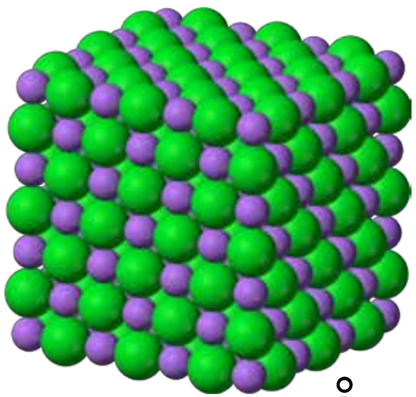
Microwave Engineering
MCC121, 7.5hec, 2014

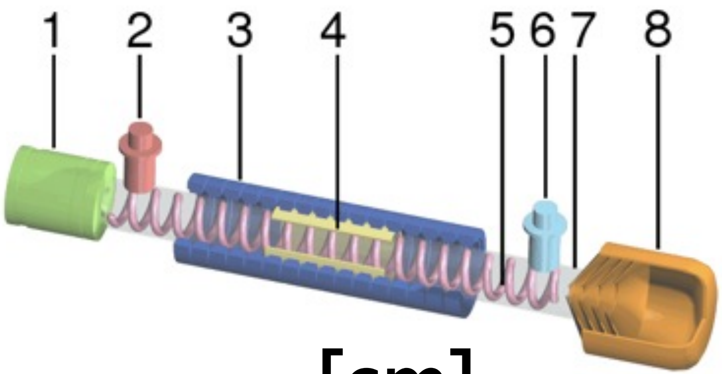
Lecture 11
Periodic structures



[Å]

State-of-the-art
Challenging
Stimulating
Rewarding

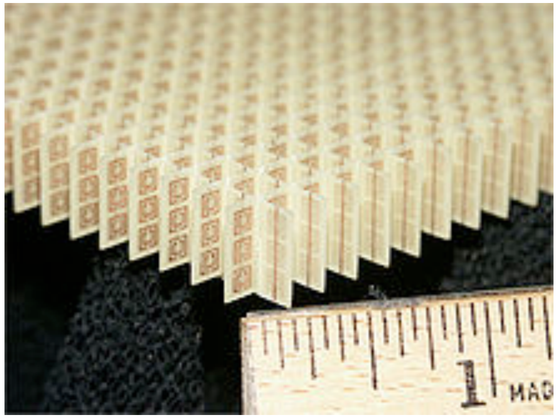
[nm]
[μm]



[cm]

Periodic structures

- EM wave propagation in periodic structures. Also called
  - photonic band gaps
  - photonic crystals
  - metamaterials
  - corrugated waveguides/surfaces
  - soft/hard surfaces
- Microwave applications:
  - miniaturised waveguides
  - antennas
  - filters
  - couplers
  - phase shifters
  - slow wave structures etc.



Course info

- Exam on January 16
- Info. in "studieportalen"

Kursplan för

MCC121 - Mikrovågsteknik

Kursplanen fastställd 2014-02-12 av programansvarig (eller motsvarande)

Ägare: MPWPS

7,5 Högskolepoäng
Betygskala: TH - Fem, Fyra, Tre, Underkänt
Utbildningsnivå: Avancerad nivå
Huvudområde: Elektroteknik, Teknisk fysik
Institution: 59 - MIKROTEKNOLOGI OCH NANOVETENSKAP

Undervisningsspråk: Engelska
Sökbar för utbytesstudenter
Blockschema: B

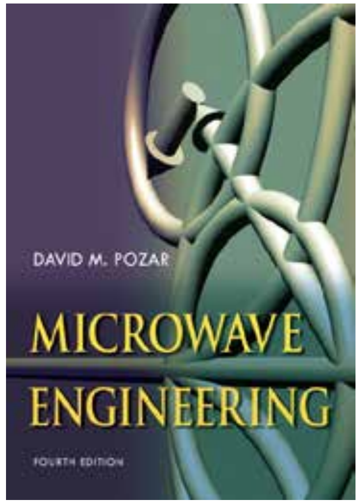
Poängfördelning

Kursmoment	Lp1	Lp2	Lp3	Lp4	Sommarkurs	Ej Lp	Tentamensdatum
0111 Laboration 1,5hp		1,5hp					
0211 Tentamen 6,0hp		6,0hp					16 Jan 2015 em V, 13 Apr 2015 em V, 26 Aug 2015 em J

I program
KOMMUNIKATIONSSYSTEM, MASTERPROGRAM, Årskurs 2
INBYGGDA ELEKTRONIKSYSTEM, MASTERPROGRAM, Årskurs 2
TRÅDLÖS TEKNIK, FOTONIK OCH RYMDTEKNIK, MASTERPROGRAM, Årskurs 1

Items allowed at the exam

- This is an open book exam. The following is allowed:
  - Calculator (approved by Chalmers)
  - ”Microwave Engineering” by D.M. Pozar
  - Mathematics handbook (Beta)
  - Smith charts



Examination MCC121 - 7.5 hec

- List of compulsory tasks:
  - Lab 1-3 : Pass/Not passed
  - Assignment: 10p (Pass ≥4p)
- Written exam: 6x10p=60p (Pass ≥24p)
- Total number of points: 70p. Note! Bonus from assignment only counted at first exam.
- You need to pass each task described above
- Final grades: 3 (≥28p), 4(≥42p) and 5 (≥56p)

Outline

- Course info
- Periodic structures (8.1)
  - Wave propagation in periodic structures
  - Slow wave structures
  - Bloch waves
  - Brillouin diagram (k-ß)
  - Photonic crystals (1D, 2D and 3D)
- Summary of the course, questions

Maxwell's equations

$\nabla \cdot \mathbf{D} = \rho_f$ Gauss's law

$\nabla \cdot \mathbf{B} = 0$

$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$ Faraday's law

$\nabla \times \mathbf{H} = \mathbf{J}_f + \frac{\partial \mathbf{D}}{\partial t}$ Ampere's law with Maxwell's correction

Helmholtz equation

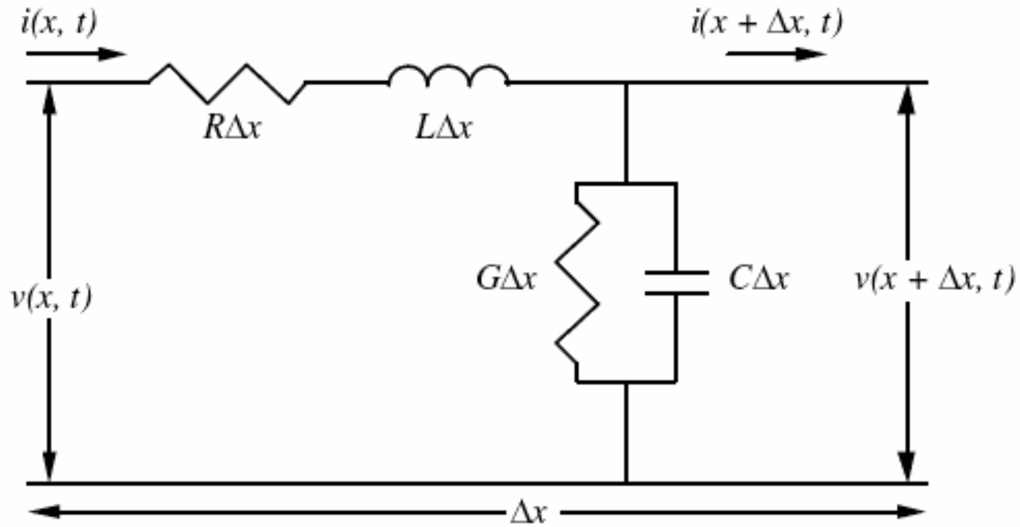
- Assume no sources:

$$\nabla^2 \overline{E} + k_0^2 \overline{E} = 0$$
$$\nabla^2 \overline{H} + k_0^2 \overline{H} = 0$$

$$k = \omega\sqrt{\varepsilon\mu}$$

- Cross section or electrical properties do not vary along z-axis (axial uniformity)
- Separable: assume solution f(z)g(x,y)

