RADIOMETRY

RADIOMETRY – MEASUREMENT OF INCOHERENT ELECTROMAGNETIC ENERGY

- ALL MATTER WHETHER GAS, VAPOUR, SOLID OR PLASMA EMITS E.M. ENERGY.
- THERMAL EMISSION IS THE DOMINANT PROCESS.
- A RADIOMETER IS A VERY SENSITIVE, LOW-NOISE RECEIVER THAT CAN DETECT THIS INCOHERENT E.M. ENERGY.

APPLICATIONS OF RADIOMETRY INCLUDE:

- MEASUREMENT OF THE ATMOSPHERE.
- SECURITY – OBJECTS HIDDEN BENEATH/UNDER CLOTHES.
- MEDICAL – CLASSIFICATION OF TISSUE TYPES.

THE FUNDAMENTAL QUANTITY IN RADIOMETRY IS THE BRIGHTNESS, B

BRIGHTNESS HAS UNITS OF $W\,m^{-2}\,Hz^{-1}\,sr^{-1}$.

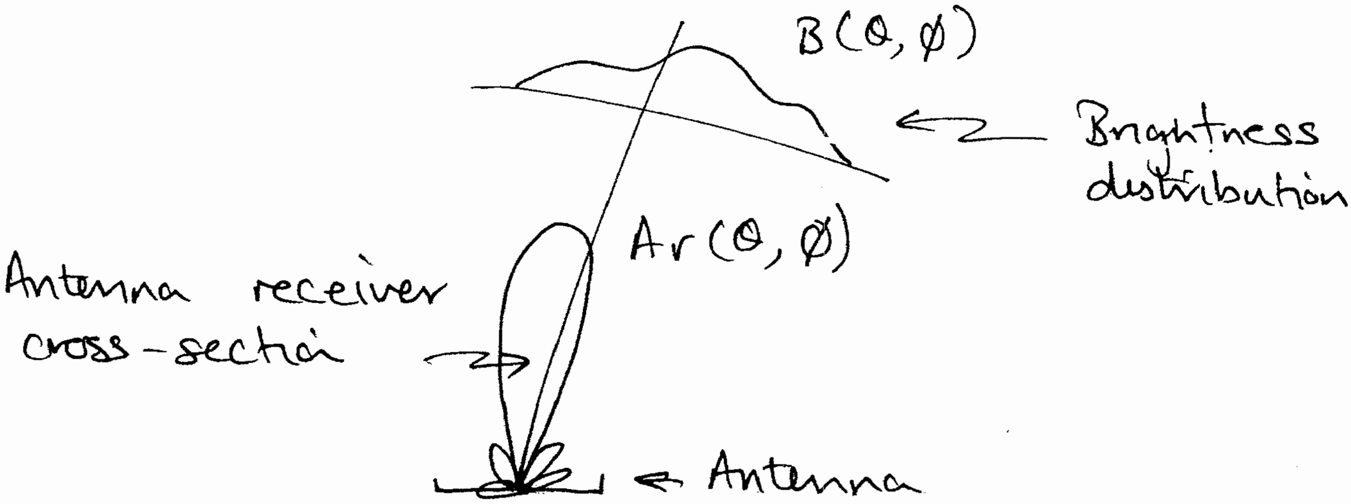
(KNOWN AS RADIANCE IN OPTICAL RADIOMETRY)

dP – POWER
da – AREA
B – BRIGHTNESS
$d\Omega$ – SOLID ANGLE
df – FREQUENCY

$$dP = B \cos\theta \, da \, d\Omega \, df.$$

B – DEPENDS ON DIRECTION – $B(\theta, \phi)$
BRIGHTNESS DISTRIBUTION.

