Memorandum

DATE: January 9, 1996

TO: Ralf Marbach, Don Janeczko and Mike Pitsakis

FROM: Kathleen Meehan

RE: Surface Reflectivity of Skin

I obtained several skin scans taken under different conditions using the FTIR assessory in August. The range of voltages of these scans was very different depending on the treatment to the skin immediately prior to the scan. For example, damp skin is more reflective than dry skin voltage at wavelengths less than 1.8um with the exception around the water peak of 1.4um (Figure 1). Lu Huang has indicated that at the longer wavelengths, the skin voltage readings are dominated more by the scattered light than by the reflected light. At shorter wavelengths, reflected light is more dominant.

I have modeled the FTIR assessory to calculate the reflected light from the skin as a function of the index of refraction of skin. I have also calculated the impact on the skin reflection of a thin layer placed between the skin and the antireflective coated lens. The thin layer was assumed to be of uniform thickness and index of refraction composed of either air or water. The indexes of refraction of all materials in the model were assumed to be constant over all wavelengths and equal for s and p polarized light. The initial intensity of light in the system was assumed to be equal at all wavelengths and angles. Absorption of light was ignored. The reflectivity was calculated at the interface of the skin with respect to the light launched within the lens.

Light is launched in glass (n_f = 1.555). An antireflective coating of MgF used (n_f = 1.38), matched at 1.5um. The index of refraction of skin was assumed to be either 1.52 or 1.42. The former would be expected after exposure to a relatively low humidity environment (dry winter day) and the latter would be expected after exposure to a high humidity environment (a humid summer day or after a shower). A 0.1um layer of air (n_f = 1.00) or water (n_f = 1.332) is placed between the skin and the MgF layer.

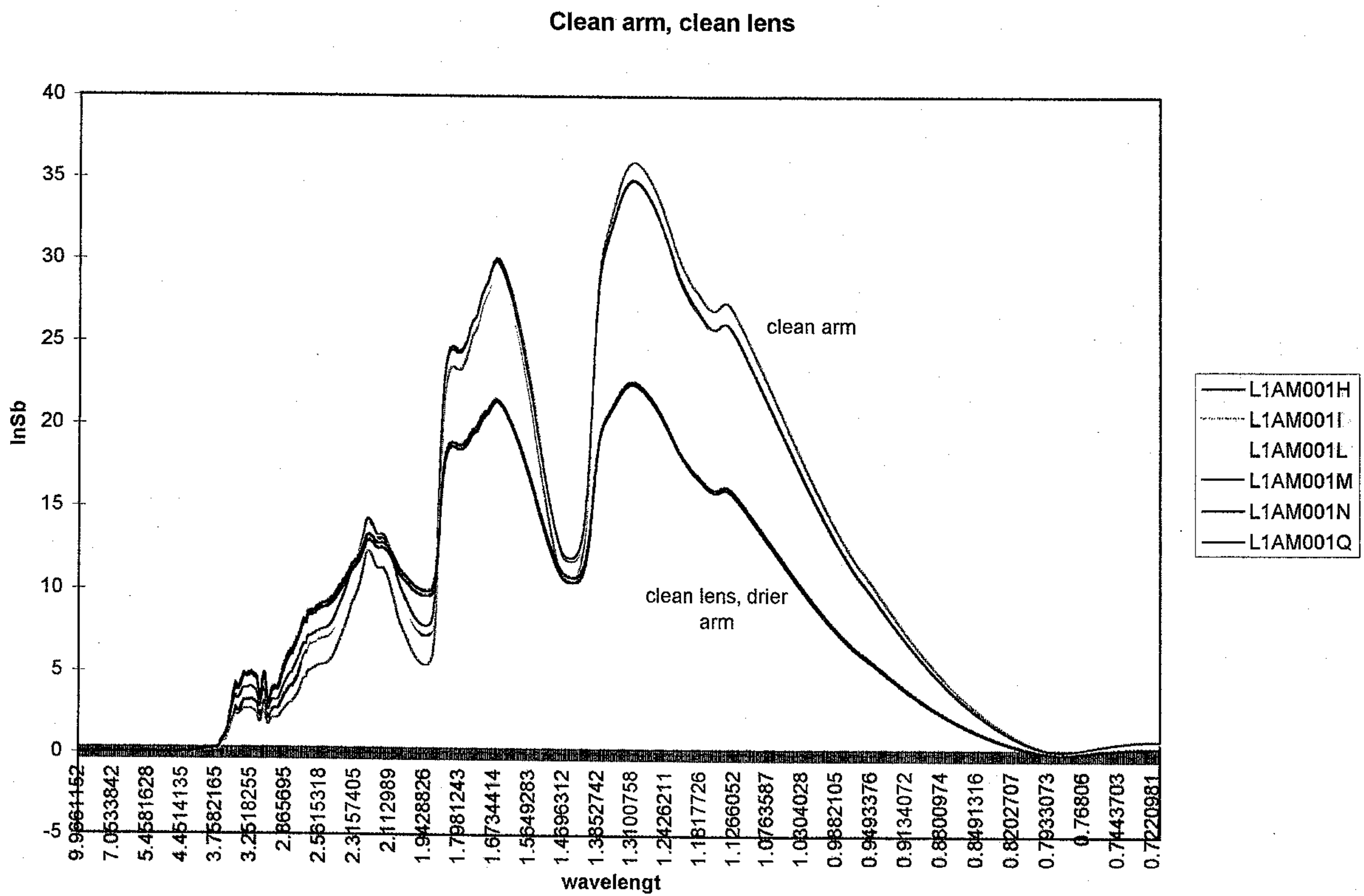
Figures 2 and 3 are the reflectivity curves for skin using an index of refraction of 1.42 and 1.52, respectively. The critical angle of 62.6° is determined by the antireflective coating (Figures 2a and 3a). As can be noted, the reflectivity of skin at an index of refraction of 1.42 differs at all wavelengths and angles of incidences as compared to that of 1.52. To highlight this, reflectivities at 30° incident angles are plotted in Figures 2b (n_f = 1.42) and 3b (n_f = 1.52) instead of 0° as directly reflected light will not be transmitted due to the input mirror imbedded in the optical path. At this angle, the reflectivity for an n_f = 1.42 is approximately half of that for an n_f = 1.52 over all wavelengths. Removal of the antireflective coating between the skin and the lens may be beneficial. The reflectivity would still vary with the refractive index of the skin. However, the critical angle for total internal reflection will be much more variable as it would then be dependent on the refractive index of the skin.