Telegrapher's equations



Distributed Element Model of a Transmission Line

TD

$$\frac{\partial v(z,t)}{\partial z} = -Ri(z,t) - L\frac{\partial i(z,t)}{\partial t}$$

$$\frac{\partial i(z,t)}{\partial z} = -Gv(z,t) - C\frac{\partial v(z,t)}{\partial t}$$

Wave equations

FD

$$\frac{\partial^2 V}{\partial z^2} - \gamma^2 V = 0$$

$$\frac{\partial^2 I}{\partial z^2} - \gamma^2 I = 0$$

$$\gamma = \alpha + j\beta = \sqrt{(R + j\omega L)(G + j\omega C)}$$

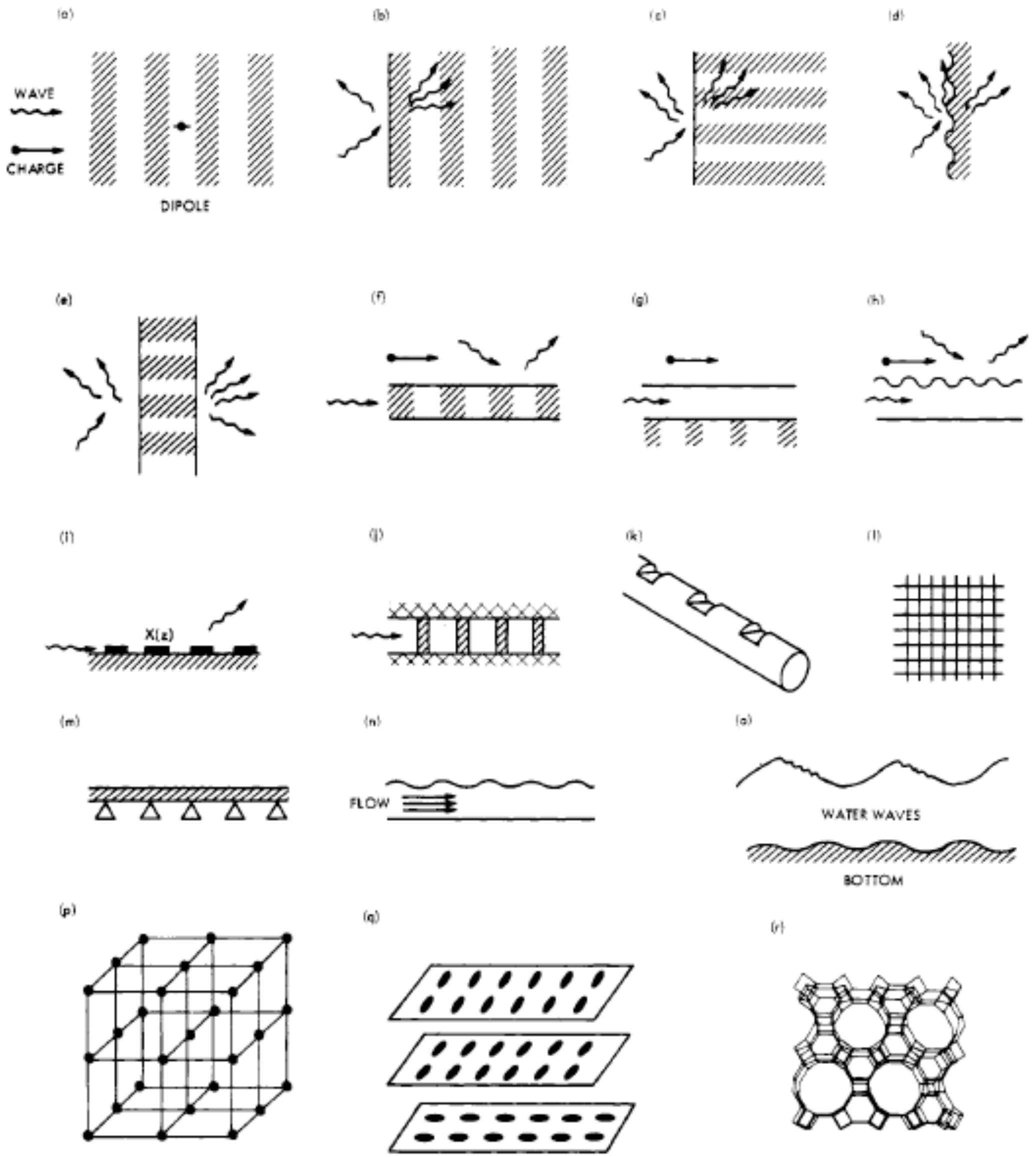
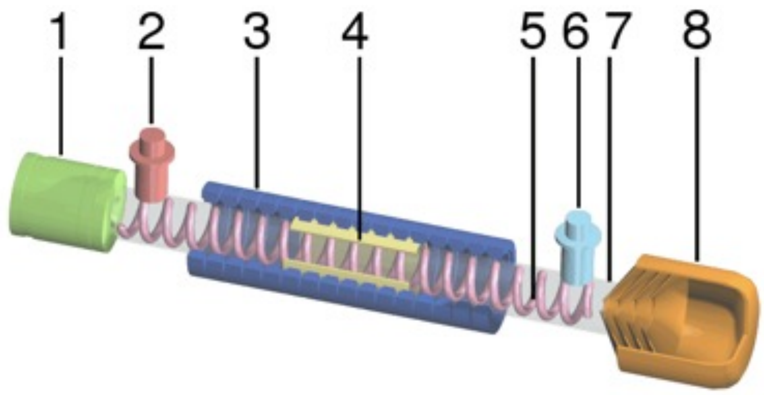


Fig. 1. Periodic structure configurations reviewed in this paper. (a) Waves and particles in an unbounded periodic medium. (b), (c) Wave scattering from a periodic half-space. (d) Wave scattering from a periodic boundary. (e) Wave scattering by a thick grating. (f), (g), (h) Waves in periodic guides and particles moving near a periodic structure. (i) Waveguiding and radiation on a surface with periodic impedance. (j) Guide with periodic loading. (k) Corrugated fiber. (l) Two-dimensional periodic mechanical mesh. (m) Flexural waves in periodically supported burns. (n) Acoustic waves and flow in a periodic duct. (o) Water waves on a periodic bottom. (p), (q), (r) Waves and particles in simple crystals, cholesteric liquid crystals, and zeolite crystals, respectively.

