RRI-EEG Internal

Technical Report :

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Calculation of radiation efficiency through poynting vector and comparing it with the efficiency obtained through Radiation patterns

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Abstract:

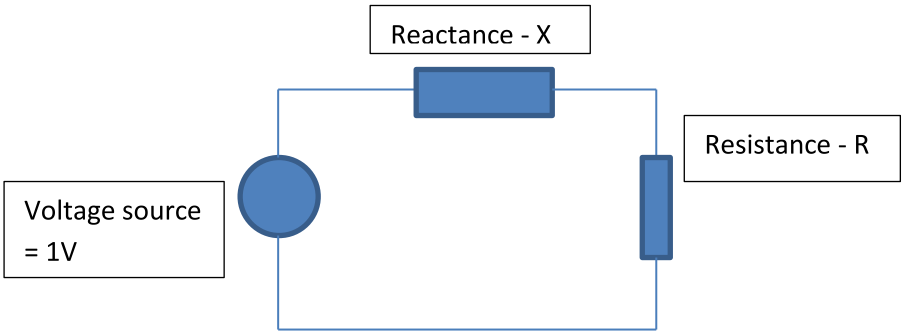
Radiation efficiency of an antenna is calculated by computing the total power accepted by it over its beam solid angle. This is performed by double integrating the radiation patterns over the elevation angular range of 0 to 90 deg. and azimuth 0 to 360 deg. This can also be done by measuring the voltage at every spatial location in oriented in both theta and phi directions and dividing it by the space impedance after properly squaring it. The present report compares the radiation efficiencies obtained from both the methods and helps calculate the ground resistance – R_g.

1. Introduction

Radiation efficiency is one of the important figure of merits of antenna indicating its ability to convert electrical signal to electromagnetic energy and radiate into space. This is found out by calculating the radiation intensity and integrating over the entire beam solid angle. Knowing the power fed in, radiation efficiency can be calculated by taking the ratio of total power radiated to the power fed in. This can also be done by calculating the voltage at every spatial location in both elevation and azimuthal angles and dividing it by the space impedance. The present report calculates radiation efficiency using both the methods and compares them for consistency. At the end, the loss resistance due to ground will also be calculated to account for the loss of radiation efficiency. Following paragraphs describe the methodology adopted by assuming a simple model for the antenna for accounting for both loss due to heat as well as radiation.

2. **To calculate power accepted by the antenna** :

Antenna is represented as a complex load with a real part and a imaginary parts as shown below.



Antenna equivalent circuit (as in WIPL-D)

The power fed to the antenna is given by :

$P\_fed = I^2 * Re(Z\_ant)$

where I is the current flowing through the antenna and Z_ant is the antenna impedance.

The current I is calculated as follows:

$I = V/(R^2+X^2)^{0.5}$

$I^2 = V^2/ (R^2+X^2)$ (Note : V = 1 V)

$$\mathbf{P\_fed = 1 * Re(Z\_ant) / (R^2+X^2)} \text{ --} \qquad (1)$$

3. To calculate the power radiated by the antenna

If E and H area the electric and magnetic fields, the poynting vector (P) is given by

$P = E \times H^*$

$= E \times \frac{E*}{Z}$

$= E^2 * \frac{1}{Z}$

Let e_θ and e_Φ represent electric fields along E and H directions at every θ and Φ.

At every (θ, Φ) sum the electric field components to get

$e^2 = (e_\theta^{\ 2} + e_\Phi^{\ 2})$

Further sum e^2 over the entire range of θ and Φ as specified in the simulation.

Perform following calculation to get:

$$\textbf{P\_radiated} = \frac{1}{Z} * d\,\theta * d\,\Phi\ (\ \Sigma\ (e_{\theta}^{2} + e_{\Phi}^{2}) * \cos(\theta\ ) \qquad (2)$$

for all values of theta and phi.