In Figures 4 and 5, comparisons between the skin reflectivities of a lens-coating-skin (n_f = 1.52) and of a lens-coating-intermediate layer-skin (n_f = 1.52) over launched angle and wavelength. In Figure 4a and b, the reflectivity is calculated when a thin layer of water is between the skin (n_f = 1.52) and the antireflective coated lens. As the index of refraction of water is approximately equal to that of the MgF, the critical angle for total internal reflection (58.9°) is similar to that of Figure 3a. In Figure 5a and b, the reflectivity is calculated when a thin layer of air is between the skin (nf = 1.52) and the antireflective coated lens. The critical angle is 40.0°. As can be noted, there are substantial changes in both the reflectivity of light at any one angle and wavelength depending on the composition of the layer between the skin and the lens.

The overall issue is that the reflected light collected is affected by any changes in the index of refraction of skin as well as by any intermediate layer. The transmission of the light into the skin is not greatly perturbed except at angles close to the critical angle for total internal reflection. This is because the reflectivity of the skin is relatively small and no absorption is assumed. As the signal detected is approximately composed of equal components of the reflected light and the scattered light, the variations in the refractive index of skin as well as potential intermediate layers (sweat, air pockets, etc.) will have a significant impact. I believe that this effect explains the changes in the skin voltage between the damp and dry skin seen in Figure 1. Extreme care should be taken in the optical design to reduce these variations in the reflected light or eliminate the contribution the reflected light makes to the detected signal.

Several improvements to this model can be made. The reflection at each interface should be summed. Multiple reflections may be taken into account. A graded index of refraction should be used for the skin. The air or water thickness actually varies across the contact area. The index of refraction of water is not that of pure water due to incorporation of oils, dirt, ions, etc. and may vary throughout the water film. A more thorough model incorporation the transmission of the light from the skin back through the optical system is recommended. Lastly, an evaluation of the desirability of an antireflective coating on the lens in contact with the skin should be made. This model should be seen as a cautionary note for the Delta-1 system which collects a substantial amount of the reflected light off of the skin.

Figure 1


Clean arm, clean lens
InSb
40
35
30
25
20
15
10
5
0
-5
wavelengt
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5.4581628
4.4514135
3.7582165
3.2518255
2.865695
2.5615318
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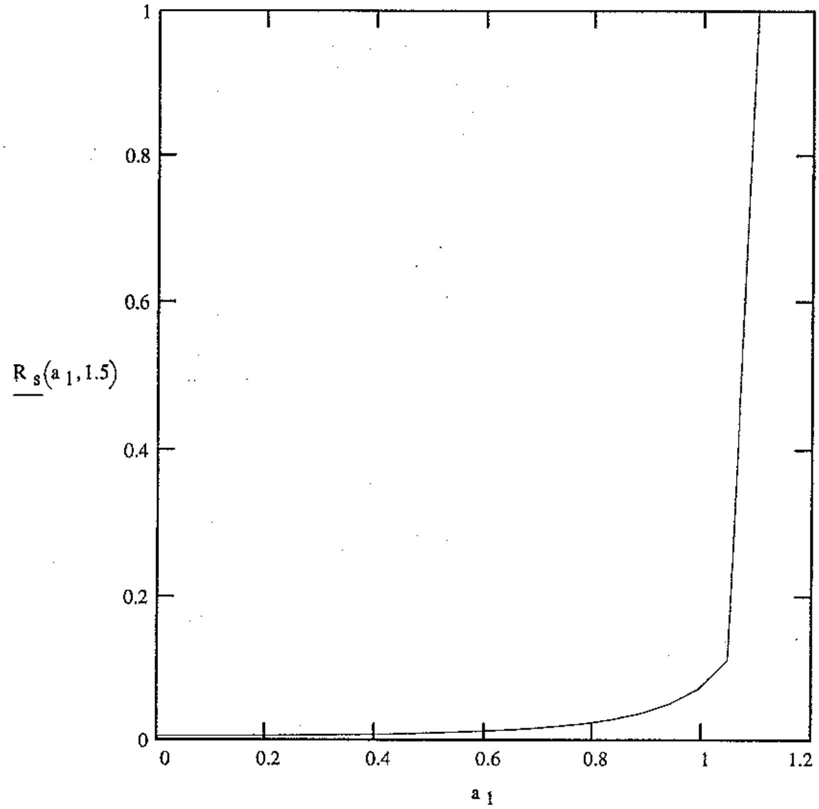
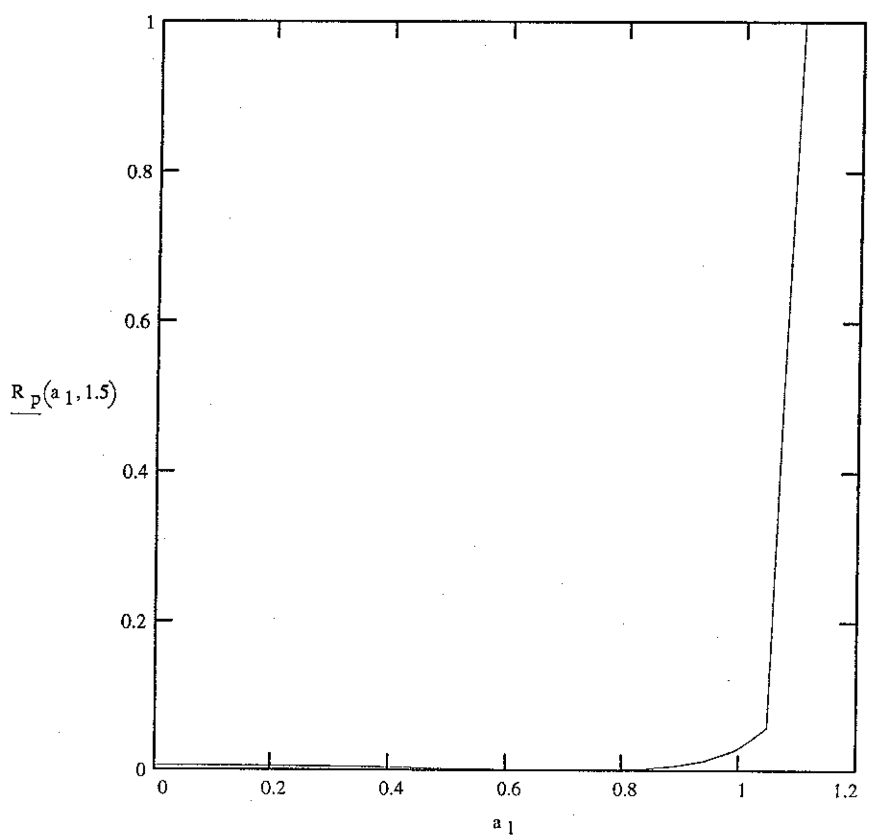
1.0304028
0.9882105
0.9493376
0.9134072
0.8800974
0.8491316
0.8202707
0.7933073
0.76806
0.7443703
0.7220981
clean arm
clean lens, drier arm
L1AM001H
L1AM001I
L1AM001L
L1AM001M
L1AM001N
L1AM001Q