Electron beam + Wave interaction

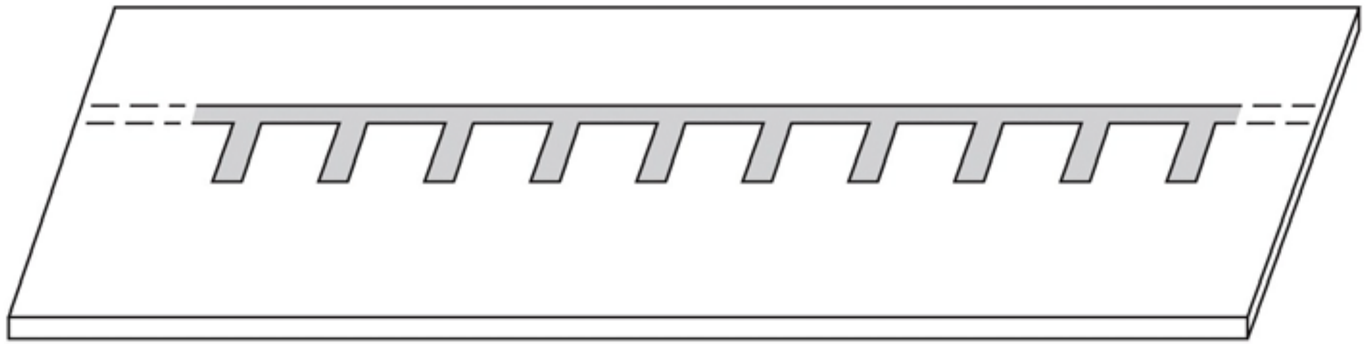
- Traveling wave tubes
- Interaction between electron beam and electromagnetic wave
- Efficient interaction only if equal phase velocities



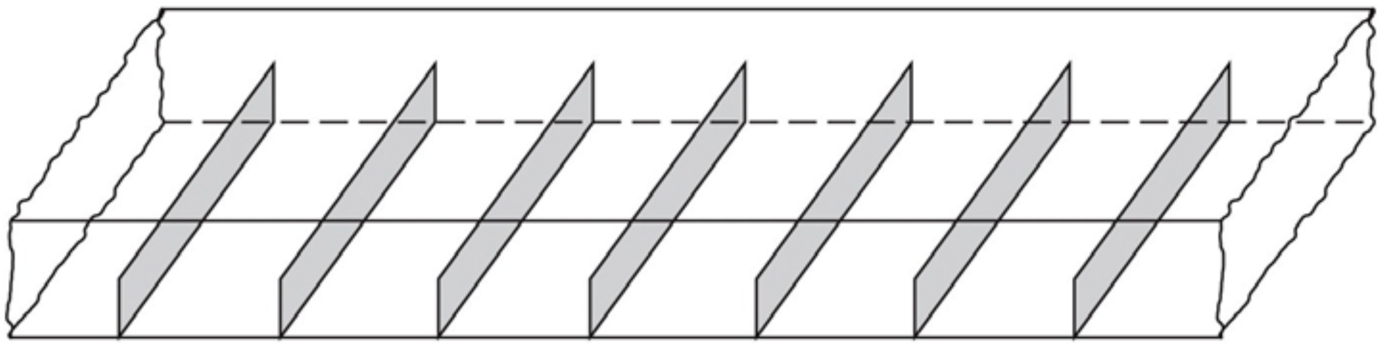
Slow wave structures

$$v_p = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{\mu_o \varepsilon_r \varepsilon_o}}$$

- Increasing dielectric constant or Increase capacitance per unit length => reduced cross section, higher order modes
- Solution: add shunt capacitor periodic intervals
- If spacing small compared to wavelength, it may be considered as an electrically smooth line, with a higher capacitance per unit length (without affecting the series inductance)



(a)



(b)

Figure 8.1

Periodic structures

Unit cell

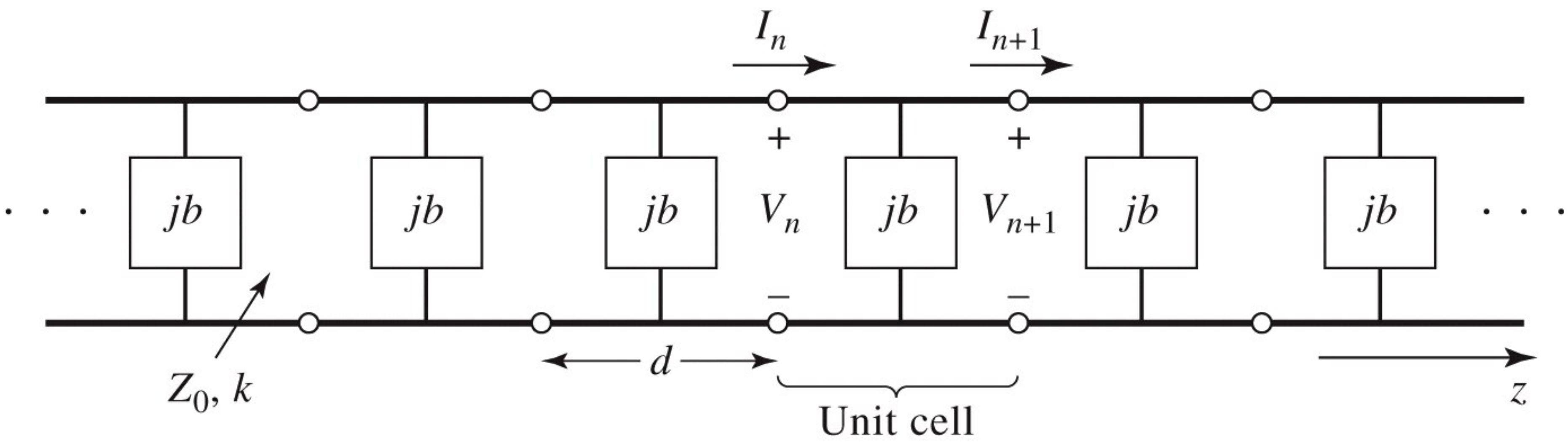
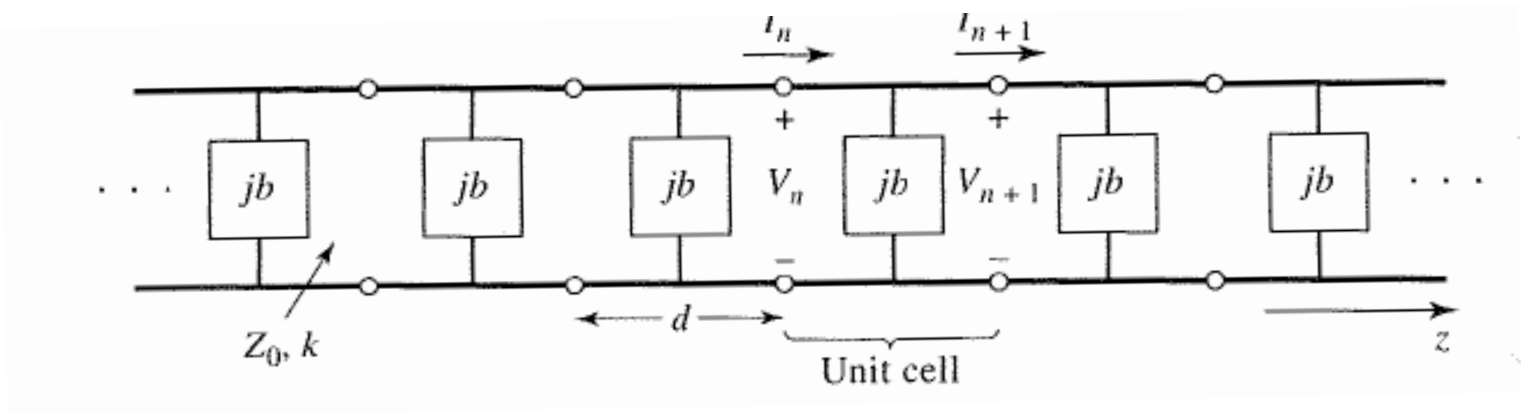