Where $d\,\theta = \dfrac{\pi}{(2*(N-1))}$, $d\,\Phi = \dfrac{2*\pi}{(M-1)}$ and Z = 120 * pi()

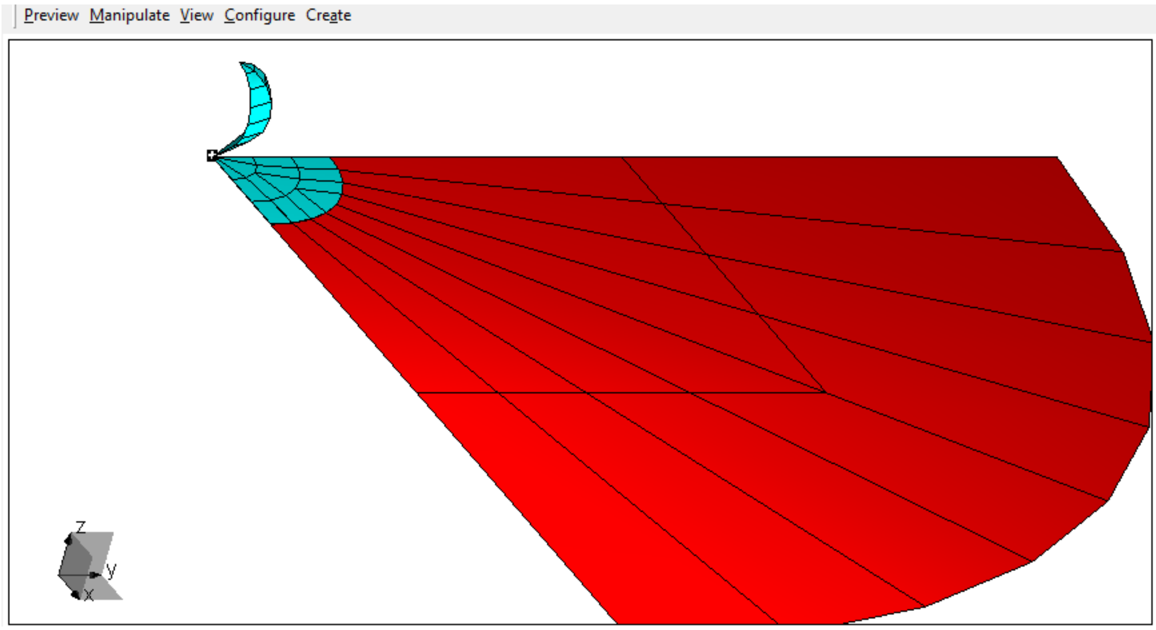
N and M are the number of angles specified in the simulation settings.

$Z = 120 * \pi$

Radiation efficiency is calculated by taking the ratio of

$$\textbf{Radiation efficiency} = (\text{P\_radiated} / \text{P\_fed\_in}) \qquad (3)$$

