Adaptively matched GPS antenna for plasma environments

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Abstract

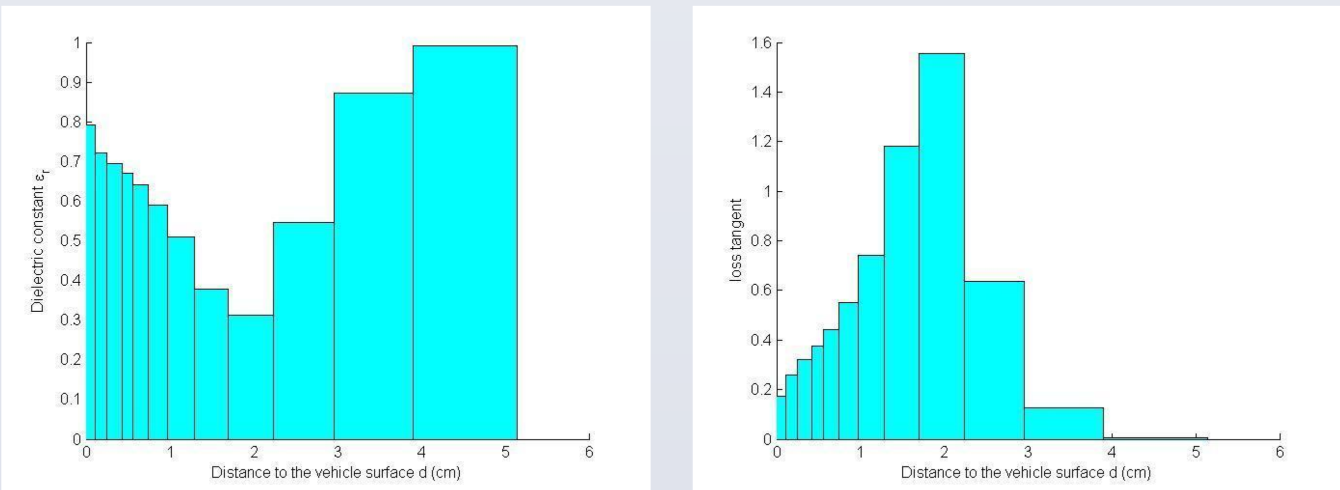
Hypersonic vehicles oftentimes experience diminished electromagnetic communication and sensing capabilities due to dense plasma that forms around the vehicle during re-entry. They can block or attenuate the radio signals, moreover, depending on the electron density, it will severely affect the performance of the communication antennas including the Global Position System (GPS) antenna. When operating in a plasma environment, these antennas' performance is affected by (i) signal loss / attenuation through the plasma layer, (ii) polarization mismatch and (iii) impedance mismatch; (ii) and (iii) further reduce the antenna's operational bandwidth. While little can be done to reduce signal loss, proper design of the antenna may mitigate (ii) and (iii). This paper proposes a novel double-feed dual band GPS antenna with AR bandwidth exceeding 150 MHz in both the L1 and L2 bands, thereby rendering making the antenna polarization highly insensitive to plasma loading. Besides, to achieve acceptable impedance bandwidth with various plasma environment, a feedback system including a sensing antenna, controller and tunable matching network is designed.

Introduction

During the hypersonic re-entry procedure of a vehicle, a continuously changing plasma layer is formed around the vehicle and block the electromagnetic communication.

- Continuous plasma layer could be discretized as several lossy dielectric layers, the relative permittivity for the dielectric is given by the classical equation