Figure 8.2

- *On white board: Analysis of infinite periodic structures.*



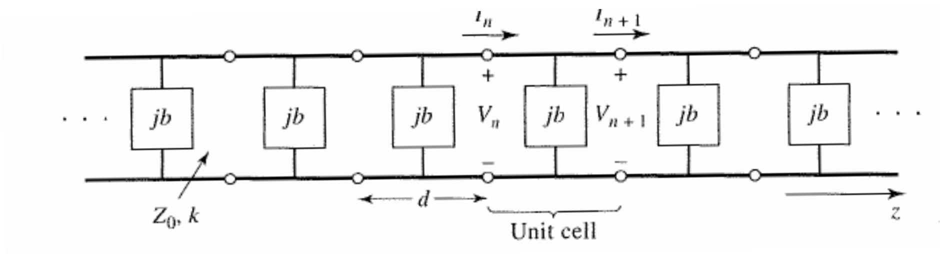
Summary EQs

Unit cell
$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cos\theta - \frac{b}{2}\sin\theta & j\left(\sin\theta + \frac{b}{2}\cos\theta - \frac{b}{2}\right) \\ j\left(\sin\theta + \frac{b}{2}\cos\theta + \frac{b}{2}\right) & \cos\theta - \frac{b}{2}\sin\theta \end{bmatrix}$$

Lossless
$$AD - BC = 1$$

Bloch wave
$$\begin{vmatrix} A - e^{\gamma d} & B \\ C & D - e^{\gamma d} \end{vmatrix} = 0$$

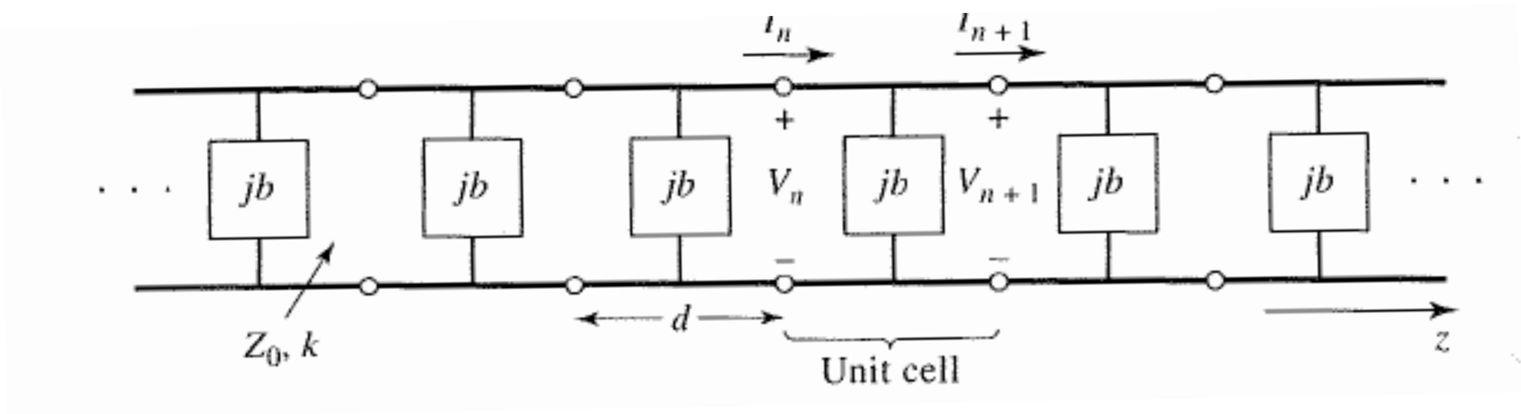
$$\Rightarrow \cosh(\gamma d) = \cos\theta - \frac{b}{2}\sin\theta$$



Filter characteristic

- Periodically loaded line
- Exhibits either stopbands or passpands depending on frequency and normalised susceptance.
- *Bloch* waves

- *On white board: Characteristic impedance.*



Terminated periodic structures

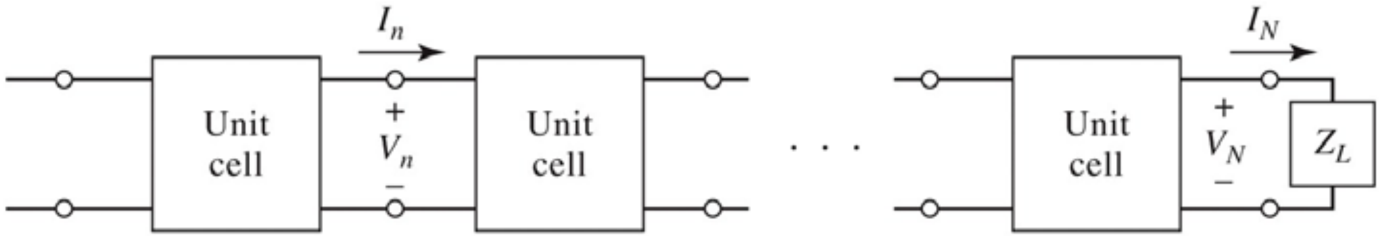


Figure 8.3

- Avoid reflections we need a transformer between the periodically line and the load

$$\Gamma = \frac{Z_L - Z_B}{Z_L + Z_B}$$ where $$Z_B = \frac{\pm B Z_0}{\sqrt{A^2 - 1}}$$

Brillouin diagram

- Propagation constant, ß, versus the propagation constant of the unloaded line, *k*. Or *k-ß* diagram

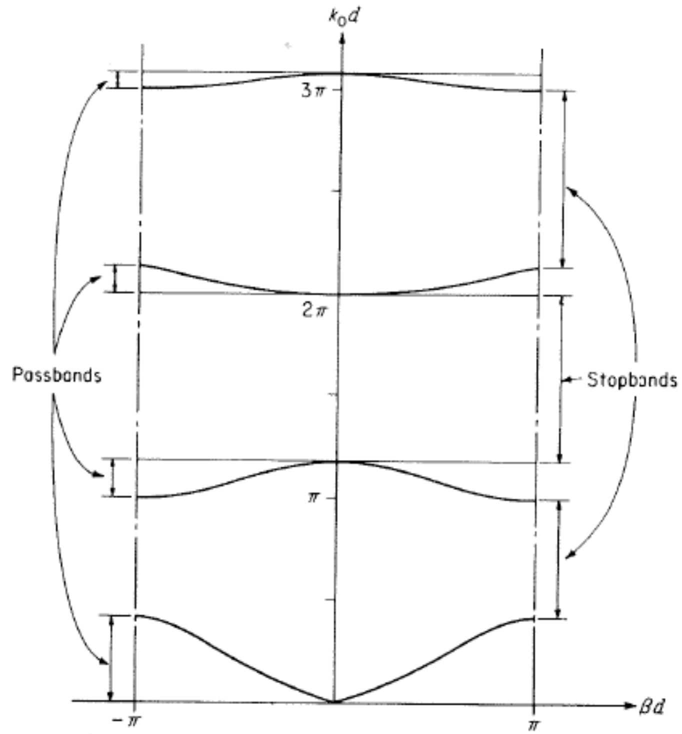


FIGURE 8.8
k_0d-βd diagram for a capacitively loaded coaxial line, $\overline{B} = 2k_0d$.

