Estimation Of Coupling Between Mobile Vehicular Radars And Satellite Radiometers

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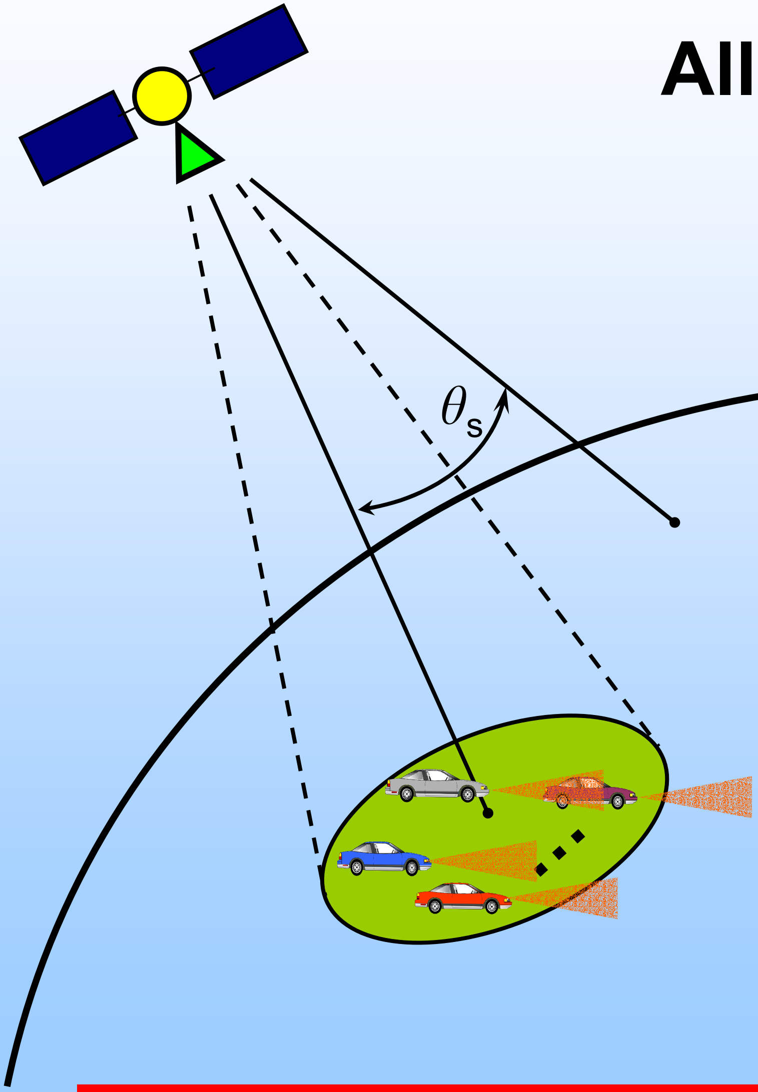
Introduction

- Coupling of emissions from wideband vehicle collision avoidance radars operating from 22-27 GHz into passive microwave satellites is a potential problem.
- The sensitivity of radiometric satellite observations over a water background within the 23.6-24.0 GHz primary EESS band to water vapor variations is ~0.4 K/(%RH). For 0.5%-1% IWV variations the required precision is ~0.2-0.4 K.
- Climatologically relevant changes in RH are estimated to be ~0.25%, therefore climatologically relevant T_B interference thresholds are ~0.1 K over water. A reduction factor of ~10 dB may be allowed for sidelobe contributions from populated coastal regions (i.e., no transmitters are expected over water).
- Surface emission measurements over land require accuracies of ~0.2-0.4 K for purposes of sounding correction.
- Overall, an interference threshold of ~0.1 K over water and ~0.2 K over land can be thus assumed.
- Only small amounts of interfering power are necessary to corrupt environmental data. Worst case is for interference power levels that are indistinguishable from thermal emission, i.e.:

$$\delta P_{INT} \sim k\delta TB \quad \text{with} \quad \sim 0.01 < T < \sim 10\ \text{K}$$

Auto Radar Interference within 23.6-24.0 GHz

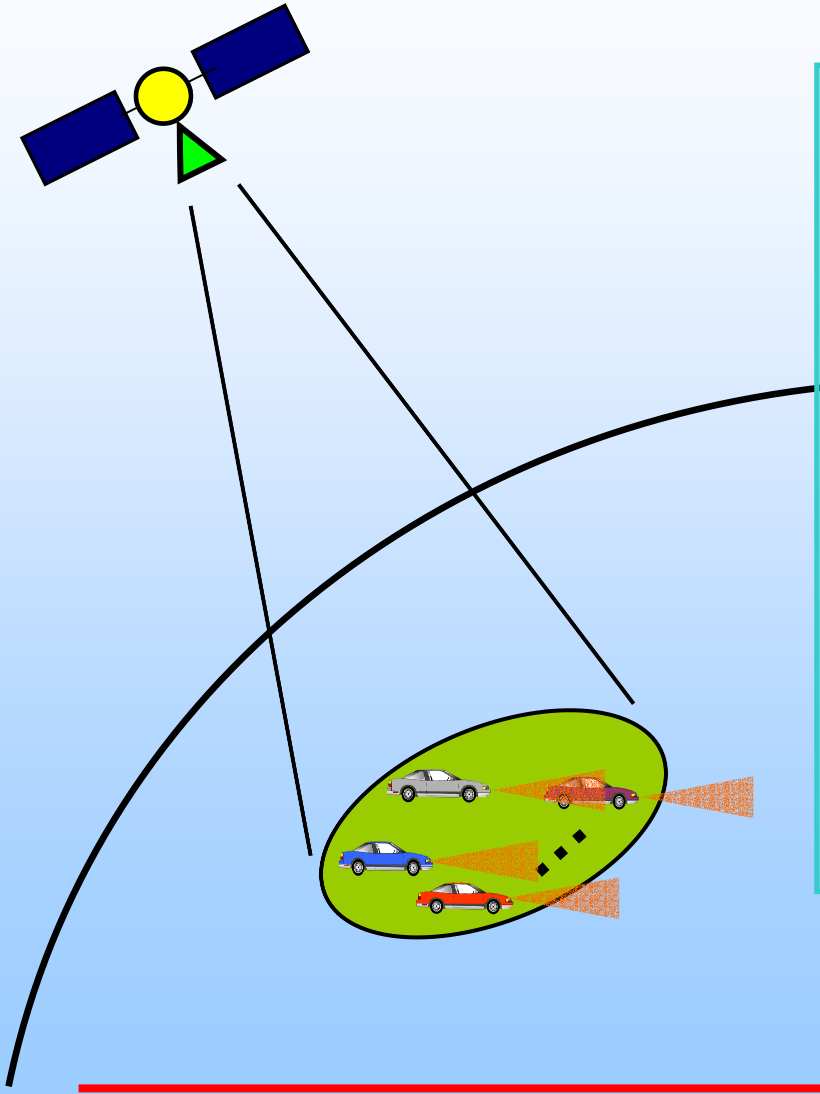


Allowed density of Interferers:

$$\rho < \frac{4\pi\, k\, \delta T\, B}{P_T\, G\, C(\theta_s)\lambda^2} e^{\tau} \cos(\theta_s)$$

ρ = Density of interfering transmitters (km^{-2})
δT = Interference threshold (K)
B = Detection bandwidth (Hz)
λ = Wavelength (m)
P_T = Avg pwr transmitted per interferer (W)
G = Interferer gain WRT isotropic
C = Antenna coupling factor
τ = Opacity to satellite (Nepers)
θ_s = Radiometer view angle (WRT nadir)
k = Boltzmann's constant (1.38E-23 J/K)