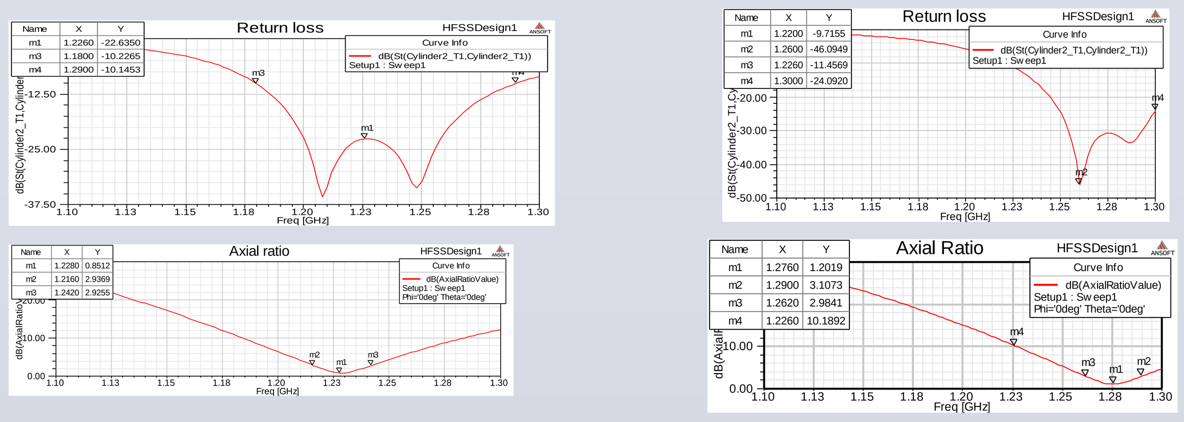
$$\varepsilon = \left(1 - \frac{\omega_p^2}{\omega^2 + \nu^2} + j\frac{\omega_p^2 \frac{\nu}{\omega}}{\omega^2 + \nu^2}\right)\varepsilon_0$$



(a) ε_r' for different plasma layers (b) $\tan\delta$ for different plasma

Fig. 1: One case of plasma modeling in discretized lossy dielectric at 1.227GHz

- The performance for the communication antenna will be severely influenced in the presence of plasma
  - Polarization mismatch
  - Impedance mismatch



(a) In free space (b) In plasma environment

Fig. 2: Comparison of the antenna performance in free space and plasma environment for one wide impedance band GPS antenna

Models

In order to mitigate the polarization and impedance mismatch, the following antenna system is proposed.

- Broadband branch-line coupler
- Dual band antenna with two capacitive feeds
- Tunable matching circuit based on varactor diode
- Single band sensing antenna

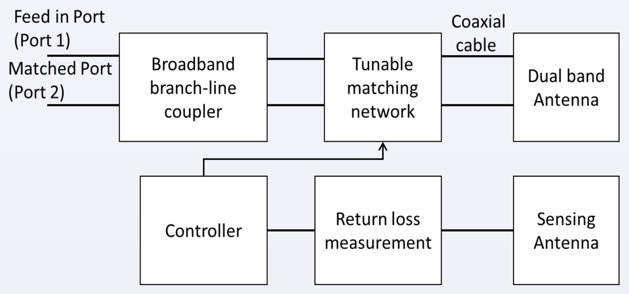


Fig. 3: Block diagram for the antenna system with matching network and feedback circuit

