ICT Elementary for Embedded Systems
Signal/Electronic Fundamental

Fourier Transform and Communication Systems

Asst. Prof. Dr. Prapun Suksompong

prapun@siit.tu.ac.th

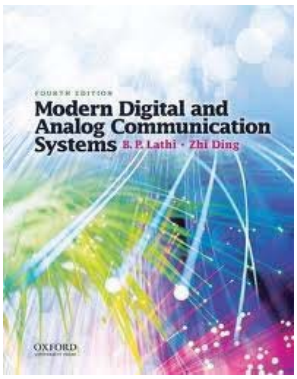
Me?

- Chairperson of **Electrical Engineering Program** (and Chairperson of **Electronics and Communication Engineering** Curriculum) at **Sirindhorn International Institute of Technology** (**SIIT**)
- Ph.D. from **Cornell** University, USA
  - In Electrical and Computer Engineering
  - Minor: Mathematics (Probability Theory)
  - Research: Neuro-Information Theory (Communications in Human Brain)
- Current Research: Wireless Communications, Localization, Game Theory
- 2009, 2013, and 2017 SIIT Best Teaching Awards
- 2017 SIIT Distinguished Teacher Award
- 2011 SIIT Research Award
- 2013 TU Outstanding Young Researcher Award

prapun.com

General Information

- **Course Website:**
  http://www2.siit.tu.ac.th/prapun/ICTES/index.html
- **Lectures:**
  - July 18, 2018: 13:00-14:20, 14:40-16:00
  - July 19, 2018: 9:00-10:20, 10:40-12:00
- **Textbook:** Modern Digital and Analog Communication Systems
  - By B.P. **Lathi** and Zhi **Ding**
  - 4nd Edition
  - ISBN 978-0-471-27214-4
  - Library Call No. TK5101 L333 2009



Website

prapun.com

Asst. Prof. Dr.Prapun Suksompong (ผศ.ดร.ประพันธ์ สุขสมปอง) is currently the Chairperson of Electrical Engineering Program (and Chairperson of Electronics and Communication Engineering (EC) Curriculum) at Sirindhorn International Institute of Technology (SIIT), Thammasat University, Thailand. In 1997, he received the King's Scholarship to study in the School of Electrical and Computer Engineering (ECE) at Cornell university. He topped the Cornell ECE class of 2002, with the highest GPA among all engineering students. He then received the Cornell's fellowship for his graduate study. Prapun joined Prof. Toby Berger's group in 2003 and got his Ph.D. in 2008.

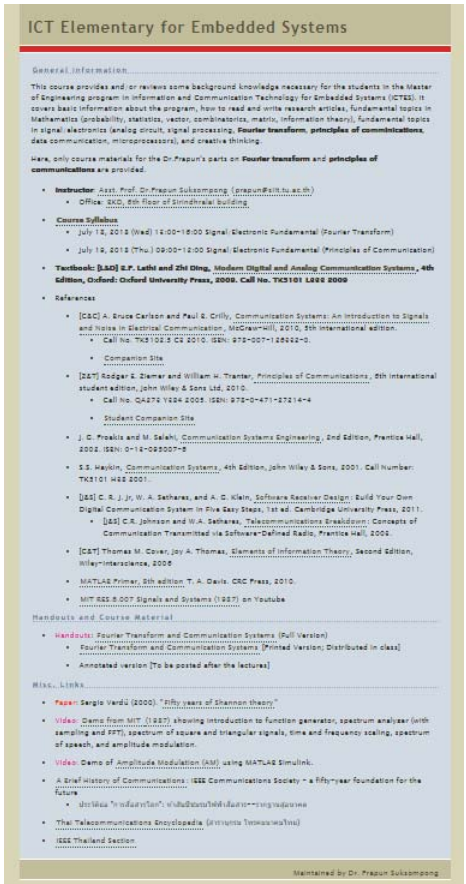
Right after his graduation, he started his teaching career at SIIT. His research interest is in the areas of communication theory, information theory, probability theory, and theoretical neuroscience. In 2012, he (along with two other faculty members in the Wireless Communication Research Group) received the 2011 SIIT Research Award. In 2014, he received the 2013 Outstanding Young Researcher Award (รางวัลนักวิจัยรุ่นใหม่ดีเด่น ระดับคณะ ประเภทอาจารย์) from Thammasat University.

Ajarn Prapun always highly values the teaching aspect of his career and his life. Many of his notes are available on his personal websites. In 2006, he received the Teaching Assistant of the Year Award from members of the Cornell IEEE Student Branch "for exemplary teaching in ECE". In 2010, 2014, and 2018, he also received the Best Teaching Awards from SIIT.