Auto Radar Interference within 23.6-24.0 GHz (cont'd)



UWB Automotive Radar Example:

δT = 0.2 K (H_2O_V climatology/coastal sidelobe contribution & surface emissivity)
B = 400 MHz (overlap in EESS primary band)
λ = 1.26 cm (23.8 GHz)
P_T = 20 uW (-43 dBm in 1 MHz BW)
G = 13 dB (~5 x 1 cm microstrip patch)
C = -21 dB (vehicle scattering coupling, c.f.)
τ = 0.23 (~1 dB atmospheric attenuation)
θ_s = 53^o (e.g., NPOESS CMIS)

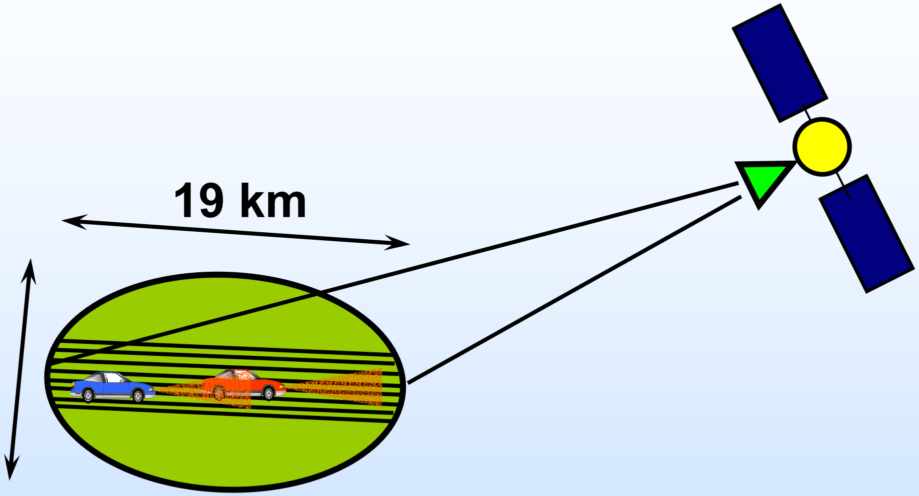
⇨ **$\rho < 20$ km^{-2}**

Or, an average transmitter separation distance of **~220 m** is required for non-interference.

Effective Transmitter Density

- Heavy Traffic Scenario -

$$\rho = \frac{4 n_L n_T M \rho_L}{\pi a}$$



19 km

Spot minor size
a = 11 km
(e.g. NPOESS CMIS)

p_L = 50 km^{-1} Average vehicle spacing of 20 m
n_L = 8 # parallel traffic lanes
n_T = 4 # transmitters per vehicle, F/R each lane only
M = 10% vehicular market penetration
a = 11 km LEO spot width - minor dimension
Satellite view along traffic lanes

⇨ **ρ = 18 (km^{-2}) or ~0.5 dB interference margin**

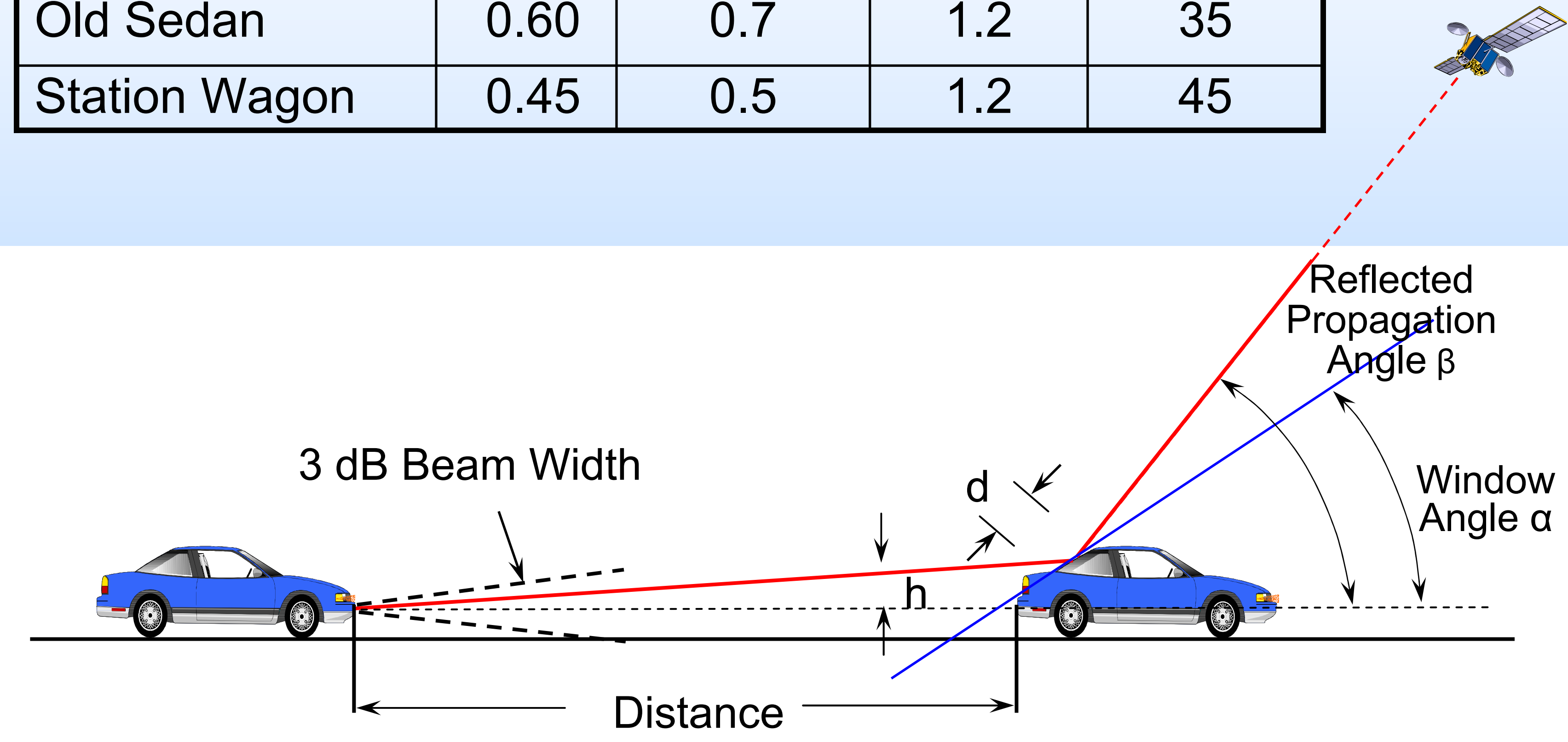
(but not worst-case scenario !)

Estimation of Coupling

- One of the most physically obvious coupling mechanisms is reflection of the main lobe of the radar by another vehicle toward the main lobe of the radiometer
- Since vehicular radars will commonly illuminate another close-in leading vehicle it is suspected that such scattering scenarios will be commonplace.
- In order to estimate the interference from a collection of such vehicular radars to a passive microwave satellite we performed numerical simulations to determine the system coupling coefficient C_{sm}.
- The only reflection taken into account is that from the rear window of the leading vehicle. We considered three typical styles of automobiles having rear window angles of 25°, 35°, and 45°.