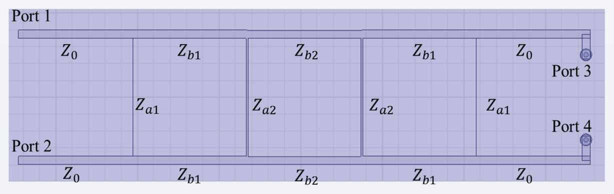
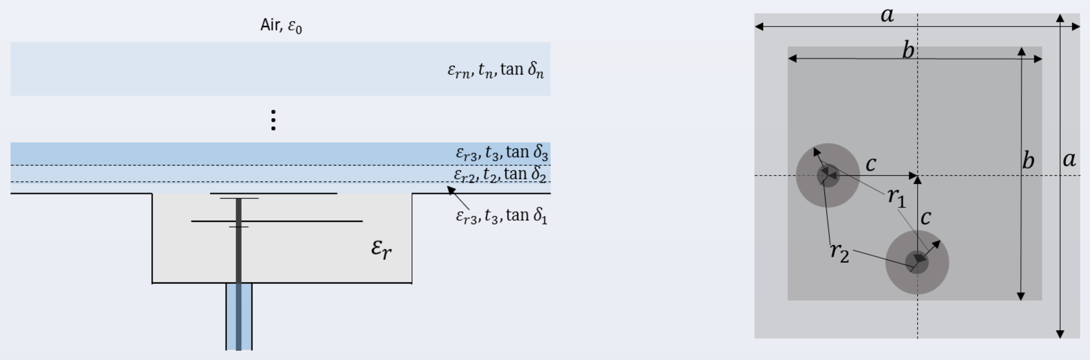
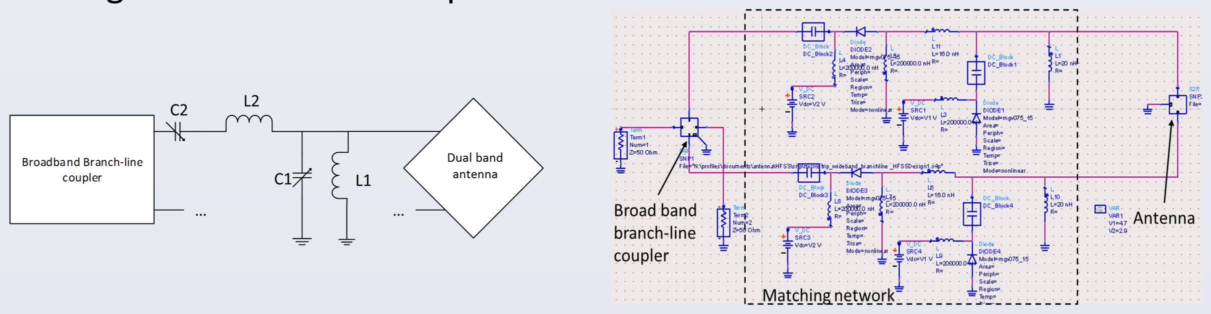