B – DEPENDS ON FREQUENCY – $B(f)$
BRIGHTNESS SPECTRUM.



$$P_r = \frac{1}{2} \int_{4\pi} B(\theta, \phi) \, Ar(\theta, \phi) \, d\Omega$$

$1/2$ – ANTENNA IS POLARIZED – INCOHERENT RADIATION IS UNPOLARIZED

IF WE NORMALIZE THE RECEIVING CROSS-SECTION A_r TO THE MAXIMUM VALUE WE HAVE;

$$P_r = \tfrac{1}{2} A_{rm} S,$$

$$S = \int_{4\pi} B(\theta,\phi)\, P_n(\theta,\phi)\, d\Omega$$

$$A_{rm}(\theta,\phi) = A_{rm} P_n(\theta,\phi)$$

A_{rm} CAN BE WRITTEN IN TERMS OF ANTENNA GAIN (G_m)

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

$$S_s = \int_{4\pi} B(\theta,\phi)\, d\Omega$$

IS THE SOURCE FLUX DENSITY $W m^{-2} Hz^{-1}$.

RADIO ASTRONOMERS CALL THIS BY ANOTHER UNIT THE JANSKY. $1\ \text{jan} = 1\ W\ Hz^{-1}\ m^{-2}$. NAMED AFTER KARL. G. JANSKY.

MOST RADIO SOURCES IN RADIO ASTRONOMY ARE OF ORDER 10^{-26} jan.

BLACKBODY RADIATION

- KIRCHHOFF'S LAW : A GOOD ABSORBER OF EM ENERGY IS A GOOD EMITTER.

- IN GENERAL RADIATION INCIDENT ON A MATERIAL WILL BE REFLECTED AND ABSORBED.

- A BLACKBODY MATERIAL – ABSORBS RADIATION AT ALL FREQUENCIES REFLECTING NONE. – IDEALIZED

- A PERFECT ABSORBER IS A PERFECT EMITTER.

- ACCORDING TO PLANCK'S RADIATION LAW A BLACKBODY RADIATES UNIFORMLY IN ALL DIRECTIONS WITH A SPECTRAL BRIGHTNESS B_f GIVEN BY:

$$B_f = \frac{2hf^3}{c^2} \frac{1}{\exp[hf/kT] - 1}$$

h – PLANCK'S CONSTANT – 6.63×10^{-34} (Js)
f – FREQUENCY (Hz)
k – BOLTZMANN'S CONSTANT – 1.38×10^{-23} (JK^{-1})
T – TEMPERATURE (K)
c – VELOCITY OF LIGHT – 3×10^8 (ms^{-1})

FOR MICROWAVE & MILLIMETRE WAVES,

$$hf \ll kT.$$

$$\exp(hf/kT) \simeq 1 + hf/kT$$

THIS APPROXIMATION IS CALLED THE RAYLEIGH-JEANS LAW;