Figure 2 a



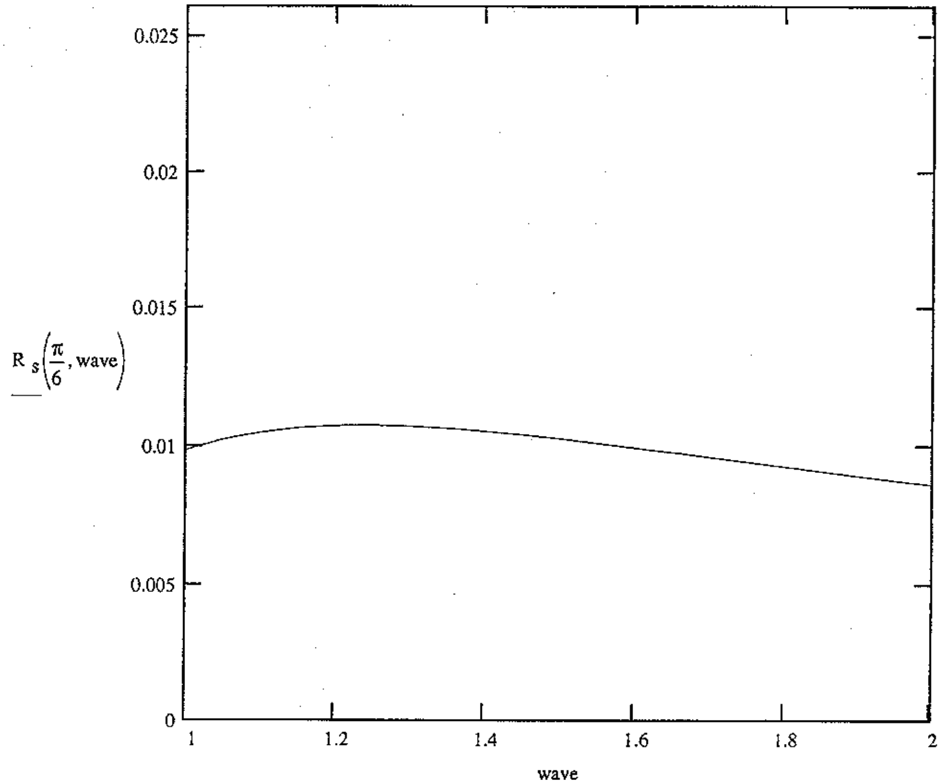


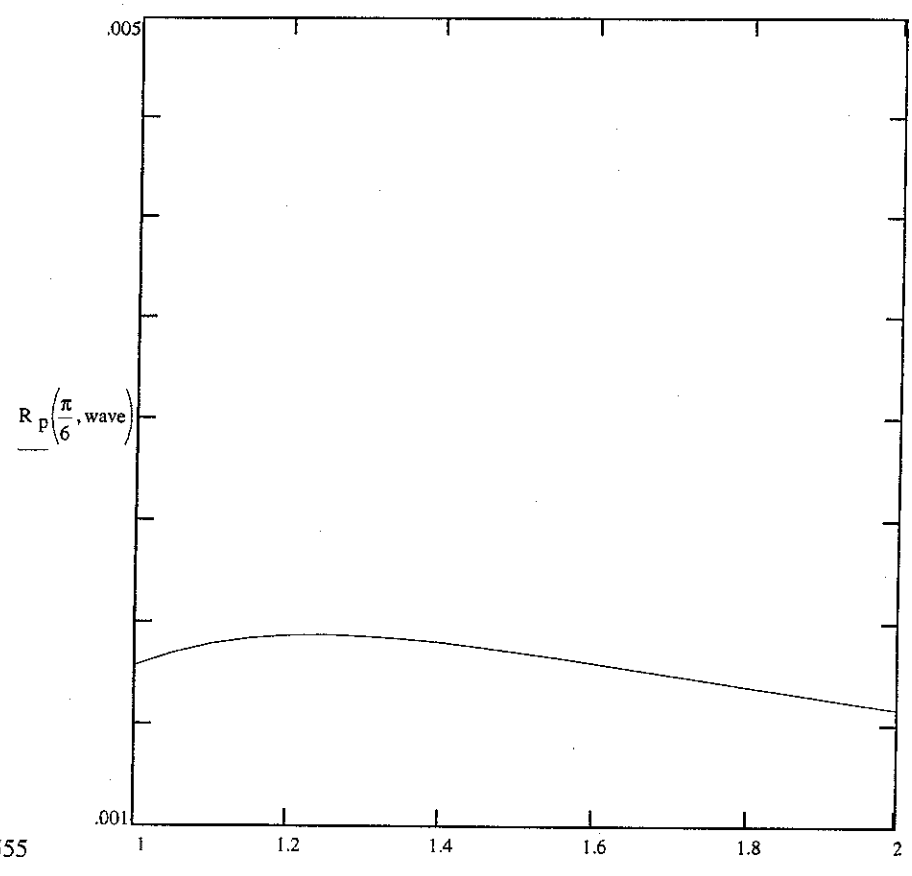
$n_1 = 1.555$

$n_2 = 1.38$

$n_3 = 1.42$

Figure 2b