Fig. 4: Top view for the broadband branch-line coupler



(a) Side view with the plasma model (b) Top view

Fig. 5: Side view and top view for the dual band GPS antenna

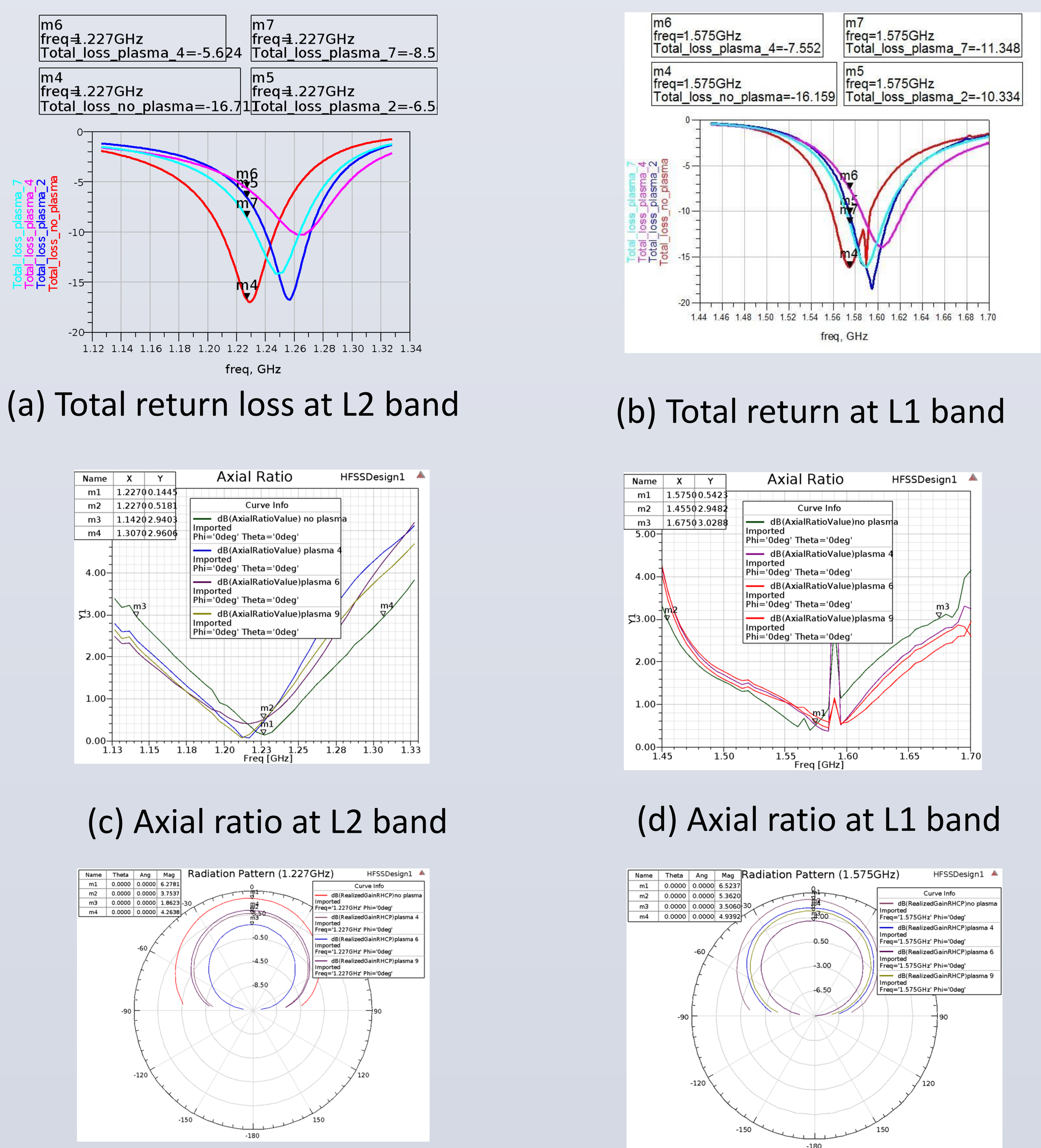


(a) Symbolic representation (b) Schematic

Fig. 6: Tunable LC matching network

Simulation result

Result for the antenna in plasma environment without matching network



(a) Total return loss at L2 band (b) Total return at L1 band

(c) Axial ratio at L2 band (d) Axial ratio at L1 band

(e) RHCP realized gain at L2 band (f) RHCP realized gain at L1 band

Fig. 7: Simulation result for the antenna system in different plasma environment without matching network

Impedance shifting for the GPS antenna at 1.227GHz and sensing antenna at 1.3GHz in Smith chart

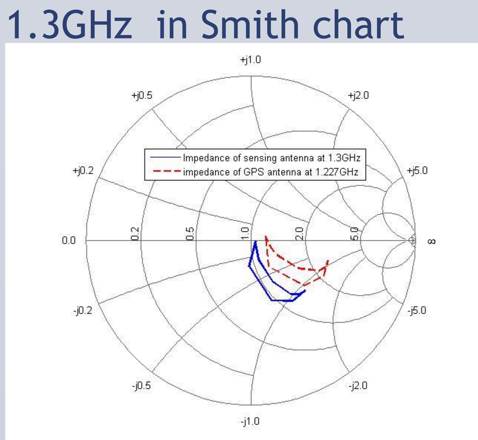


Fig. 8: Impedance shifting for both GPS antenna and the sensing antenna

From the figure, the shifted impedance for the GPS antenna at 1.227GHz and that of the sensing antenna at 1.3GHz has a linear relationship, by linear regression method, their relation could be revealed as:

$$Z_{GPS} = aZ_t + b$$

With a=1.1318+j*0.6696, b=-0.0506-j*0.628, and with mean squared error(MSE) of $1.134 \times 10^{-5} + j * 5.13 \times 10^{-4}$ for normalized impedance. Thereby, the impedance for the GPS antenna could be obtained from the return loss of the sensing antenna. Then, the required capacitance value for the tunable matching network and the corresponding bias voltage can be determined.