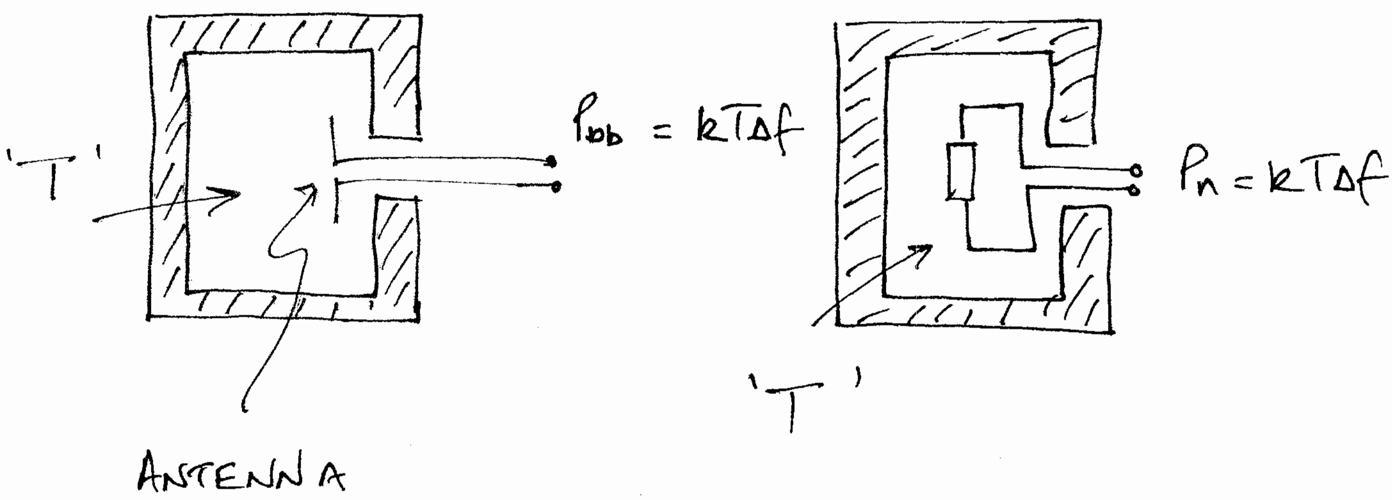
$$B_f = \frac{2k}{\lambda^2} T.$$

STEFAN - BOLTZMANN LAW - TOTAL BRIGHTNESS AT TEMPERATURE T

$$B = \int_0^\infty B_f \, df = \frac{\sigma T^4}{\pi}$$

σ - STEFAN BOLTZMANN CONSTANT
5.673×10^{-8} W m^{-2} K^{-4} sr^{-1}.

POWER - TEMPERATURE CORRESPONDENCE



$$P_{bb} = kT\Delta f \frac{A_r}{\lambda^2} \iint_{4\pi} F_n(\theta, \phi) \, d\Omega$$

$$\Omega_A = \iint_{4\pi} F_n(\theta, \phi)\, d\Omega = \frac{\lambda^2}{A_r}$$

HENCE $\quad P_{bb} = kT\Delta f \equiv P_n.$

NON BLACKBODY RADIATION

NON BLACKBODIES CALLED "GREY BODIES"

BRIGHTNESS OF BLACKBODY:

$$B_{bb} = B_f\, \Delta f = \frac{2kT}{\lambda^2} \Delta f.$$

FOR A NARROW BANDWIDTH, Δf.

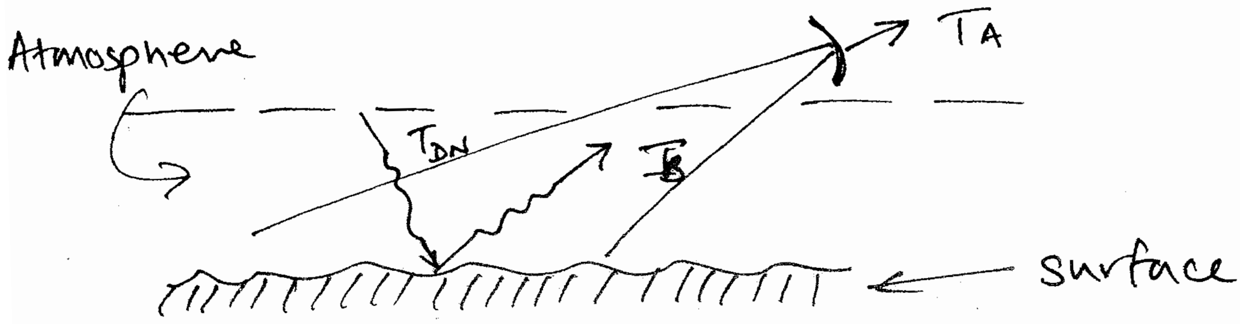
$$B(\theta, \phi) = \frac{2k}{\lambda^2} T_B(\theta, \phi)\, \Delta f.$$

$$e(\theta, \phi) = \frac{B(\theta, \phi)}{B_{bb}} = \frac{T_B(\theta, \phi)}{T}.$$