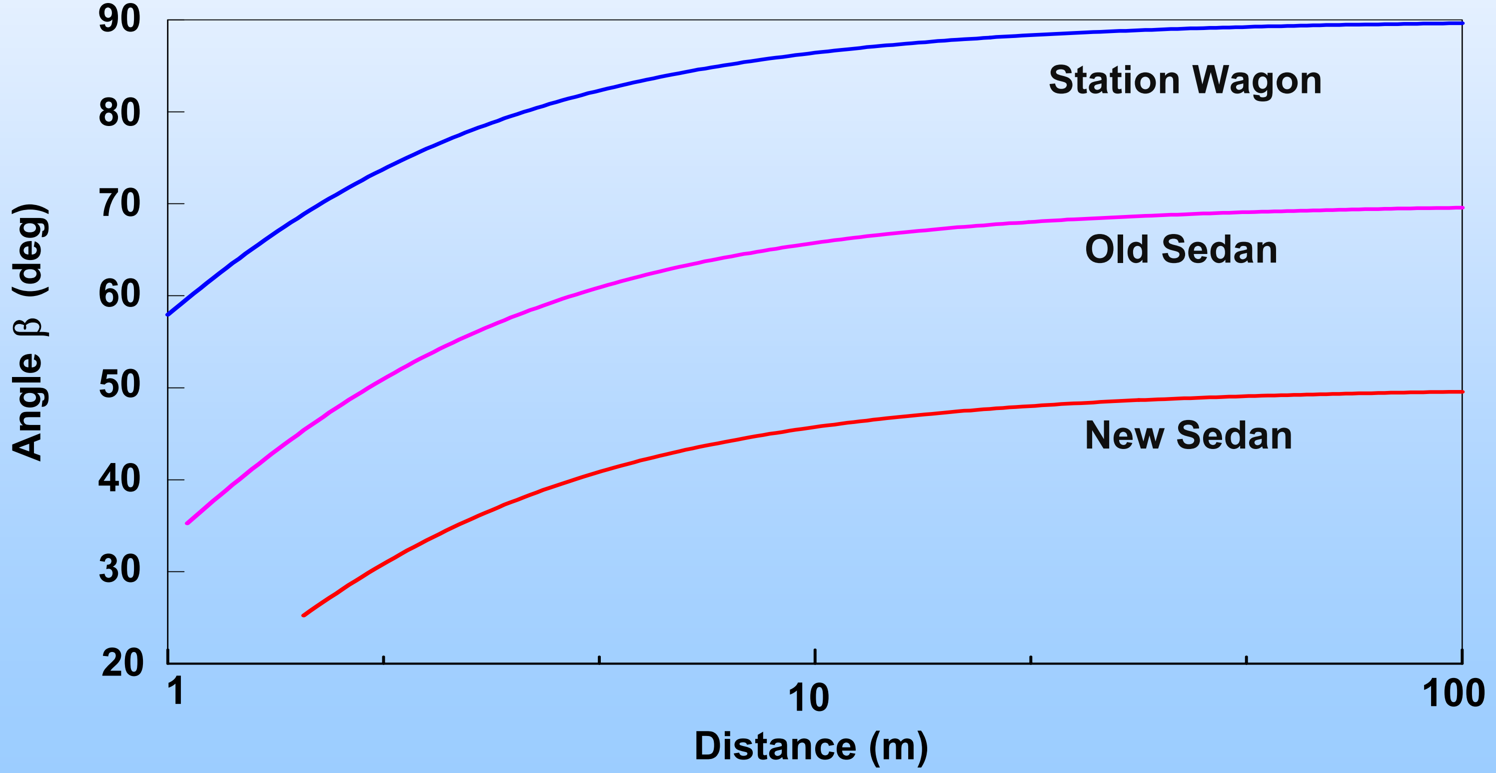
Vehicle Geometry

Vehicle Style	***h*** **(m)**	***d*** **(m)**	***b*** **(m)**	**α (deg)**
New Sedan	0.60	0.7	1.2	25
Old Sedan	0.60	0.7	1.2	35
Station Wagon	0.45	0.5	1.2	45



Reflected Propagation Angular Range

- For different α and *h* the reflected propagation angles β range from 30° to 90°
- This range covers practically all viewing angles for passive earth remote sensing from space



Coupling Model

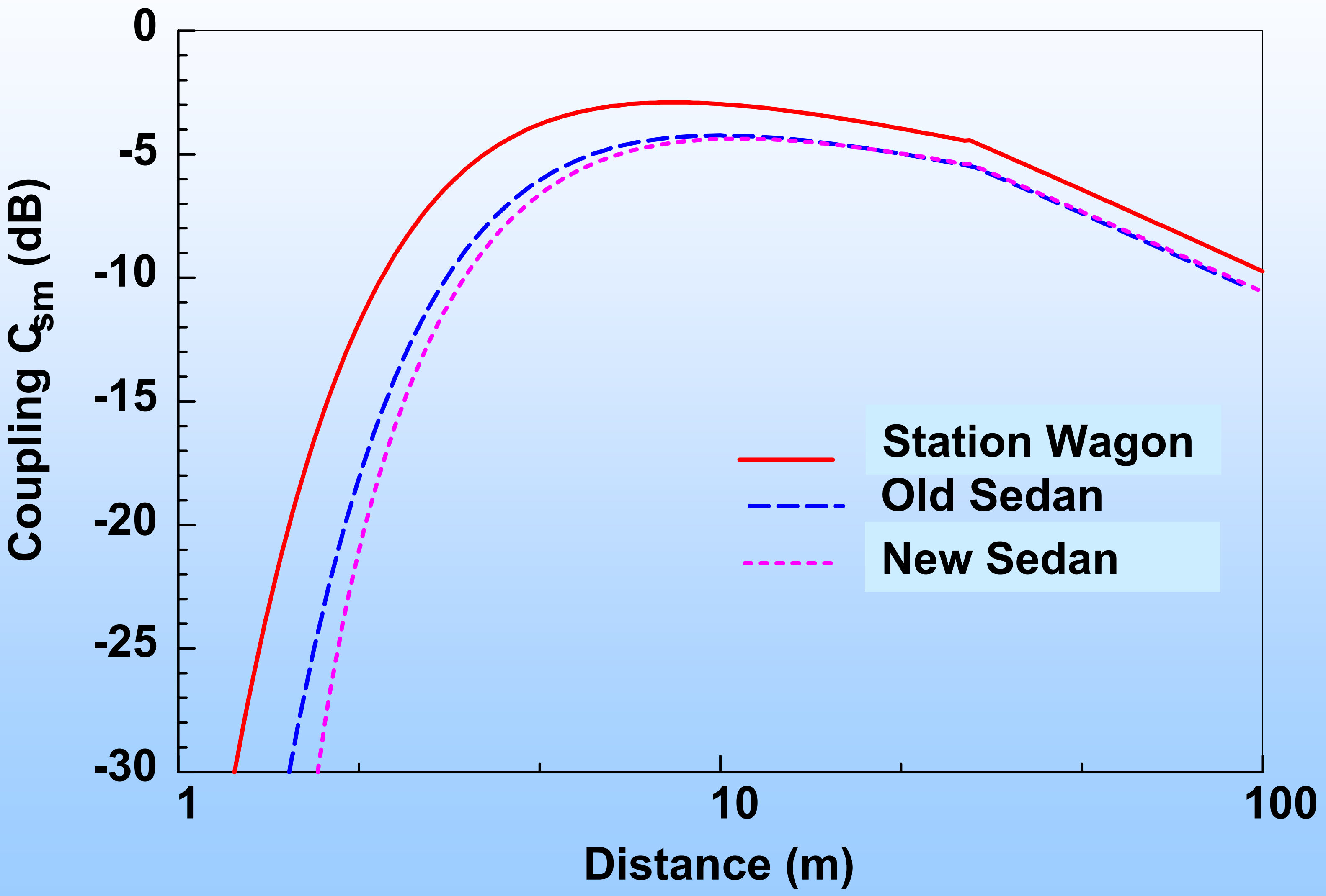
- Geometric optics is used in this model because the electrical sizes *d* of auto windows are large
- The distance *D* is much smaller than the distance to the radiometer antenna

