGY IS CONTAINED WITHIN A CONE CLOSE TO THE DIRECTION FOR WHICH THE ANGLE OF REFLECTION IS EQUAL TO THE ANGLE OF INCIDENCE

THE SPECULAR COMPONENT IS THE RESULT OF THE RE-RADIATION OF ENERGY FROM POINTS ON A FRESNEL ELLIPSOID WHICH WILL GIVE RISE TO EQUAL PHASE AT THE

RECEIVER. SUCH POINTS WILL LIE WITHIN A LIMITED AREA ON THE PATH. EXCEPT FOR THE CASE OF A <u>PERFECTLY SMOOTH SURFACE</u> THE AMPLITUDE AND PHASE WILL EXHIBIT SMALL FLUCTUATIONS IN SPACE, AND ALSO TIME IF THERE ARE ANY TIME VARIATIONS IN THE SURFACE BOUNDARY

FOR EXAMPLE;



DIFFUSE REFLECTION

THE DIFFUSE COMPONENT HAS VERY LITTLE DIRECTIVITY, AND ORIGINATES OVER A LARGER AREA OF THE SCATTERING SURFACE THAN THAT WHICH PRODUCES THE SPECULAR COMPONENT. THE AMPLITUDE FLUCTUATIONS HAVE A <u>RAYLEIGH</u> DISTRIBUTION SO IT CAN HAVE A LARGE AMPLITUDE. ITS PHASE WILL ALSO BE INCOHERENT (THAT IS AT ANY POINT IN SPACE, IT CAN HAVE ANY VALUE WITH EQUAL PROBABILITY)

HOW ROUGH IS ROUGH?

SURFACE ROUGHNESS IS OFTEN TESTED USING THE "RAYLEIGH CRITERION"

THE RAYLEIGH CRITERION DEFINES A CRITICAL HEIGHT FOR SURFACE PERTURBATIONS, FOR A GIVEN INCIDENCE ANGLE.

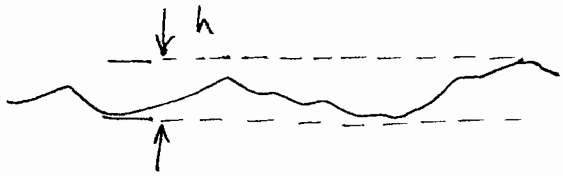
THUS

$$h_c = \frac{\lambda}{8 \sin \theta_i}$$

WHERE:

θ_i - INCIDENCE ANGLE
h_c - CRITICAL HEIGHT.

FOR EXAMPLE:



IF $h < h_c$ <u>SMOOTH</u>

IF $h > h_c$ <u>ROUGH</u>

h - HEIGHT OF PERTURBATION (MIN-TO-MAX)

WHAT CAN WE DO FOR ROUGH SURFACES?

FOR ROUGH SURFACES, WE CAN CORRECT THE FLAT SURFACE REFLECTION COEFFICIENT, TO ACCOUNT FOR THE DIFFUSE SCATTERING LOSS.

BY ASSUMING THE SURFACE HEIGHT, h, TO BE A GAUSSIAN DISTRIBUTED RANDOM VARIABLE WITH STANDARD DEVIATION ABOUT THE MEAN SURFACE HEIGHT σ_h, AMENT (1953) FOUND THE FOLLOWING:

$$\rho_s = \exp\left[-8\left(\frac{\pi \sigma_h \sin\theta_i}{\lambda}\right)^2\right]$$

WHERE ρ_s IS THE <u>SCATTERING LOSS FACTOR</u>

BOITHAS (1987) MODIFIED AMENT'S EQUATION IN LIGHT OF EXPERIMENTAL EVIDENCE HENCE;

$$\rho_s = \exp(-x)\, J_0(x)$$

WHERE; $x = 8\left(\frac{\pi \sigma_h \sin\theta_i}{\lambda}\right)^2$, AND $J_0(x)$ IS A FIRST KIND, ZERO ORDER BESSEL FUNCTION.