4. A Case study : Scaled sphereical antenna on real Earth (er=5, conduct.=0.002 S/m) (Version : short_sphere v82)



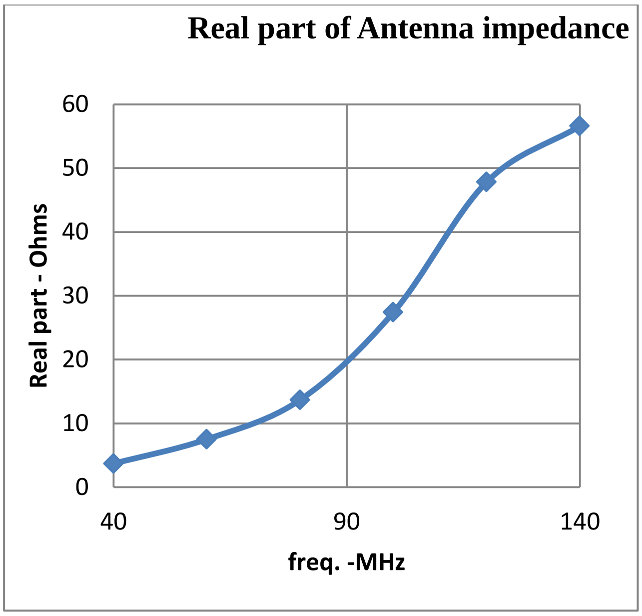


Fig. 1

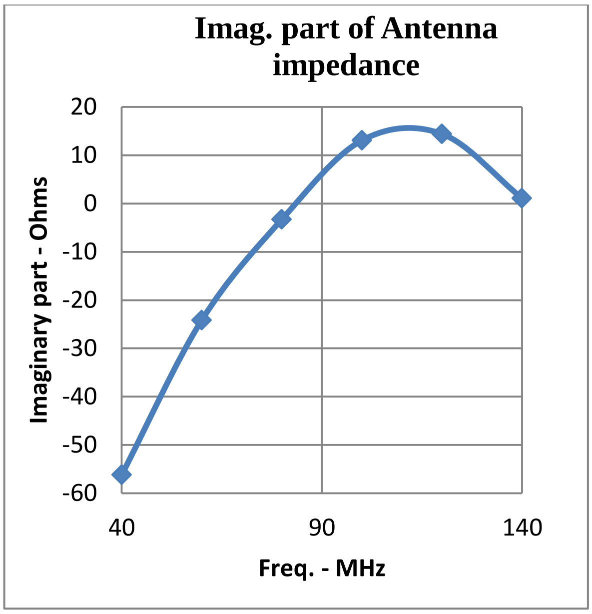


Fig. 2

Real and Imaginary parts of antenna impedance

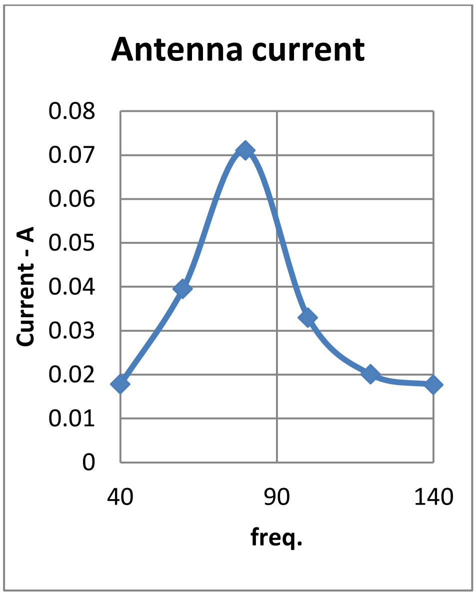


Fig. 3

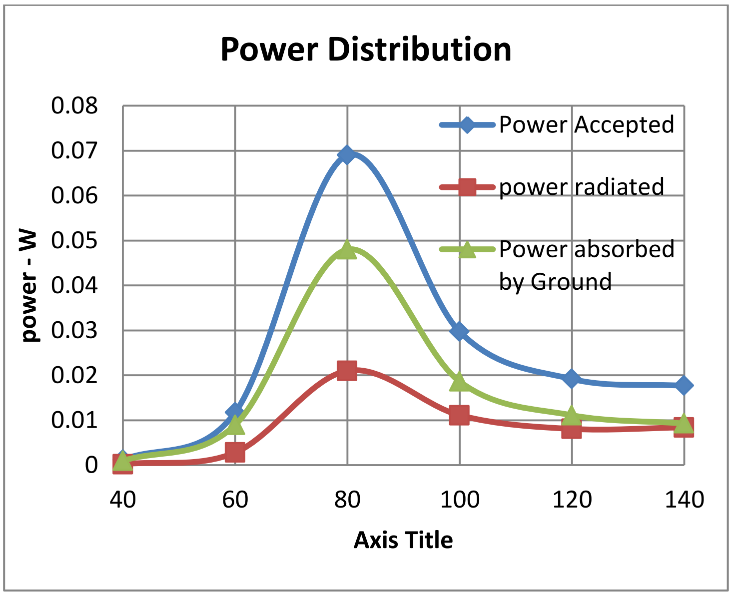


Fig. 4

Fig. 1 and 2 show the real and imaginary parts of antenna impedance. From these values, the current shown in Fig. 3 is calculated using the relation

$$I = V/(R^2+X^2)^{0.5}$$

Fig. 4 shows the power fed into the antenna. This is found out using the relation

$$P\_fed = I^2 * Re(Z\_ant)$$

This is shown as power accepted in the graph Fig. 4

Out of this power, power radiated is calculated using E and H fields at various values of theta and phi using the following relationships.