=> The coupling coefficient can be expressed as:

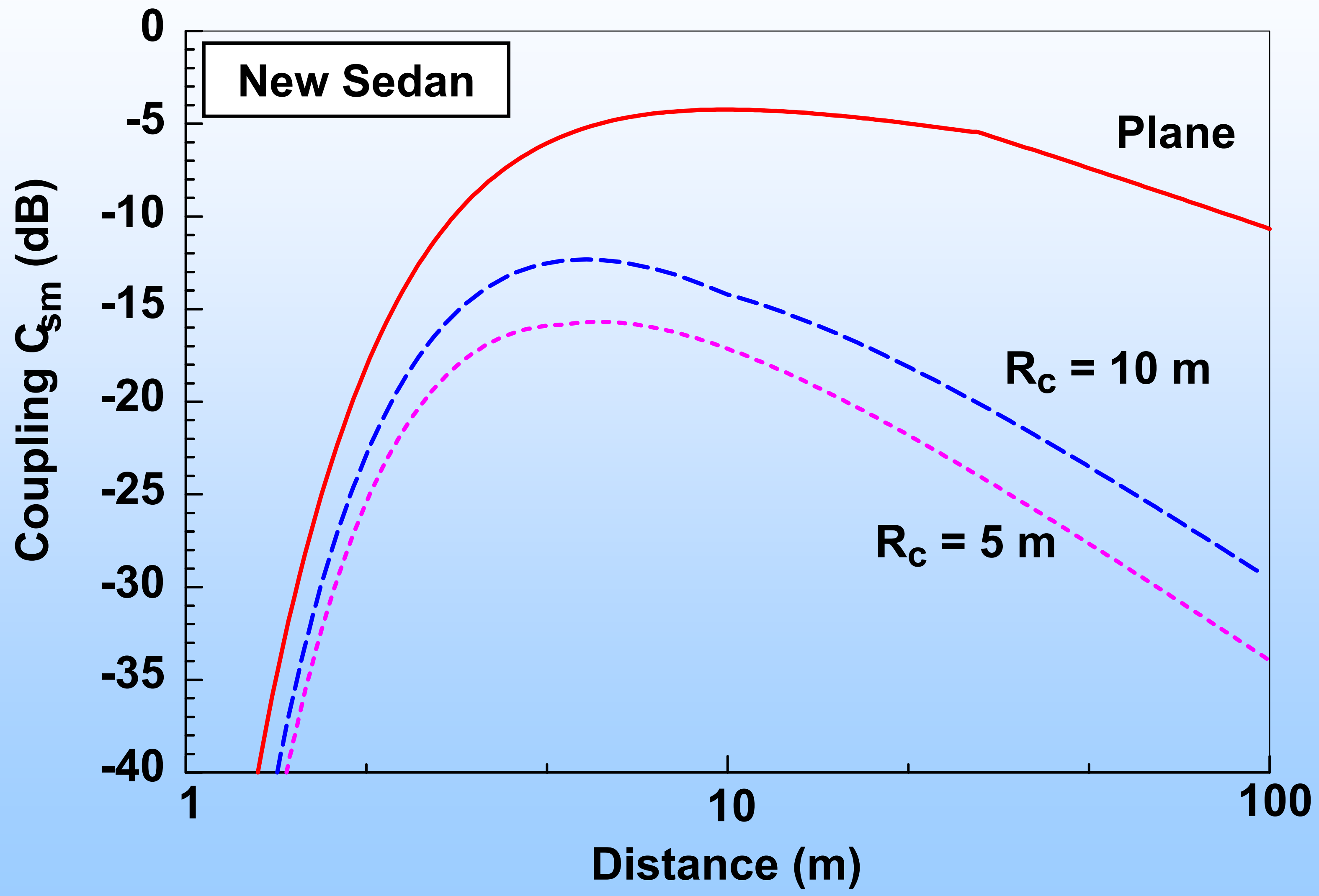
$$C_{sm}(D) = |R|^2 \cdot F \cdot S \cdot W$$

where: C_{sm} = Coupling WRT to main-main alignment
D = Vehicle separation distance
$|R|^2$ = Fresnel reflectivity of window
F = Normalized radar antenna gain function
S = Intercepted power factor
W = Divergence factor to for window curvature

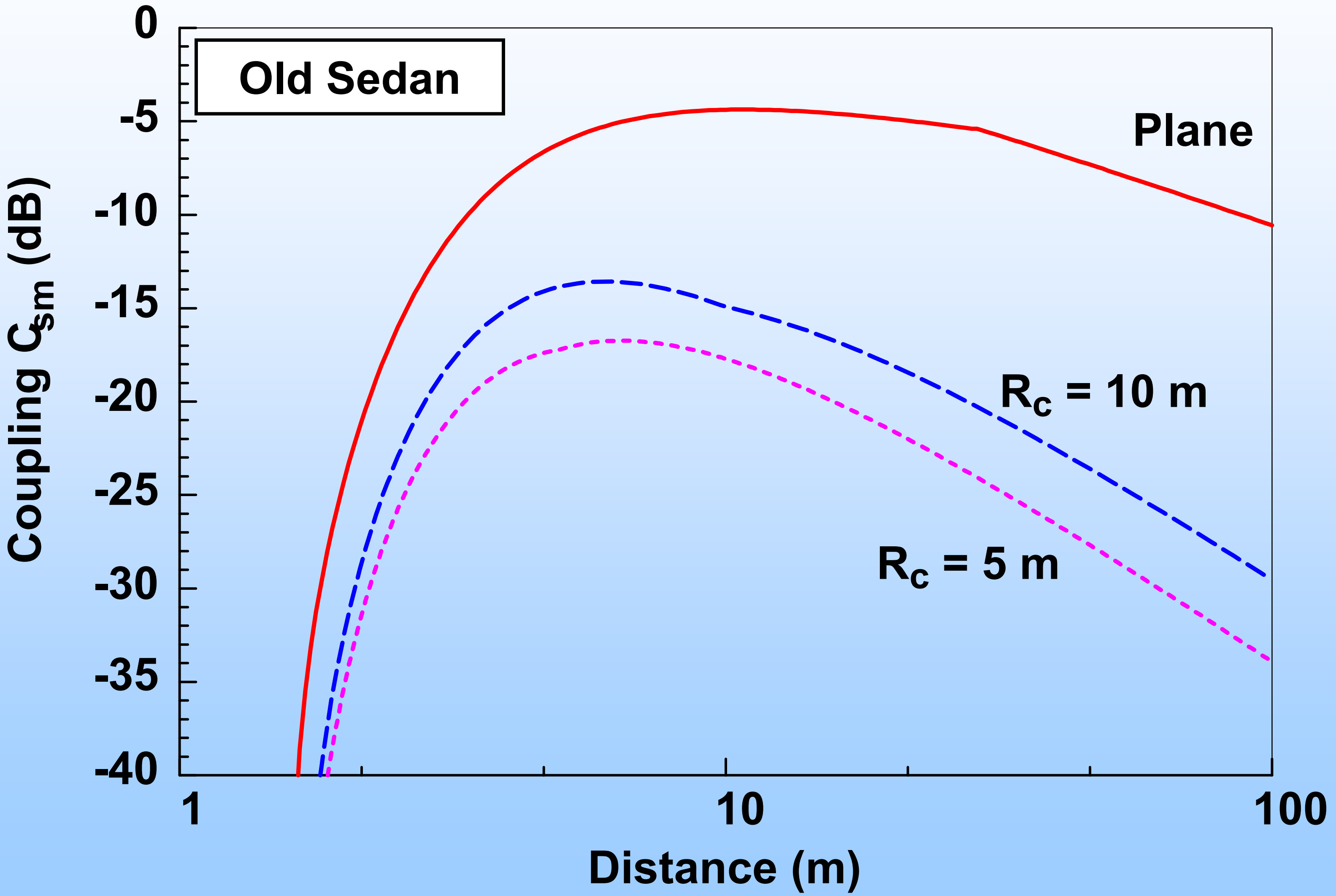
Coupling Effects of a Flat Window: Perfect Electrical Conductor