For more information, here is his CV. (Download pdf version.)

Teaching

- For 3/2017, he taught
  - ICT Elementary for Embedded Systems (Fourier transform and principles of communications)
- For 2/2017, he teaches
  - ECS452 (Digital Communication Systems)
- For 1/2017, he taught
  - ECS315 (Probability and Random Processes)
  - ECS332 (Principles of Communications)



ICT Elementary for Embedded Systems

General Information

This course provides and/or reviews some background knowledge necessary for the students in the Master of Engineering program in Information and Communication Technology for Embedded Systems (ICTES). It covers basic information about the program, how to read and write research articles, fundamental topics in Mathematics (probability, statistics, vector, combinatorics, matrix, information theory), fundamental topics in signal: electronics (analog circuit, signal processing, **Fourier transform, principles of communications**, data communication, microprocessors), and creative thinking.

Here, only course materials for the Dr.Prapun's parts on **Fourier transform** and **principles of communications** are provided.

- **Instructor**: Asst. Prof. Dr.Prapun Suksompong (prapun@siit.tu.ac.th)
  - Office: 9XD, 8th floor of Sirindhralai building
- **Course Syllabus**
  - July 18, 2018 (Wed) 13:00-16:00 Signal: Electronic Fundamental (Fourier Transform)
  - July 19, 2018 (Thu.) 09:00-12:00 Signal: Electronic Fundamental (Principles of Communication)
- **Textbook: [LDZ] B.P. Lathi and Zhi Ding, Modern Digital and Analog Communication Systems, 4th Edition, Oxford: Oxford University Press, 2009. Call No. TK5101 L333 2009**
- References
  - [CBC] A. Bruce Carlson and Paul B. Crilly, Communication Systems: An Introduction to Signals and Noise in Electrical Communication, McGraw-Hill, 2010, 5th international edition.
    - Call No. TK5102.5 C3 2010. ISBN: 978-007-126552-3.
    - Companion Site
  - [ZAT] Rodger E. Ziemer and William H. Tranter, Principles of Communications, 6th international student edition, John Wiley & Sons Ltd, 2010.
    - Call No. QA276 Y184 2005. ISBN: 978-0-471-27214-4
    - Student Companion Site
  - J. G. Proakis and M. Salehi, Communication Systems Engineering, 2nd Edition, Prentice Hall, 2002. ISBN: 0-14-095007-8
  - S.S. Haykin, Communication Systems, 4th Edition, John Wiley & Sons, 2001. Call Number: TK5101 H428 2001.
  - [LS] C. R. J. Jr, W. A. Sethares, and A. C. Klein, Software Receiver Design : Build Your Own Digital Communication System in Five Easy Steps, 1st ed. Cambridge University Press, 2011.
    - [LS] C.R. Johnson and W.A. Sethares, Telecommunications Breakdown: Concepts of Communication Transmitted via Software-Defined Radio, Prentice Hall, 2003.
  - [CAT] Thomas M. Cover, Joy A. Thomas, Elements of Information Theory, Second Edition, Wiley-Interscience, 2006
  - MATLAB Primer, 8th edition T. A. Davis. CRC Press, 2010.
  - MIT RES.8-007 Signals and Systems (1987) on Youtube

Handouts and Course Material

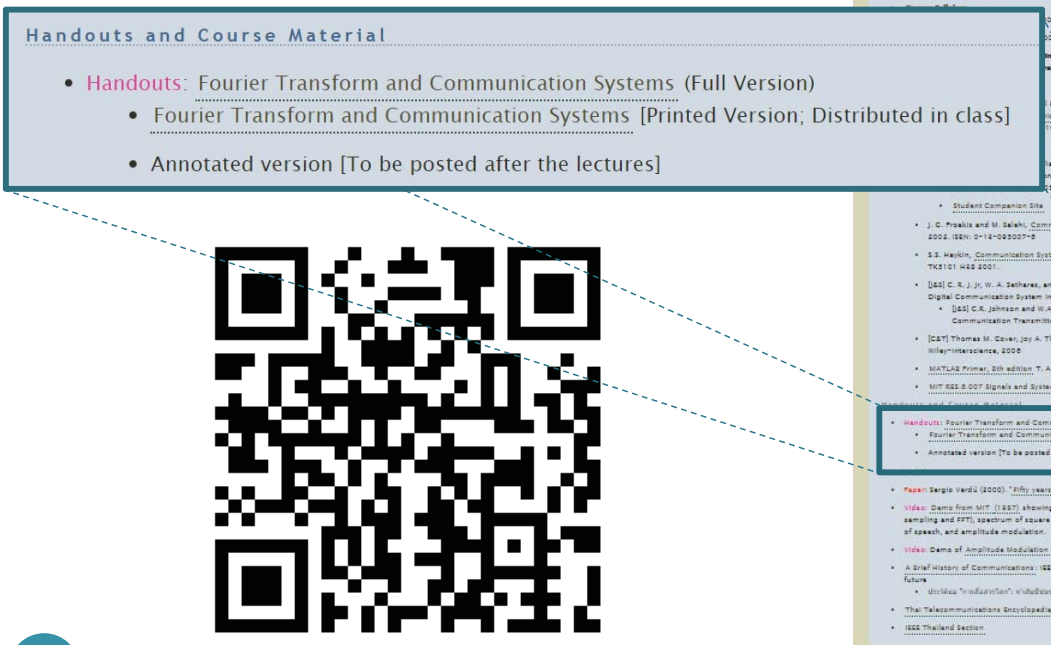
- Handouts: Fourier Transform and Communication Systems (Full Version)
  - Fourier Transform and Communication Systems [Printed Version; Distributed in class]
  - Annotated version [To be posted after the lectures]