Wave velocities

- Phase velocity $$v_p = \frac{\omega}{\beta} = c\frac{k}{\beta}$$
- Group velocity $$v_g = \left(\frac{d\beta}{d\omega}\right)^{-1} = c\frac{dk}{d\beta}$$

k-*β* diagram

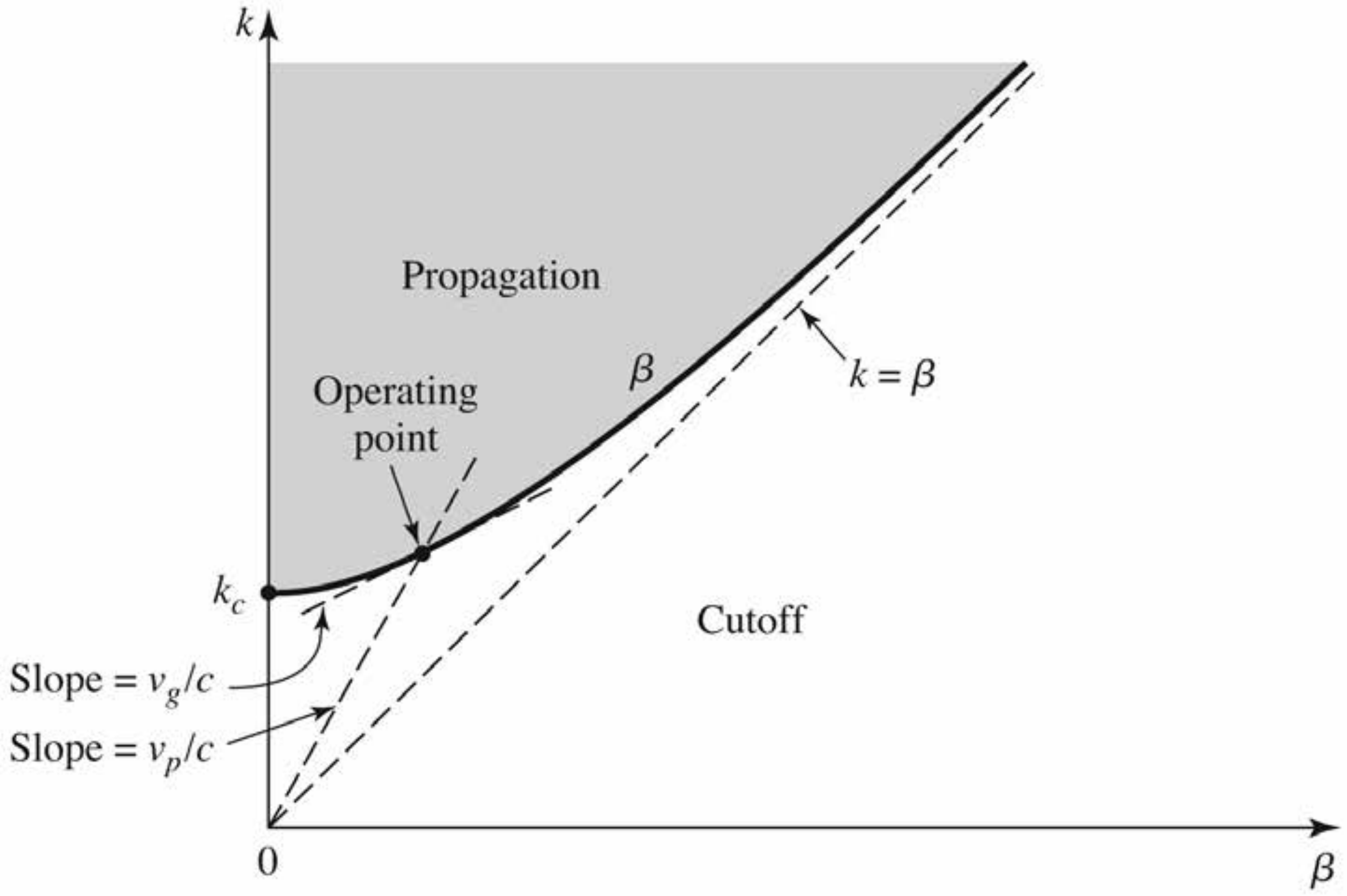


Figure 8.4

Ex) capacitively loaded line

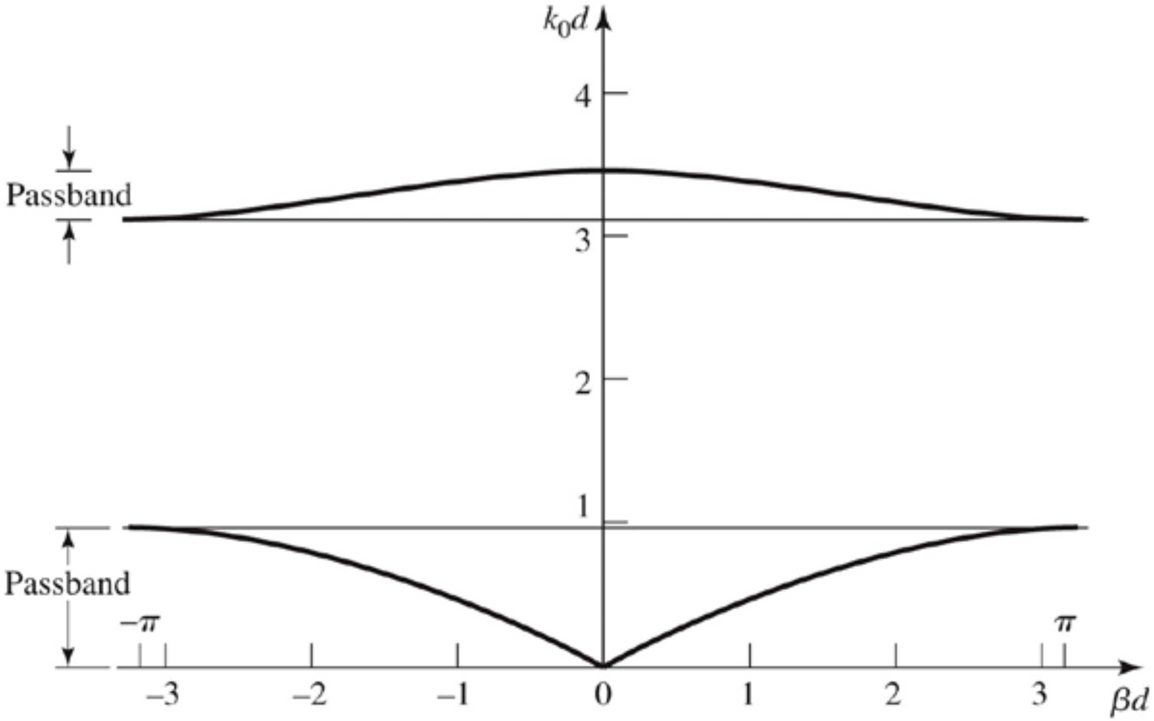


Figure 8.6

Zo=50
C_0=2.67pF
d=1cm
f=3GHz