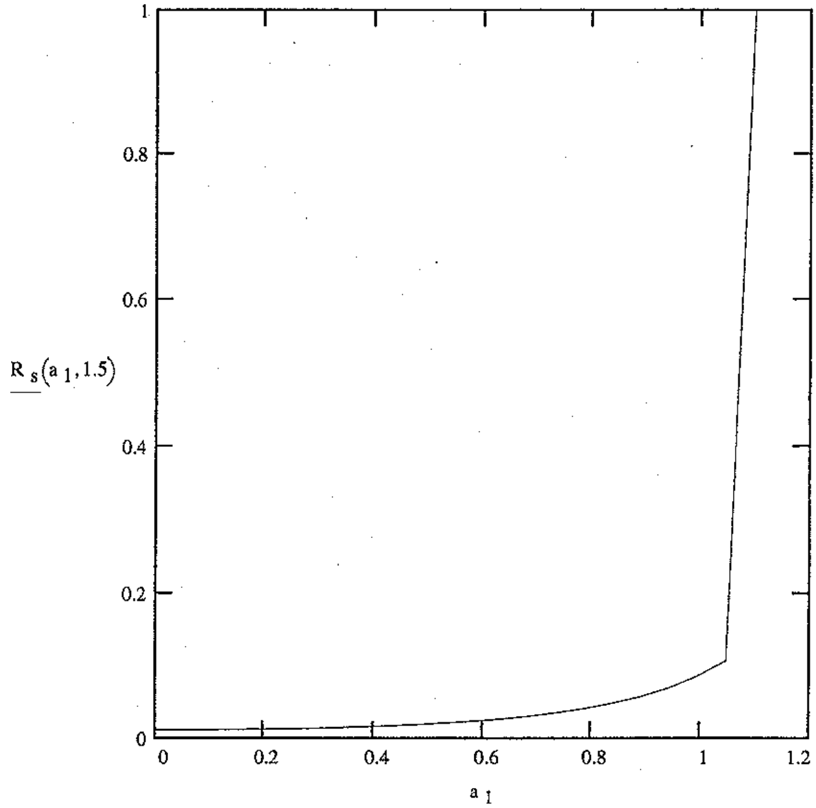


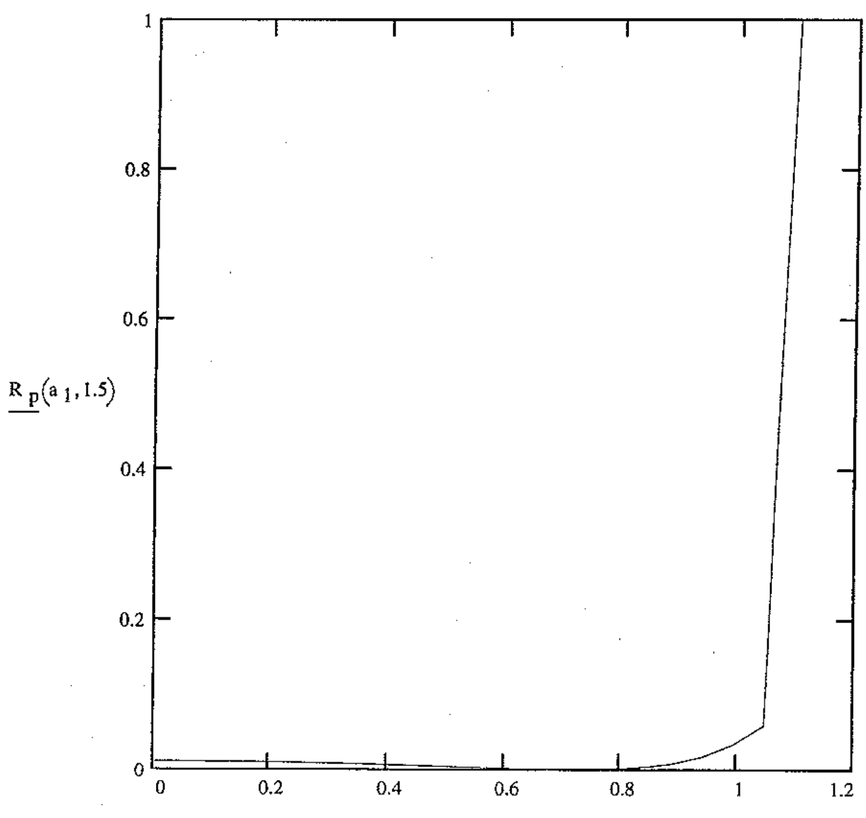
$n_1 = 1.555$

$n_2 = 1.38$

$n_3 = 1.42$

Figure 2a



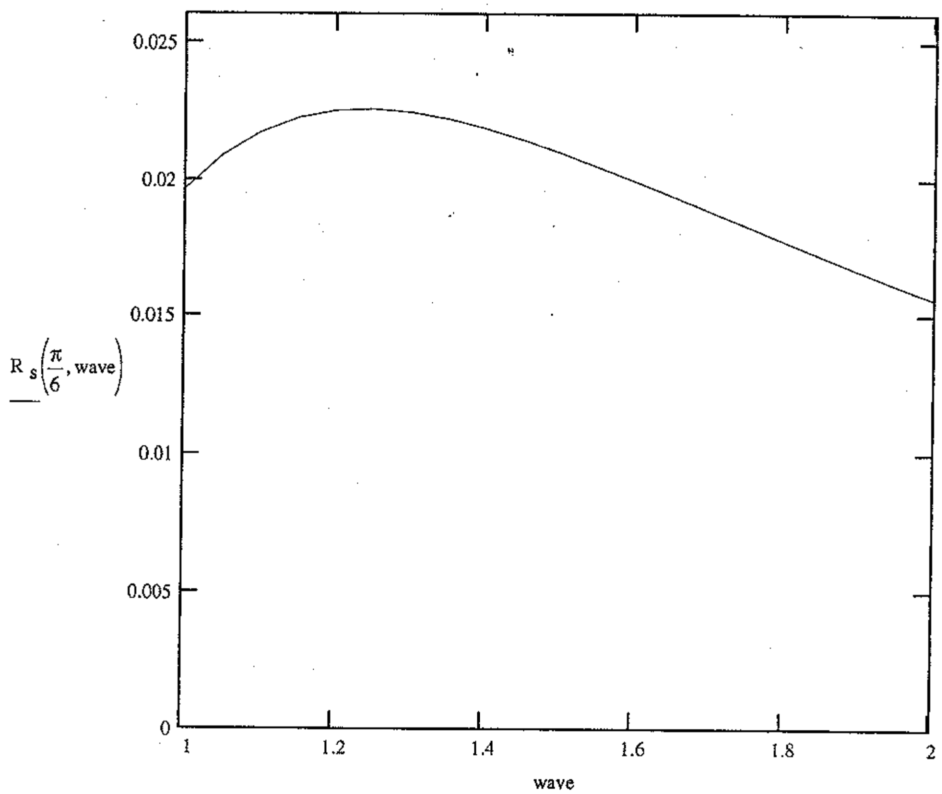