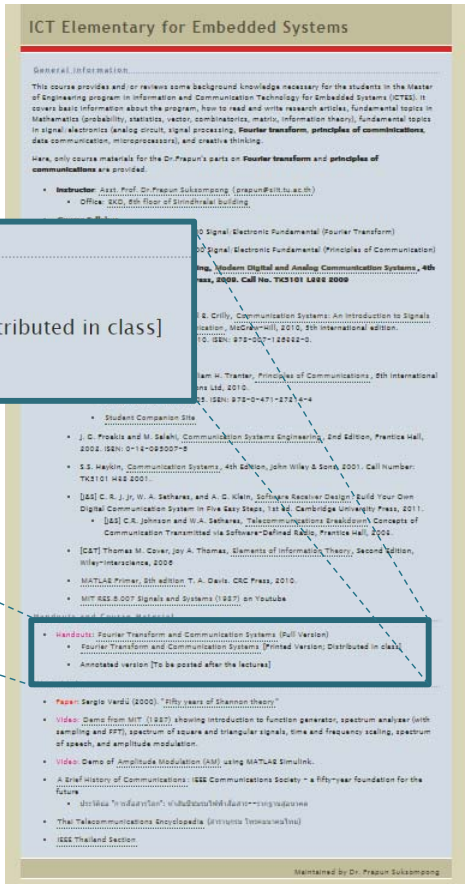
Misc. Links

- Paper: Sergio Verdú (2000). "Fifty years of Shannon theory"
- Video: Demo from MIT (1987) showing introduction to function generator, spectrum analyzer (with sampling and FFT), spectrum of square and triangular signals, time and frequency scaling, spectrum of speech, and amplitude modulation.
- Video: Demo of Amplitude Modulation (AM) using MATLAB Simulink.
- A Brief History of Communications : IEEE Communications Society - a fifty-year foundation for the future
- Thai Telecommunications Encyclopedia
- IEEE Thailand Section

Maintained by Dr. Prapun Suksompong

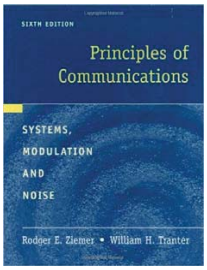
Website

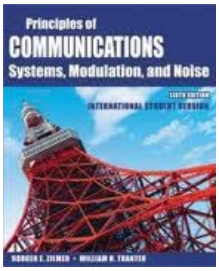




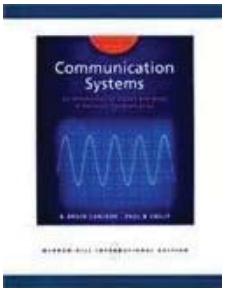
More references

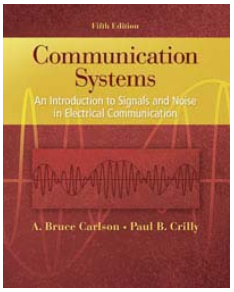
- Principles of Communications
  - By Rodger E. **Ziemer** and William H. **Tranter**
  - 6th International student edition
  - ISBN 978-0-470-39878-4
  - Library Call No. TK5105 Z54 2010
  - Student Companion Site: http://bit.ly/mN18kQ