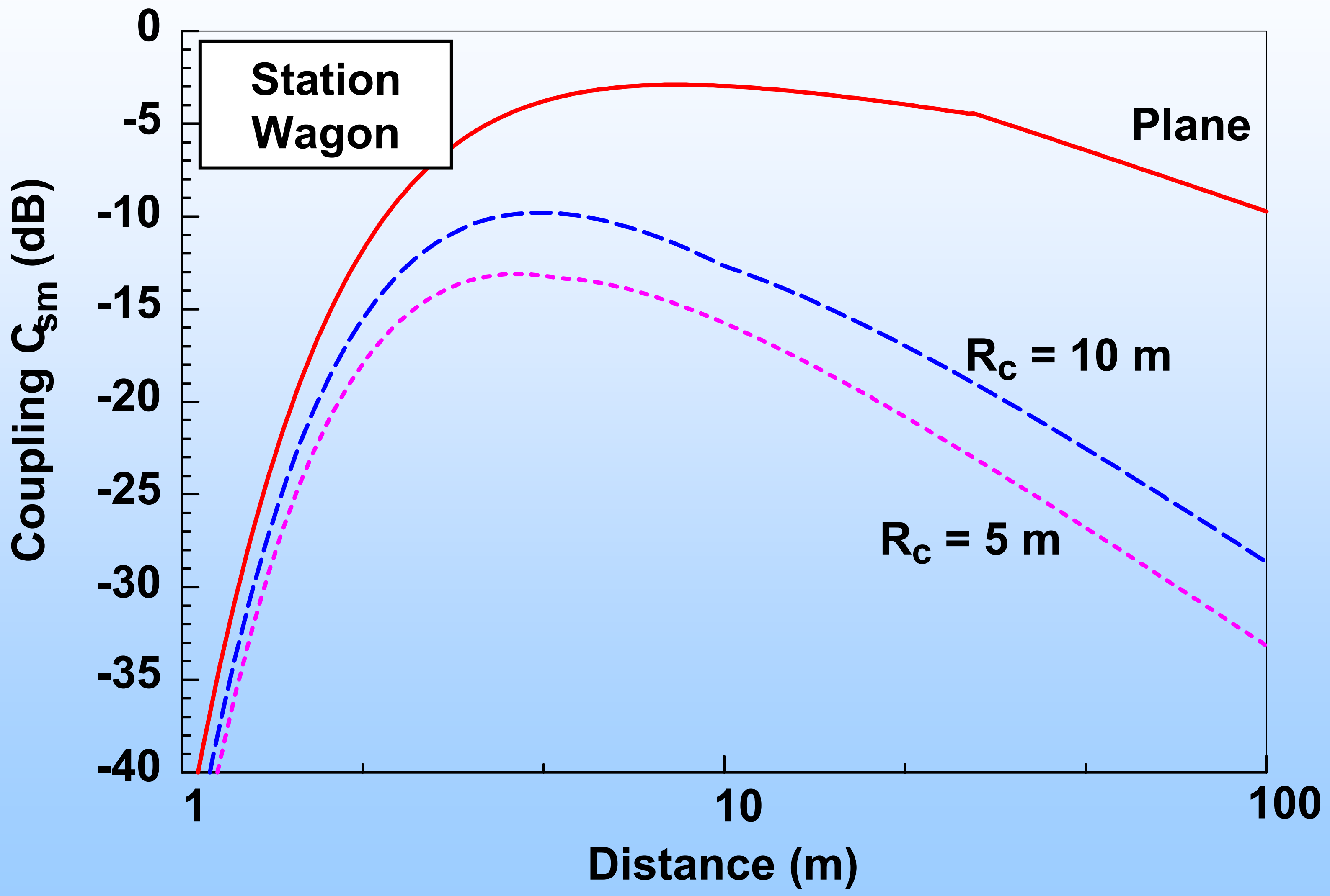
Coupling Effects of Window Curvature: PEC



Coupling Effects of Window Curvature: PEC (cont'd)



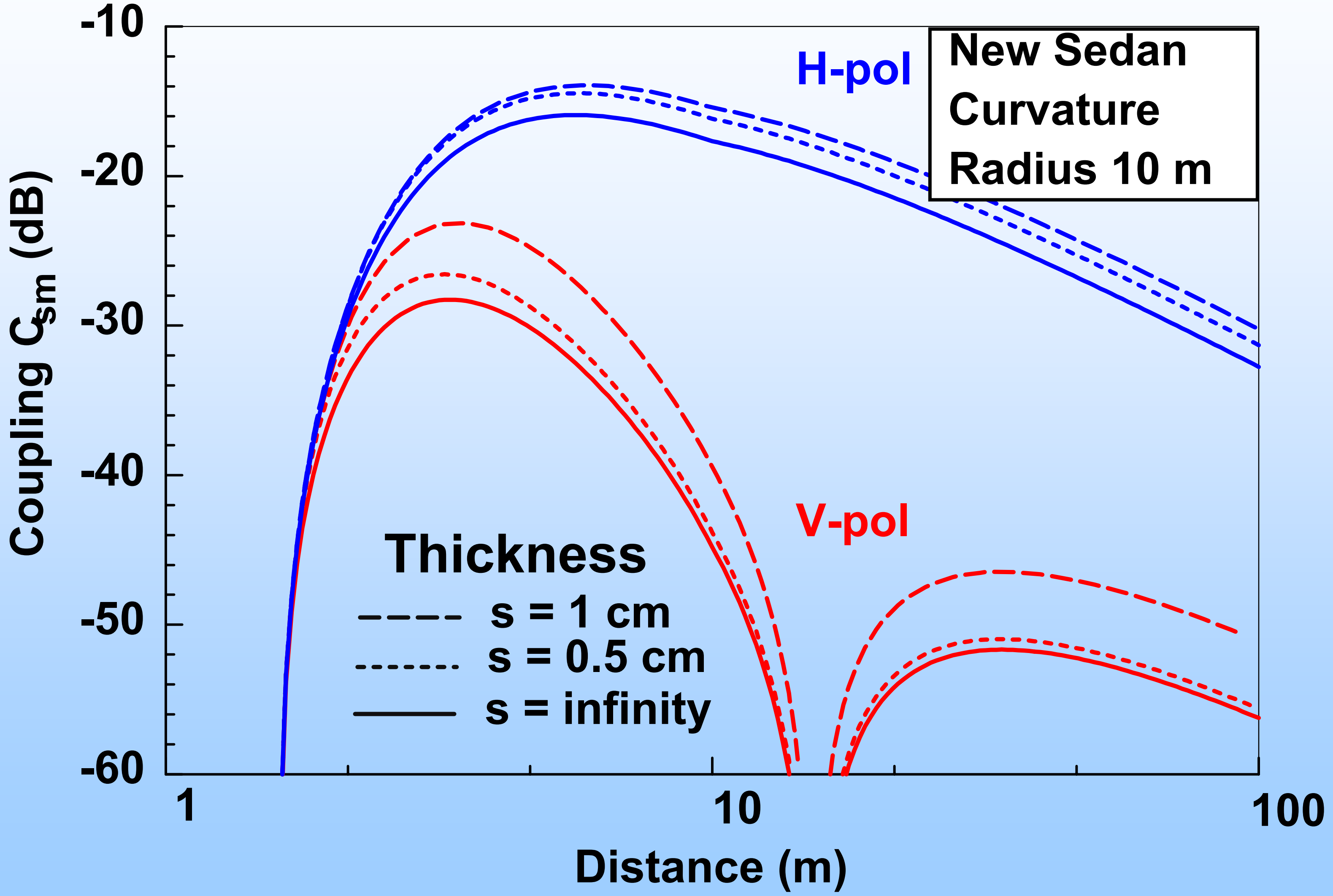
Coupling Effects of Window Curvature: PEC (cont'd)