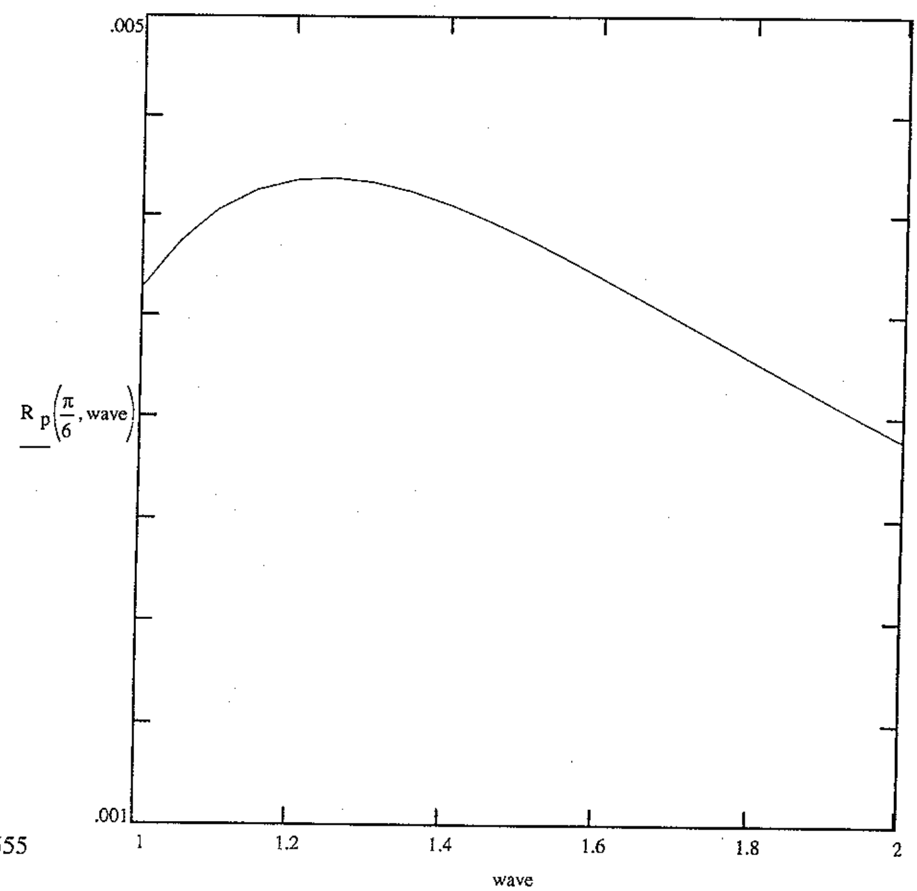
$n_1 = 1.555$

$n_2 = 1.38$

$n_3 = 1.52$

Figure 5B



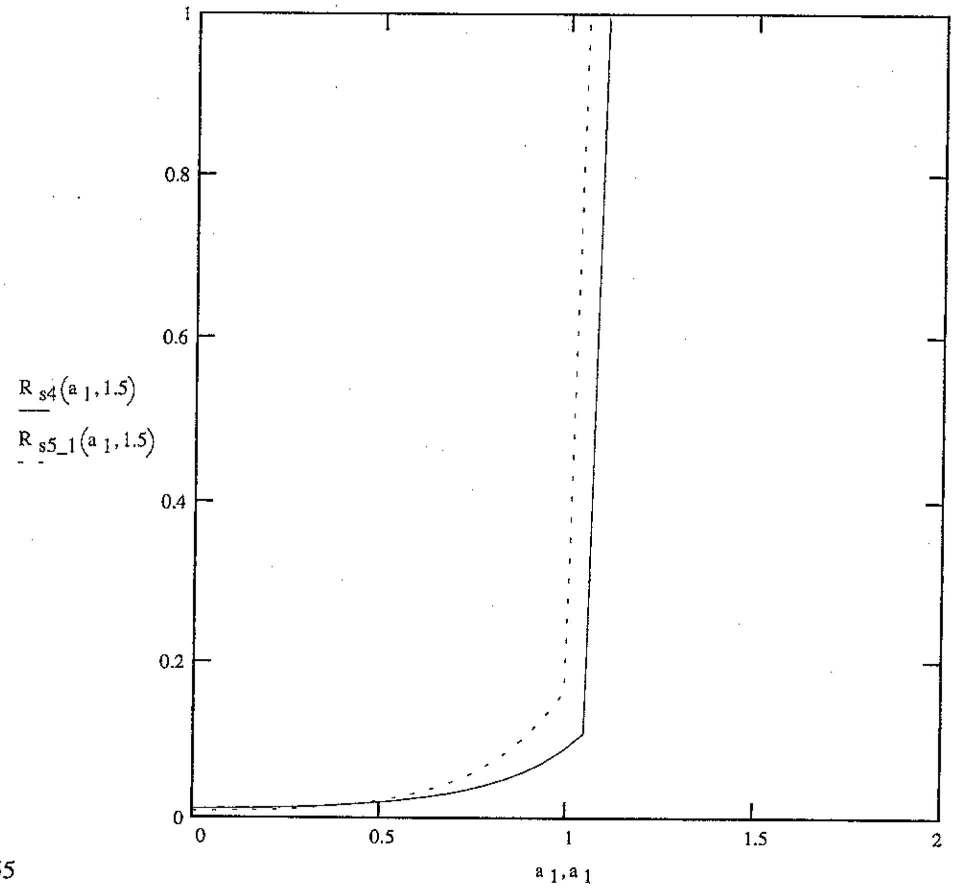


$n_1 = 1.555$

$n_2 = 1.38$

$n_3 = 1.52$

