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An Alternative to Rugate Coatings

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Rugate optical thin films have been studied for several decades, particularly for the application to laser eye protection filters (LEPF). The principles of rugates and Herpin equivalent layers are briefly reviewed. The combination of these concepts to overcome the bandpass limitations of shortwave pass filters is shown. The use of Alfred Thelen's minus filters to make LEPF is discussed. The use of higher harmonic bands of quarter wave optical thickness (QWOT) stacks for LEPF is explained. The application of thickness ratios in layer pairs other than QWOTs is shown to lead to better alternatives for LEPF than rugates.

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Abstract

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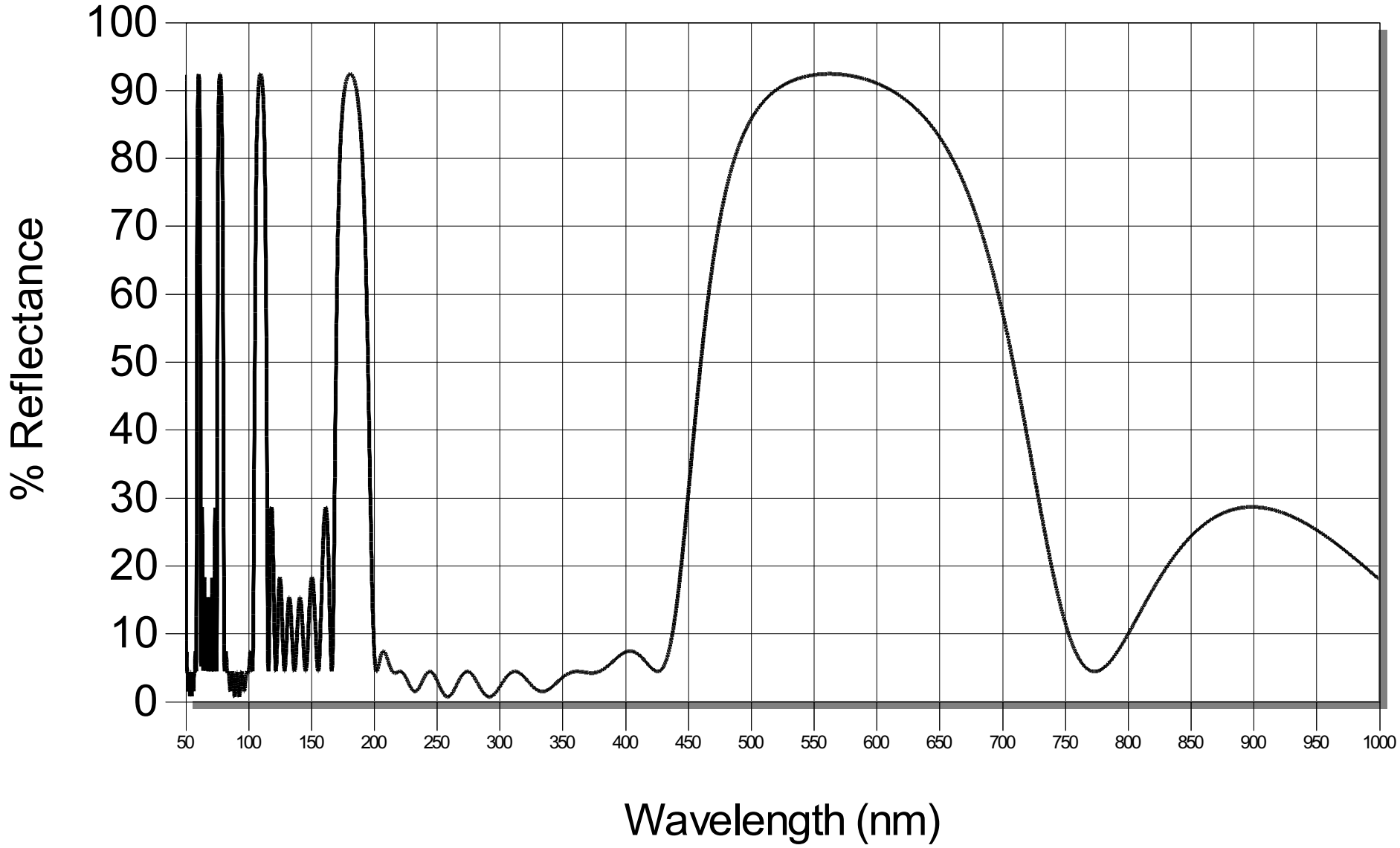
The combination of these concepts to overcome the bandpass limitations of shortwave pass filters is shown.

The use of Alfred Thelen's minus filters to make LEPF is discussed. The use of higher harmonic bands of quarter wave optical thickness (QWOT) stacks for LEPF is explained.

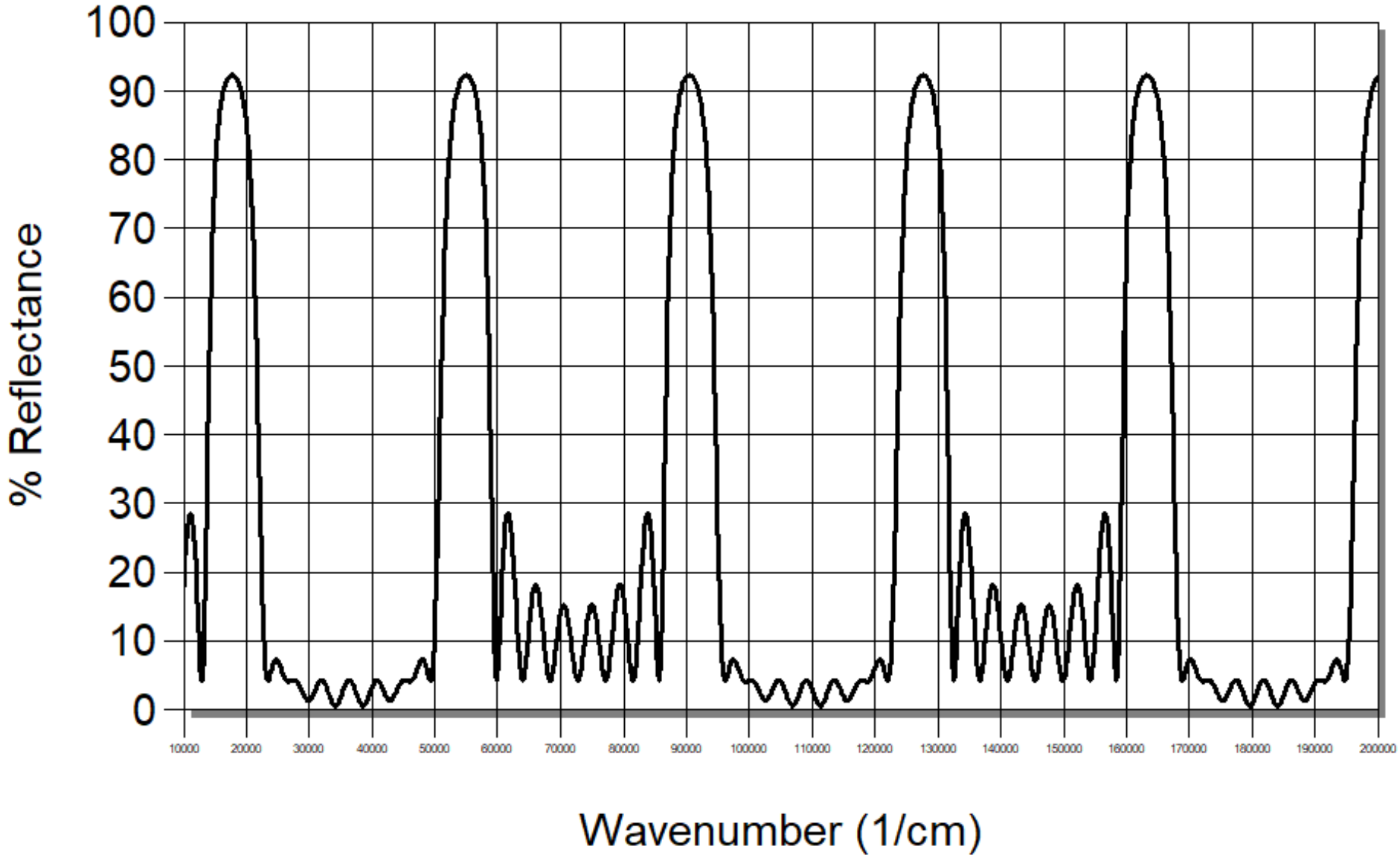
The application of thickness ratios in layer pairs other than QWOTs is shown to lead to better alternatives for LEPF than rugates.