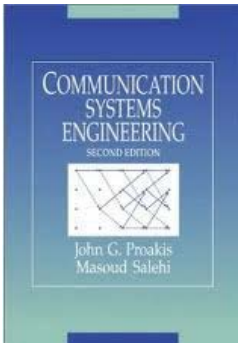
- Communication Systems: An Introduction to Signals and Noise in Electrical Communication
  - By A. Bruce Carlson and Paul B. Crilly
  - 5th International edition
  - Call No. TK5102.5 C3 2010
  - ISBN: 978-007-126332-0



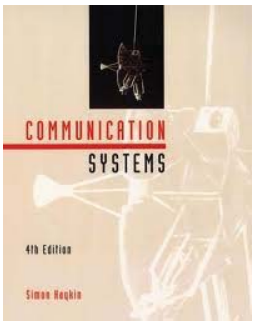


More references

- J. G. **Proakis** and M. **Salehi**, Communication Systems Engineering, 2nd Edition, Prentice Hall, 2002. ISBN: 0-13-095007-6



- S.S. **Haykin**, Communication Systems, 4th Edition, John Wiley & Sons, 2001. Call Number: TK5101 H38 2001.



Another Reference (in Thai)

- สุวิทย์ นาคพีระยุทธ และคณะ
- หลักการไฟฟ้าสื่อสาร
- พิมพ์ครั้งที่ 3, 2558
- ISBN: 9789740333890

- หนังสือ หลักการไฟฟ้าสื่อสาร เล่มนี้กล่าวถึง ทฤษฎีการแปลงฟูเรียร์ (Fourier transform) ระบบเชิงเส้น สหสัมพันธ์ (Correlation) ความหนาแน่นสเปกตรัม (Spectral density) การมอดูเลตเชิงแอมพลิจูด (amplitude modulation) การมอดูเลตเชิงมุม (angle modulation) กระบวนการกลุ่ม (random process) สัญญาณรบกวน (noise) ทฤษฎีการชักตัวอย่าง (sampling theory) การมอดูเลตโดยใช้พัลส์ (pulse modulation) การส่งผ่านพัลส์เบสแบนด์ (basenand pulse transmission) การมอดูเลตแบนด์พาส (digital passband transmission) และทฤษฎีข่าวสาร (information)
- เป็นผลจากความร่วมมือทางวิชาการของคณาจารย์จากหลายสถาบันการศึกษาที่มีชื่อเสียงของประเทศหลายแห่ง

[http://www.chulabook.com/description.asp?barcode=9789740333890]

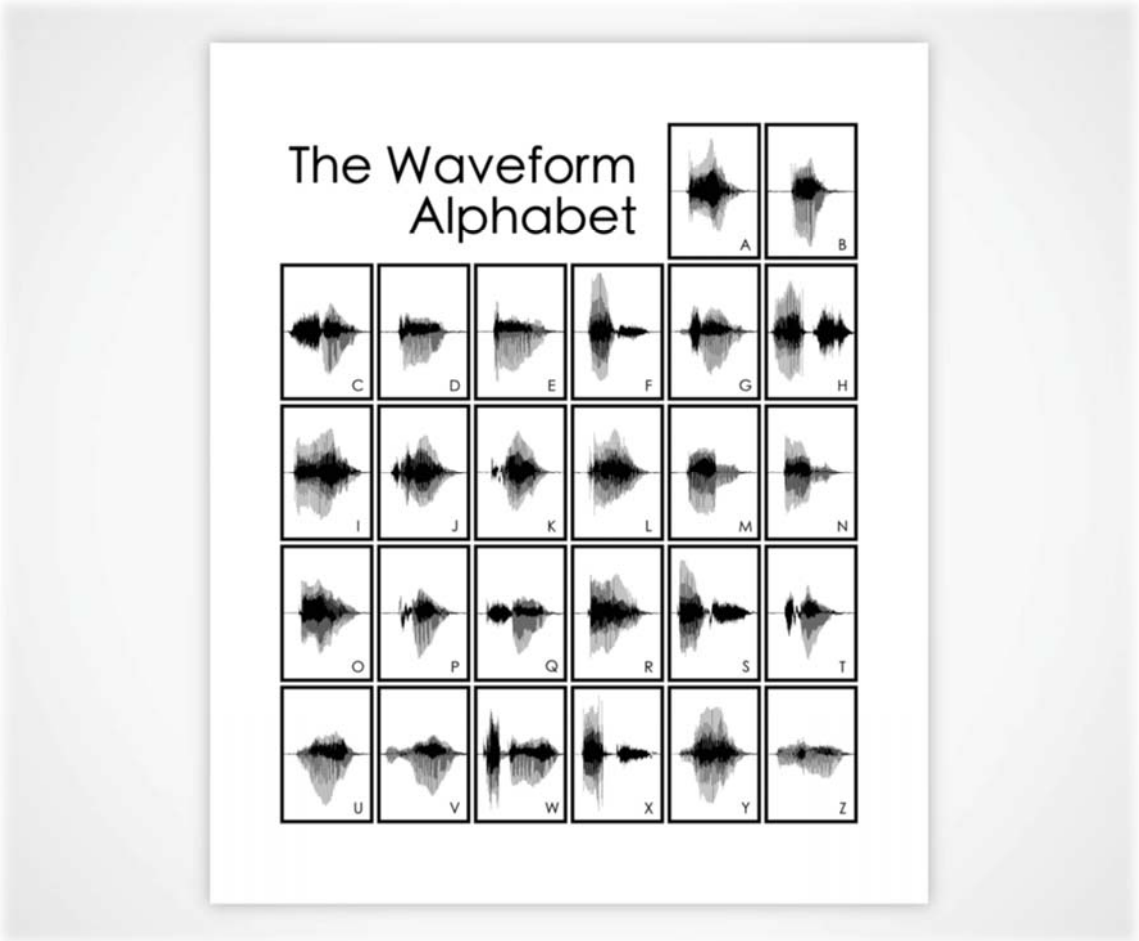
Fourier Transform and Communication Systems