$$Power\_radiated = \frac{1}{z} * d\,\theta * d\,\Phi\,(\,\Sigma\,(e_\theta{}^2 + e_\Phi{}^2) * \cos(\theta\,)$$

This is shown in Fig. 5 along with power absorbed by the ground.

Ground resistance is calculated using the difference between the power fed in and power radiated and the current through the antenna.

Ground Resistance = Power absorbed by Ground / I^2

= (Power fed in – Power radiated) / I^2

It is shown in Fig. 5 along with real part of antenna impedance which includes both radiation resistance and ground resistance.

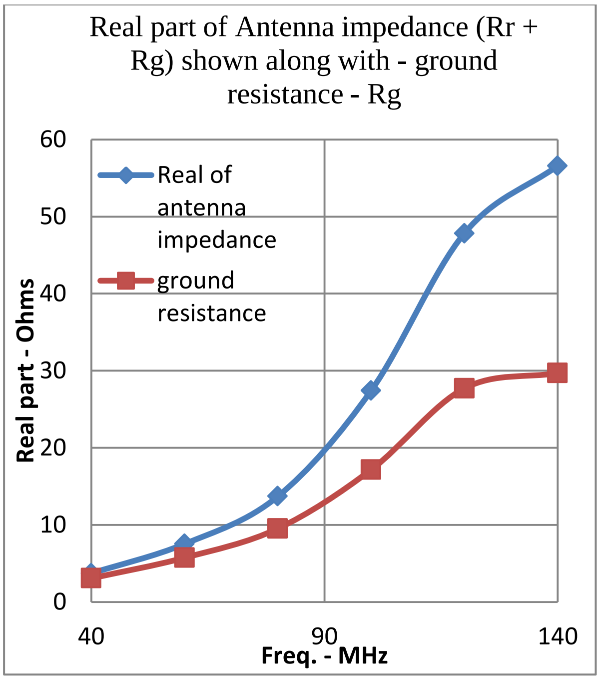


Fig. 5.Real part of antenna impedance as a function of frequency.

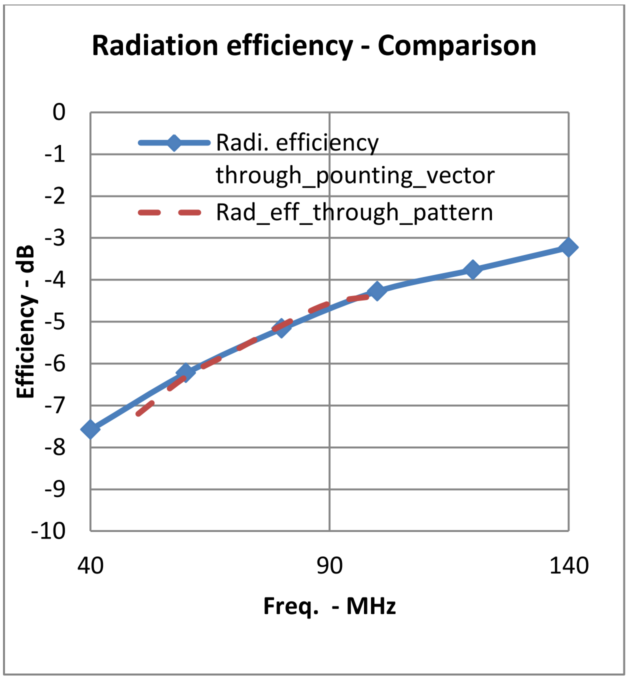


Fig. 6.Radiation efficiency – calculated through a) Poynting vector(solid line) and b) Radiation pattern (dotted line)