MAKING A HIGH REFLECTOR

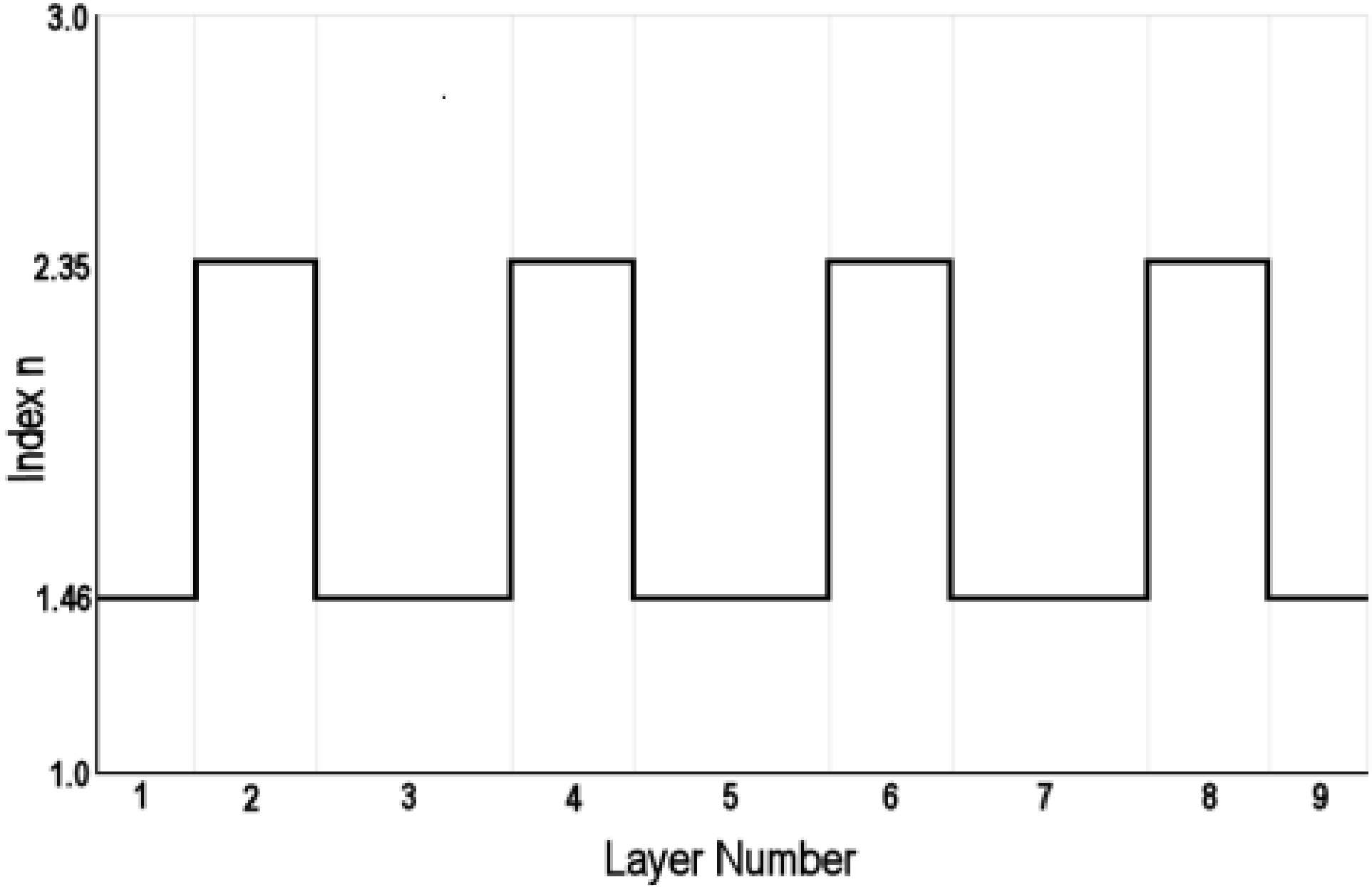
550 nm Reflector in Wavelength



550 nm Reflector in Wavenumber

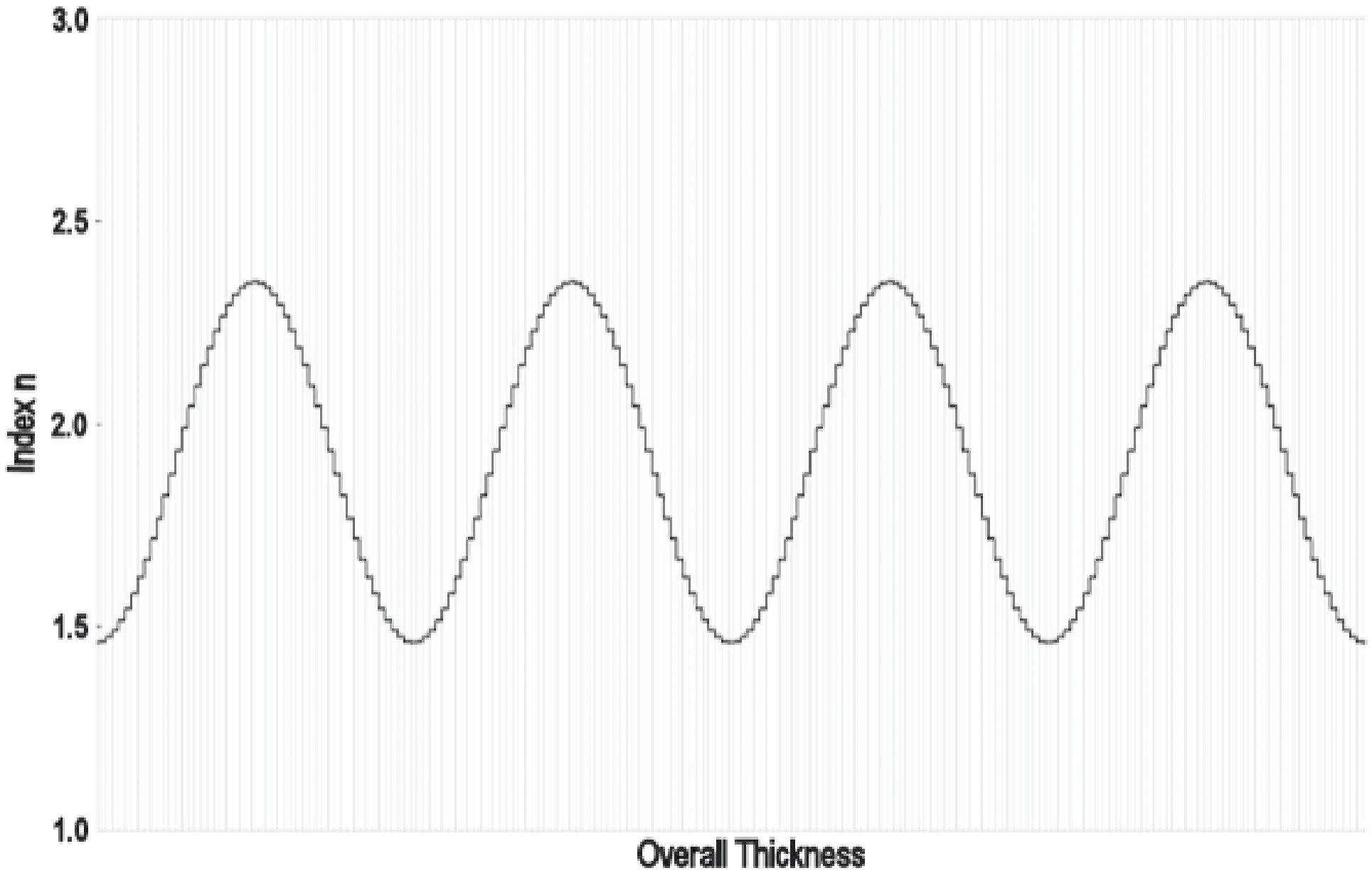


HOMOGENEOUS INDEX LAYERS

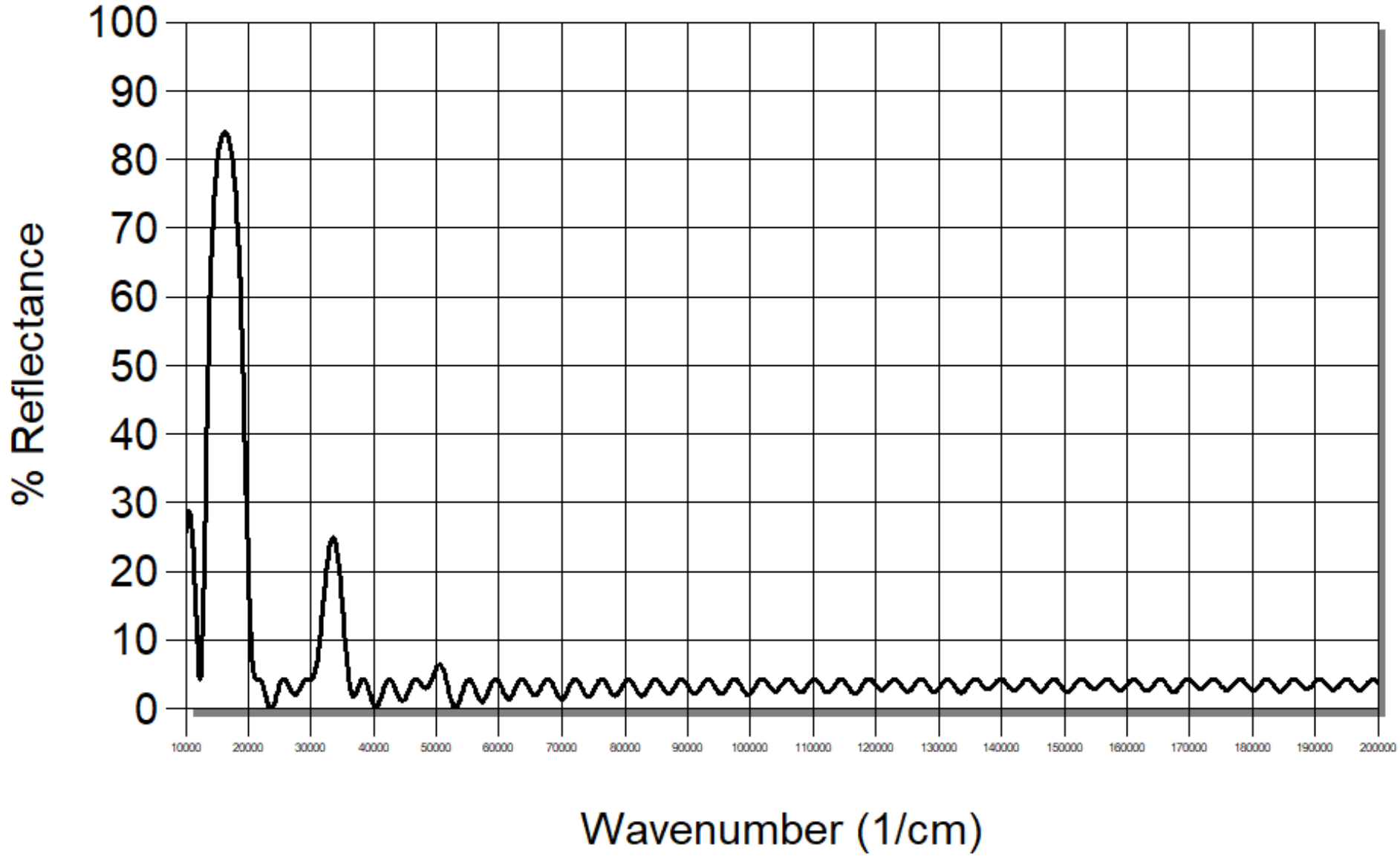


WHAT IS A RUGATE

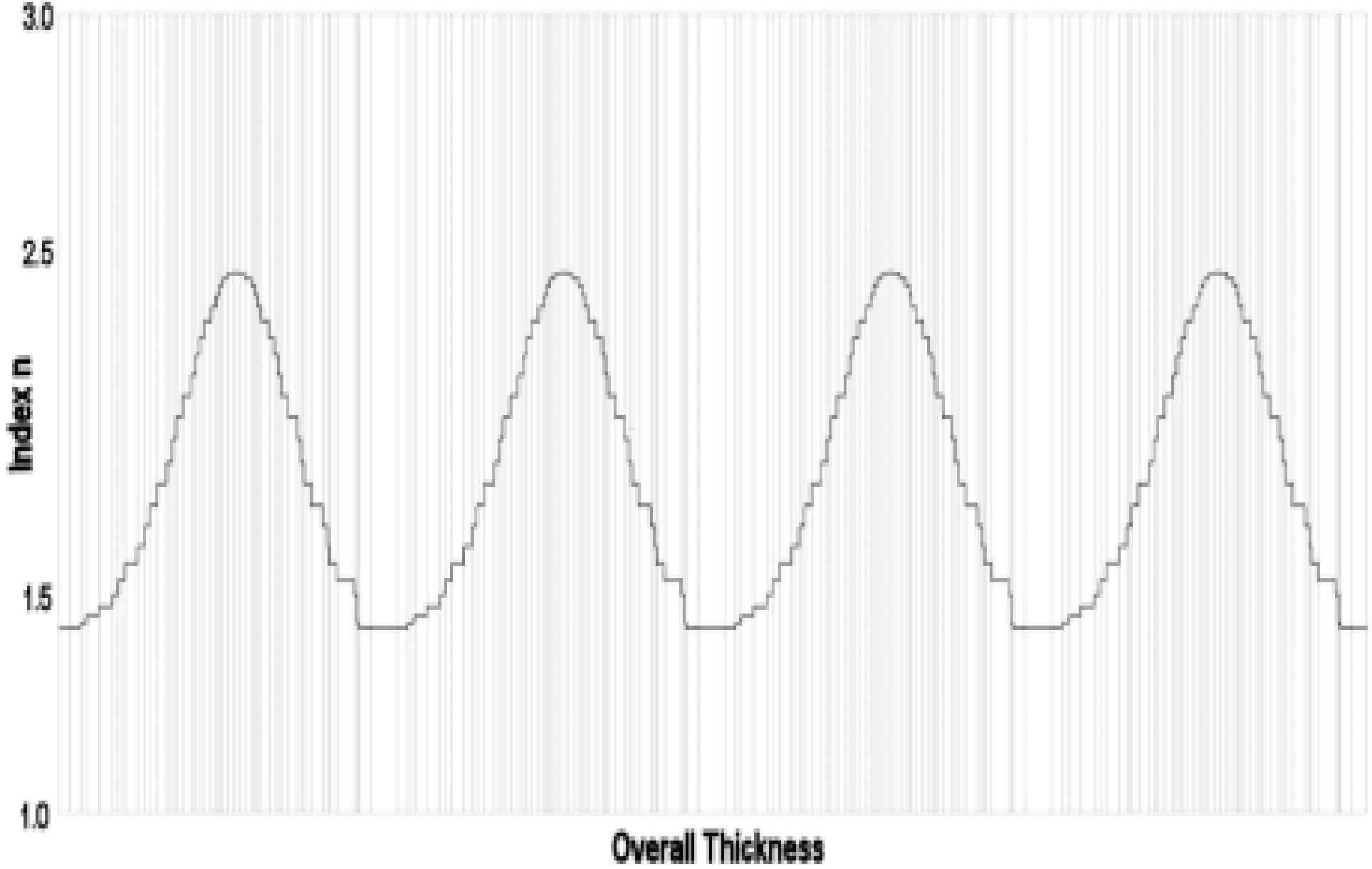
SINE WAVE INDEX LAYERS



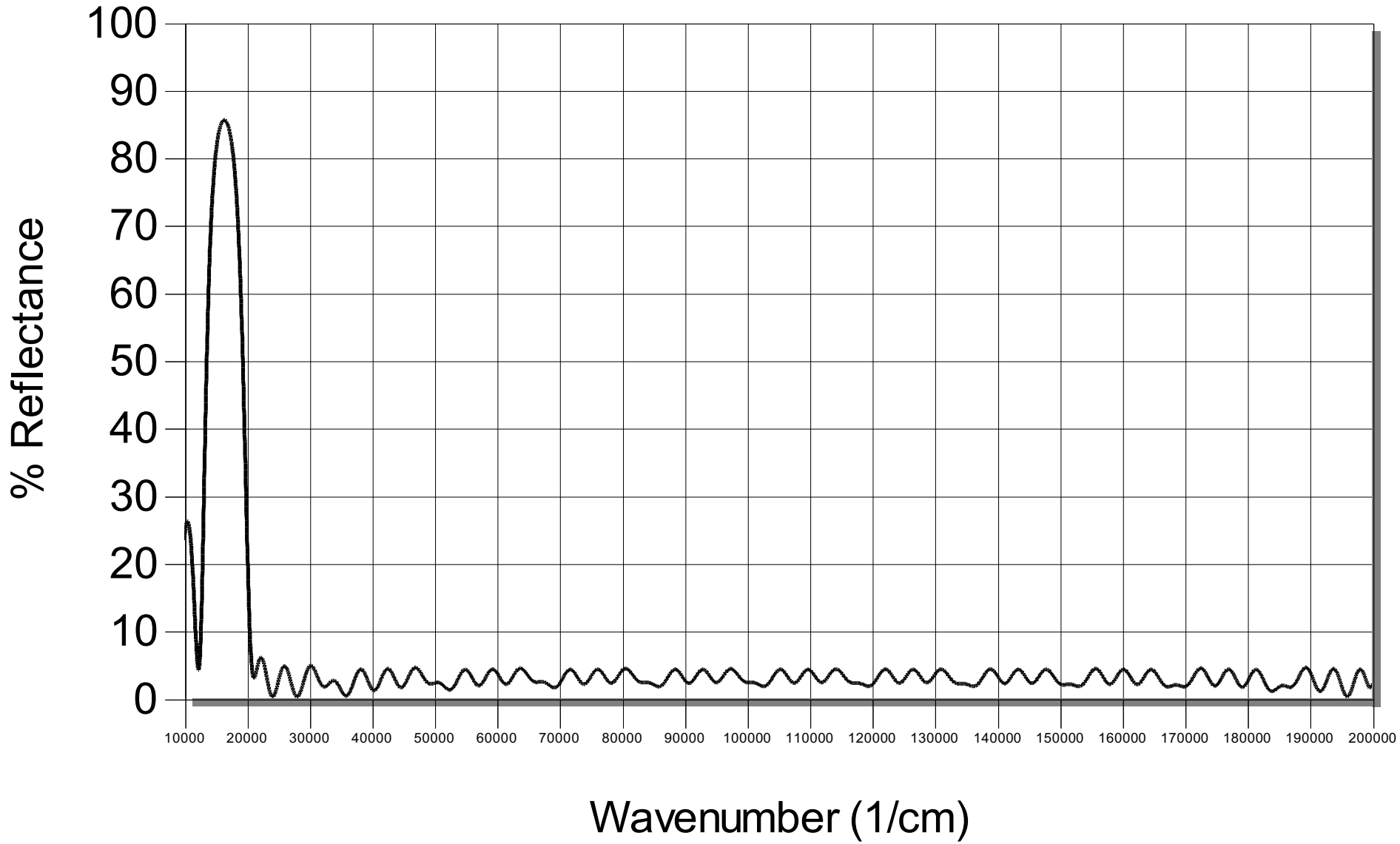
SINE INDEX REFLECTOR



OPTIMIZED INDEX LAYERS



OPTIM. RUGATE REFLECTOR

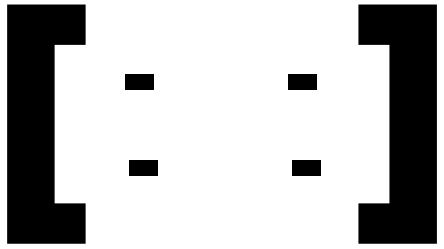


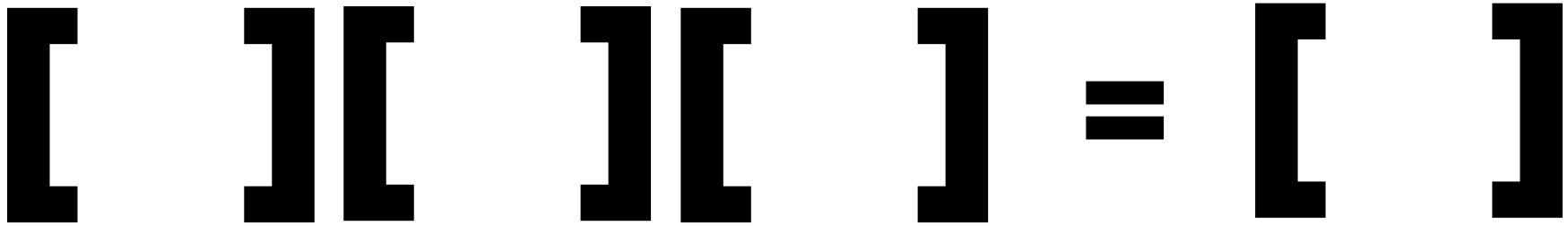
WHAT IS A HERPIN APPROXIMATION

APPROXIMATIONS OF INDICES AND DESIGNS

Herpin-Epstein Equivalent Layers

2 x 2 Matrix Describes layer





1947 Herpin concept

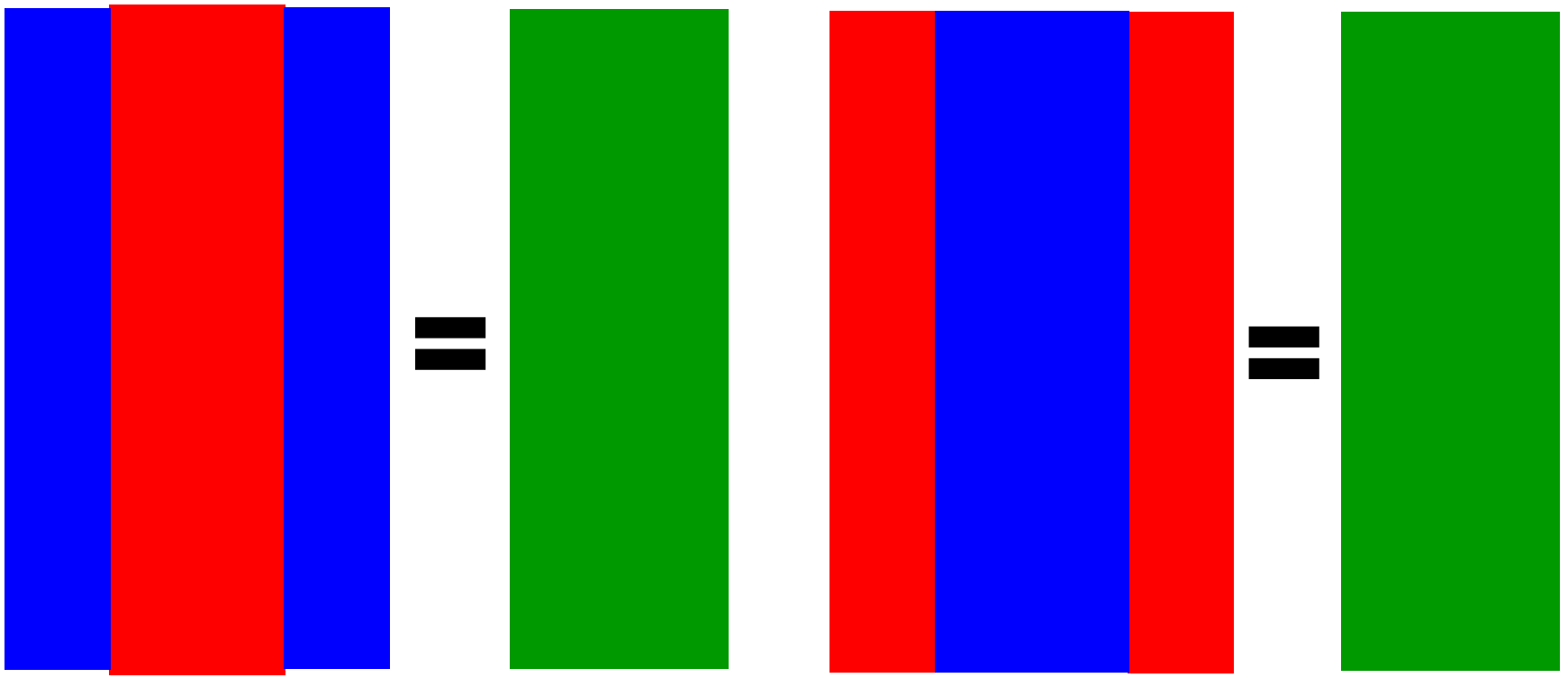
1950s Matrix Formulation (Abeles & Herpin)

1952 Epstein periods

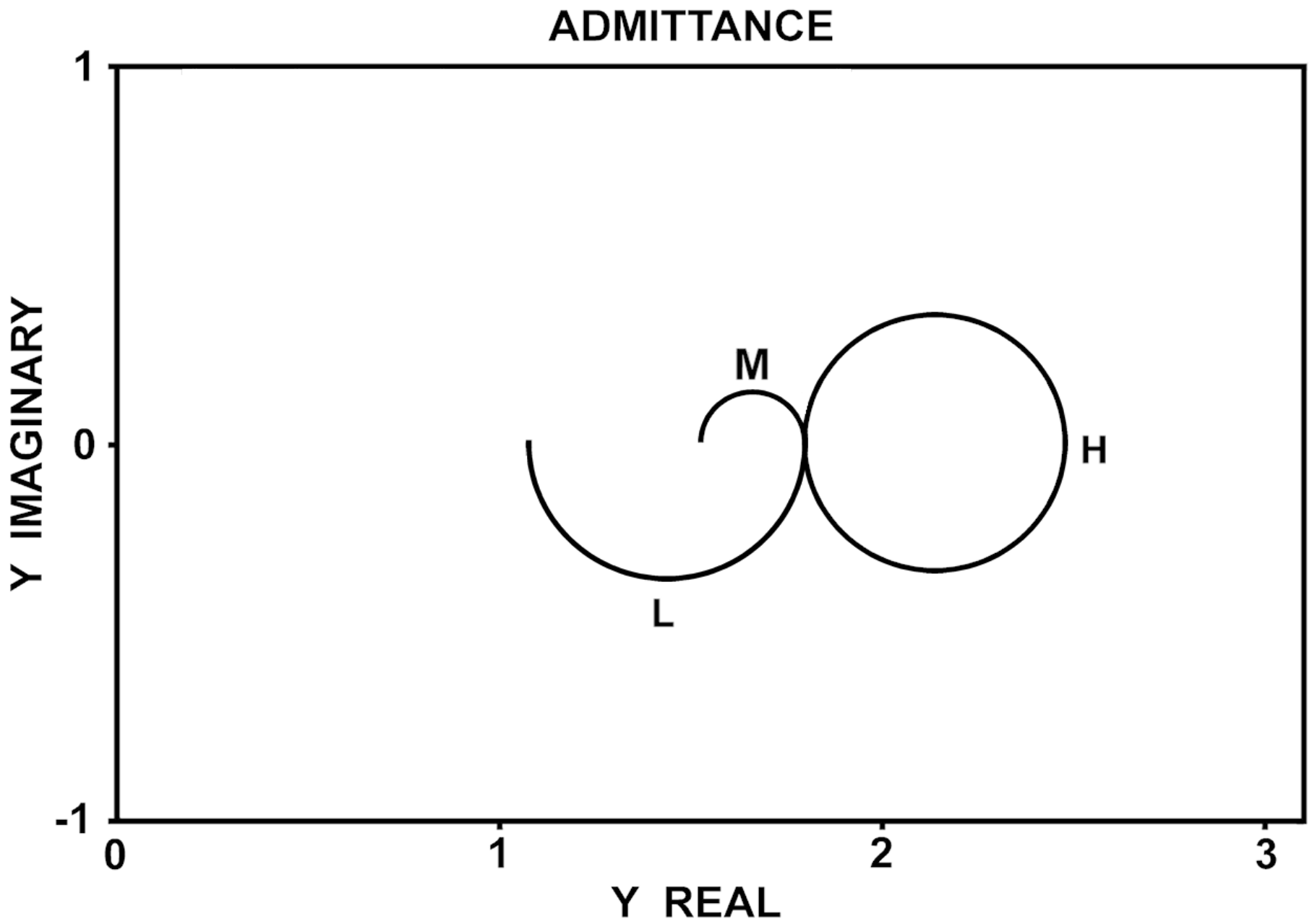
1978 Formulas for 3-Layer Equivalent Films (Ohmer)

Herpin-Epstein Equivalent Layers

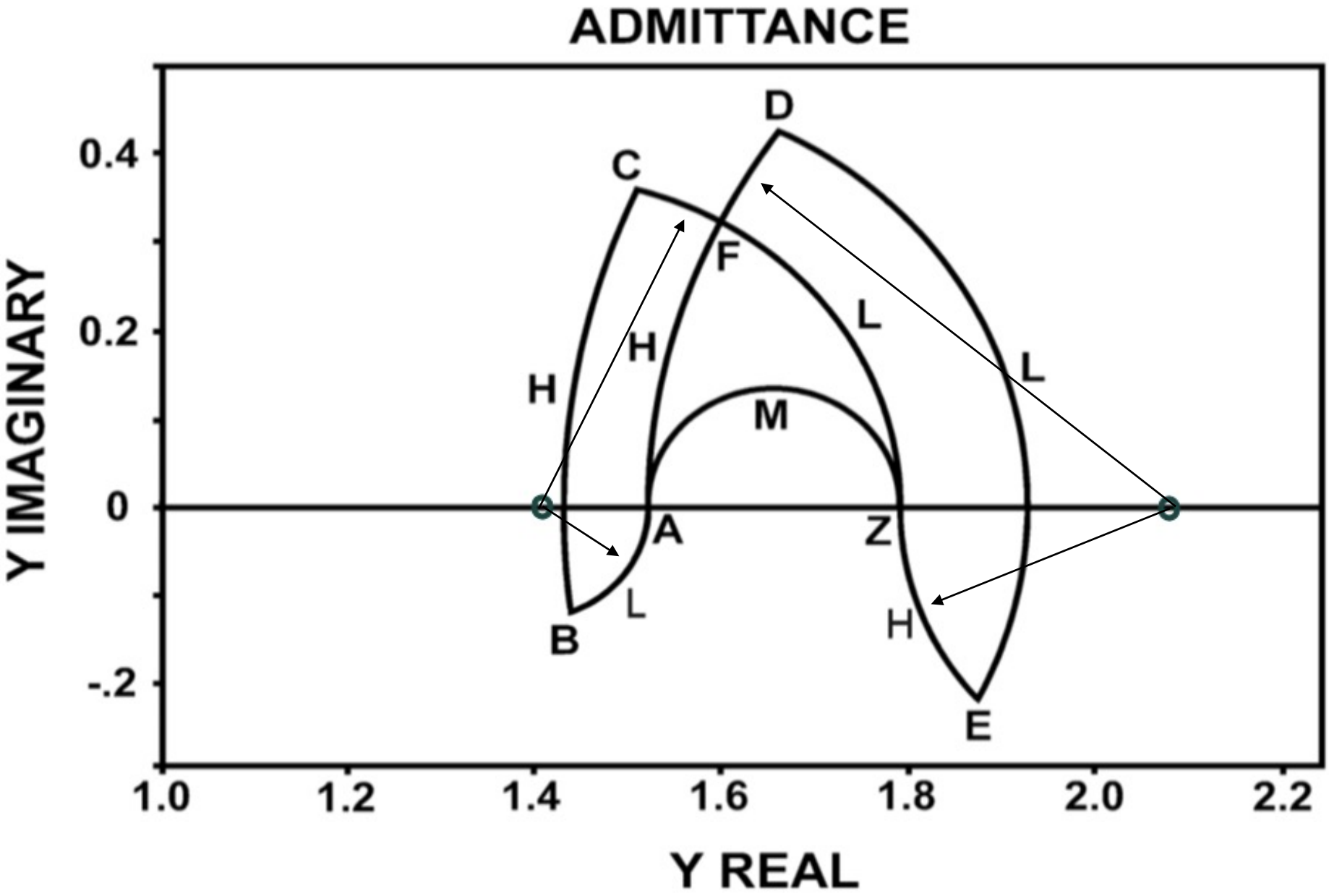
[H][L][H] = [M] [L][H][L] = [M]