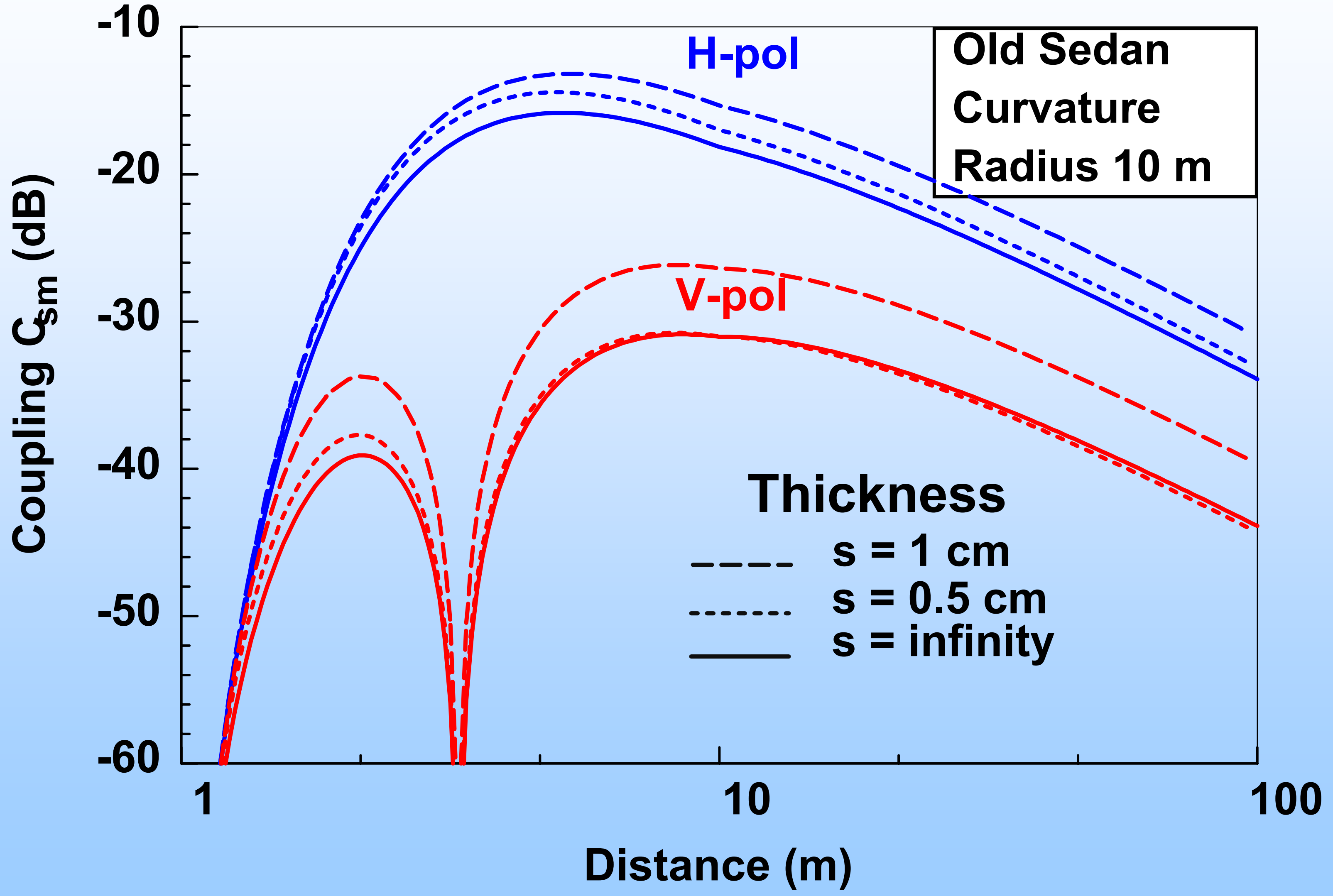
Coupling Effects of Window Curvature: PEC Summary

- Differences in C_{sm} as a function of distance between cars for the three styles are small but result in significant differences in the angles of the reflected rays.
- For flat windows the coupling reaches a maximum of -5 dB at separation distances between ~5 and ~10 m.
- Accounting for the surface curvature leads to a reduction in peak coupling of ~10-15 dB, with much faster decrease at larger separation distances.

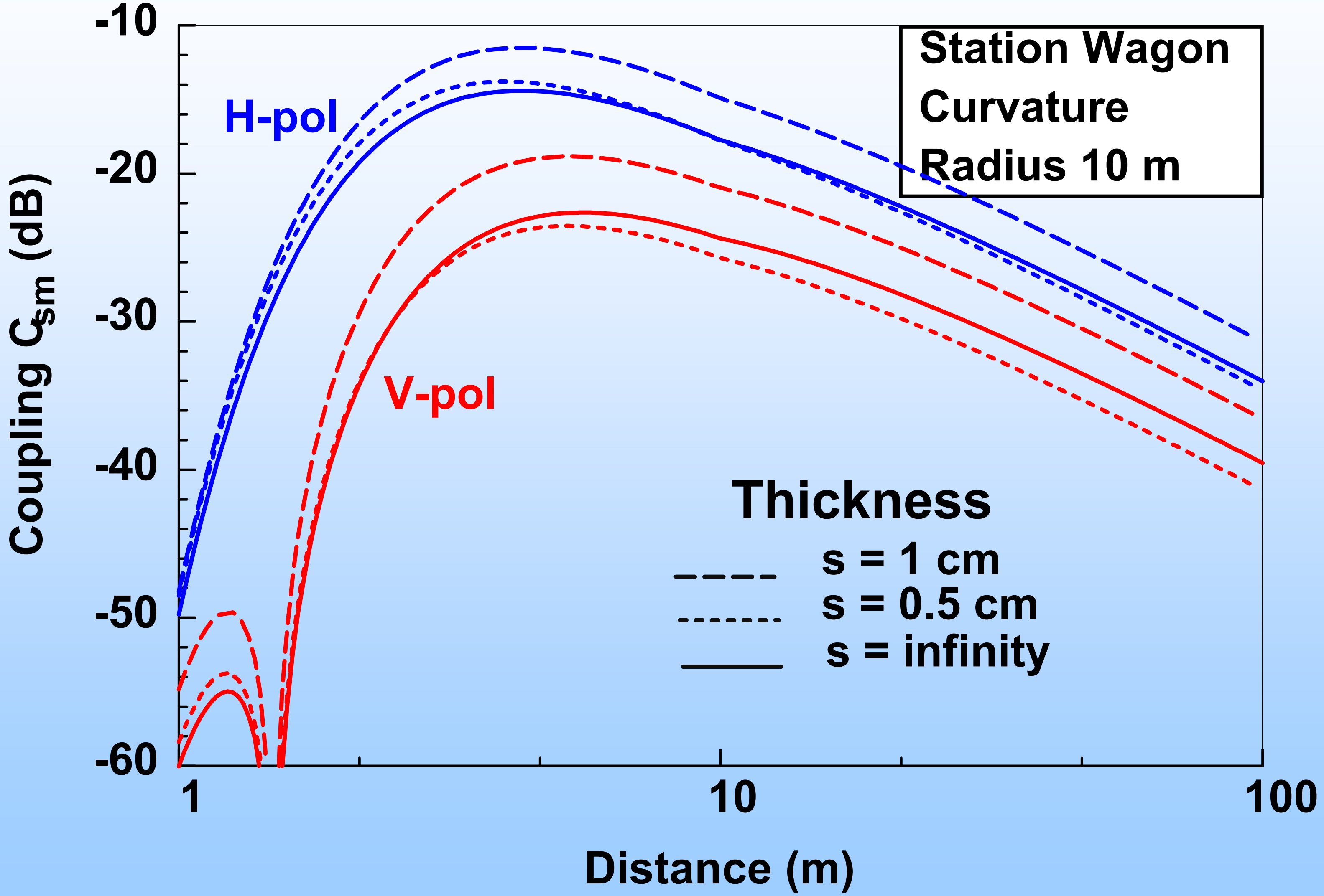
Coupling Effects of Window Glass Thickness