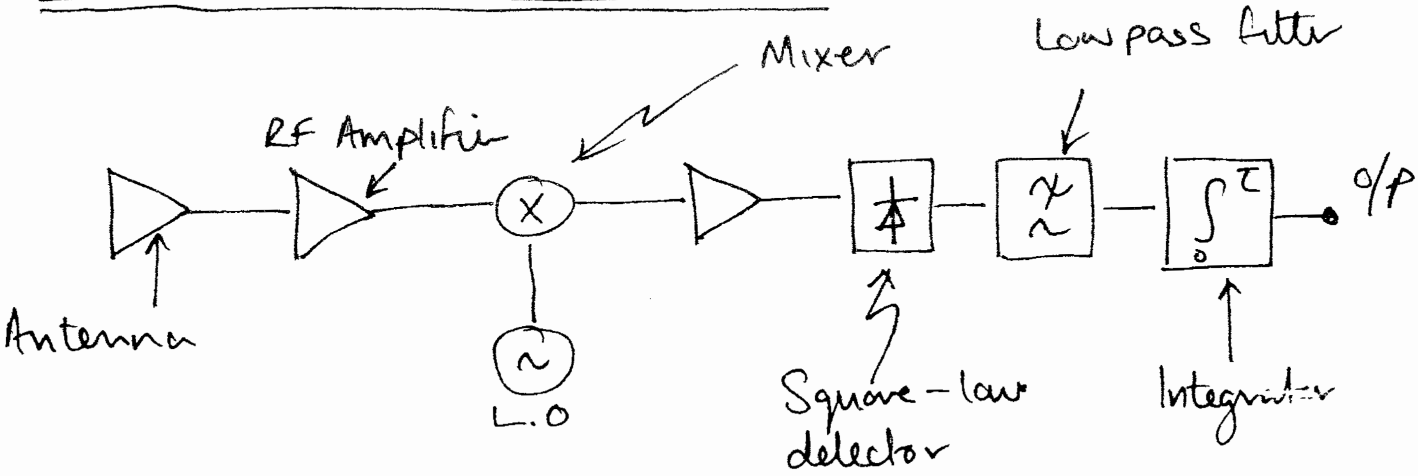
$e(\theta, \phi)$ — EMISSIVITY $\quad 0 \leq e(\theta, \phi) \leq 1.$

TO SENSE T_B WE USE AN ANTENNA AND MEASURE ITS TEMPERATURE, T_{AP}

IDEALLY $\quad T_{AP} = T_B$



TOTAL POWER RADIOMETER



POWER MEASURED CONSISTS OF, T_{sys}, SYSTEM TEMPERATURE (BACKGROUND) AND SIGNAL TEMPERATURE ΔT.

SQUARE-LAW DETECTOR – OUTPUT VOLTAGE PROPORTIONAL TO OUTPUT NOISE POWER

OUTPUT FROM SYSTEM NOISE = $(k T_{sys} BW)^2$
BW – BANDWIDTH OF RECEIVER.
AVERAGED BY INTEGRATION = $BW\tau$.
SIGNAL OUTPUT = $(k \Delta T BW)^2$

$$V_{sys} \simeq \frac{(k T_{sys} BW)^2}{BW\tau} \quad \text{– OUTPUT VOLTAGE SIGNAL.}$$

EFFECTIVE REDUCTION IN NOISE TEMPERATURE FROM T_{sys} TO $T_{sys} / (BW\tau)^{1/2}$

SIGNAL OUTPUT $V_s \simeq (k \Delta T BW)^2$

$V_s = V_{sys} \Rightarrow \Delta T = \Delta T_{min}$

$$\Delta T_{MIN} = \frac{T_{sys}}{\sqrt{BW\tau}}$$

IN GENERAL;

$$\overline{V_{OUT}} = g_{LF}\, C_d\, G\, k\, T_{sys}\, BW$$

BW - BANDWIDTH
T_{sys} - TEMPERATURE
k - BOLTZMANN'S CONSTANT
G - SYSTEM GAIN
C_d - DETECTOR SENSITIVITY ($V\,W^{-1}$)
g_{LF} - LOW-PASS FILTER GAIN.

THE PROBLEM:

$$\overline{V_{OUT}} \propto G\, T_{sys}.$$

$G_s \rightarrow \Delta G_s + G_s$ AS GAIN VARIES
LEADS TO INCREASE IN T_{sys} BY

$$\Delta T_G = \Delta T_{sys} = T_{sys}\left(\frac{\Delta G_s}{G_s}\right)$$

SINCE NOISE FLUCTUATIONS (ΔT_{MIN}) AND GAIN FLUCTUATIONS ARE UNCORRELATED, TOTAL UNCERTAINTY (RMS.) GIVEN BY;

$$\Delta T = \left[(\Delta T_{MIN})^2 + (\Delta T_G)^2\right]^{1/2}$$

$$= T_{sys}\left[\frac{1}{BW\,\tau} + \left(\frac{\Delta G_s}{G_s}\right)^2\right]^{1/2}.$$