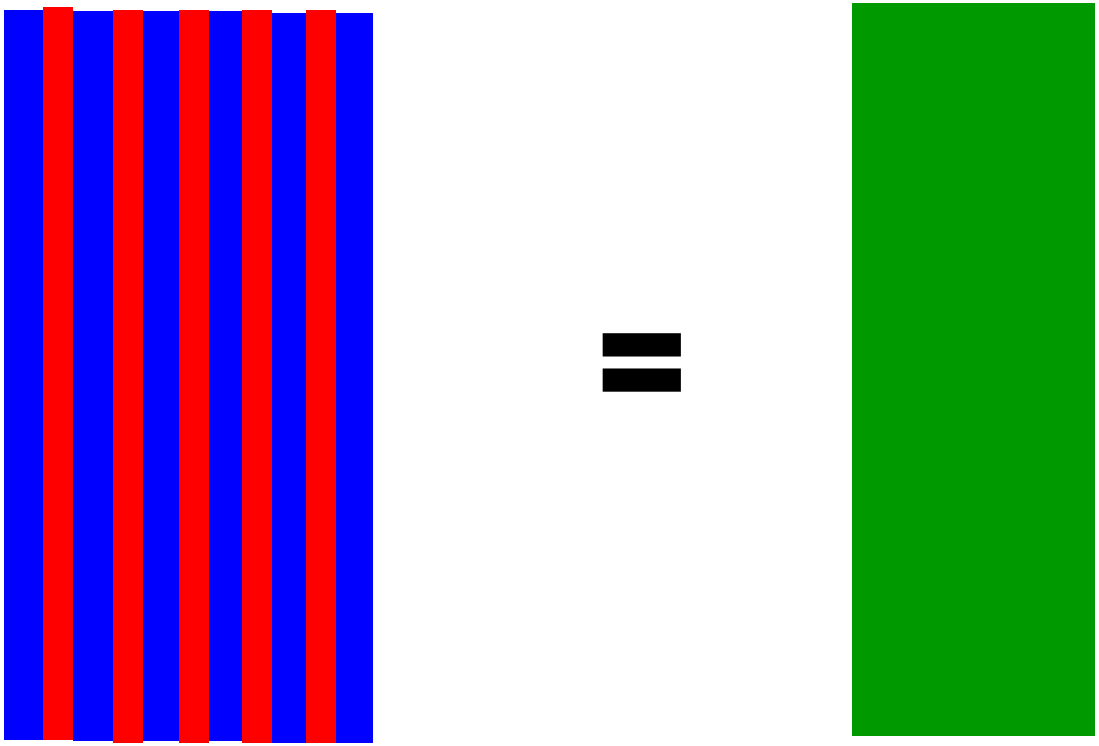
ADMITTANCE DIAGRAM



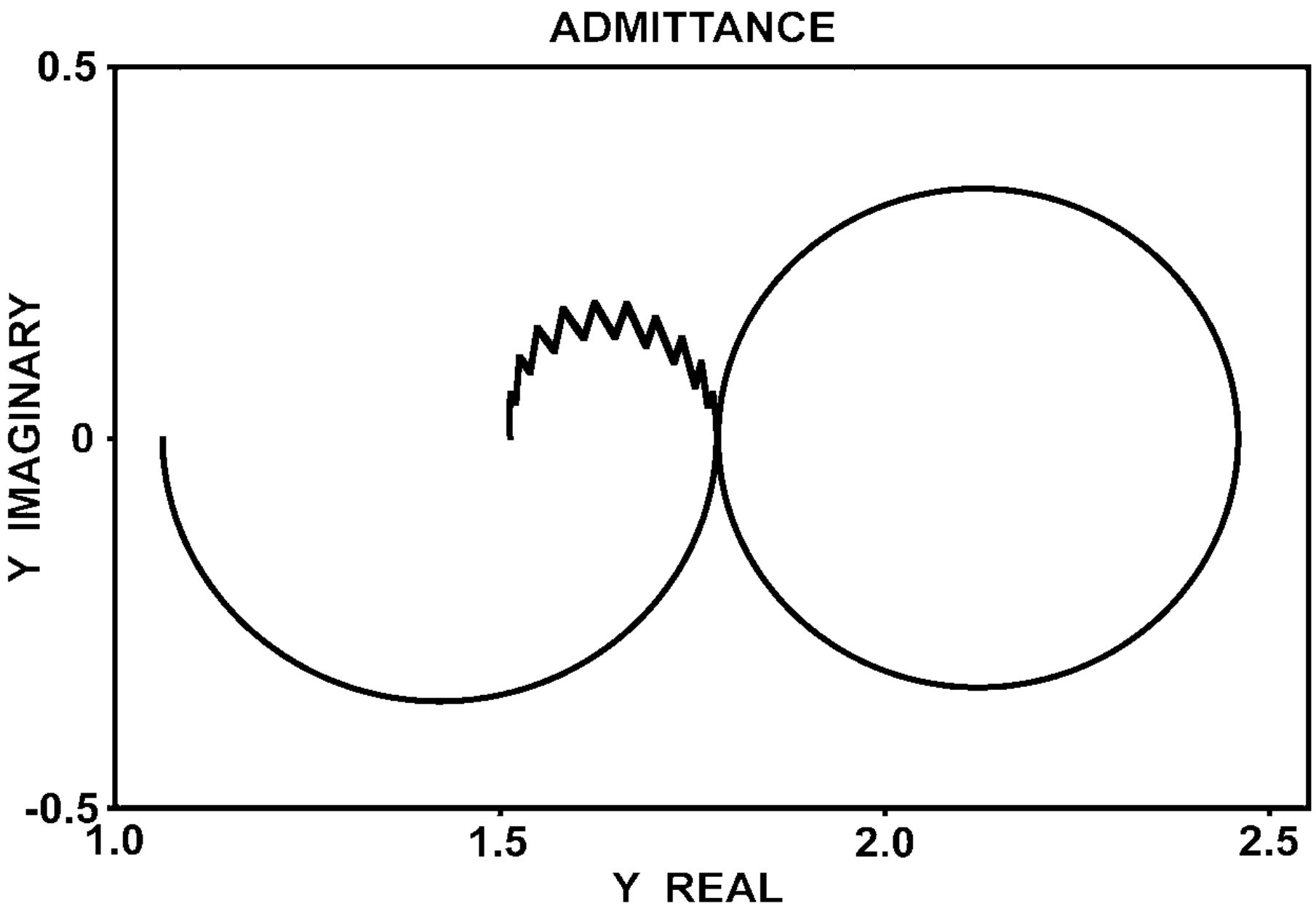
APPROXIMATIONS OF "M"



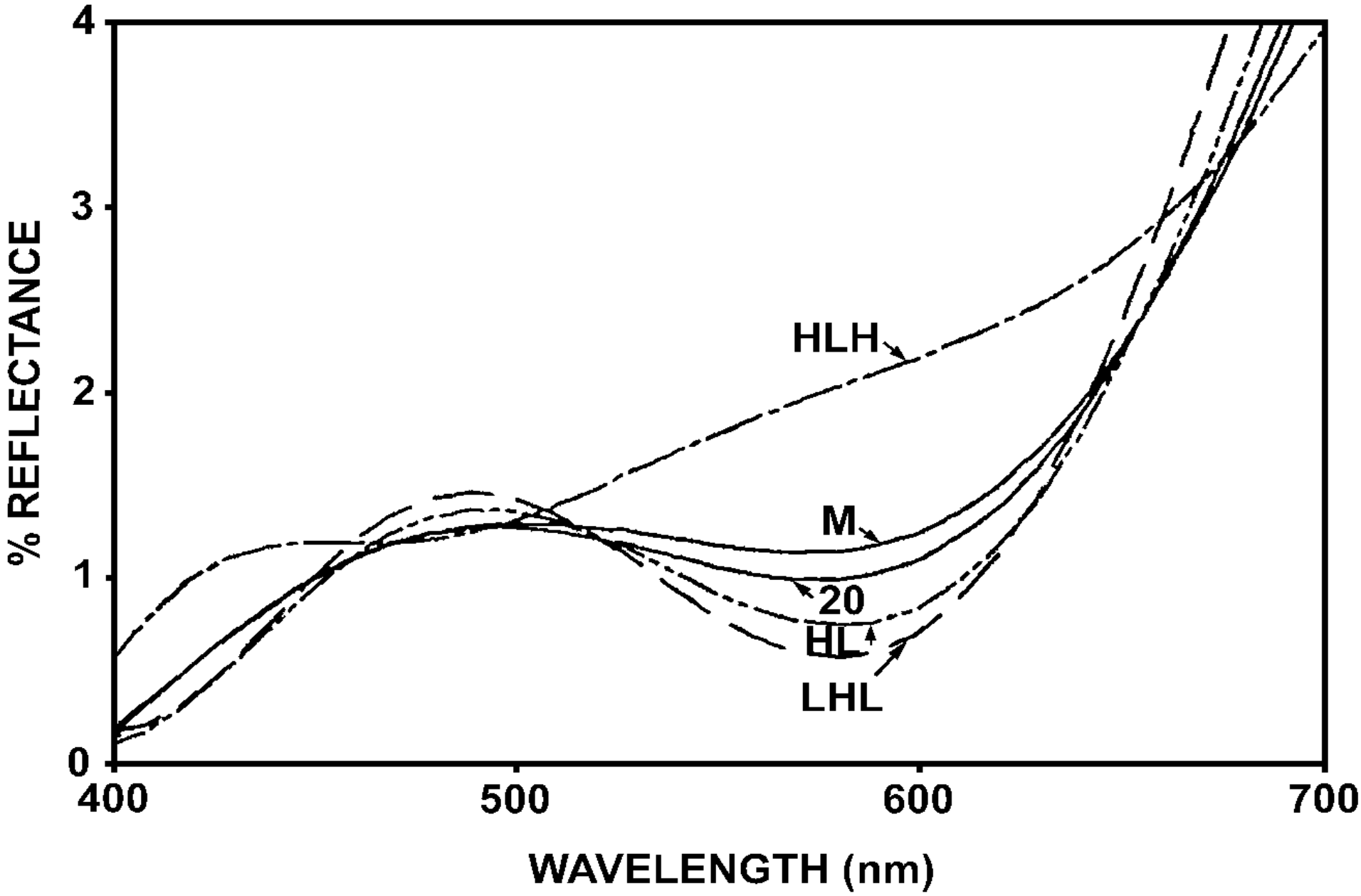
20-Layer Approximation



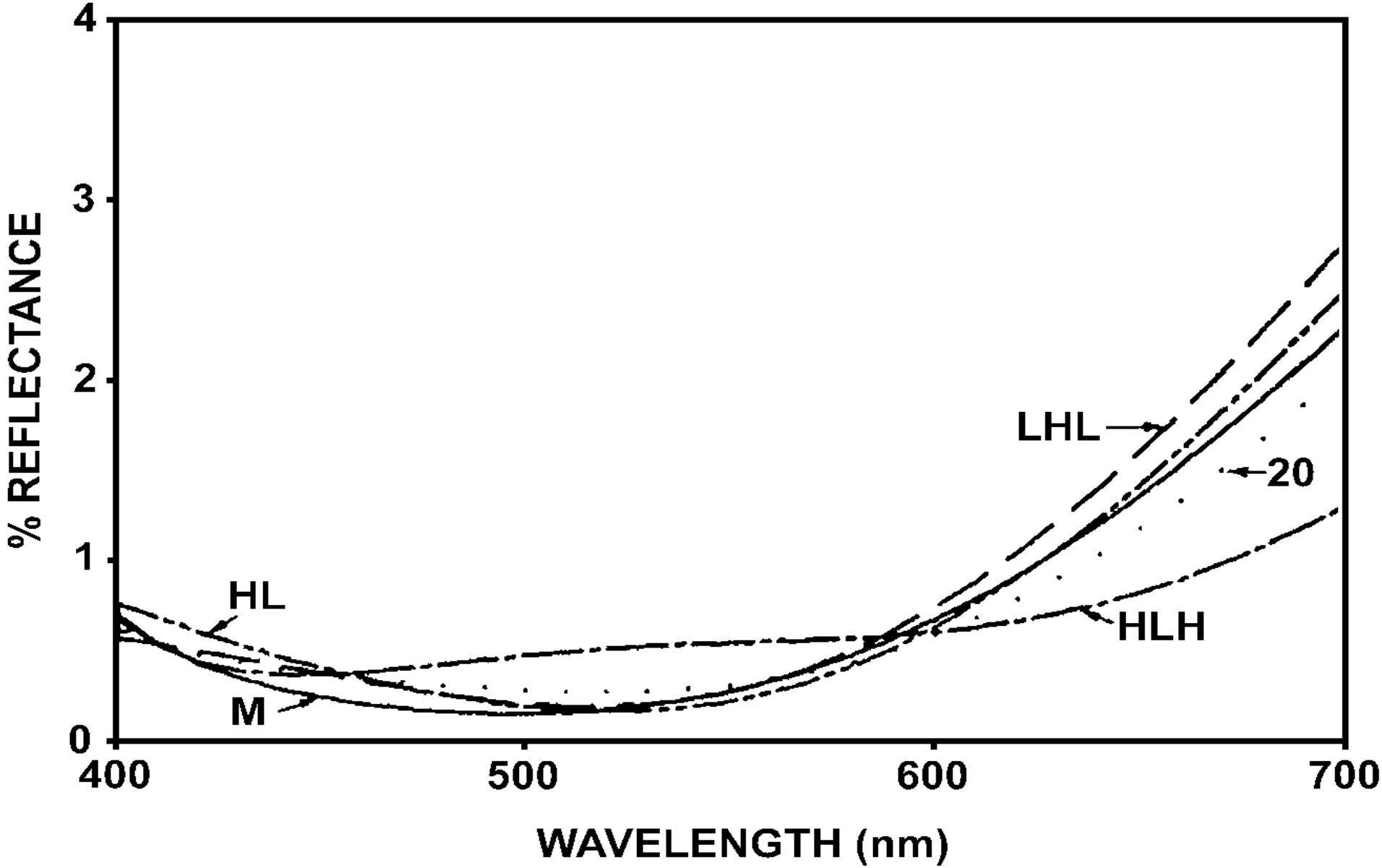
“THREE” LAYER AR



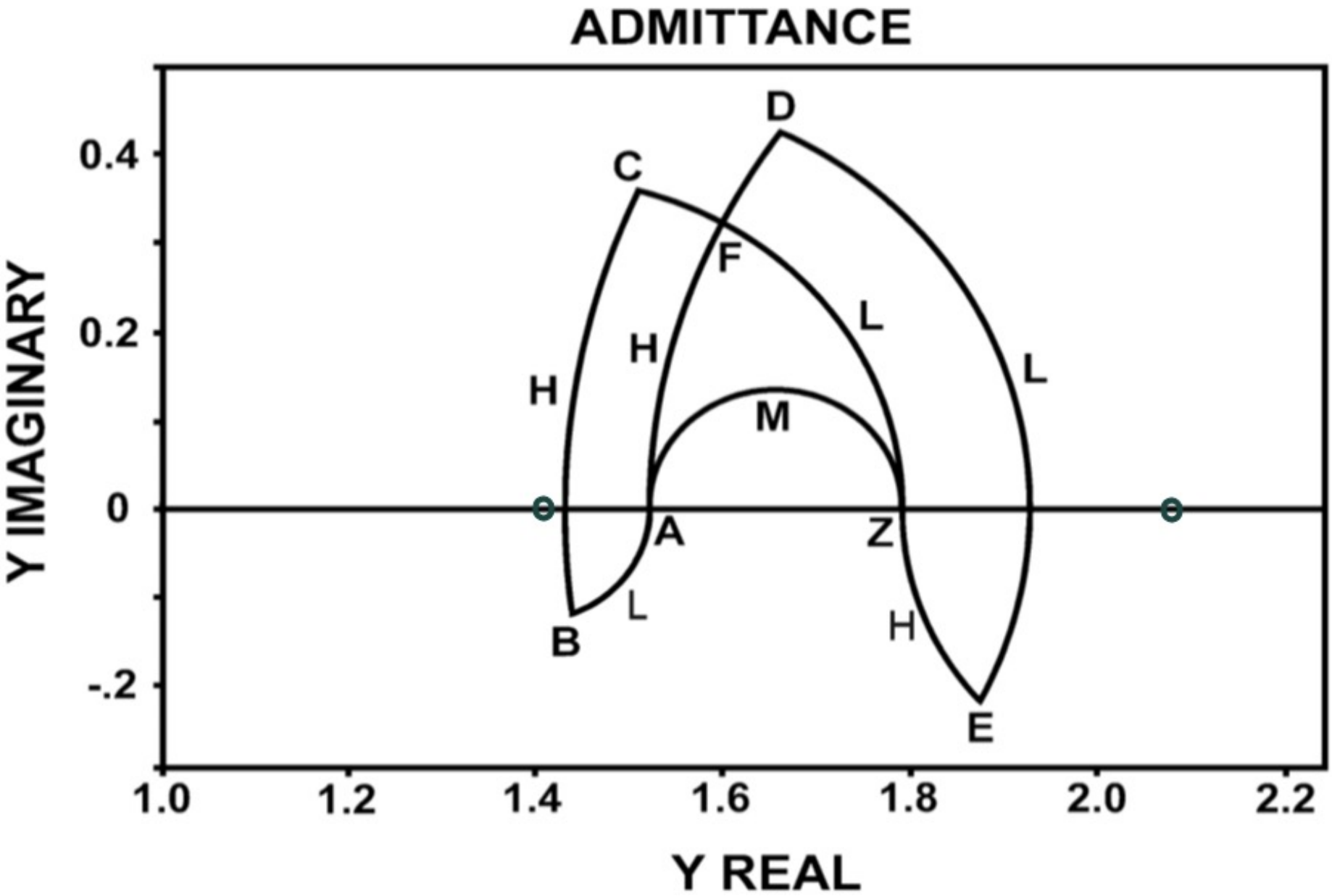
S-POL. OF APPROX. @ 45°



P-POL. OF APPROX. @ 45°



APPROXIMATIONS OF “M”