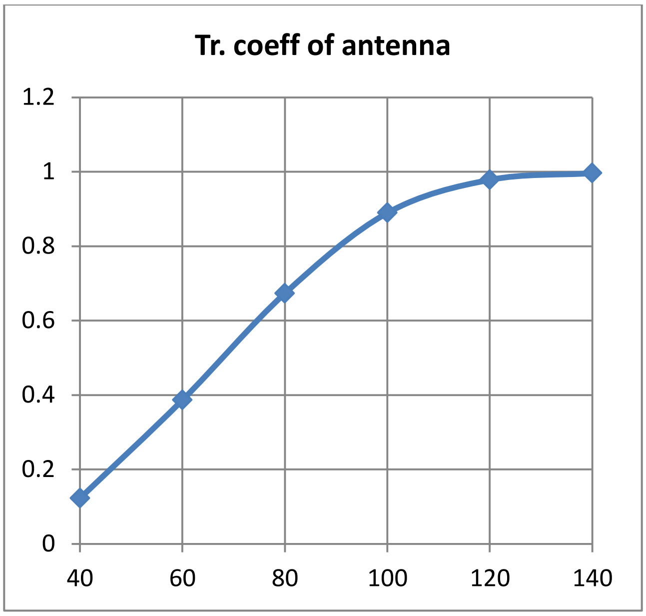


Fig. 7.Transmission coefficient of the antenna as a function of frequency.

Radiation efficiency is calculated by taking the ratio of power radiated to the power fed in as shown below

Radiation efficiency = (P_radiated / P_fed_in)

This is shown by solid line in the Fig. 6. Dotted line shows the radiation efficiency calculated through radiation pattern using the following relation

$$U_0 = \frac{W_{rad}}{4\pi} = \frac{1}{4\pi} \int_0^{2\pi} \int_0^{\pi} U(\theta, \phi) d\Omega.$$

5. To calculate the Tsky available at the antenna terminals knowing the values of Rr and Rg.

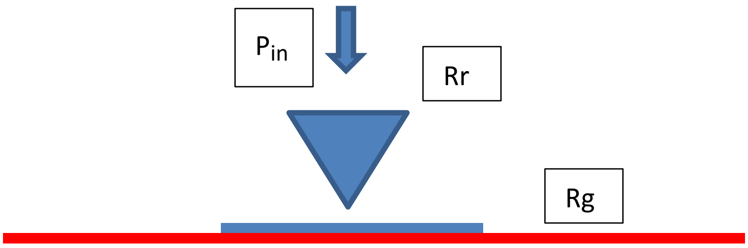


Fig. 8 Antenna placed on ground :Pin is the incident sky power, Rr is the radiation resistance and Rg is the ground resistance.

If P_{in} is the power incident on the antenna, then the fraction of it accepted by it is given by

$$(1 - \frac{Rg}{Rg+Rr}) * Pin$$

where Rg and Rr are the ground and radiation resistances. In addition to the sky signal, antenna also will have ground noise as the second component of its input signal. So the net power available at the antenna is given by

$$P_{total} = (1 - \frac{Rg}{Rg+Rr}) * Pin + (\frac{Rg}{Rg+Rr}) * Pgnd$$

where Pgnd represents the noise power due to the ground. If Tsky and Tgnd are the noise temperatures of sky and ground noise, then the above equation could be rewritten in terms of temperature as

$$T_{total} = (1 - \frac{Rg}{Rg+Rr}) * Tsky + (\frac{Rg}{Rg+Rr}) * Tgnd \qquad (1)$$