Coupling Effects of Window Glass Thickness



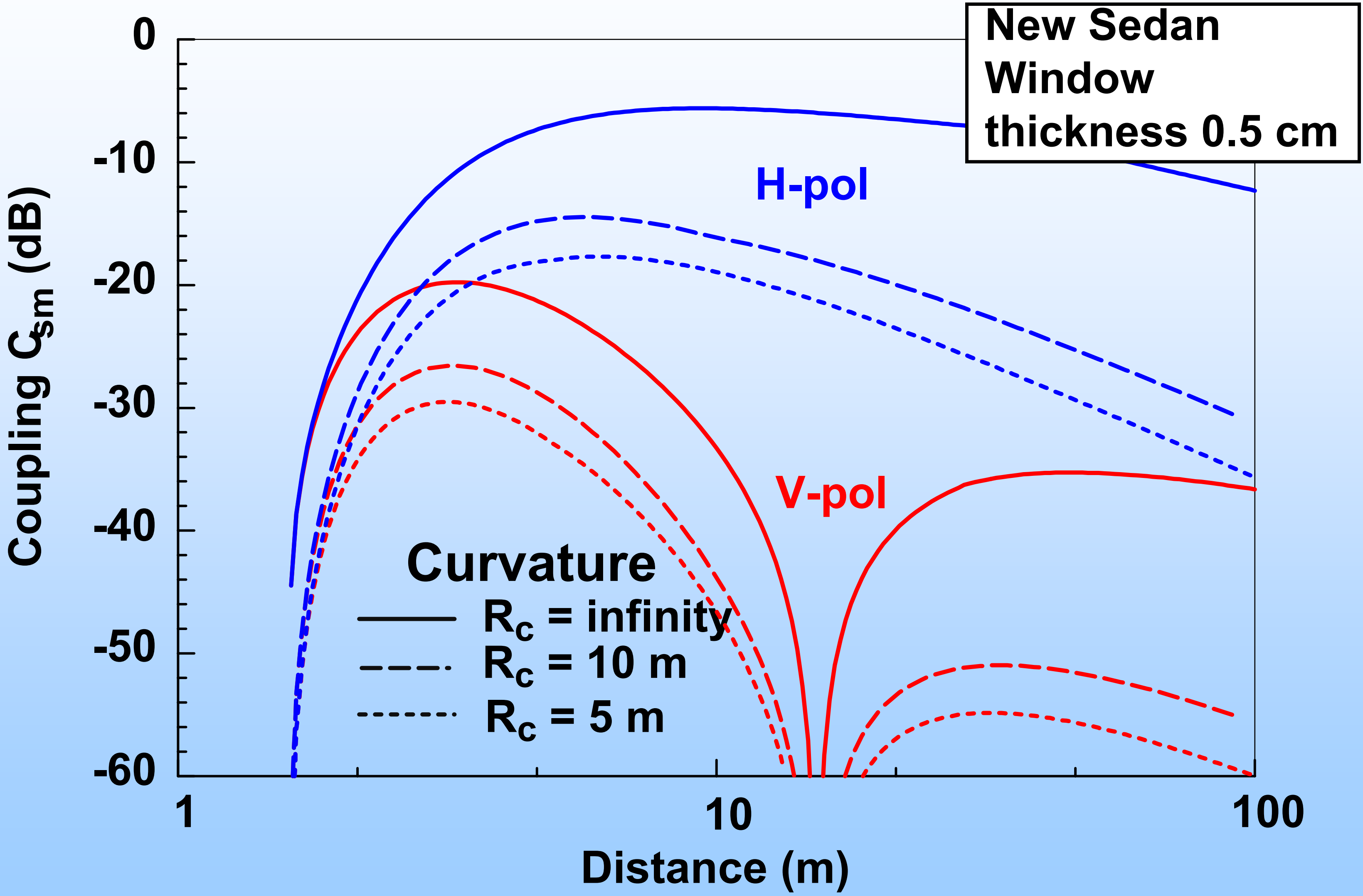
Coupling Effects of Window Glass Thickness



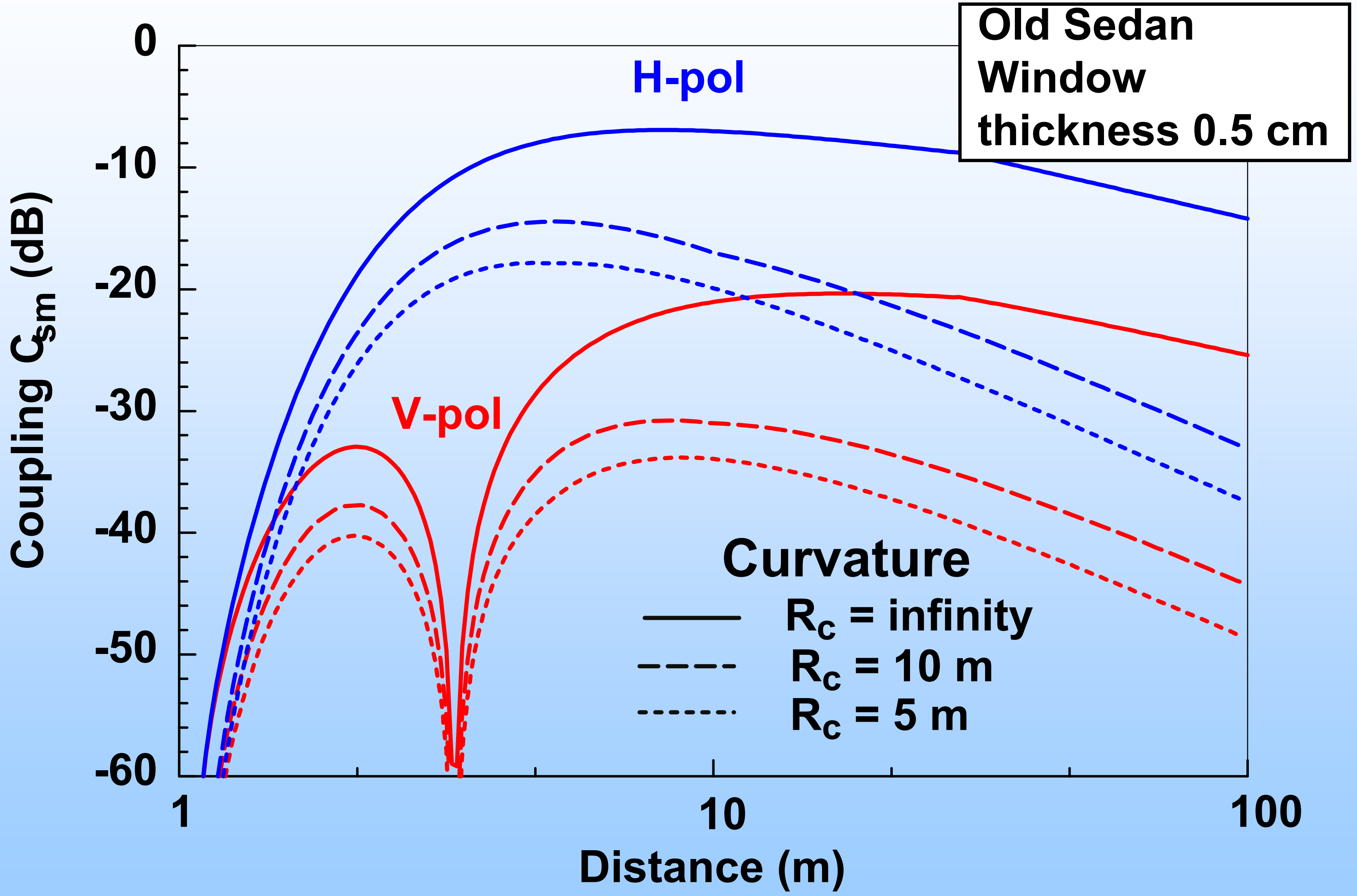
Coupling Effects of Window Glass Thickness: Summary