From time domain to frequency domain

Signal (Waveform)

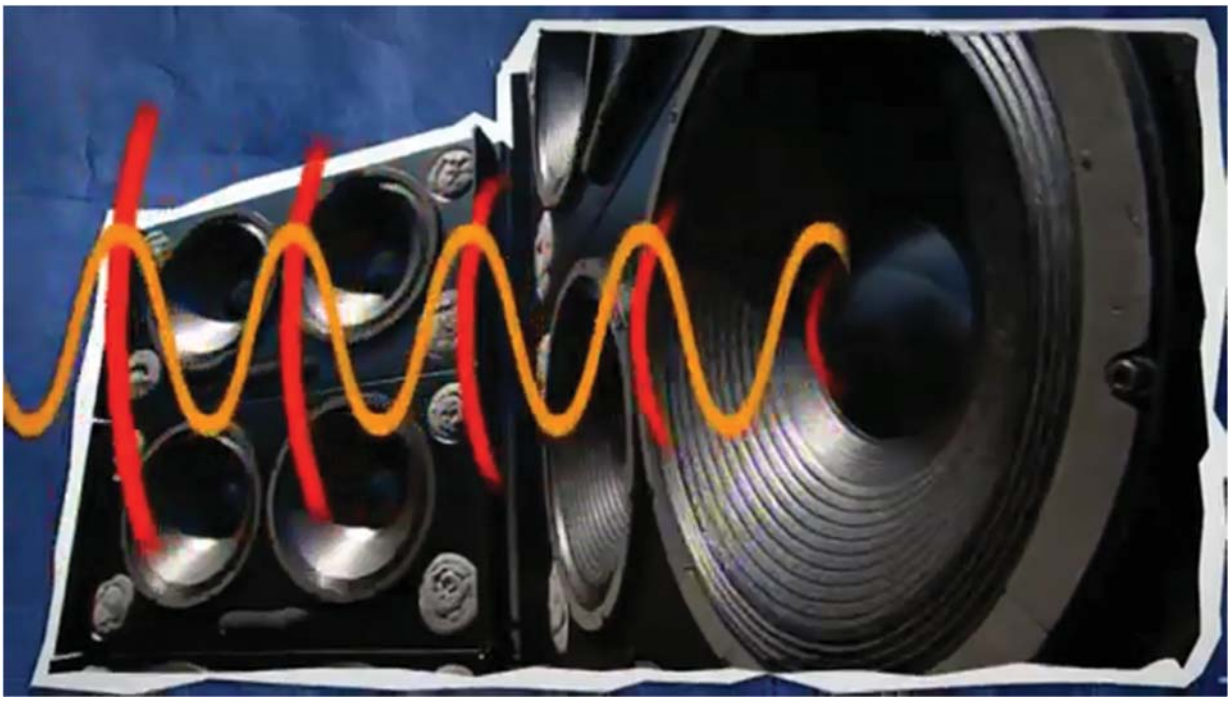
Signal in the time domain (audio)

[https://www.youtube.com/watch?v=cq7hXp7xUn8]



[http://www.bespokenart.com/modern_art_prints/print8big.jpg]