If Γ represents the reflection coefficient of the antenna, then the amount of power available at the antenna input terminals is given by

$$T\_available = T_{total} * (1- \Gamma^2) \qquad (2)$$

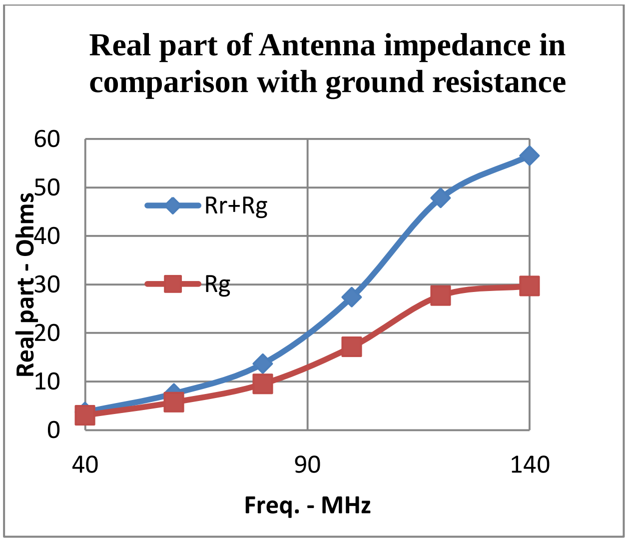


Fig. 9 Grond resistance and real part of antenna impedance as a function of frequency

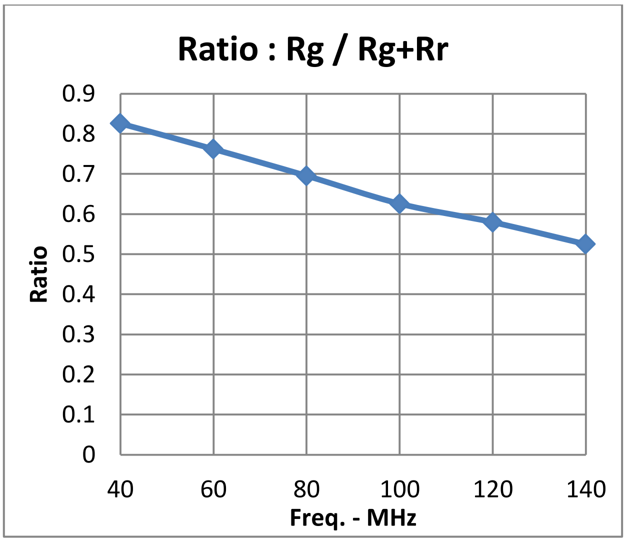
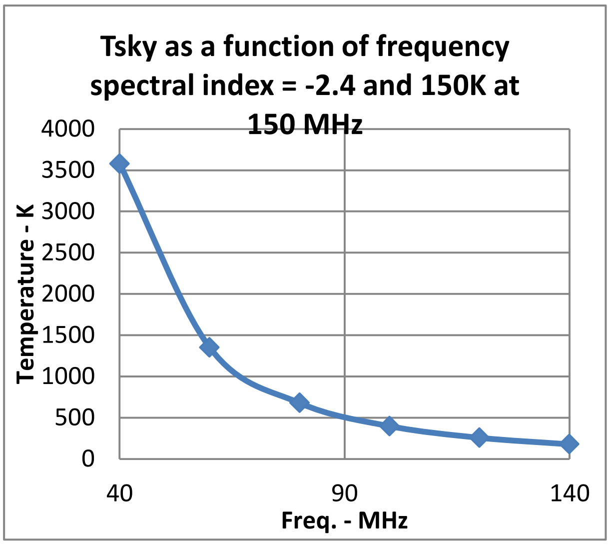