Figure 4a



$n_1 = 1.555$

$n_2 = 1.38$

$n_4 = 1.52$

$n_{4\_1} = 1.332$

$n_{5\_1} = 1.52$

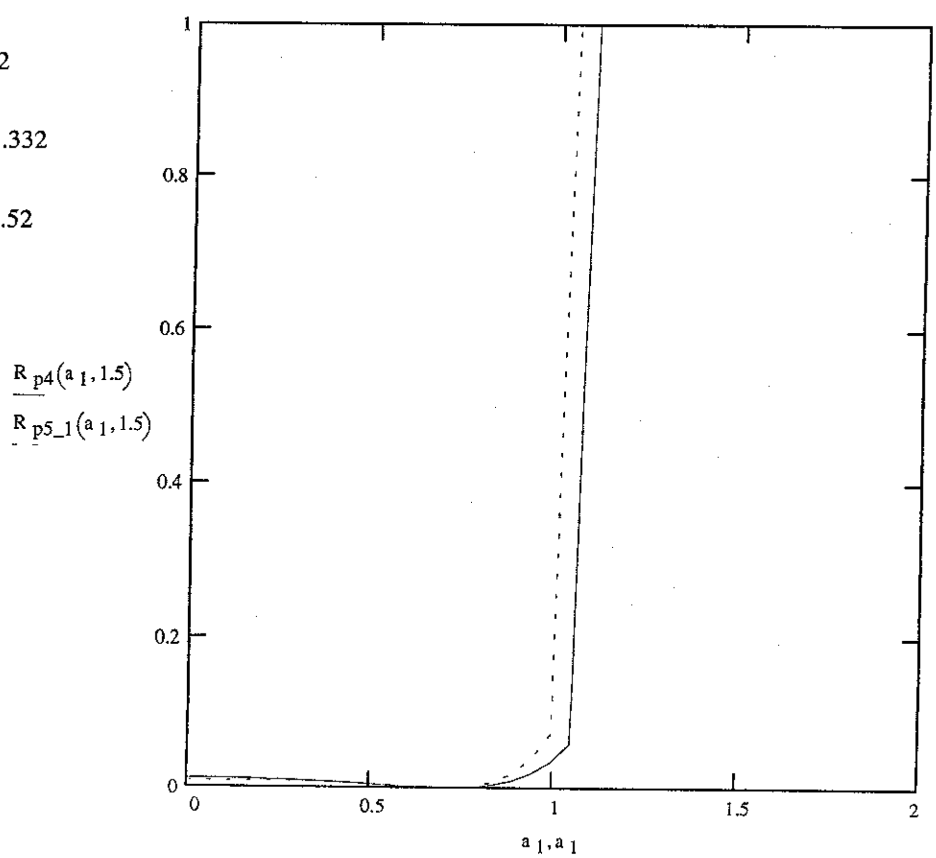
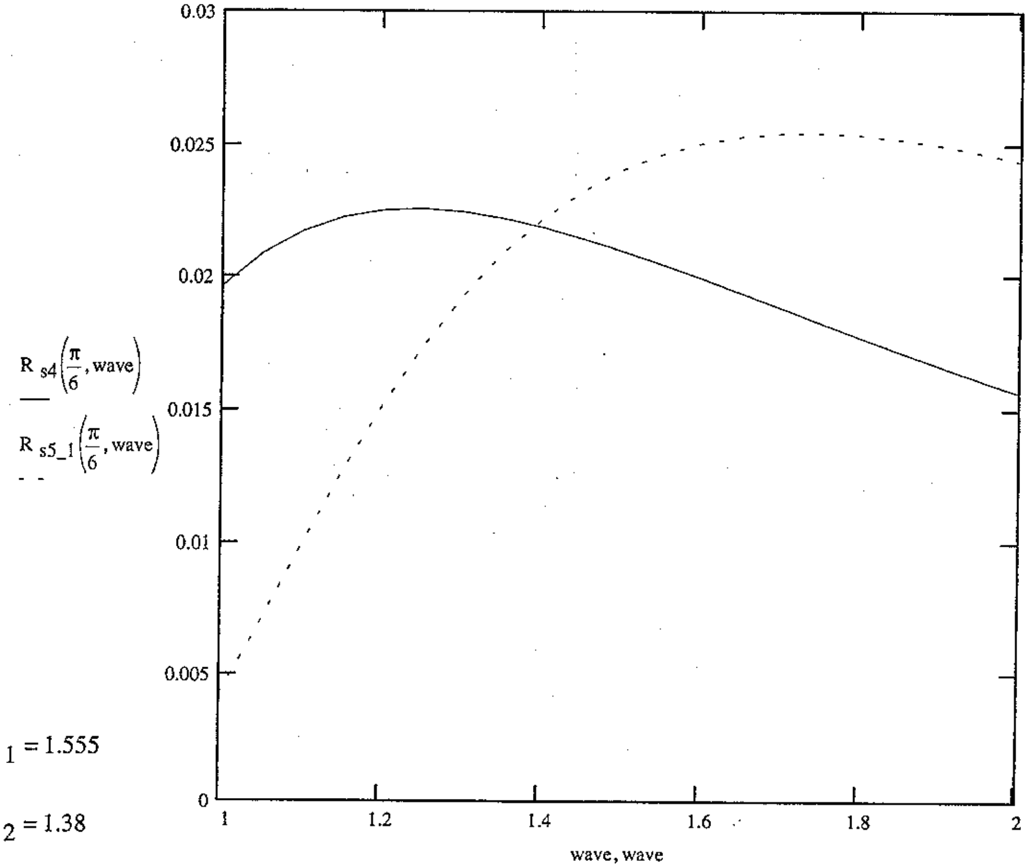