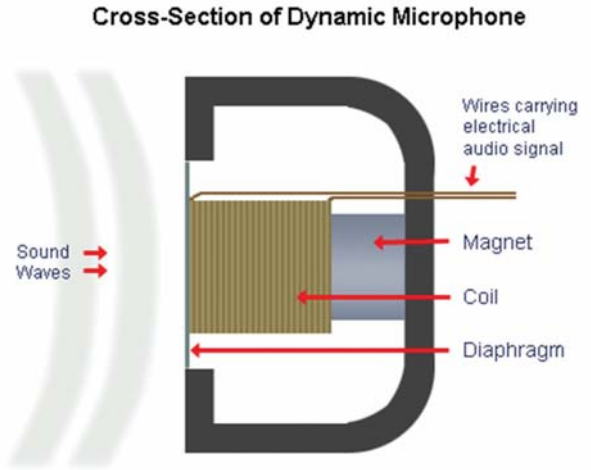
Sound as Vibration



[https://www.youtube.com/watch?v=LH0PD_dX5Z4]

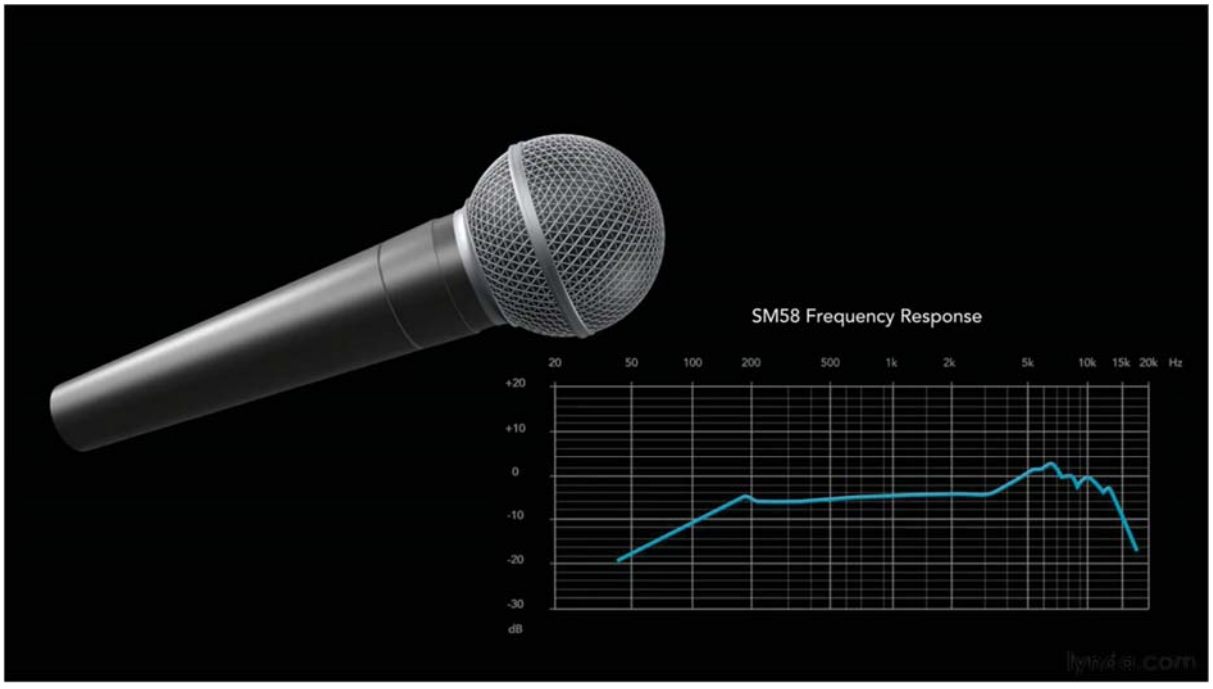
Microphone

- Microphones are a type of **transducer**.
- They convert acoustical energy (sound waves) into electrical energy (the audio signal).
- **Dynamic** microphones