HENCE FOR ROUGH SURFACES WHERE $(h > h_c)$ WE CAN WRITE THE REFLECTION COEFFICIENT AS;

$$\Gamma_{ROUGH} = \Gamma_{SMOOTH} \times \rho_s$$

AMENT, W.S 1953: "TOWARD A THEORY OF REFLECTION BY A ROUGH SURFACE". PROC. IRE Vol 41, pp 142-146

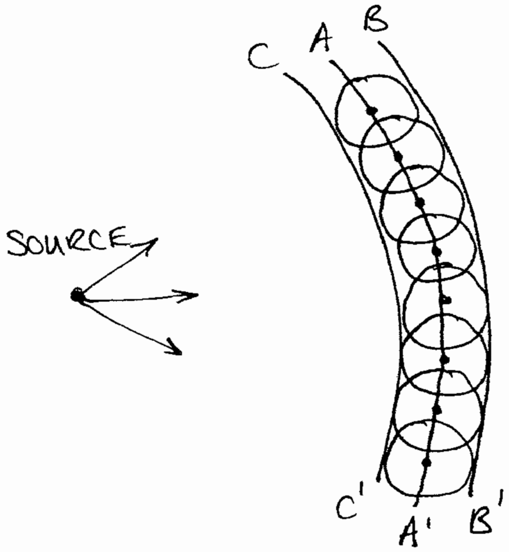
BOITHIAS, L. 1987: "RADIO WAVE PROPAGATION" pub. MCGRAW-HILL

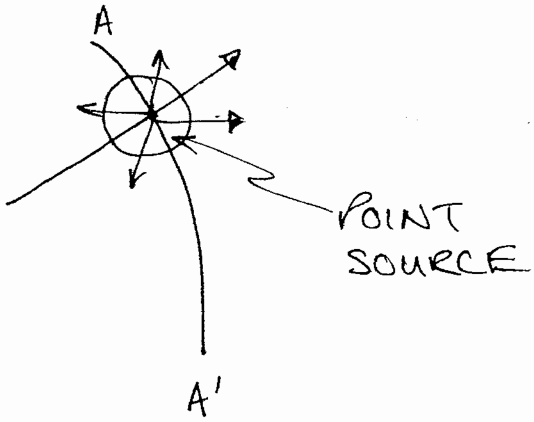
DIFFRACTION

HUYGEN'S PRINCIPLE

DIFFRACTION IS THE PROPERTY OF ALL E-M WAVES BY WHICH THEY CURVE AROUND THE EDGE OF OBSTACLES.

THE FULL MATHEMATICAL TREATMENT OF DIFFRACTION IS BEYOND THE SCOPE OF THIS COURSE – WE WILL ONLY LOOK QUALITATIVELY AT THE ORIGIN OF DIFFRACTION





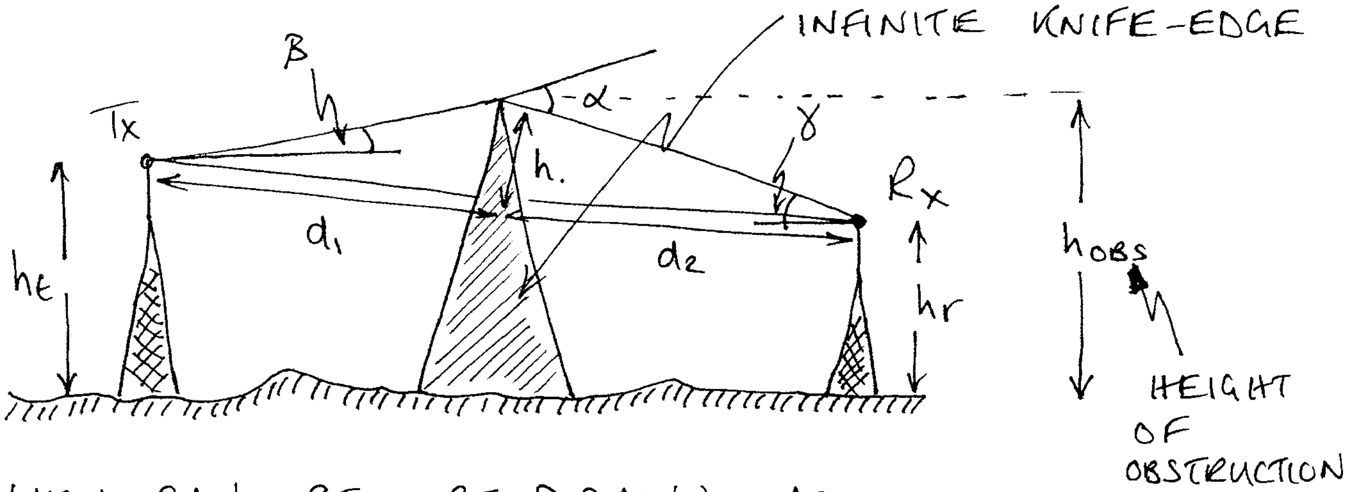
HUYGENS SUGGESTED THAT EACH POINT ON A WAVE FRONT (AA') COULD BE CONSIDERED AS A POINT SOURCE THAT PRODUCES A SECONDARY WAVELET. THESE SOURCES COMBINE TO PRODUCE A NEW WAVE FRONT IN THE DIRECTION OF PROPAGATION (BB'), BUT <u>NOT</u> (CC')