Figure 4b



$n_1 = 1.555$

$n_2 = 1.38$

$n_4 = 1.52$

$n_{4\_1} = 1.332$

$n_{5\_1} = 1.52$

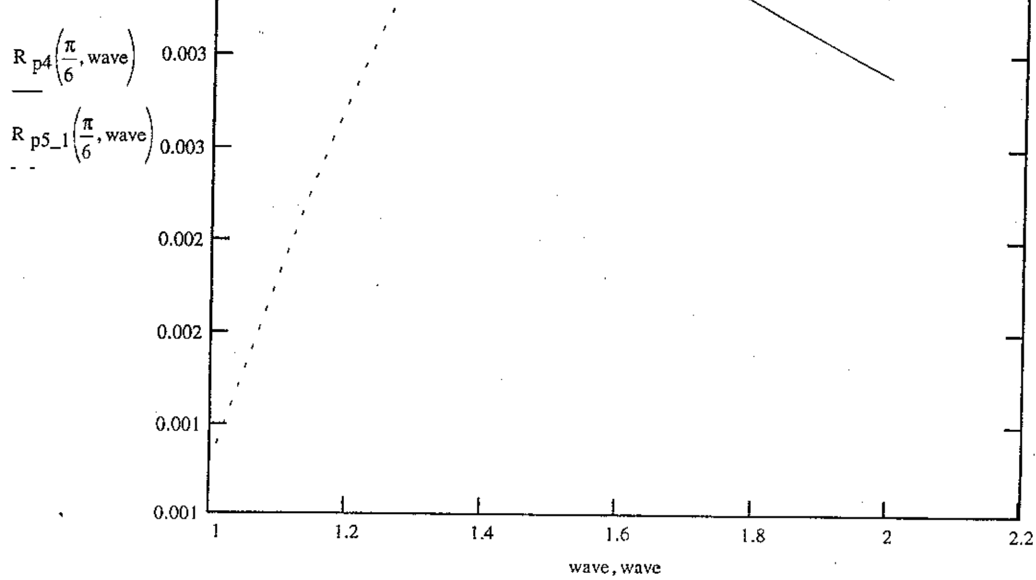
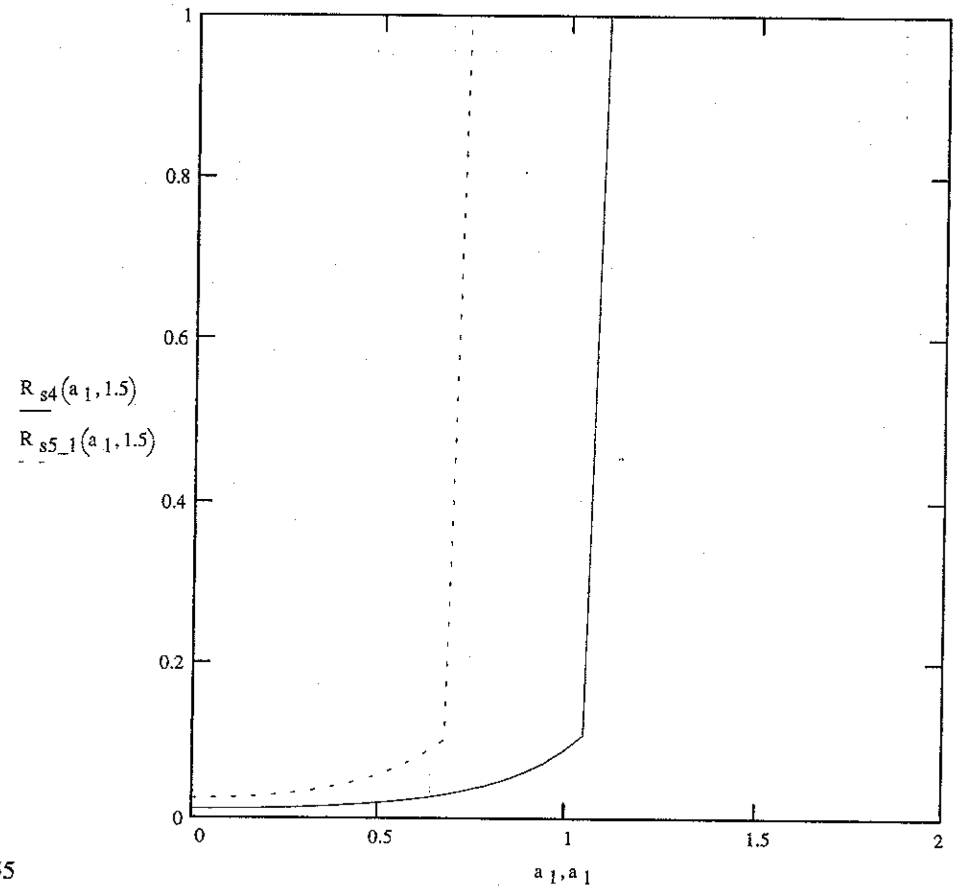