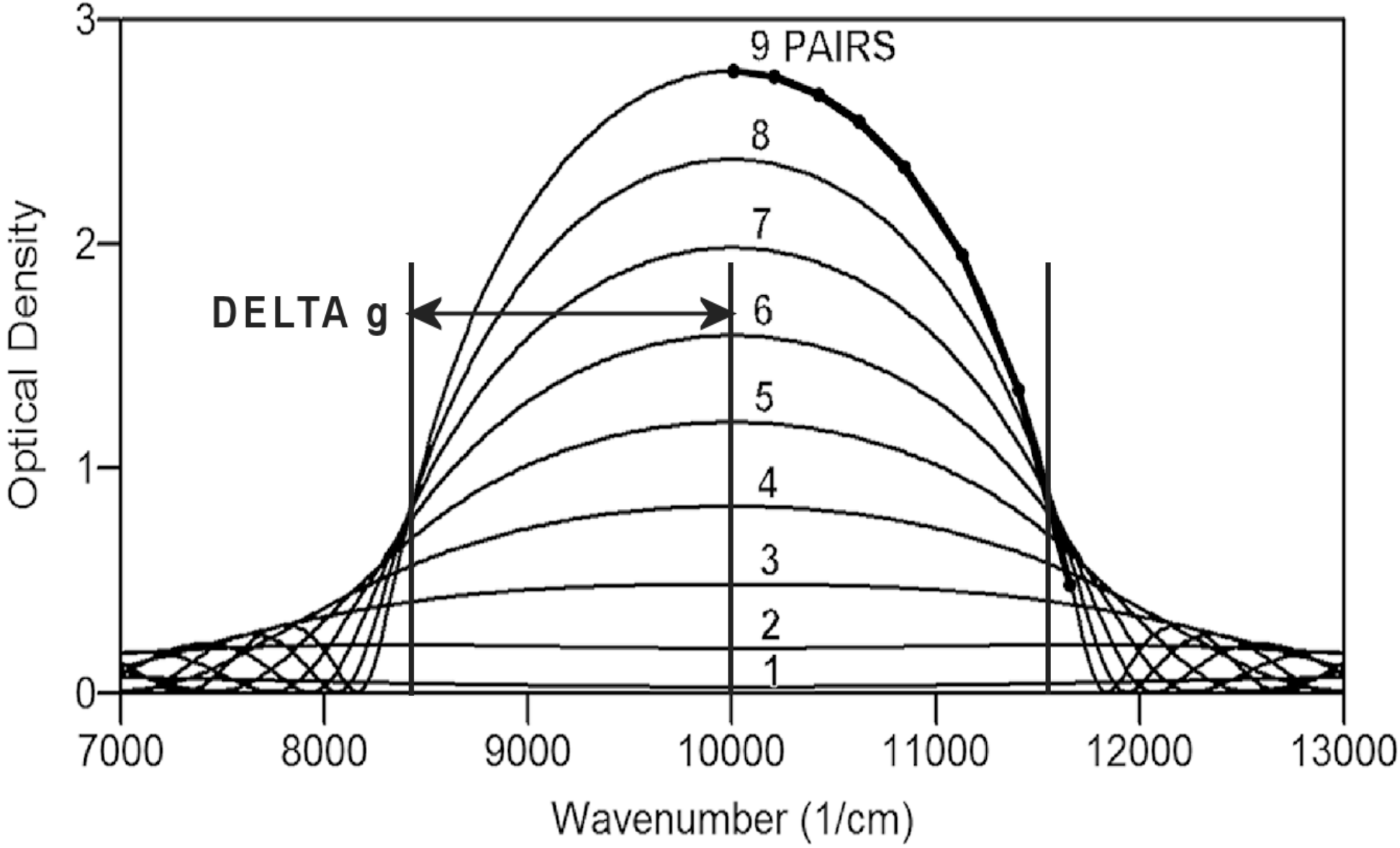


WHAT IS OPTICAL DENSITY

$$OD = \log_{10}(1/T)$$

%Trans.	Optical Density	Decibels db
100	0	0
10	1	10
1	2	20
0.1	3	30
0.01	4	40

OD versus LAYER PAIRS



Optical Density at Peak of a QWOT Stack of "p" Layer-pairs

$$OD_P \approx 2 \log \tfrac{1}{2} \left[\left(\frac{n_H}{n_L} \right)^p + \left(\frac{n_L}{n_H} \right)^p \right] \qquad (2.5)$$

Make a Low Reflector

BANDPASS LIMITATIONS OF SWP FILTERS

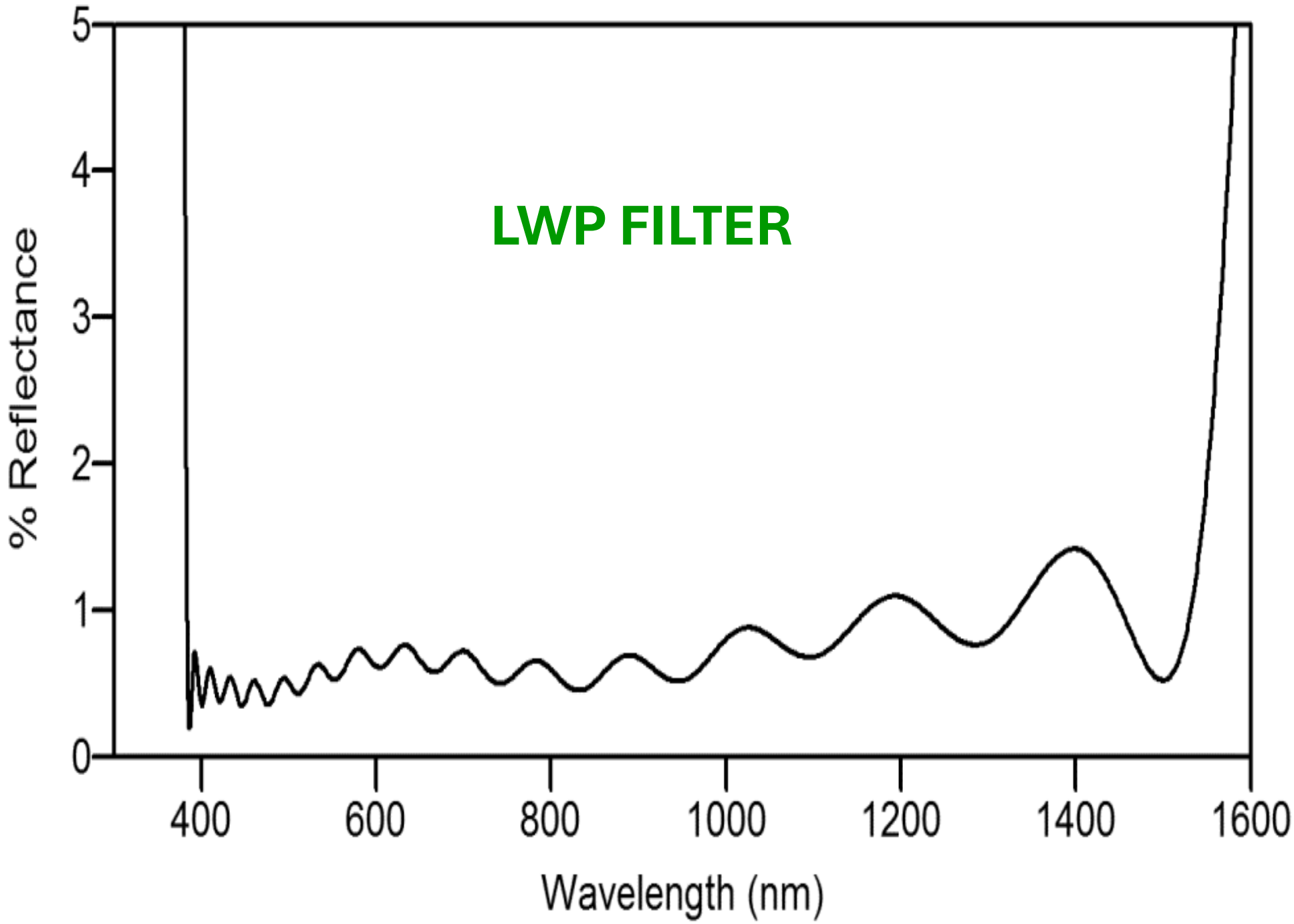
ABSTRACT

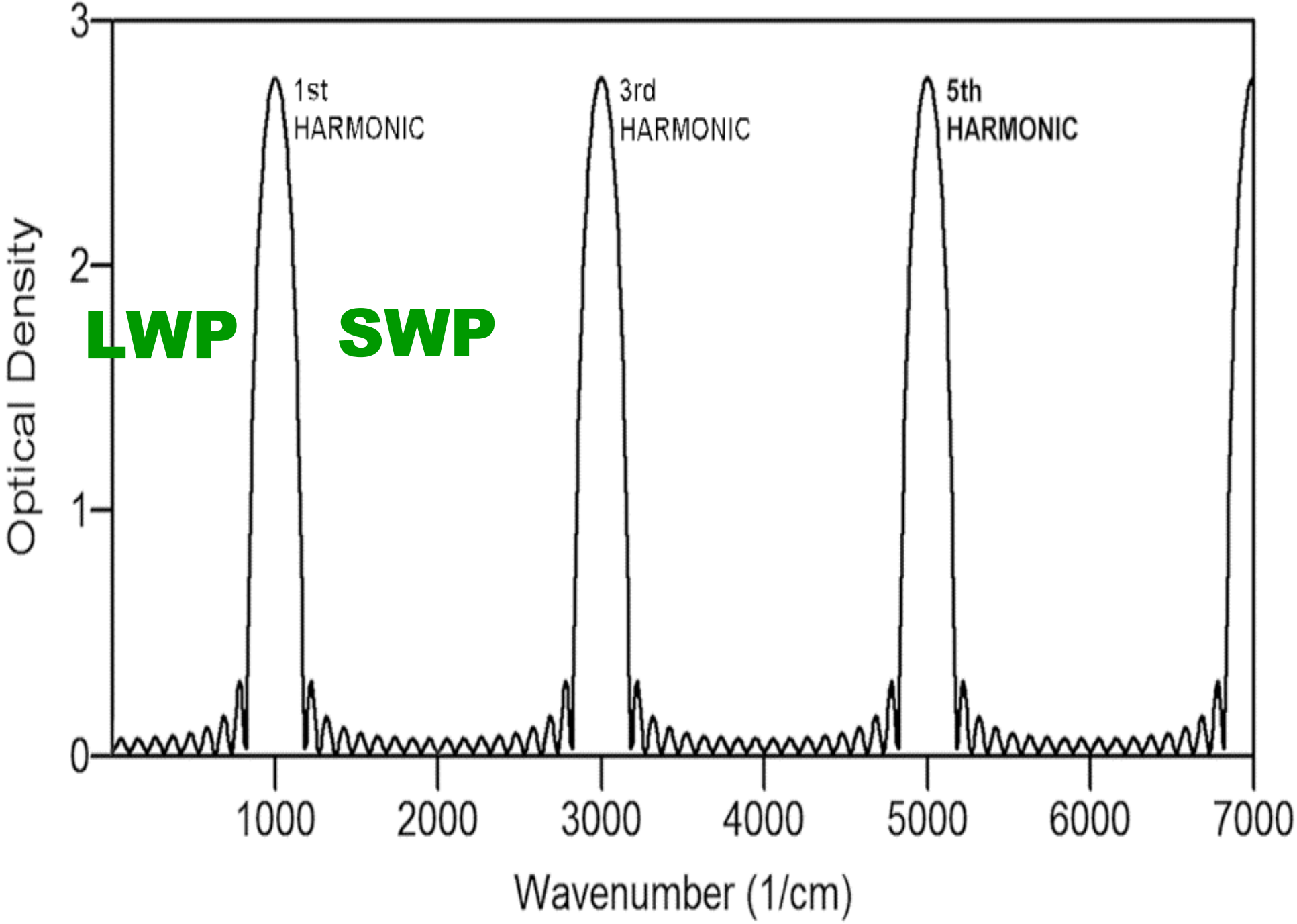
Pass bandwidth of a SWP filter is limited in the case of the usual QWOT stack designs.

When band-passes broader than about 2 are needed for SWP edge filters, rugate-like designs are required.

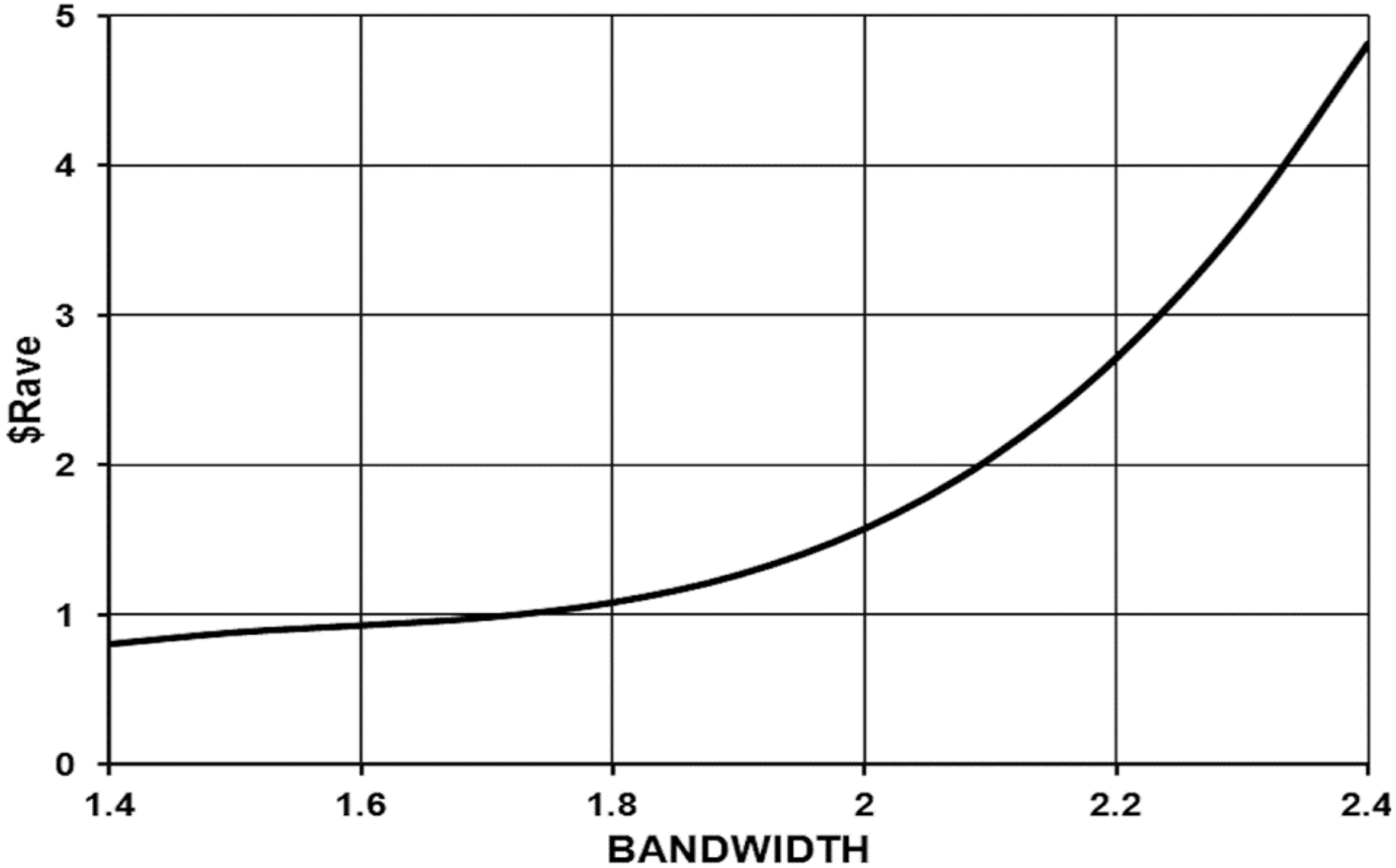
BANDWIDTH DEFINITION

Longest wavelength
in the band
divided by the shortest

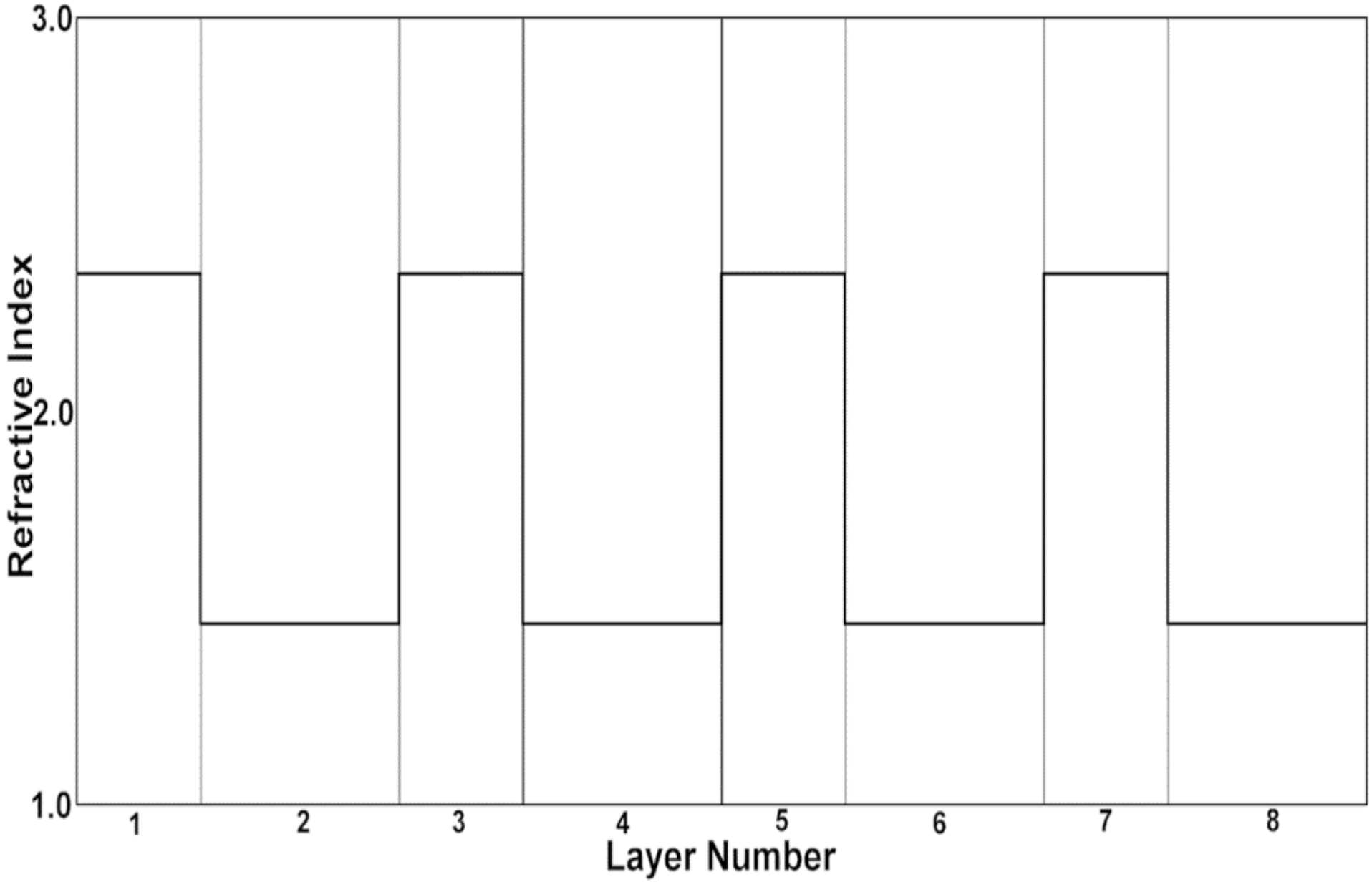

LWP FILTER
% Reflectance
5
4
3
2
1
0
400
600
800
1000
1200
1400
1600
Wavelength (nm)