Fig.10. Ratio of Rg and Rg + Rr



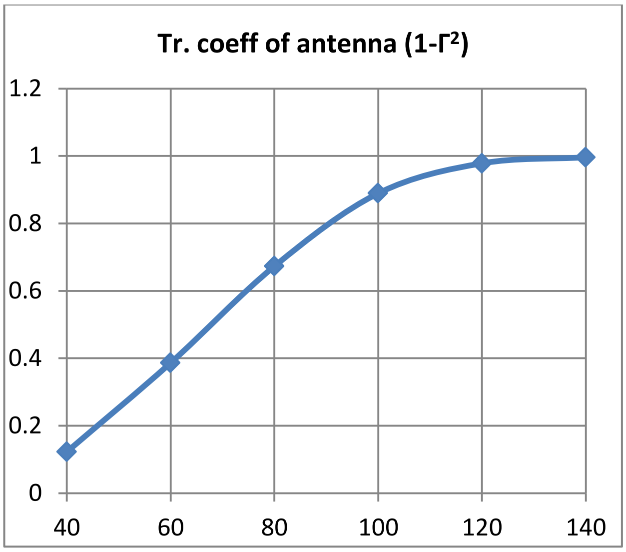
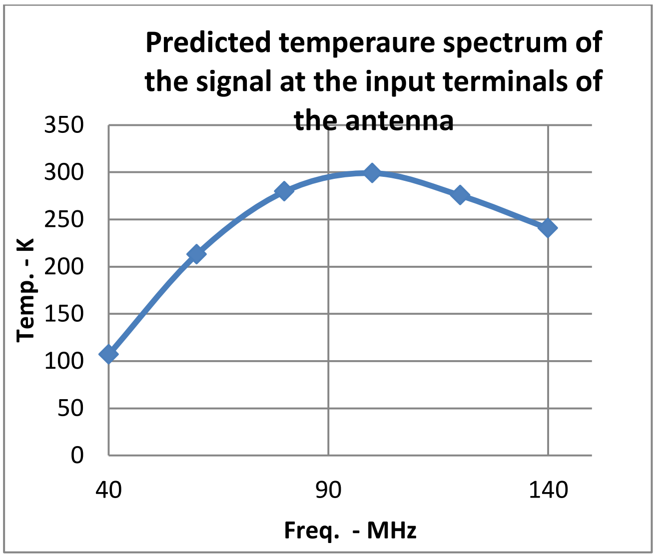


Fig. 11 Sky temperature as a function of freq. with a spectral index of -2.4

Fig. 12 Transmission coefficient of the antenna

Fig. 9 shows the real part of antenna impedance which is the sum of radiation (Rr) and ground resistances.(Rg) Fig. 10 is the ratio of ground resistance and real part of antenna impedance. Fig. 11 is the expected sky temperature assuming a spectral index of -2.4, 150 K at 150 MHz and Fig. 12 is the reflection coefficient of the antenna.



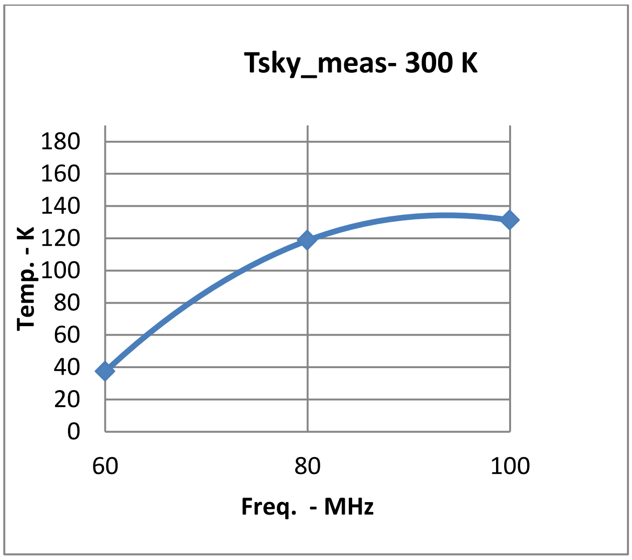


Fig. 13 Expected sky spectrum at the input terminals of the antenna taking into its account reflection coeff.

Fig. 14 Differential temperature

Assuming ground temperature of about 300 K, the expected sky spectrum at the output of the antenna is calculated using the equations1 and 2 and is shown in Fig 13 and 14.

Comments:

Radiation efficiencies calculated through poynting vector and the radiation pattern match very closely. It clearly indicates that the network analogy used to represent the antenna is valid ? But one discrepancy that I am finding is that according to this method, maximum power transfer is taking place at 80 MHz. where as we normally expect it to occur at 130 MHz where transmission coeff. Maximizes as shown in Fig. 7. At both the frequencies, imaginary part of antenna impedance is very close to zero.