Result of the antenna after applying the matching network

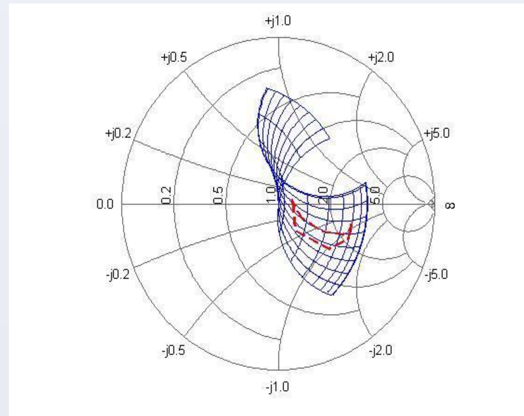


Fig. 9: Matching range for the designed tunable matching network

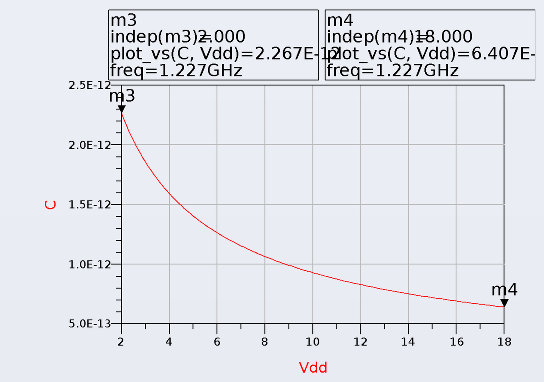
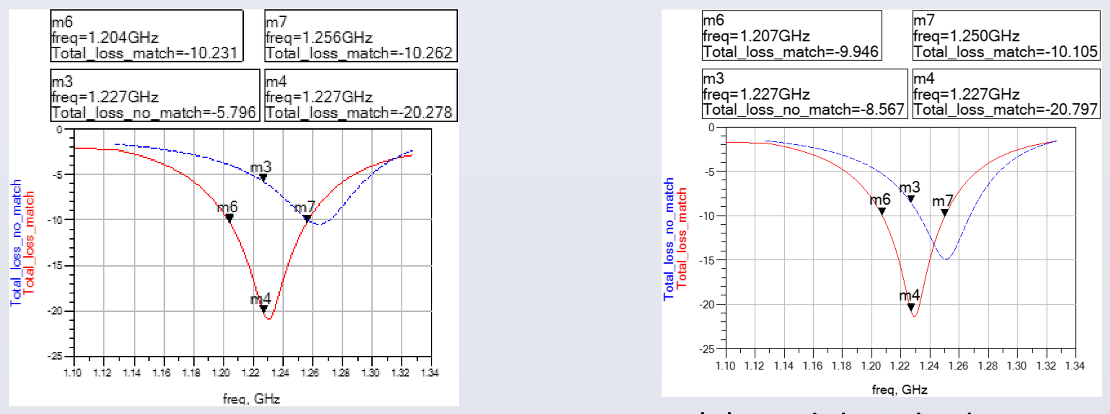


Fig. 10: Capacitance of the varactor diode with different bias voltage



(a) model With plasma 4 (a) model With plasma 7

Fig. 11: Total return loss for the model with and without matching

Table 1: The return loss and bandwidth comparison at L2 band for the matched and not matched GPS antenna with variable plasma environments

Plasma #	RL not matched(dB)	RL matched(dB)	Bandwidth(MHz)
1	-11.9	-19.7	35
2	-6.6	-21.5	35
3	-5.6	-21.1	42
4	-5.8	-20.3	55
5	-5.9	-20.7	49
6	-6.3	-20.6	46
7	-8.6	-20.8	43
8	-13.0	-19.7	40

Conclusion

- An ultra-wide axial ratio bandwidth dual band GPS antenna is proposed to compensate the polarization mismatch caused by the dynamic plasma environment, and a self-matching mechanism is implemented by a feedback system including tunable matching network and a sensing antenna.
- Future work will be further optimized the antenna, study the response time for the self-adjusting process, and apply some alternatives, like the MEMS varactors to the tunable matching network.

References

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