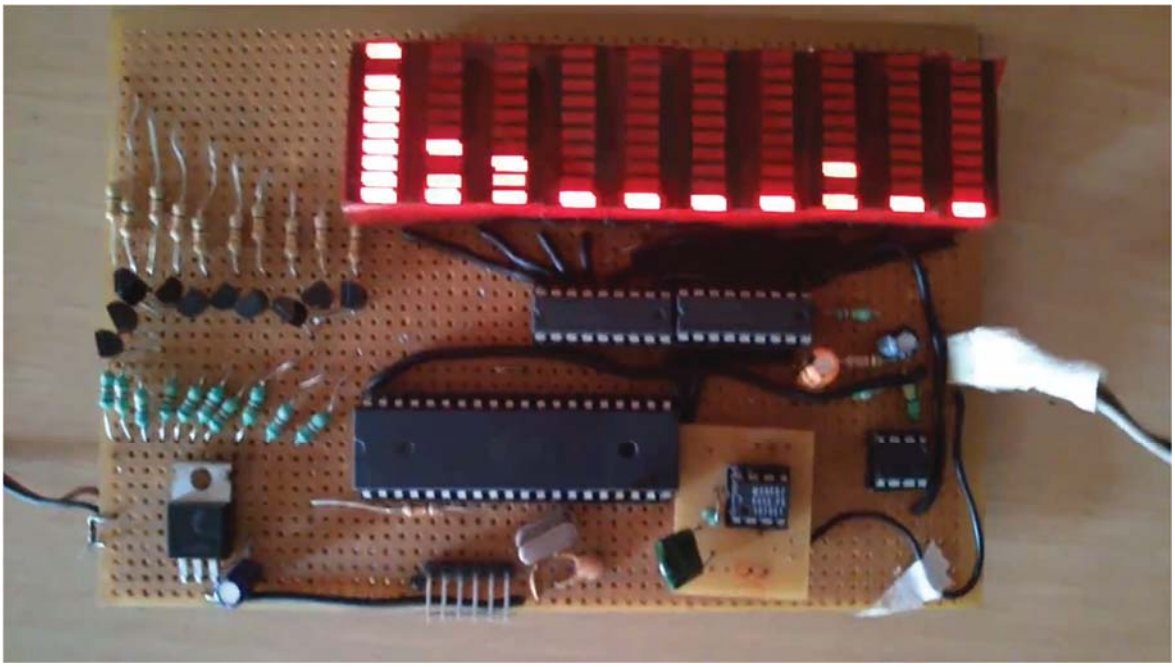


[http://www.totalvenue.com.au/articles/microphones/microphones.html]

Dynamic Microphone



LED Audio Spectrum Analyzer

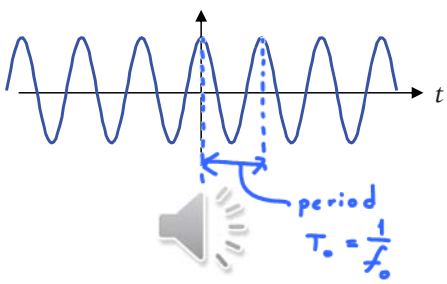


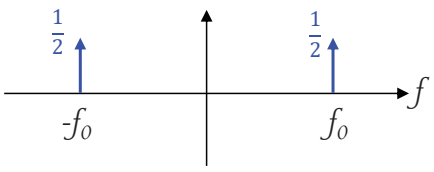
[http://www.instructables.com/id/100-LED-10-band-Audio-Spectrum-atmega32-MSGEQ7-wit/]

Fourier transform ($\mathcal{F}$)

- The Fourier transform is a **frequency domain representation** of the original signal.
- The term Fourier transform refers to both the frequency domain representation and the corresponding mathematical operation ($\mathcal{F}$).

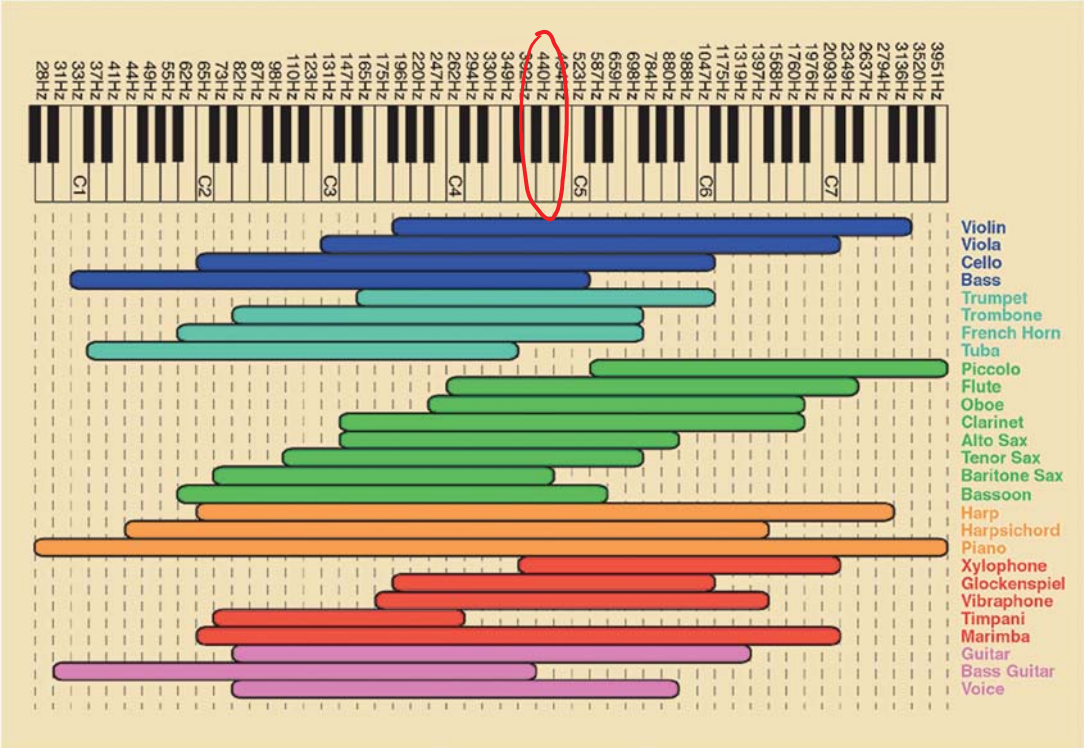
$$\cos(2\pi f_0 t) \xrightarrow{\mathcal{F}} \frac{1}{2}\delta(f+f_0)+\frac{1}{2}\delta(f-f_0)$$