3
2
1
0
Optical Density
1st
HARMONIC
3rd
HARMONIC
5th
HARMONIC
LWP
SWP
1000
2000
3000
4000
5000
6000
7000
Wavenumber (1/cm)

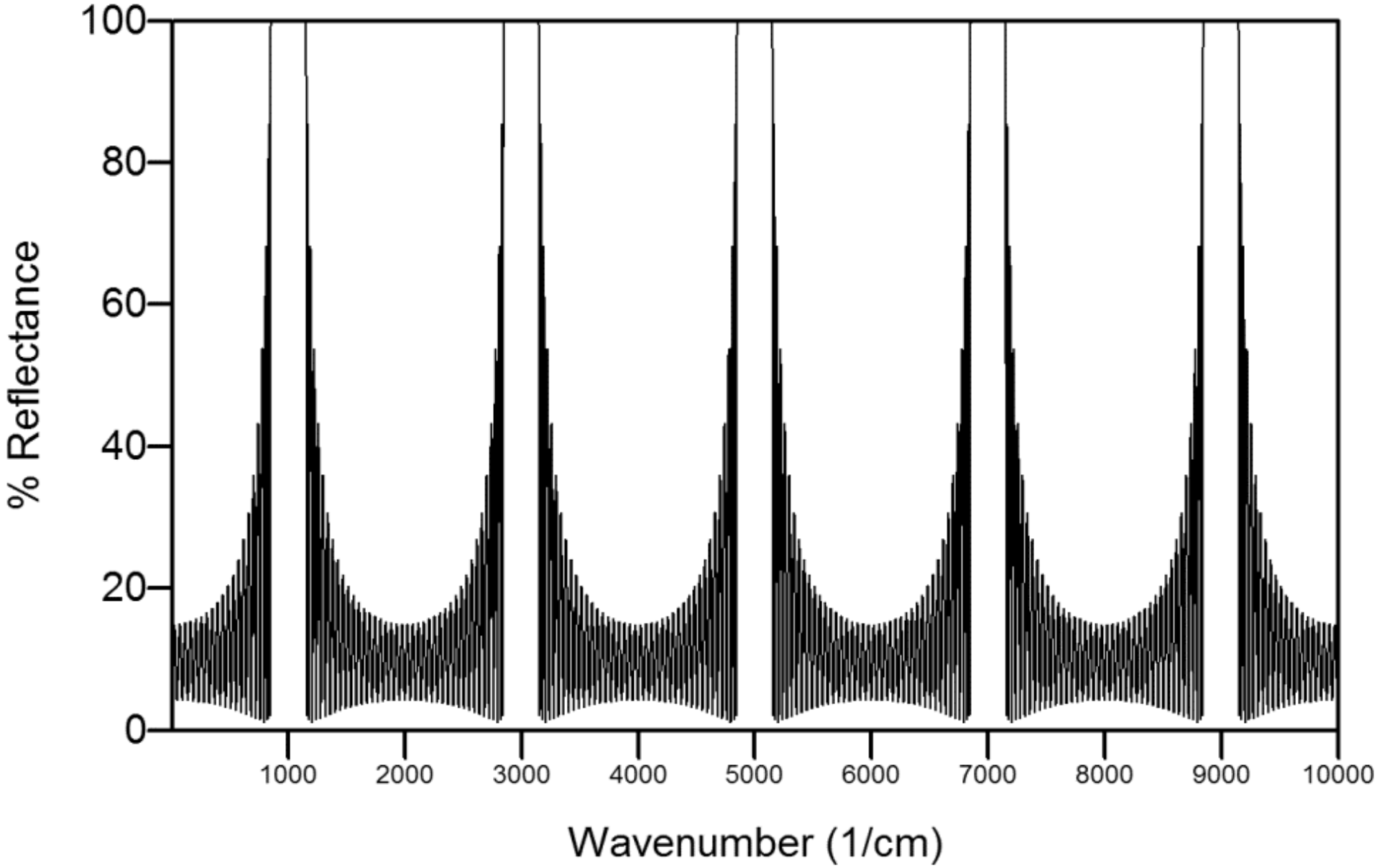
PROBLEM OF INCREASED BW

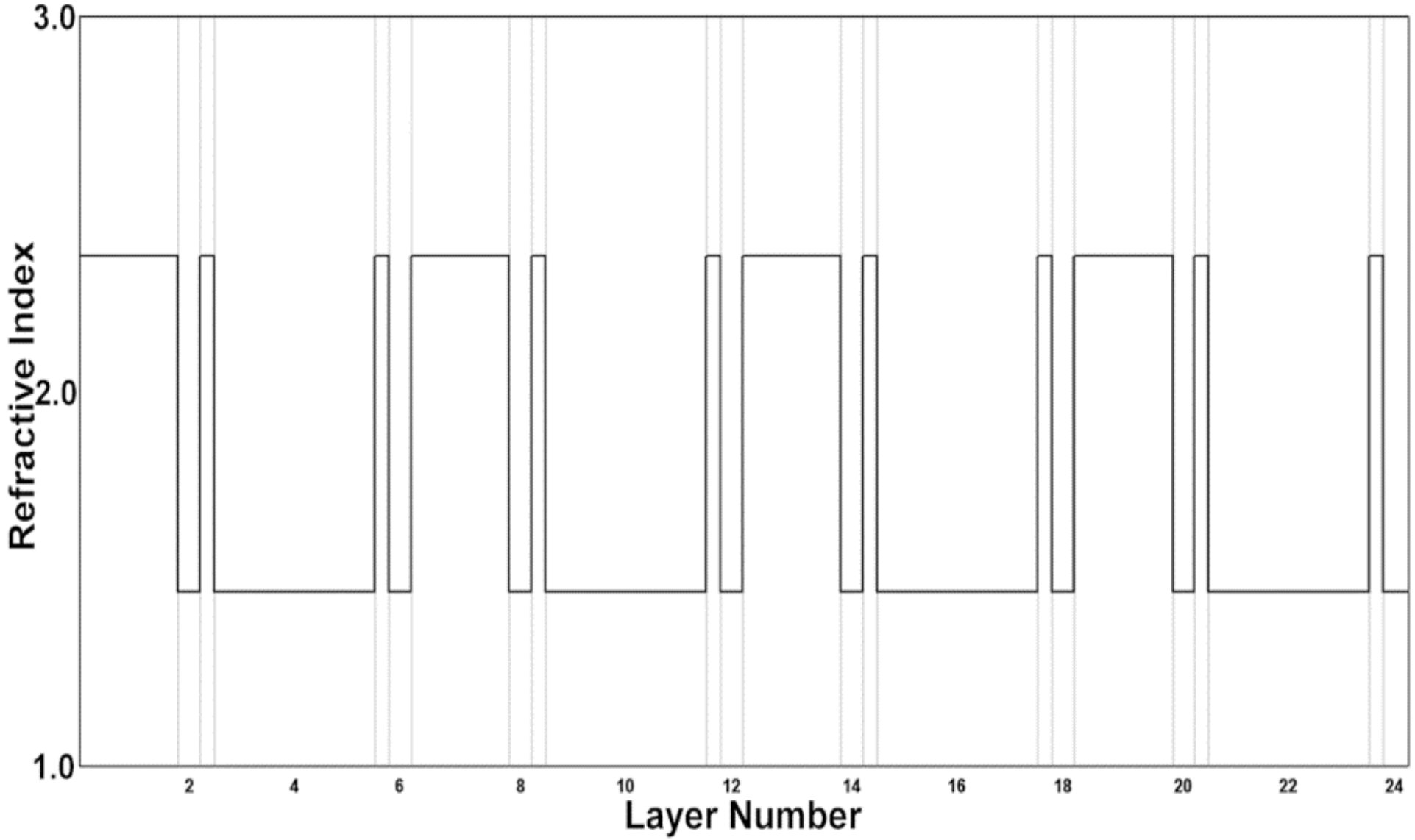


HOMOGENEIUS LAYERS

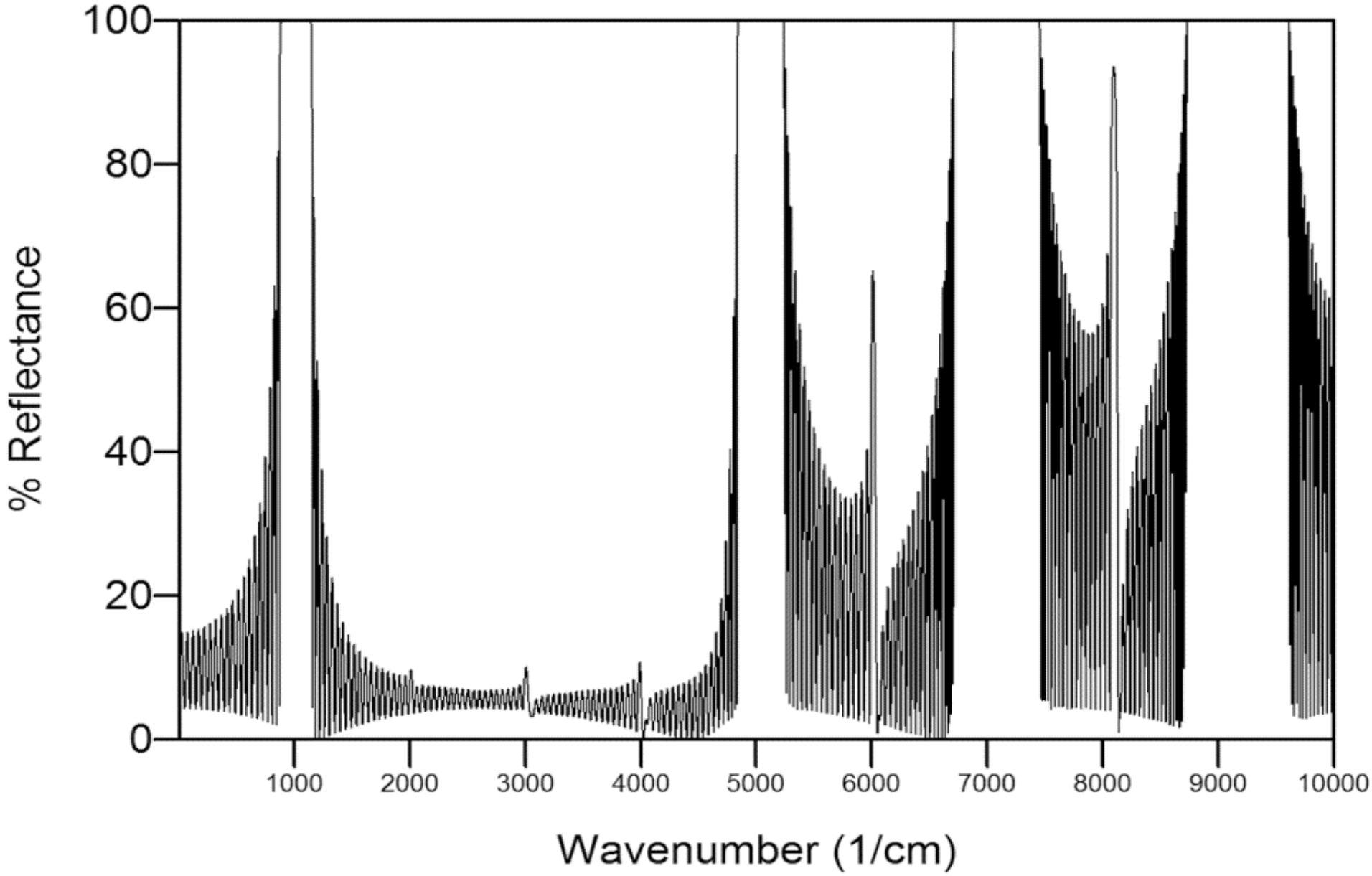


ODD HARMONIC BANDS



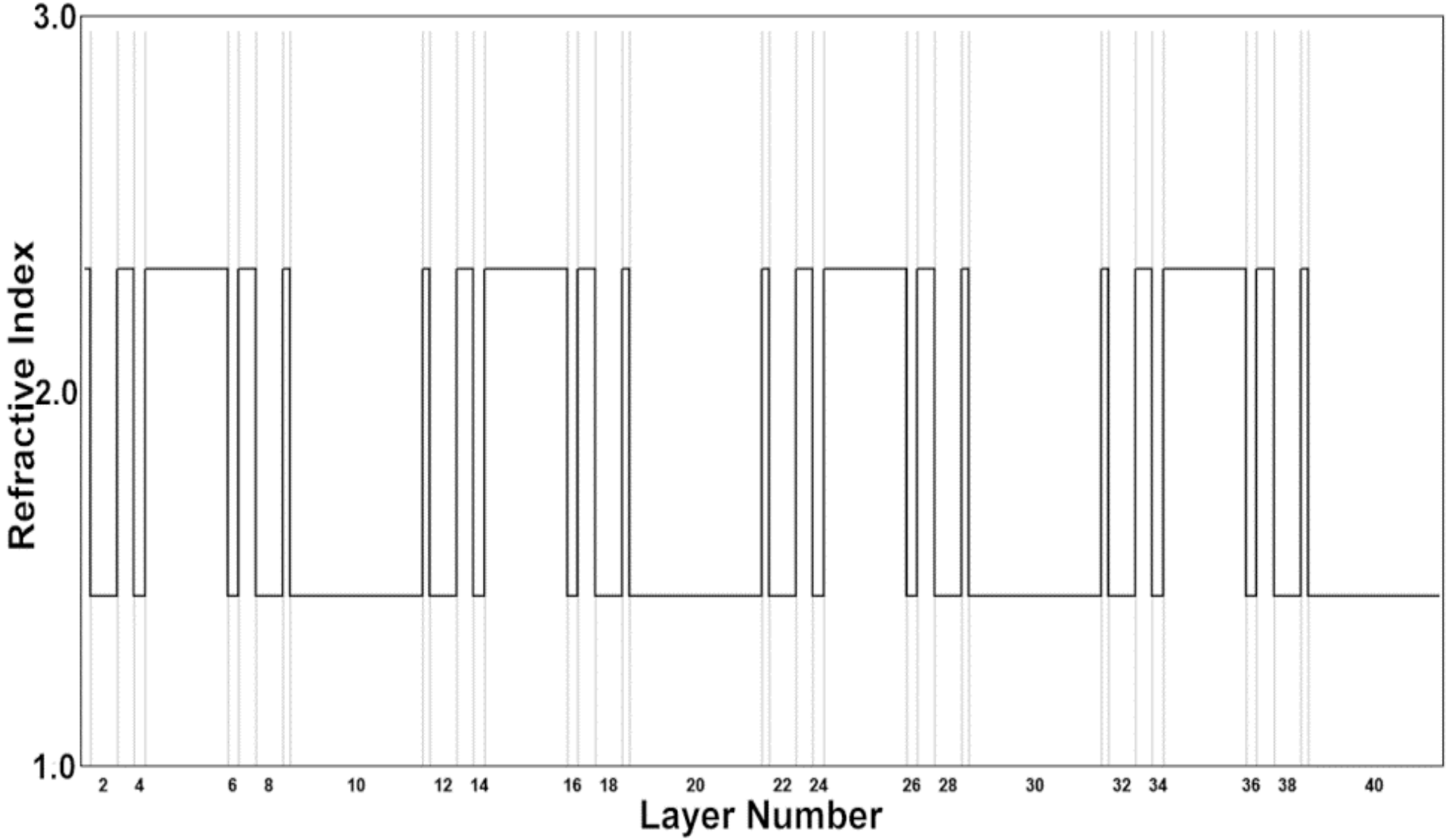


Index versus thickness profile of symmetric layer stack with 6 layers per cycle. This gives blocking bands at harmonics 1, 5, 7, etc., but NOT at the 3rd harmonic, as seen in the next slide.



Blocking- and pass-bands produced by the index versus thickness profile of the previous slide.

These substitutions of Herpin equivalent layers or Epstein periods (homogeneous layers) as **surrogates** for **rugate** (inhomogeneous) structures will be here called **“surrugate”** designs.



Index versus thickness profile of symmetric layer stack with 10 layers per cycle. This gives blocking bands at harmonics 1, 7, etc., but NOT at the 3rd and 5th harmonics, as seen in the next slide.