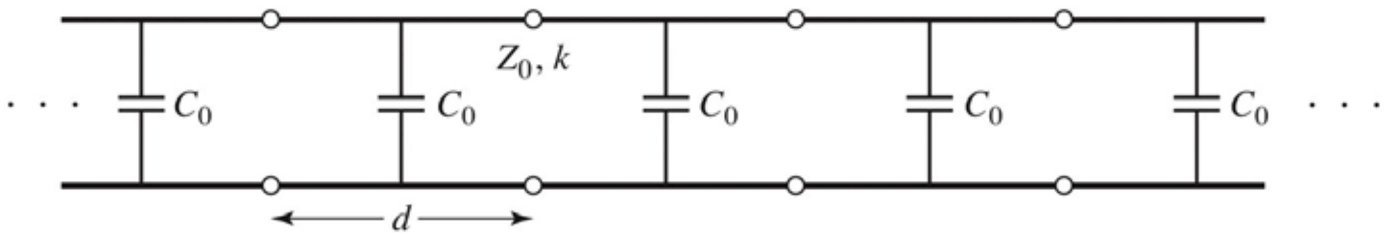


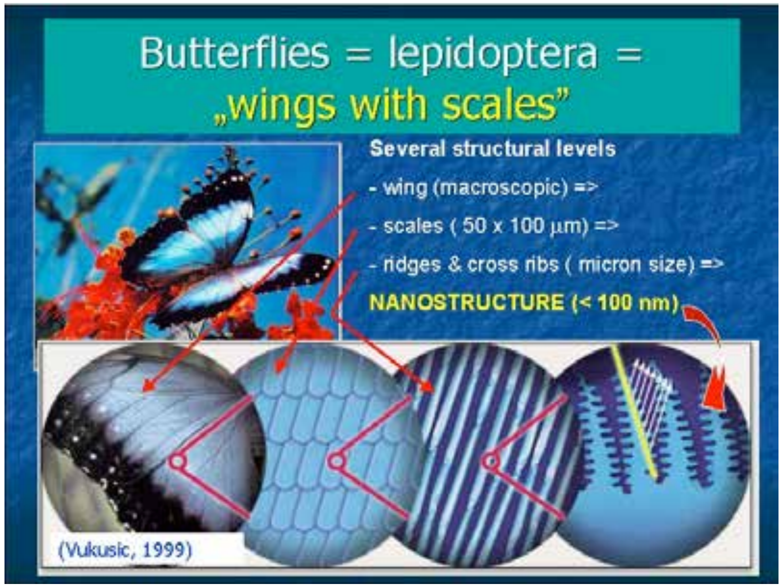
Figure 8.5

Bloch waves

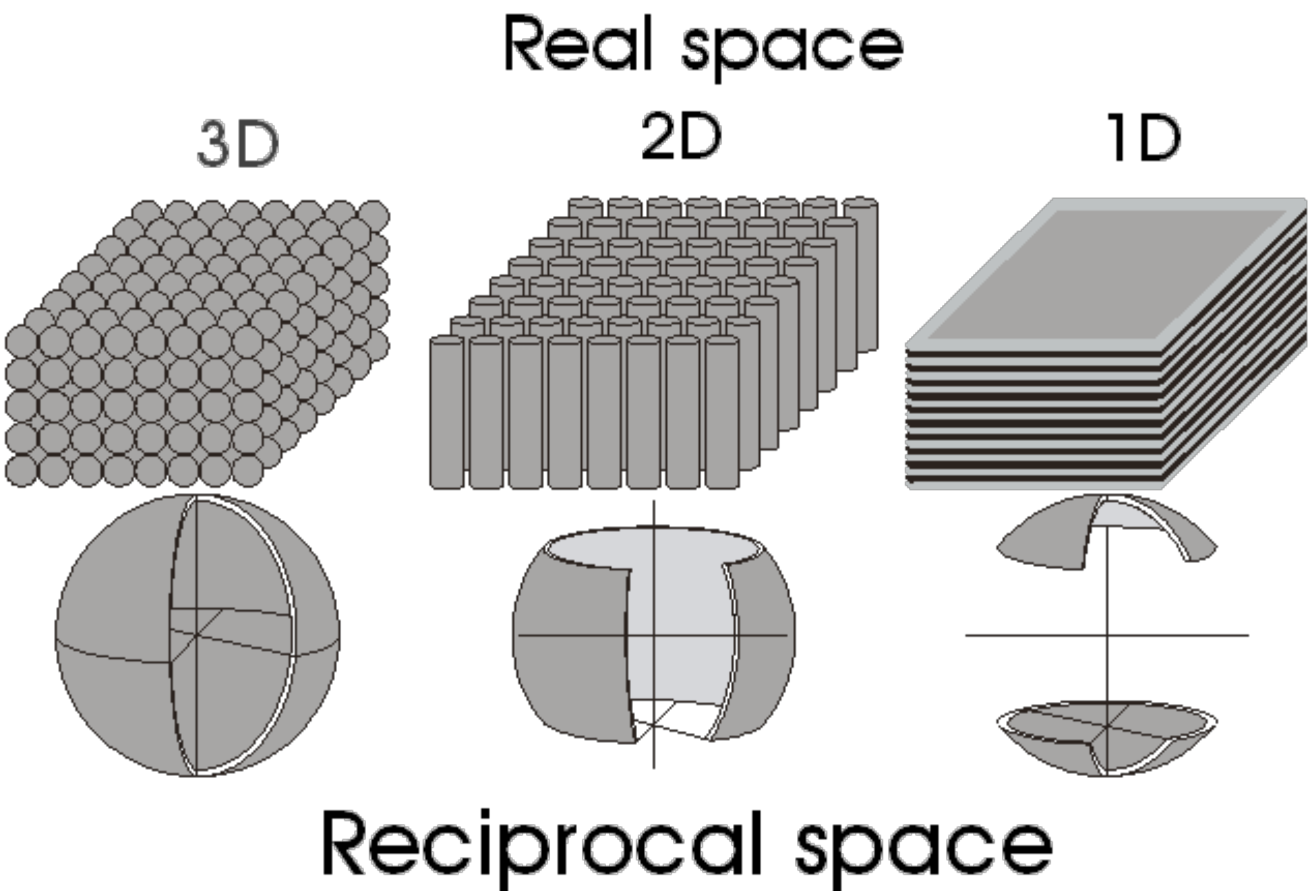
- Acoustics (elastic waves)
- Electrons in a crystal
- EM waves / Light (photons)

Periodic structures or photonic crystals

- Analogy with electrons in a crystal
- Forbidden frequencies or wavelengths = photonic bandgap (PBG)
- Appear in nature...