- Curves for V-polarization are significantly lower then for H-polarization and show typical notches at quasi-Brewster angles.
- The H-polarization coupling reaches a maximum of approximately -15 dB at about 5-m distance for all three types of vehicles.
- Accounting for the finite thickness of glass yields ~2-3 dB more coupling than by disregarding it. Multiple reflections from two air-glass interfaces increase typical overall reflection.

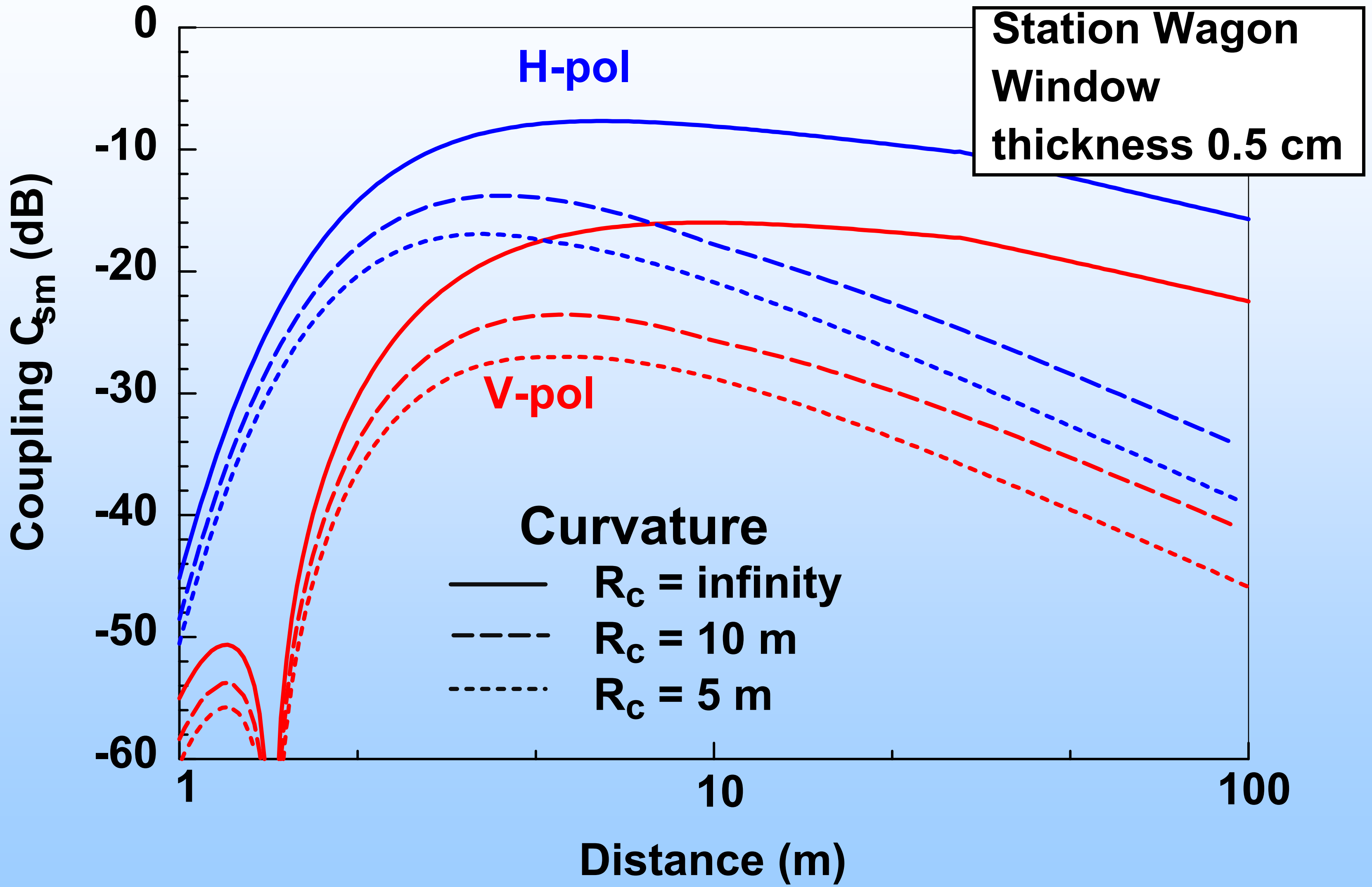
Coupling Effects of Glass Window with Curvature


New Sedan Window thickness 0.5 cm

Coupling Effects of Glass Window with Curvature (cont'd)



Coupling Effects of Glass Window with Curvature (cont'd)



Coupling Effects of Glass Window with Curvature: Summary

- The analysis show how different window curvatures can affect coupling estimates for various styles of vehicles.
- In general, increasing curvature lowers V-polarization coupling and increases H-polarization coupling.
- The largest coupling occurs for the station wagon.
- For realistic curvature radii of ~5-10 m the peak coupling at the H-polarization reaches a level of -15 dB to -18 dB.
- For V-polarization the coupling peak is lower, at -25 dB to -28 dB.

Summary

- Significant interference (~0.2 K over land, 0.1 K over water) from vehicle collision avoidance radars to passive microwave satellites can be expected in the EESS primary allocated band from 23.6-24.0 GHz, with an amount dependent on traffic density and radar market penetration.
- The cases considered show a significant level of coupling between vehicular radars and space-borne radiometers: $\langle C_{sm}(D = 3\text{-}8\ \text{m})\rangle \sim -5$ to -20 dB for H-polarization and ~ -15 to -35 dB for V-pol.
- The study considered only scattering by one element of a leading vehicle, the rear window.
- Additional scattering can be expected by other metal parts of the leading vehicle and by other objects such as trees, railings, roadway barriers, and tilted roofs of buildings.