DIFFRACTION IS CAUSED BY THE PROPAGATION OF SECONDARY WAVELETS INTO THE SHADOWED REGION. (GENERATED BY THE BLOCKING OBSTACLE)

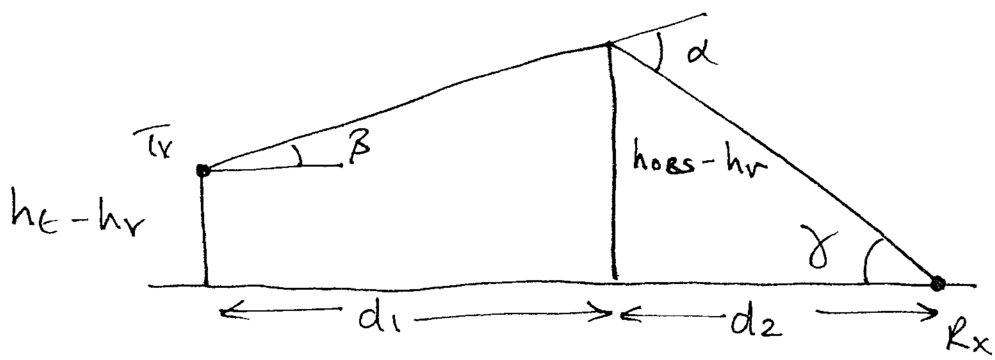
THE FIELD STRENGTH OF A DIFFRACTED WAVE WAVE IN THE SHADOWED REGION IS THE VECTOR SUM OF THE ELECTRIC FIELD COMPONENTS OF ALL THE SECONDARY WAVELETS IN THE SPACE AROUND THE OBSTACLE

KNIFE - EDGE DIFFRACTION

CONSIDER THE FOLLOWING FIGURE;



WHICH CAN BE RE-DRAWN AS;



FROM THE EQUATIONS WE DEVELOPED WHEN WE LOOKED AT FRESNEL ZONES, WE KNOW THAT THE EXCESS PATH LOSS IS;

$$\Delta = \frac{h^2}{2}\frac{(d_1+d_2)}{d_1 d_2}$$

WE ALSO KNOW THAT THE PHASE DIFFERENCE IS;

$$\phi = \frac{\Delta . \omega_c}{c} = \frac{2\pi\Delta}{\lambda} \quad \text{(SEE LECTURE \#3)}$$

$$\Rightarrow \phi = \frac{2\pi}{\lambda} \times \left[\frac{h^2}{2}\frac{(d_1+d_2)}{d_1 d_2}\right] \quad \text{— (5)}$$