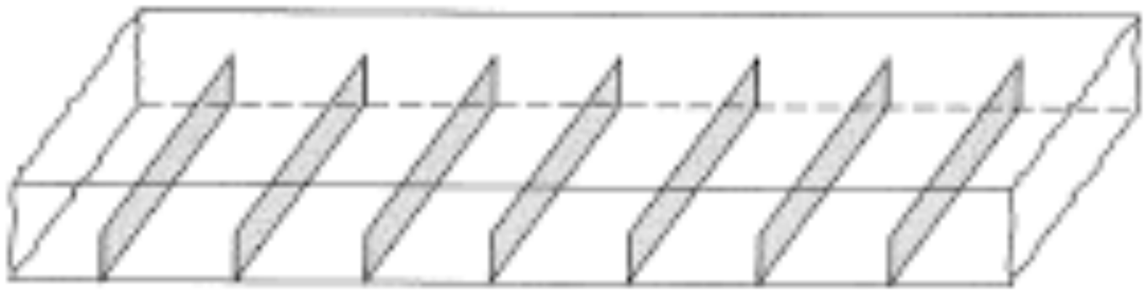


1D, 2D and 3D



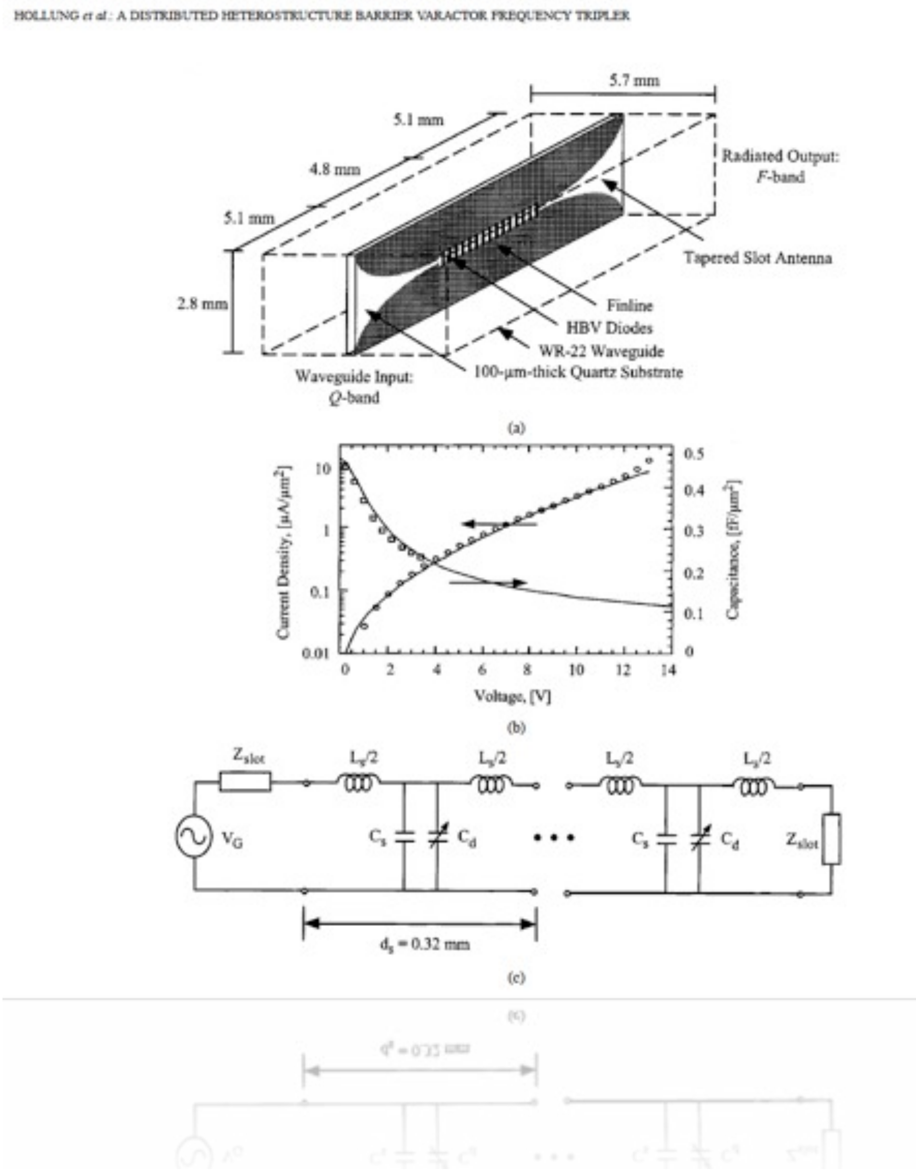
Slow wave structure


(a)



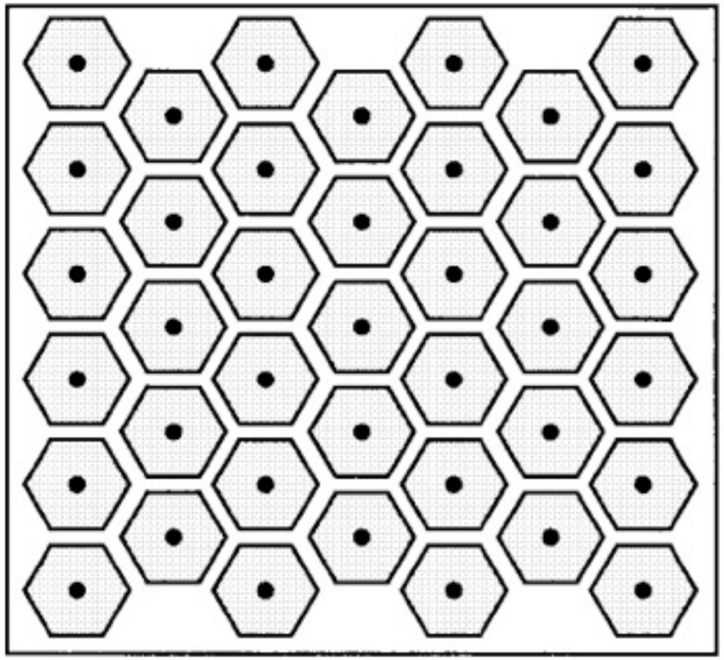
Typically for use in traveling wave amplifiers
passband-stopband responses

Nonlinear transmission lines



High impedance metallic surface!

(a)



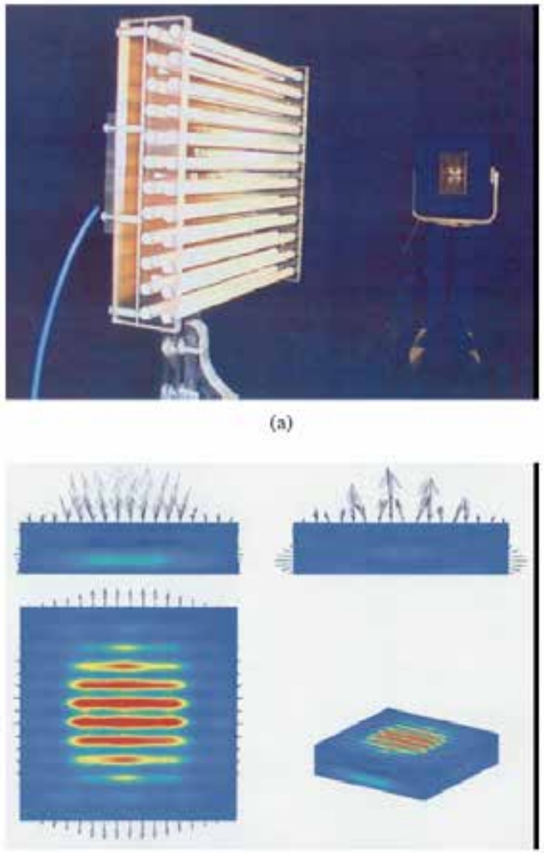
(b)

Fig. 1. (a) Cross section of a high-impedance surface, fabricated as a printed circuit board. The structure consists of a lattice of metal plates, connected to a solid metal sheet by vertical conducting vias. (b) Top view of the high-impedance surface, showing a triangular lattice of hexagonal metal plates.