$T_{sys} = 600K$, $BW = 100MHz$ $\tau = 10ms$ $\Delta G_s/G_s = 0.01$
$T_A = 300K$ $\Rightarrow$ $\Delta T_{MIN} = 0.9K$, $\Delta T_G = 9K$ $\Delta T = 9.05K$

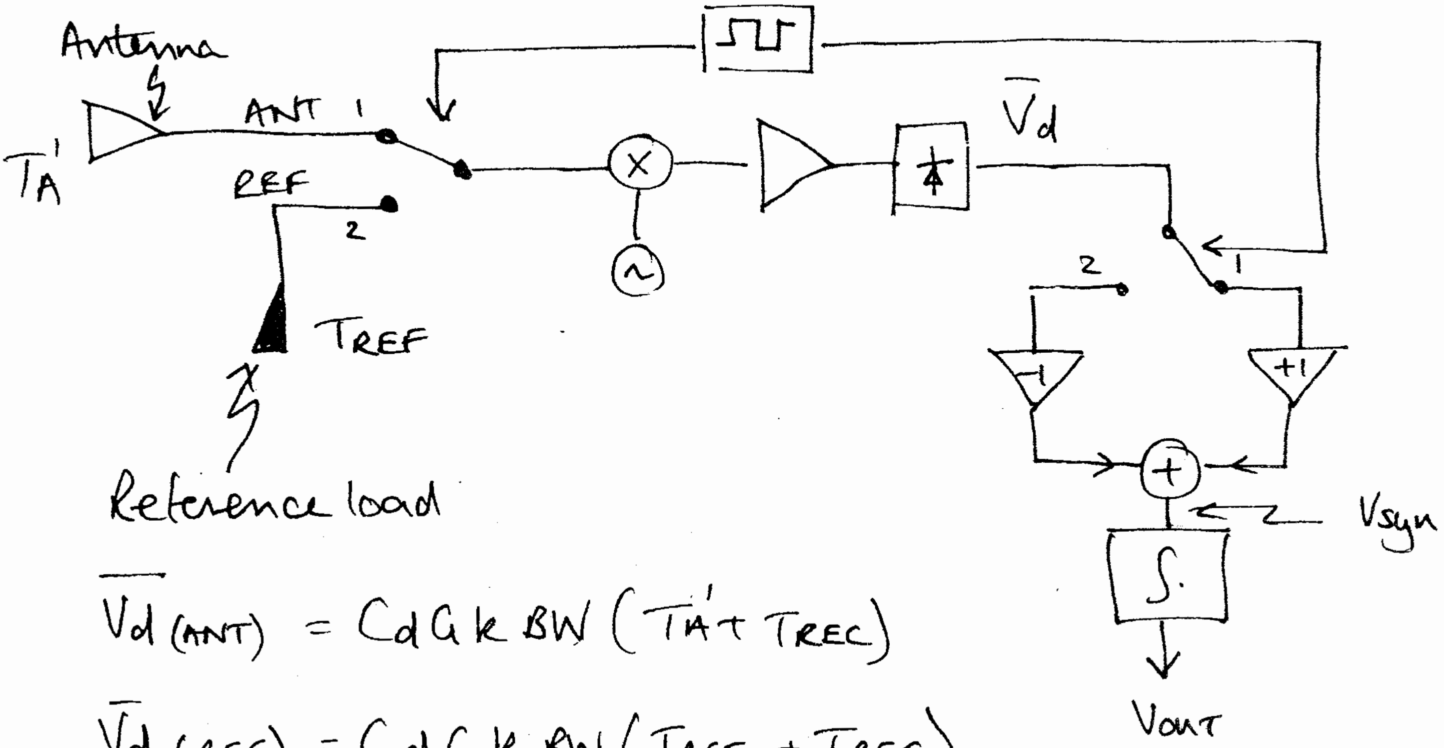
GAIN VARIATIONS CAN DOMINATE SENSITIVI[T]

→ REDUCE GAIN FLUCTUATIONS!