Figure 5a



$n_1 = 1.555$

$n_2 = 1.38$

$n_4 = 1.52$

$n_{4\_1} = 1$

$n_{5\_1} = 1.52$

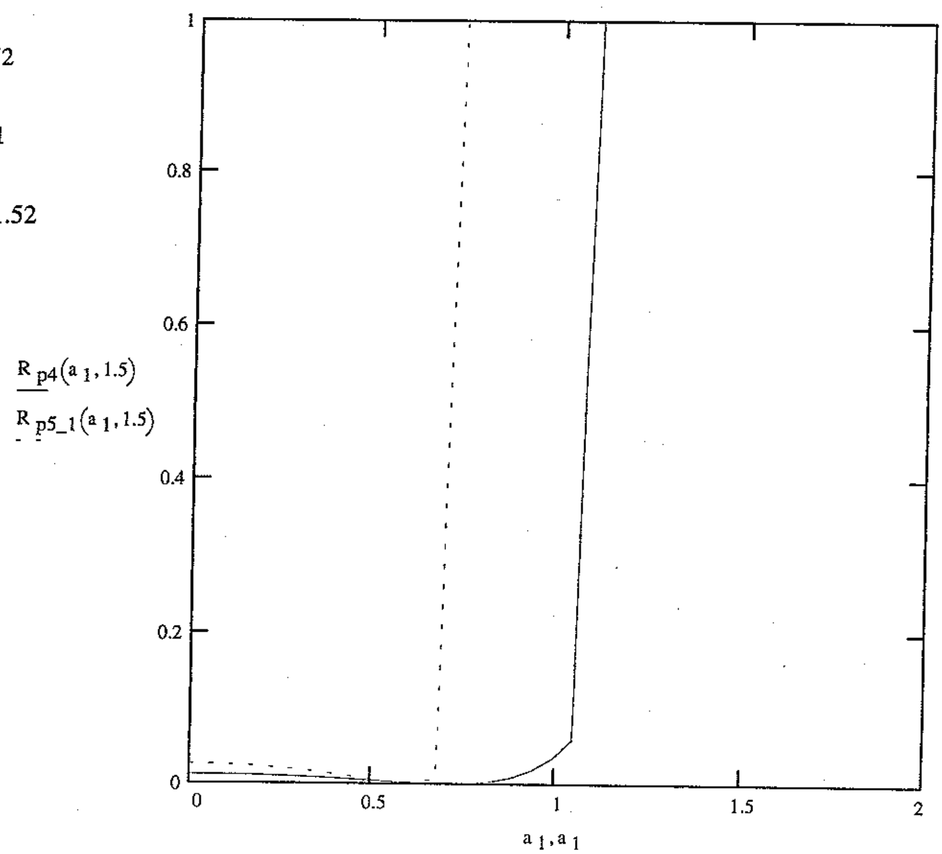
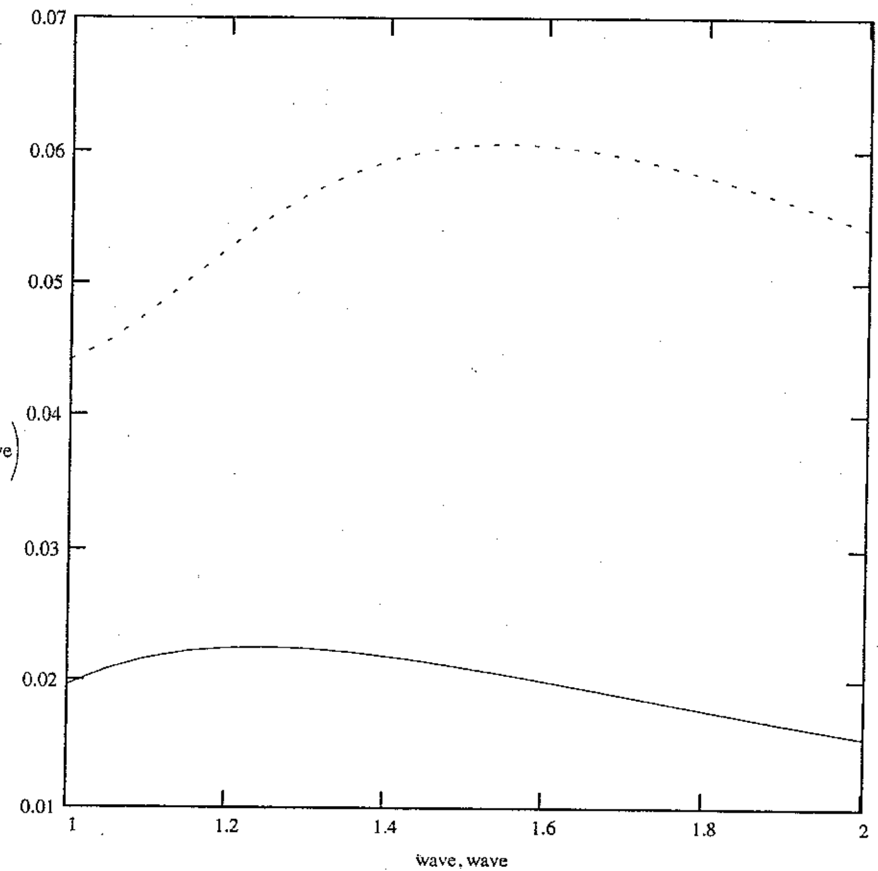


Figure 5b



$n_1 = 1.555$

$n_2 = 1.38$

$n_4 = 1.52$

$n_{4\_1} = 1$

$n_{5\_1} = 1.52$