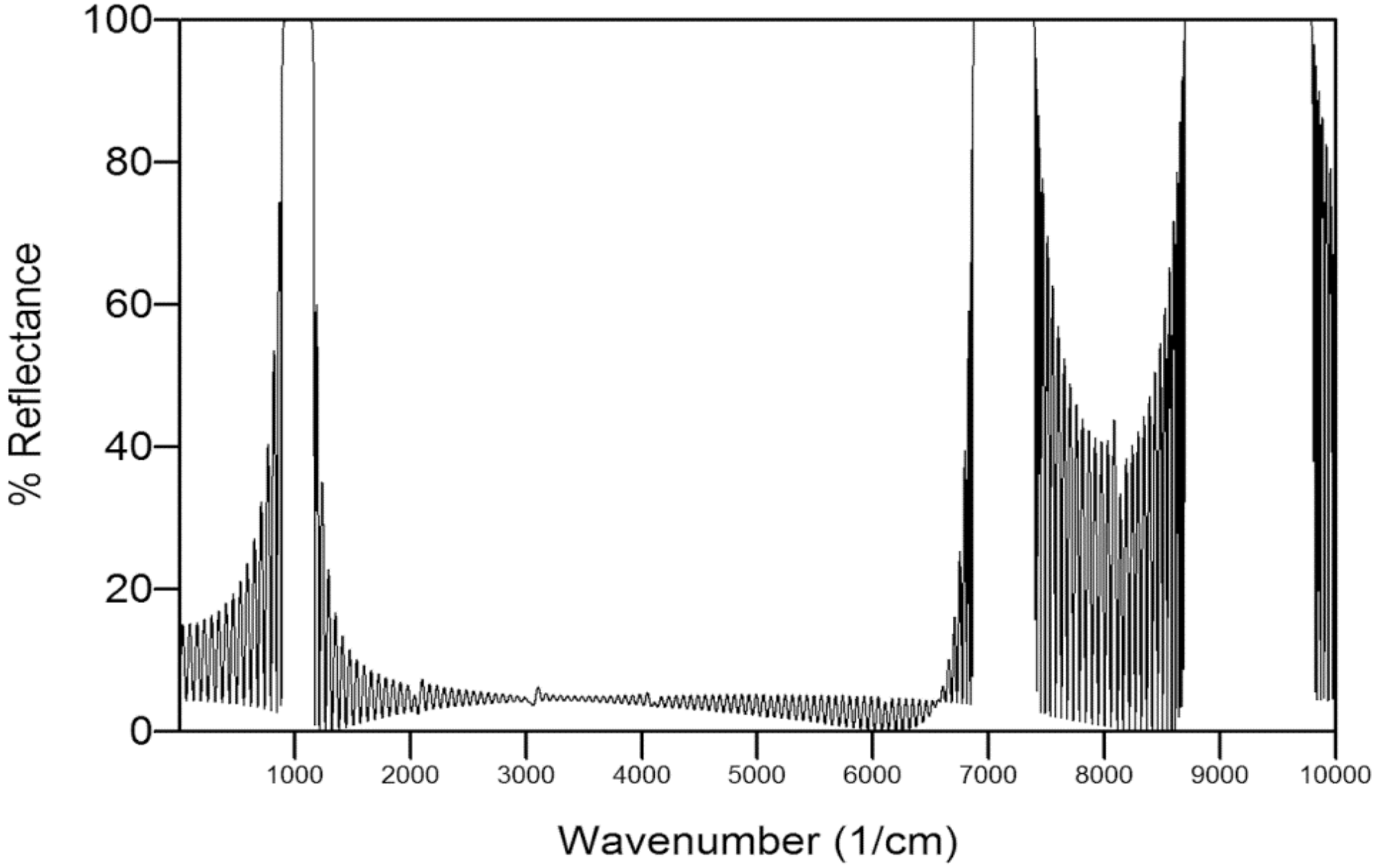
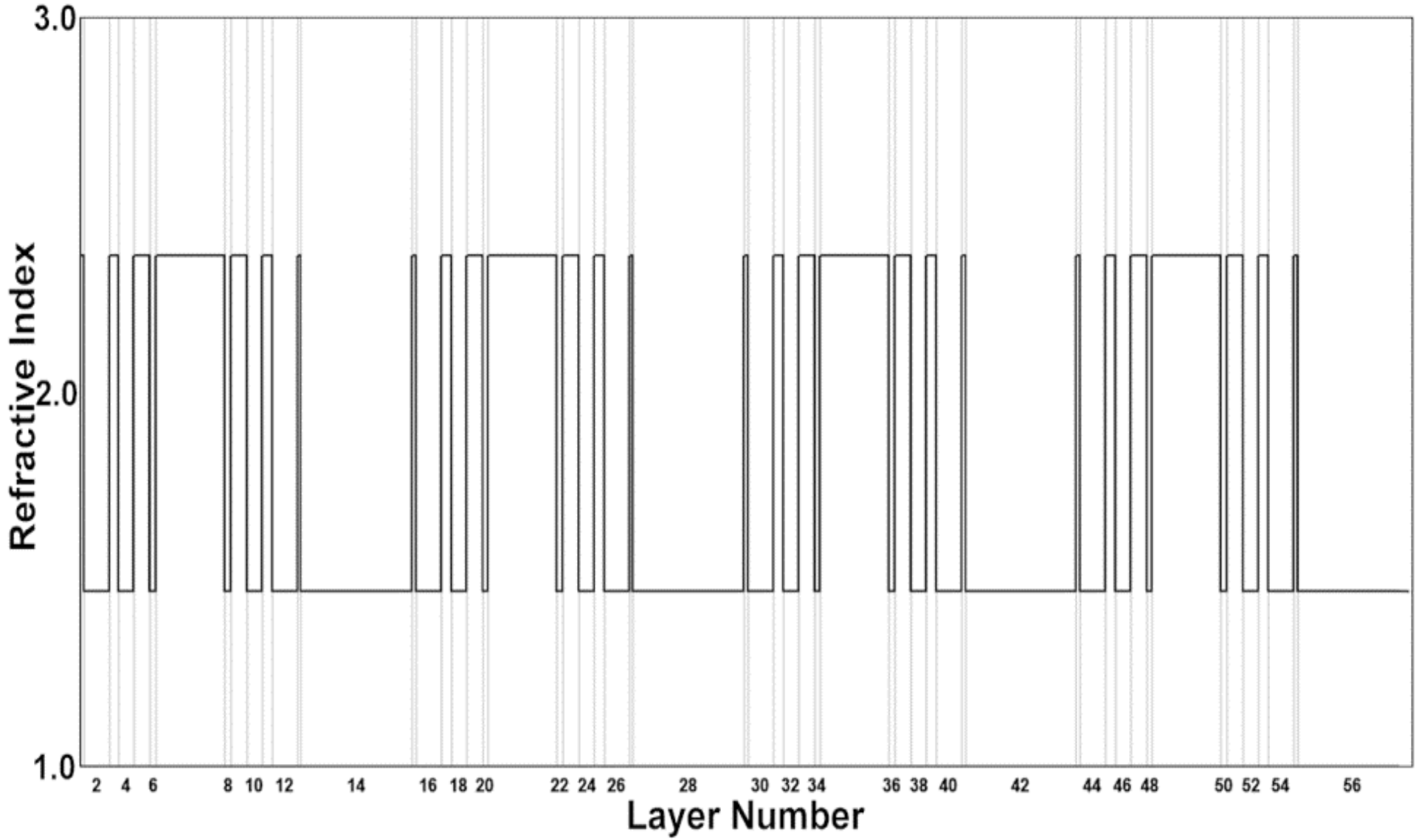
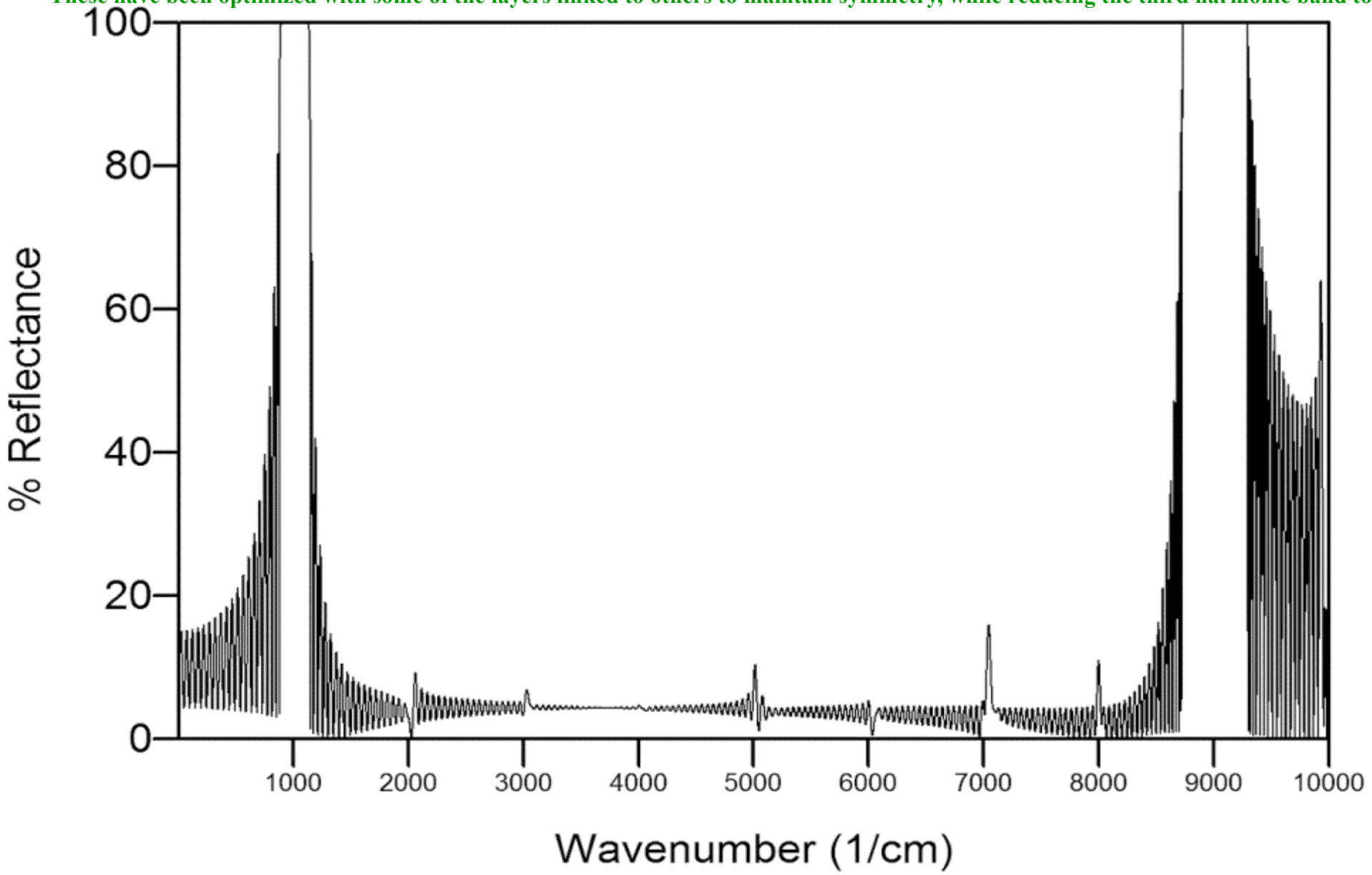


Fig. 9. Blocking- and pass-bands produced by the index versus thickness profile of the previous slide.



Index versus thickness profile of symmetric layer stack with 14 layers per cycle. This gives blocking bands at harmonics 1, 9, etc., but NOT at the 3rd, 5th, and 7th, as seen in the next slide.

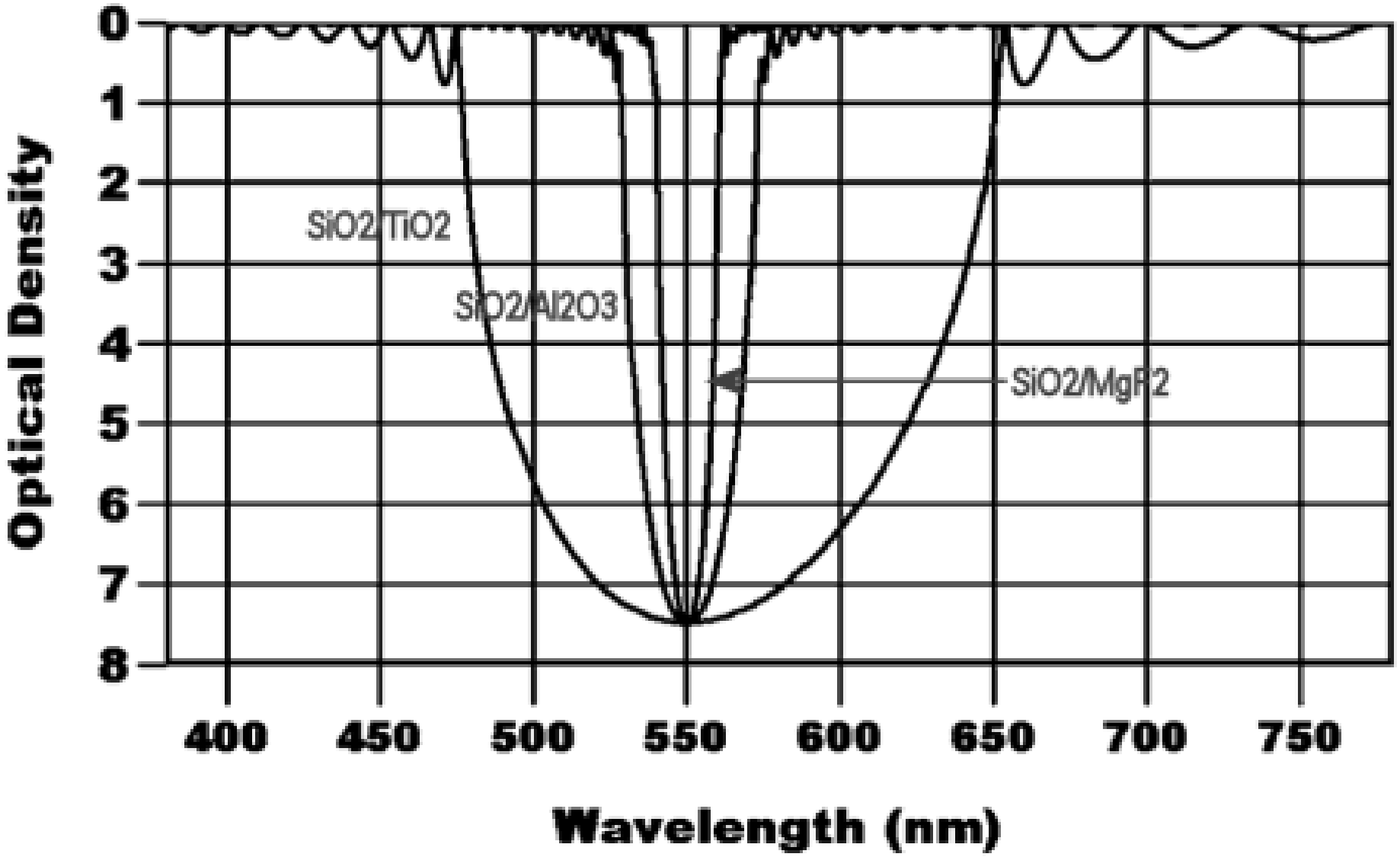
These have been optimized with some of the layers linked to others to maintain symmetry, while reducing the third harmonic band to z



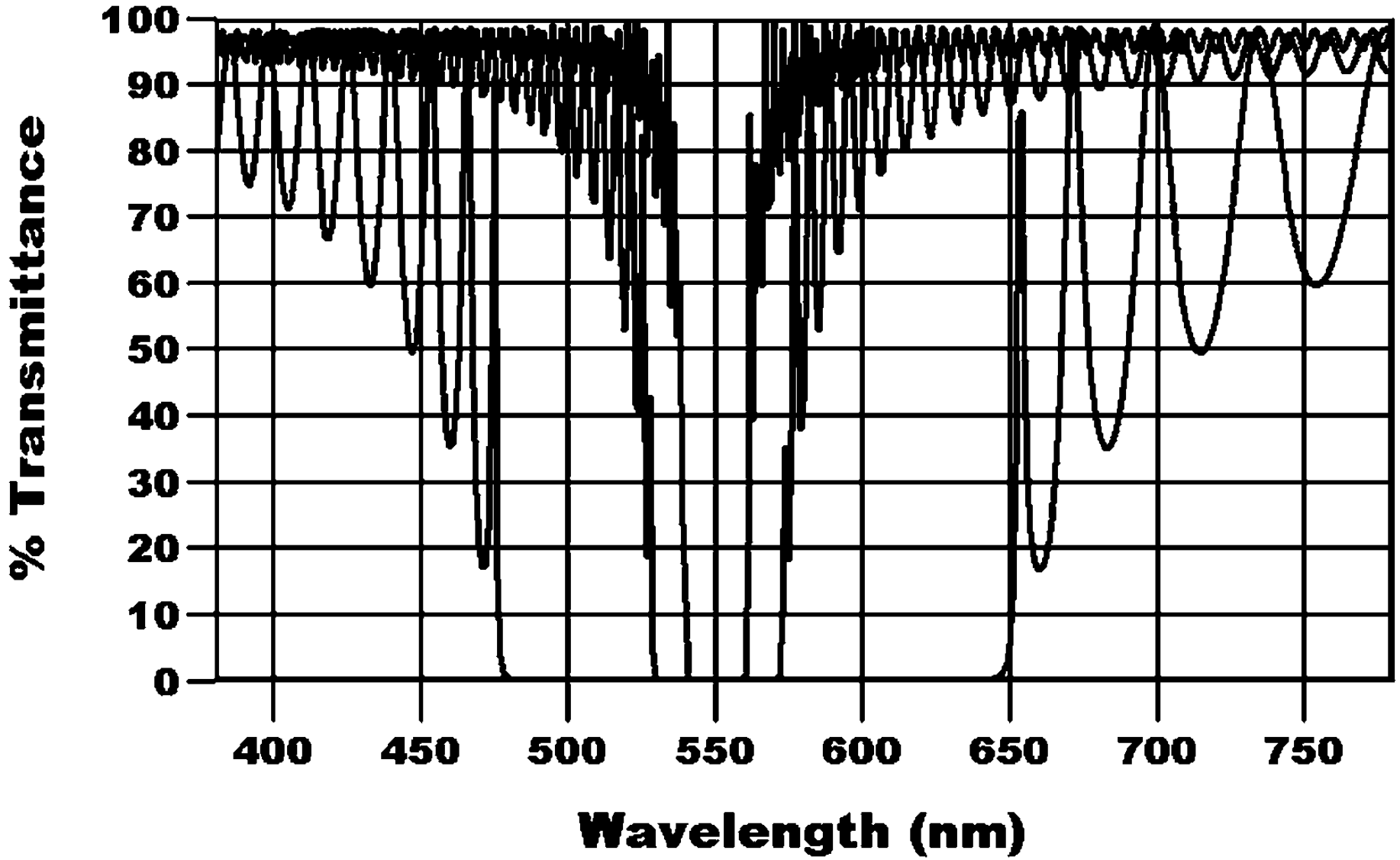
Blocking- and pass-bands produced by the index versus thickness profile of the previous slide.