$\Delta G_S / G_S < 10^{-5}$ CAN BE ACHIEVED, BUT CAN BE COSTLY PARTICULARLY AT MILLIMETER WAVELENGTHS.

DICKE RADIOMETER

R.H DICKE (1946) SOLVED THIS PROBLEM;



$$\overline{V_d}(ANT) = C_d G k BW (T_A' + T_{REC})$$

$$\overline{V_d}(REF) = C_d G k BW (T_{REF} + T_{REC})$$

$$\overline{V_{syn}} = \tfrac{1}{2} (\overline{V_d}(ANT) - \overline{V_d}(REF))$$

$$= \tfrac{1}{2} C_d G k BW (T_A' - T_{REF})$$

IF $T_A' = T_{REF}$ GAIN FLUCTUATIONS ARE NIL.

$$\Delta T_{MIN} = \left[\frac{2(T_A' + T_{REC})^2 + 2(T_{REF} + T_{REC})^2}{BW \tau} + \frac{\Delta G_S}{G_S} (T_A - T_{REF} \ldots \right.$$

FOR A BALANCED DICKE RADIOMETER

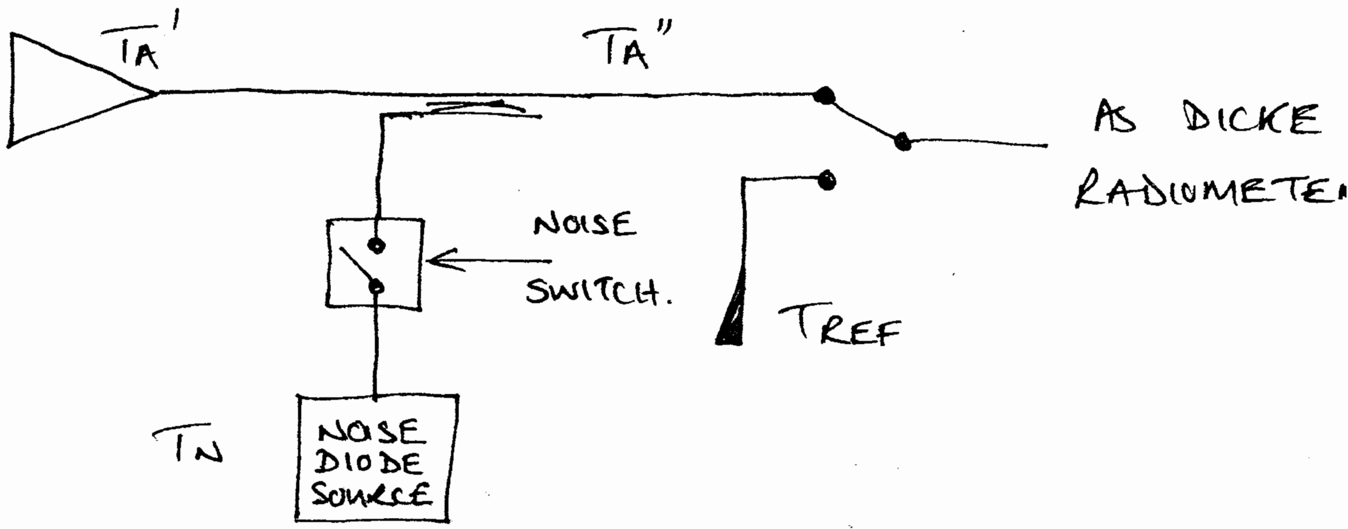
$T_A' = T_{REF}$, SENSITIVITY CAN BE WRITTEN AS;

$$\Delta T_{MIN} = \frac{2(T_A + T_{REC})}{\sqrt{BW\tau}}$$

$T_{sys} = T_A + T_{REC}$.

$$\Delta T_{MIN\,(DICKE)} = 2\,\Delta T_{MIN\,(IDEAL)}$$

PULSED NOISE INJECTION BALANCING



AT BALANCE $T_A'' = T_{REF} \Rightarrow \overline{V_{syn}} \equiv 0$.

$$\left(\overline{T_A' + \alpha T_N}\right) = T_A'' = T_{REF}$$

ADJUST α BY PULSING NOISE SWITCH.