D. Sievenpiper, L. Zhang, R. F. J. Broas, N. G. Alexopolous, and E. Yablonovitch, "High-impedance electromagnetic surfaces with a forbidden frequency band," IEEE Transactions on Microwave Theory and Techniques, vol. 47, no. 11, pp. 2059–2074, 1999.

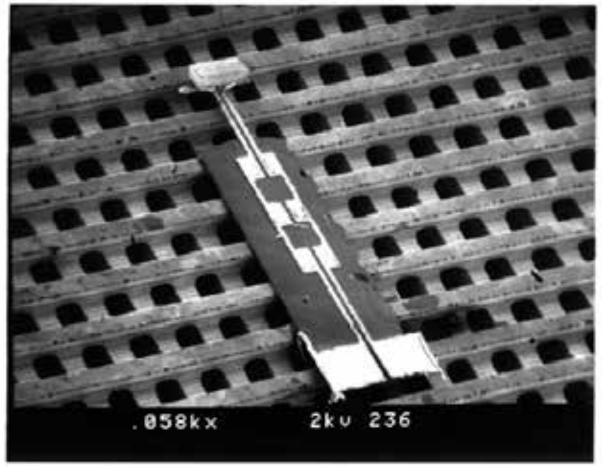
Antenna applications

- Reduce side lobes
- Reduce substrate loss

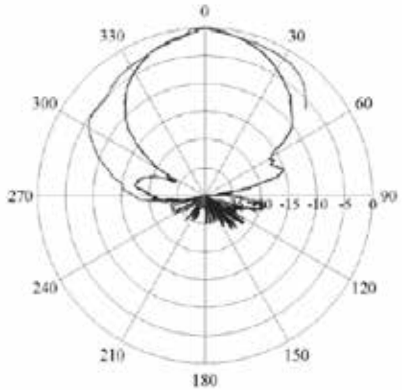


(a) (b)

Fig. 3. (a) Resonant EBG antenna using a 2-D EBG as superstrate. (b) Poynting vector and electric field distribution on the 2-D EBG structure. Reproduced with the kind permission of Bernard Jecko.



(a)



P. de Maagt, R. Gonzalo, Y. C. Vardaxoglou, and J. M. Baracco, "Electromagnetic bandgap antennas and components for microwave and (sub)millimeter wave applications," IEEE Transactions on Antennas and Propagation, vol. 51, no. 10, pp. 2667–2677, Oct. 2003.

Summary of lecture 12

- Read chapter 8.1 (periodic structures).
    - Slow waves
    - Bloch waves
    - Forbidden frequencies / photonic bandgaps (filter)

Further reading

- C. Elachi, "Waves in active and passive periodic structures: A review," in Proceedings of the IEEE, 1976, vol. 64, no. 12, pp. 1666–1698.

Extra

Aim

- *Microwave way of thinking, applicable across a large fraction of the EM spectrum*

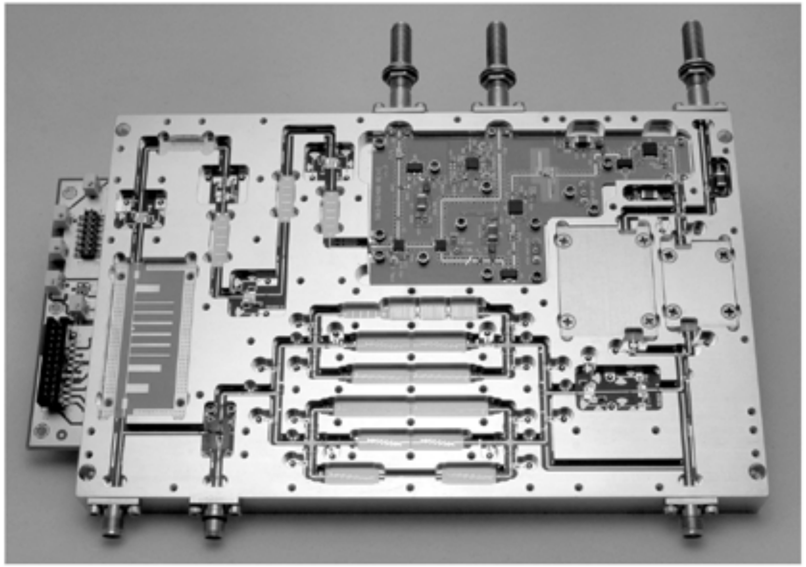
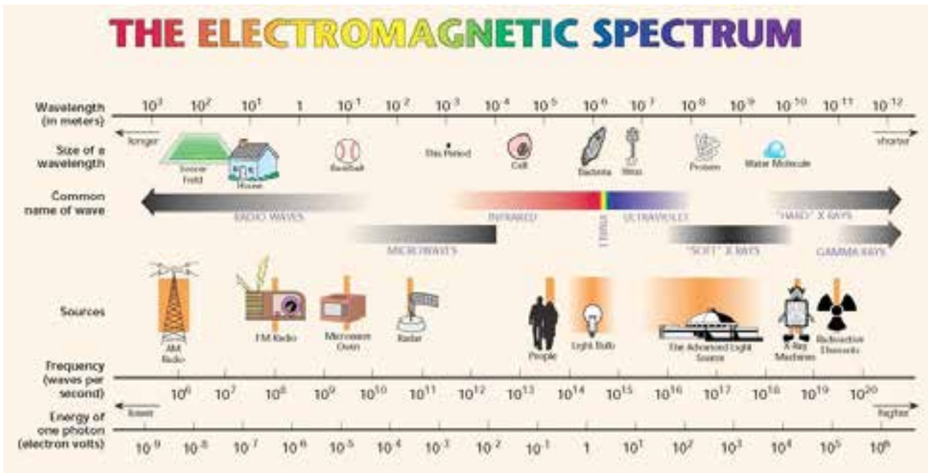


Figure 8.55
Courtesy of LNX Corporation, Salem, N.H.



Microwave way of thinking

- short wavelengths -> same order of magnitude as the circuit elements and devices employed
  - jump between EM / Equivalent circuits
- calculates everything in dB
- and like to use Smith charts for almost everything

Frequency	**Type of components**
f<1 GHz	lumped ($\lesssim \lambda/10$)
f >1 GHz	distributed

- short wavelength gives propagation time comparable with the period of the propagating wave
- Kirchhoff's laws are not applicable, standard voltage-current concepts are no longer sufficient (but still convenient...)

Questions?

Future...

- Master thesis - Contact academic staff for the latest information and possible projects
- Course selection for a future career within THz science and technology
  - THz track: http://www.chalmers.se/mc2/EN/laboratories/thz-millimetre-wave/education/thz-track