LASER EYE PROTECTION

THELEN MINUS FILTERS

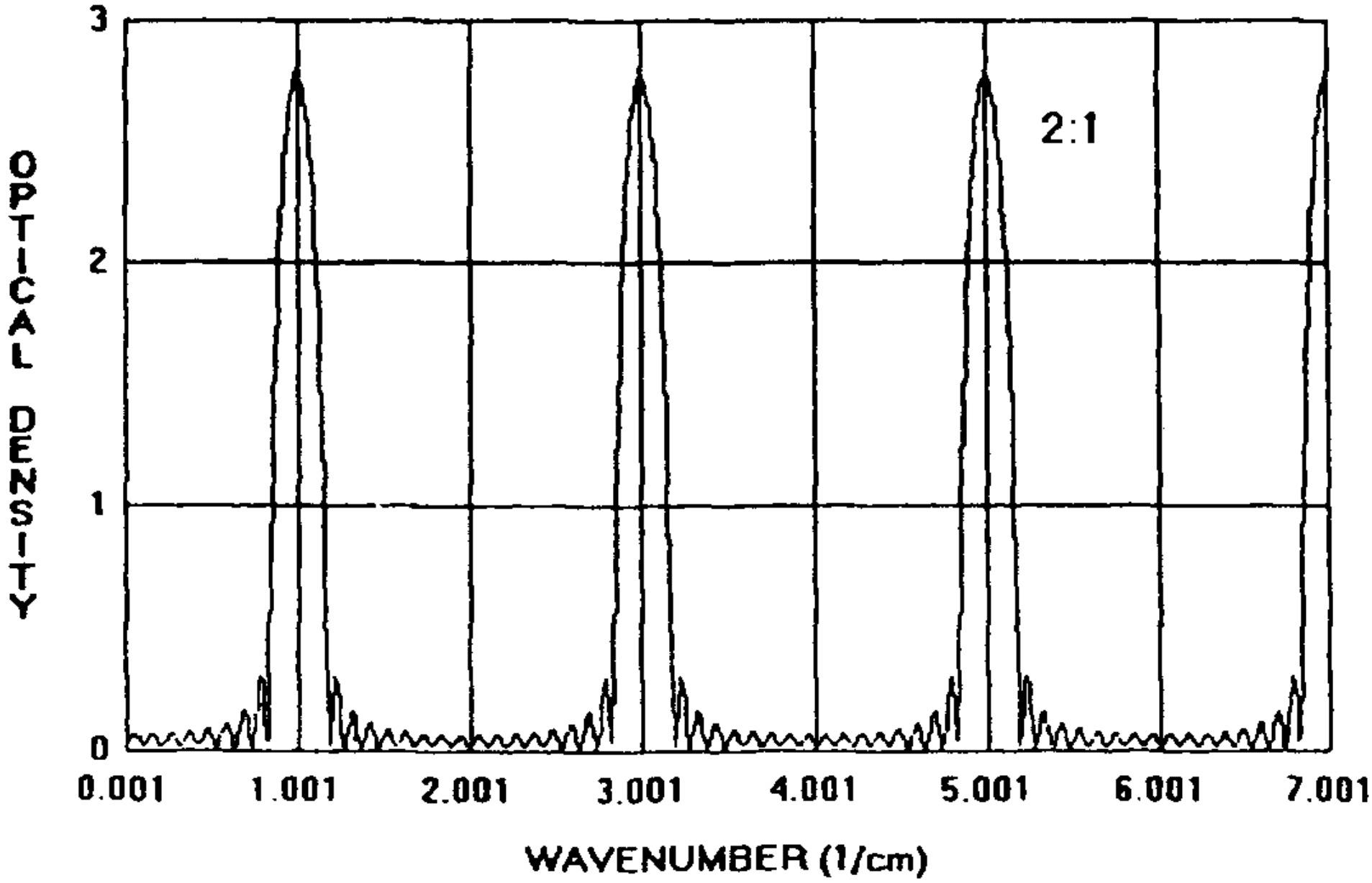


UGLY ON WAVELENGTH SCALE

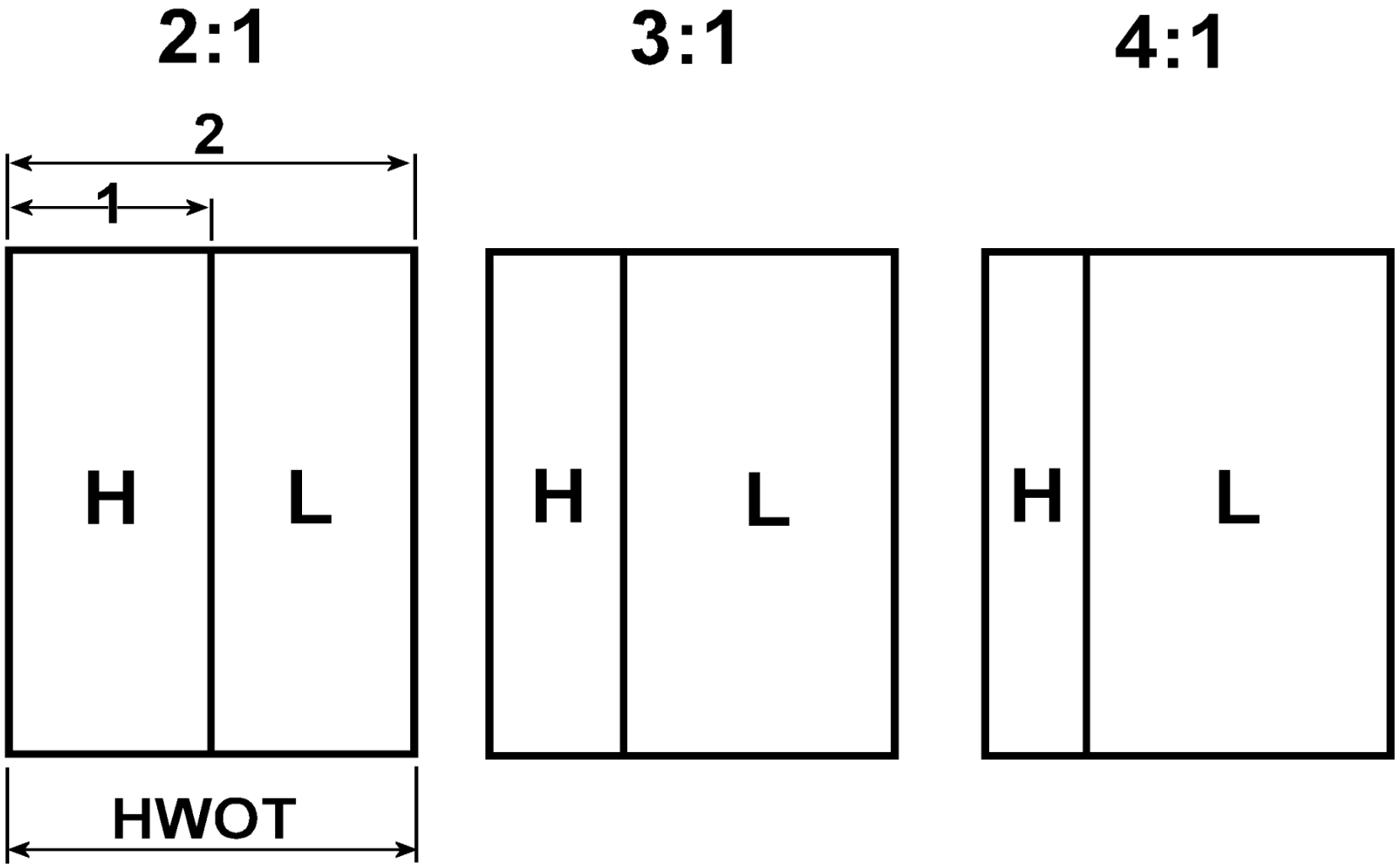


HIGHER HARMONIC REFLECTION BANDS

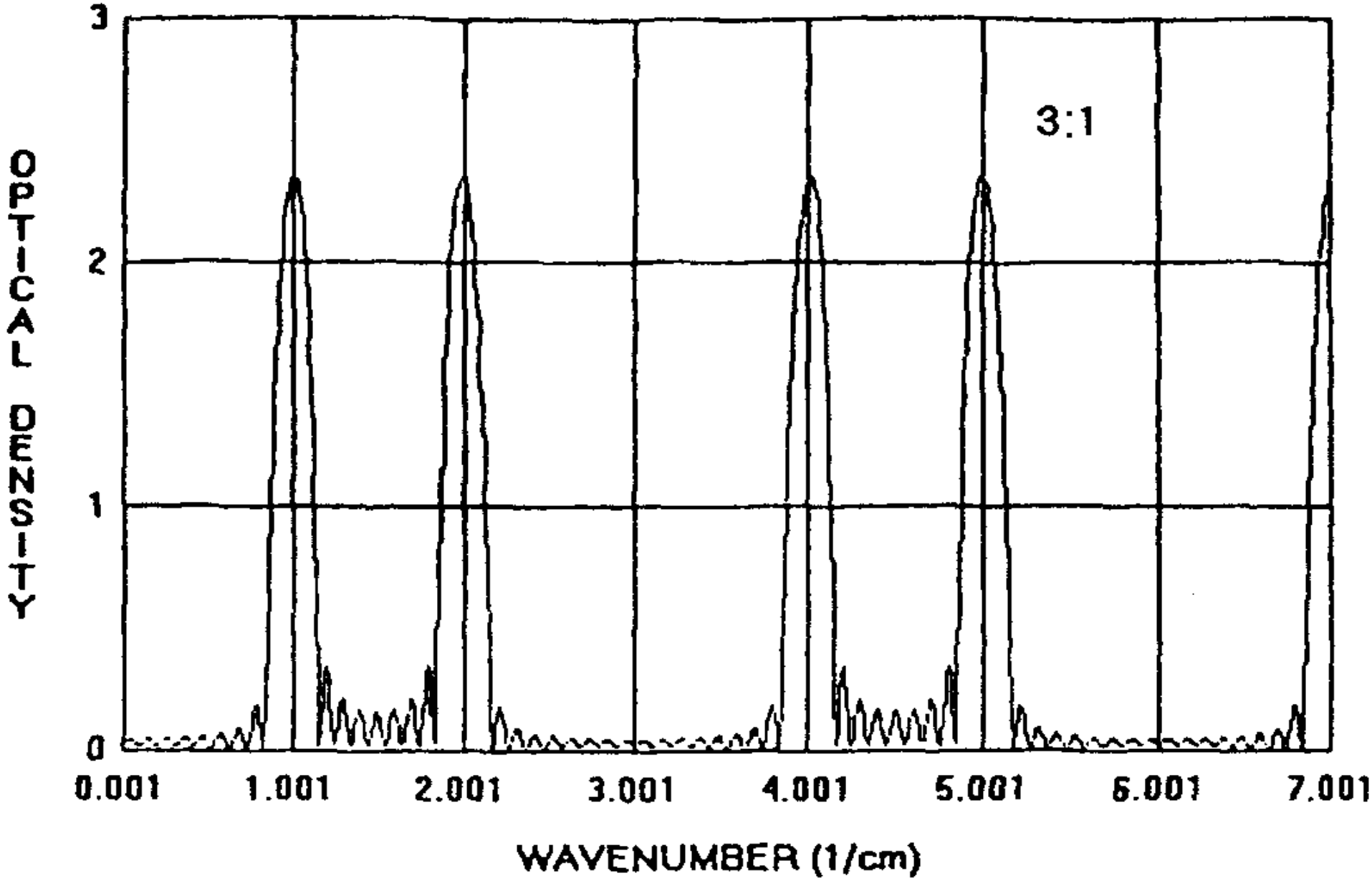
HARMONICS OF A 2:1 DESIGN



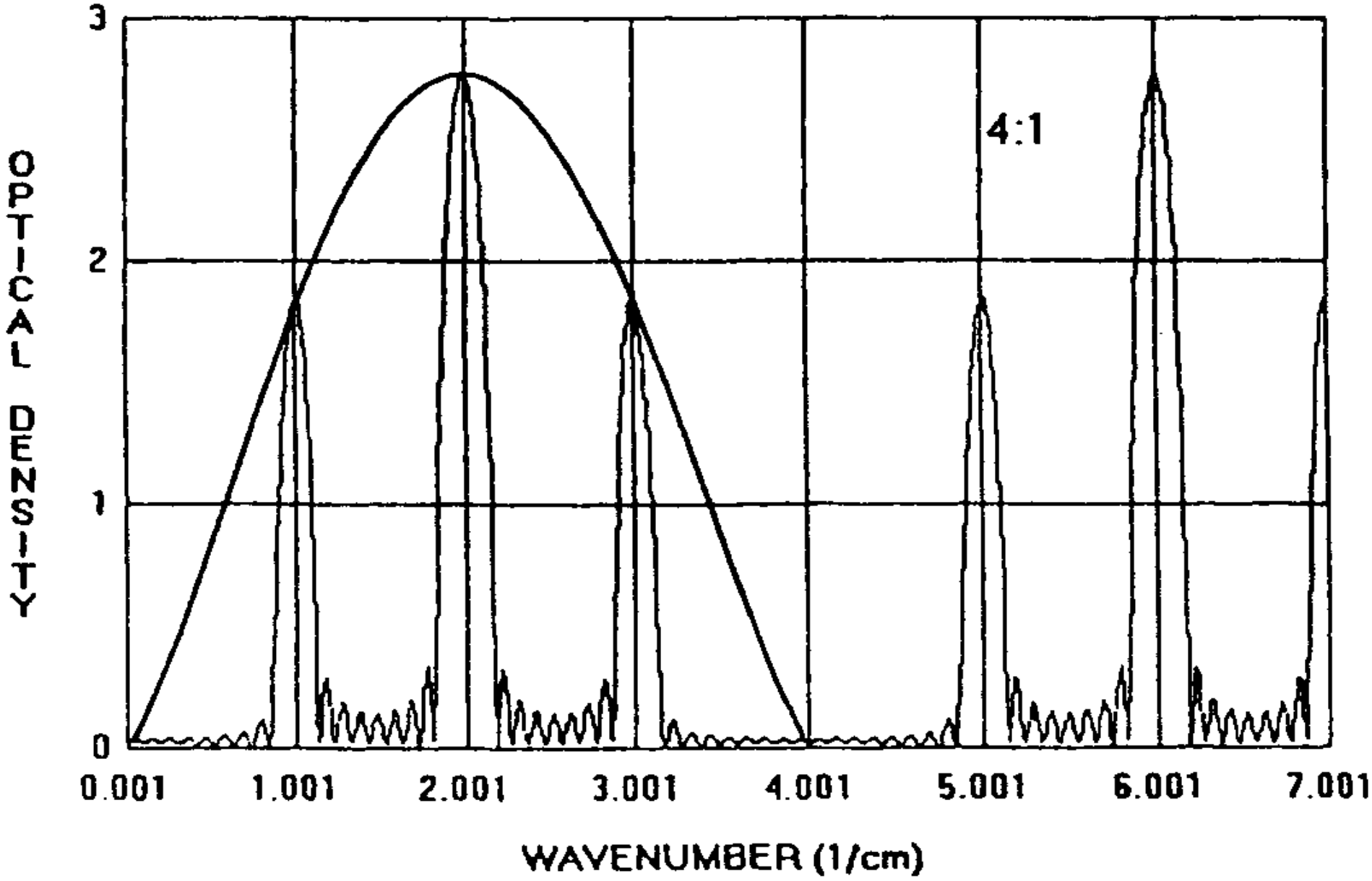
RATIO OF THINNEST LAYER



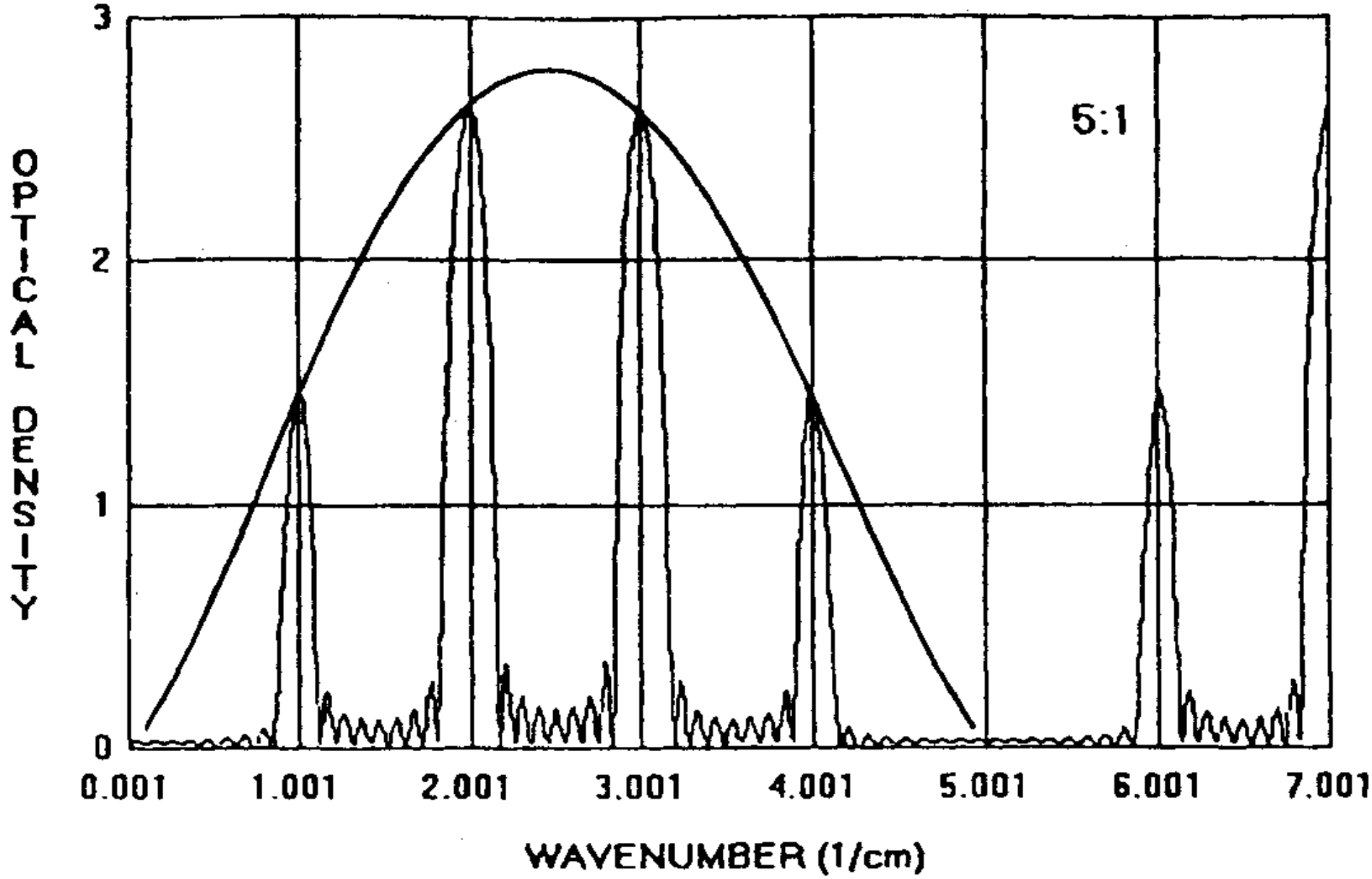
HARMONICS OF A 3:1 DESIGN



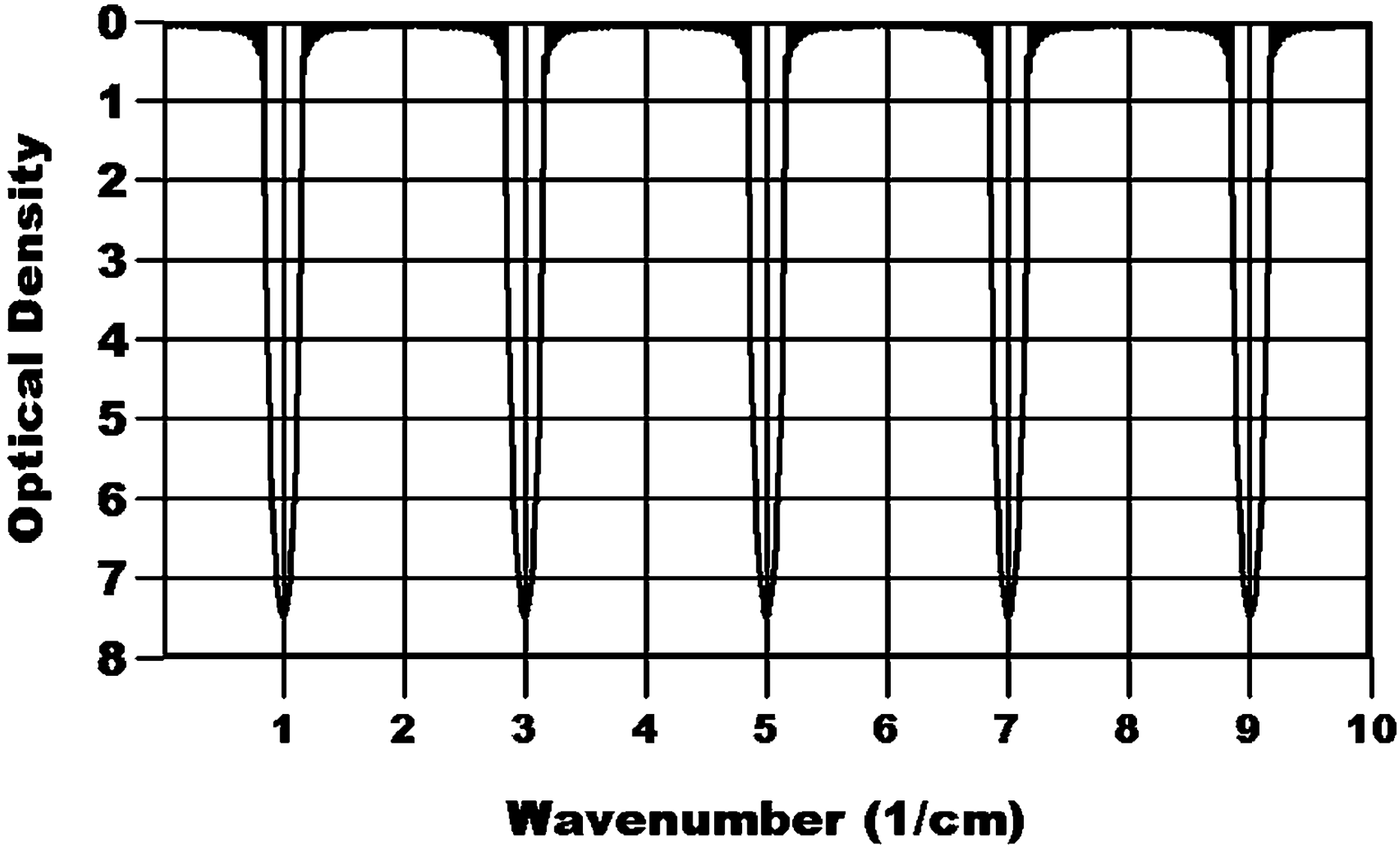
HARMONICS OF A 4:1 DESIGN



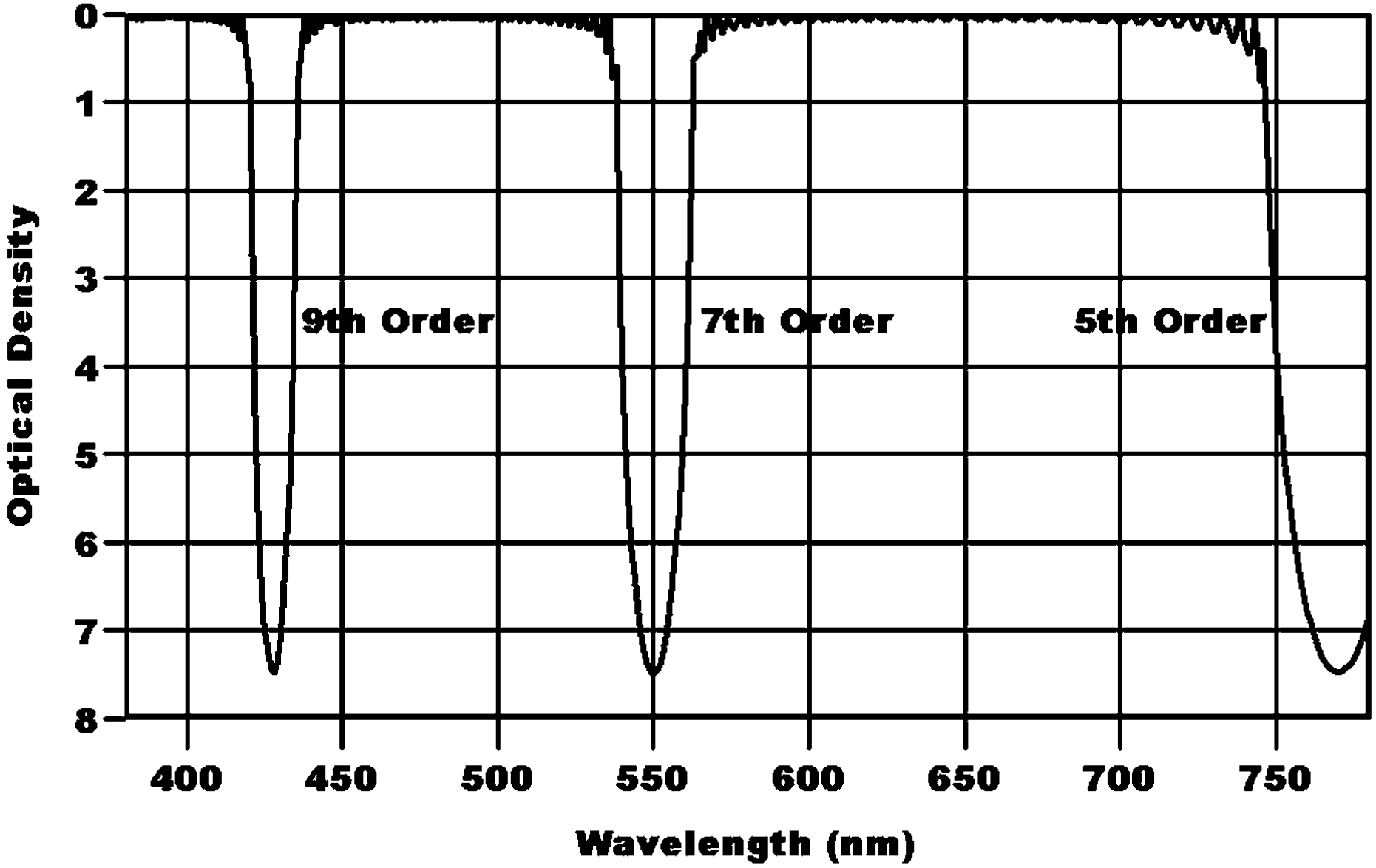
HARMONICS OF A 5:1 DESIGN



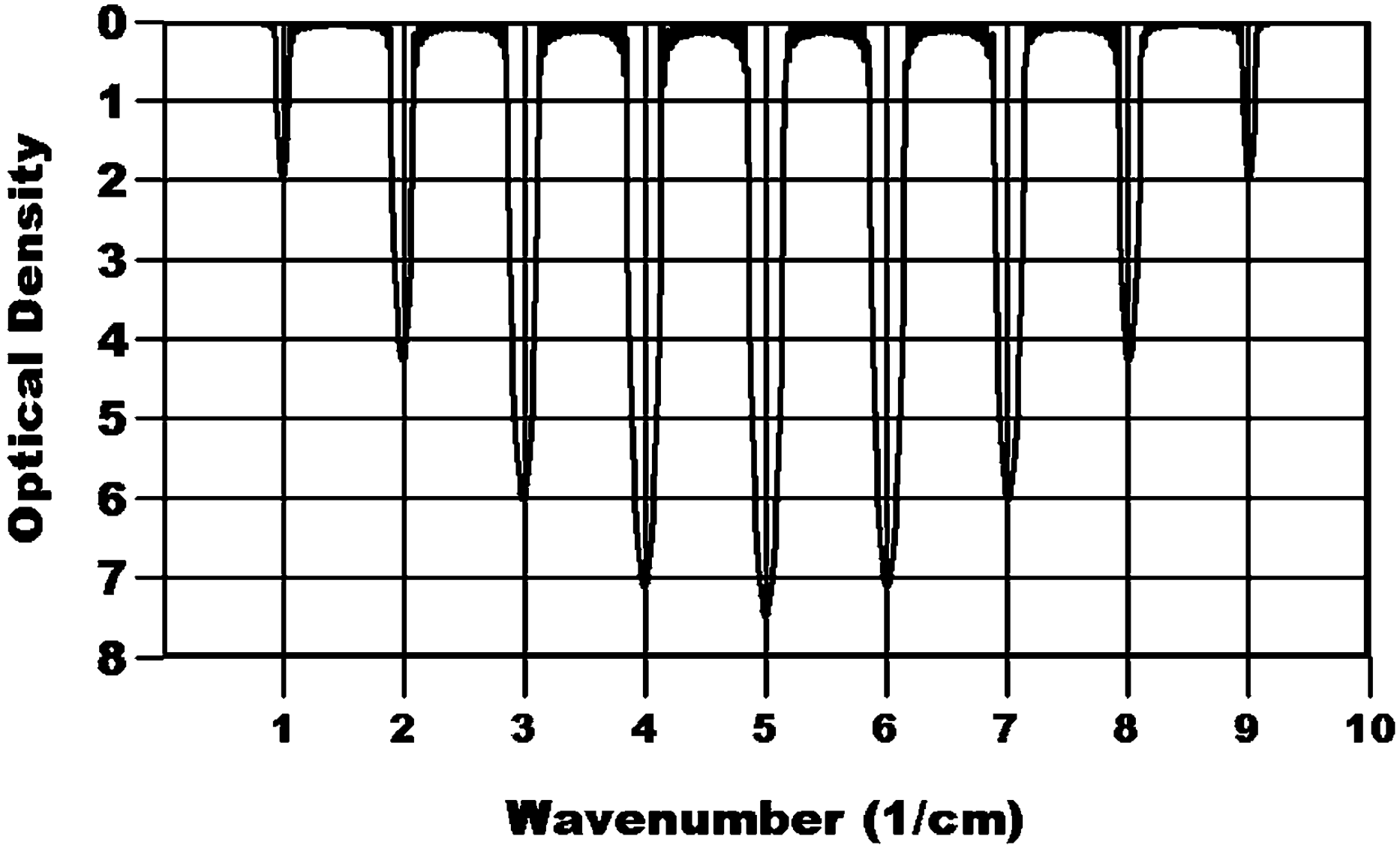
NARROW BANDS IN Δσ/σ or Δλ/λ