SINCE $\alpha = \beta + \gamma$ AND ($\tan x = x$ IN RADIANS) THEN:

$$\alpha \cong h\,\frac{d_1+d_2}{d_1 d_2}$$

WE CAN WRITE EQ^N (5), BY NORMALIZING USING THE DIMENSION LESS <u>FRESNEL - KIRCHOFF</u> PARAMETER v, AS:

$$v = h\left[\frac{2(d_1+d_2)}{\lambda\, d_1 d_2}\right]^{1/2}$$

$$= \alpha\left[\frac{2\, d_1 d_2}{\lambda(d_1+d_2)}\right]^{1/2}$$

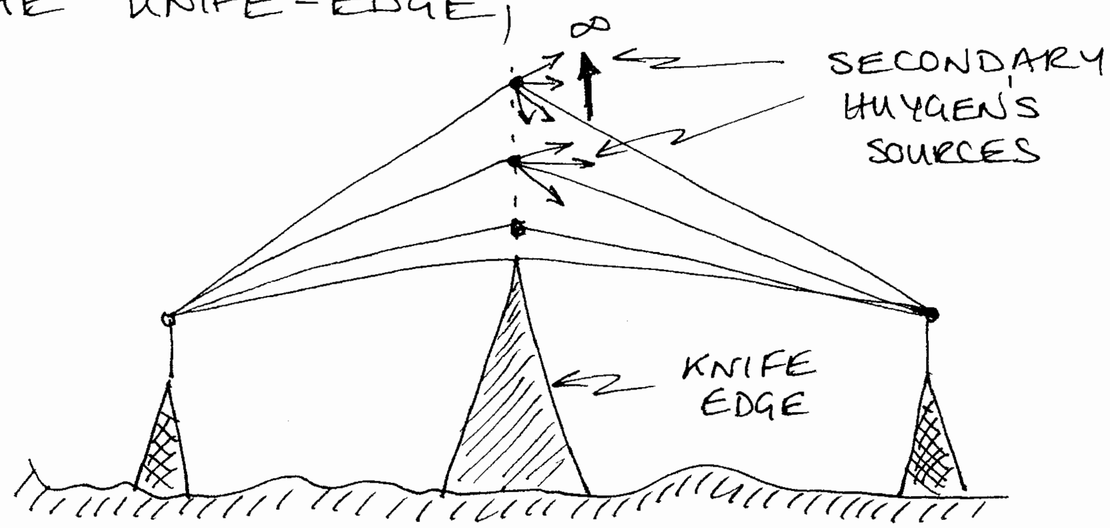
HENCE $\phi = \frac{\pi}{2} v^2$

THE ELECTRIC FIELD OF A KNIFE-EDGE DIFFRACTED WAVE E_d, IS GIVEN BY

$$E_d = F(v)\, E_0$$

WHERE: $F(v)$ IS THE COMPLEX FRESNEL INTEGRAL
E_0 - IS THE FREE-SPACE ELECTRIC FIELD IN THE ABSENCE OF THE GROUND OR THE KNIFE-EDGE.

THE FRESNEL INTEGRAL IS THE SUM OF THE FIELDS DUE TO ALL THE SECONDARY HUYGENS SOURCES IN THE PLANE ABOVE THE KNIFE-EDGE;



THE FRESNEL INTEGRAL IS;

$$F(v) = \frac{(1+j)}{2} \int_{v}^{\infty} \exp\left[-\frac{j\pi t^2}{2}\right] dt.$$

THIS IS A PRETTY NASTY INTEGRAL, NOT THE SORT OF THING YOU CAN DO EASILY. ITS VALUE IS USUALLY FOUND FROM TABLES OR GRAPHS/APPROXIMATIONS.

WE ARE USUALLY ONLY INTERESTED IN THE MAGNITUDE^2 OF $F(v)$, FROM WHICH WE CAN DETERMINE THE DIFFRACTION GAIN (LOSS)

THAT IS;

$$G_d(dB) = 10\log_{10}|F(v)|^2$$

$$G_d(dB) = 20\log_{10}|F(v)|$$

G_d CAN BE APPROXIMATED;

$$G_d(dB) = \begin{cases} 0 & v \leq -1 \\ 20\log_{10}(0.5-0.62v) & -1 \leq v \leq 0 \\ 20\log_{10}(0.5\exp(-0.95v)) & 0 \leq v \leq 1 \\ 20\log_{10}\left(0.4-\left[0.1184-(0.38-0.1v)^2\right]^{1/2}\right) & 1 \leq v \leq 2.4 \\ 20\log_{10}\left(\frac{0.225}{v}\right) & v > 2.4 \end{cases}$$

Knife-edge diffraction loss