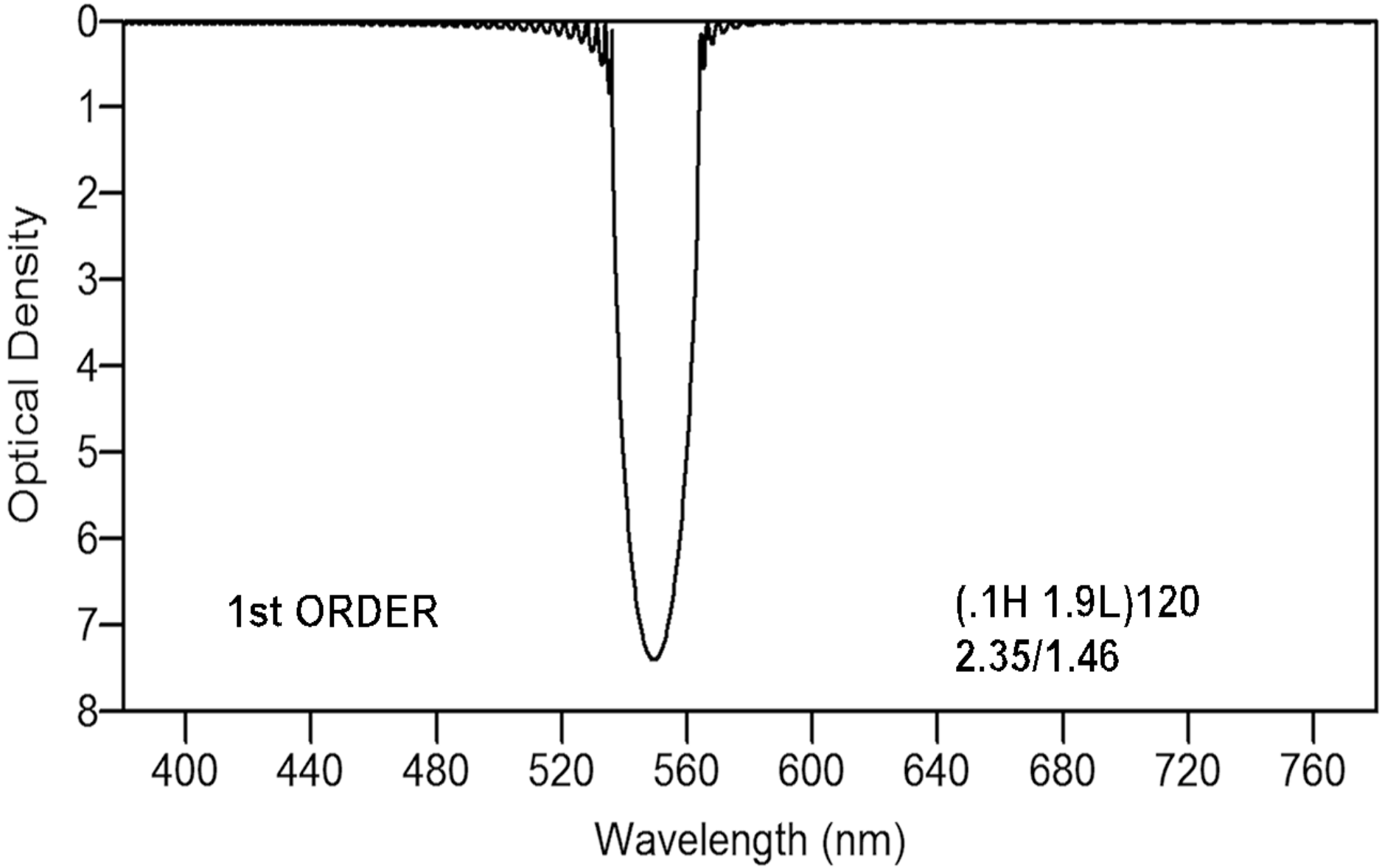
OLD HARMONIC APPROACH



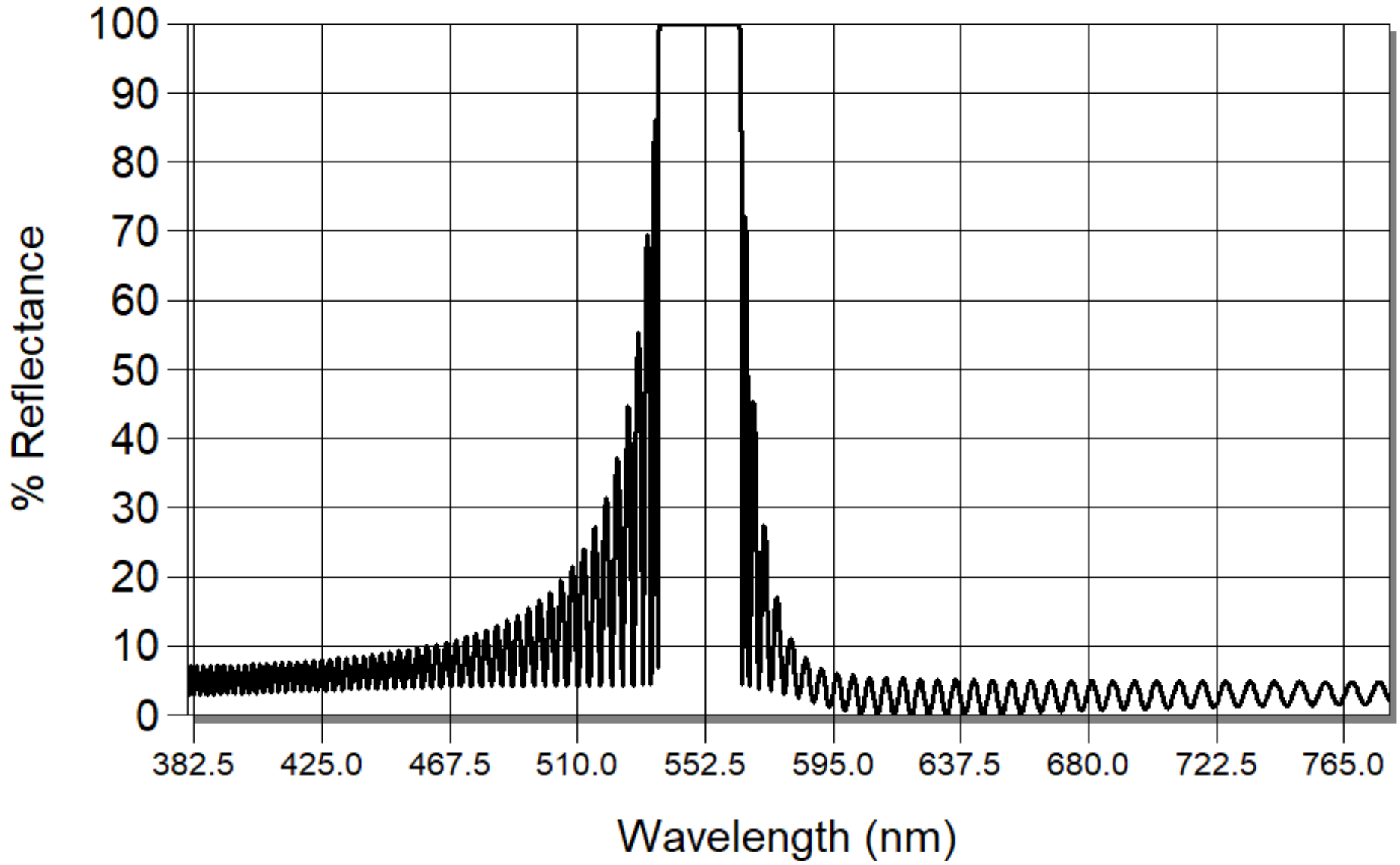
NARROW 1st & 9th HARMONICS



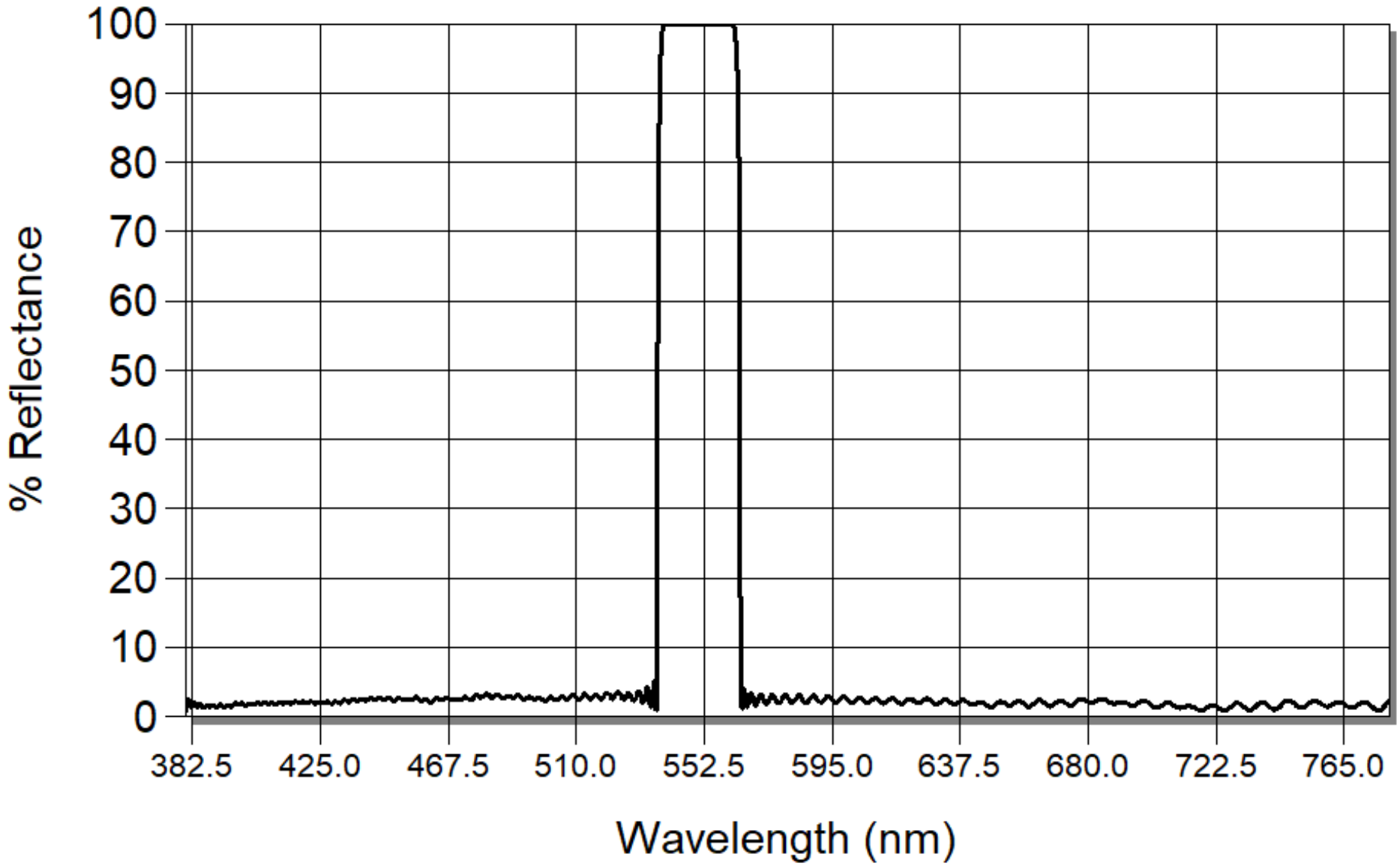
1st SAME AS 7th ORDER



Design on %T Scale



Design with Matching Layers



CONCLUSIONS

It has been shown that homogeneous layers can be used to design narrow band high reflecting mirrors, laser eye protection filters, and low reflectors like AR coatings of broad bandwidth.

Rugate designs are not needed.

Homogeneous layers are also easier to produce and control.

THANK YOU
FOR YOUR
ATTENTION

ron@willeyoptical.com