The (Fundamental) Frequencies of Musical Instruments

Note frequency



[http://www.psbspeakers.com/articles/The-Frequencies-of-Music]

A440 on Different Instruments

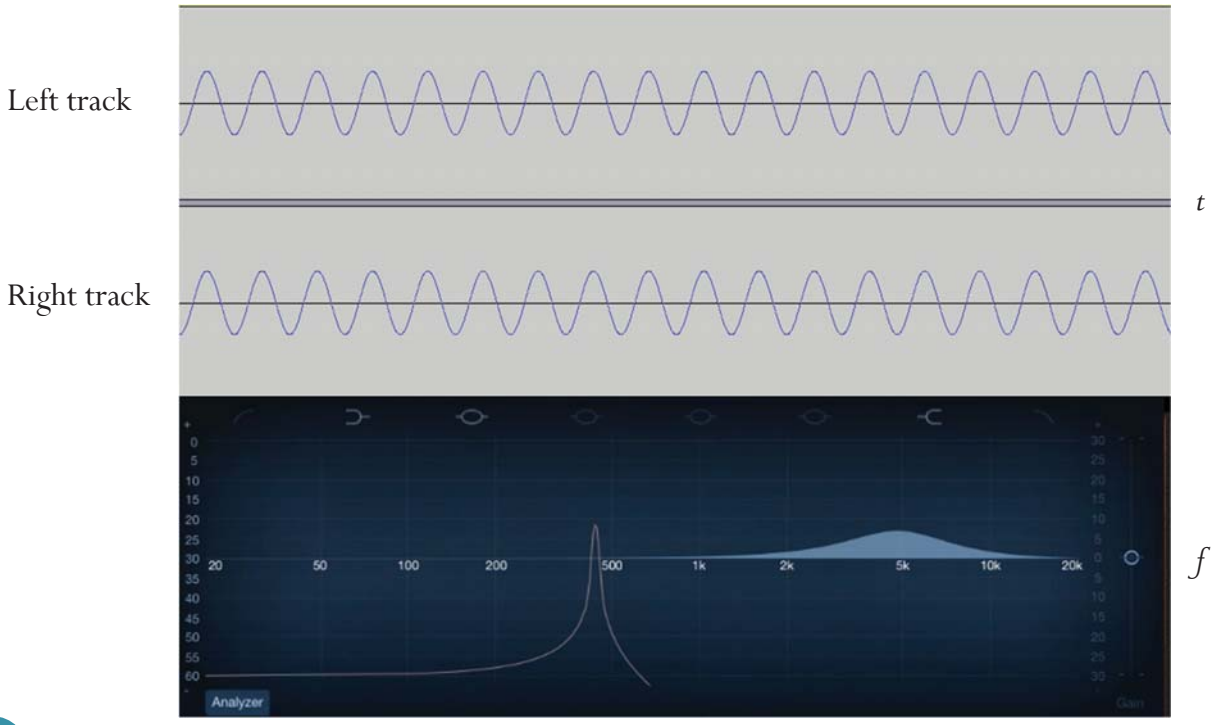
"Same" timbre of a tuning fork ("pure" tone)

Any physical instrument is not only going to play the fundamental but also harmonics. These harmonics are frequencies in the sound that are integer multiples of the fundamental tone.

[GarageBand]

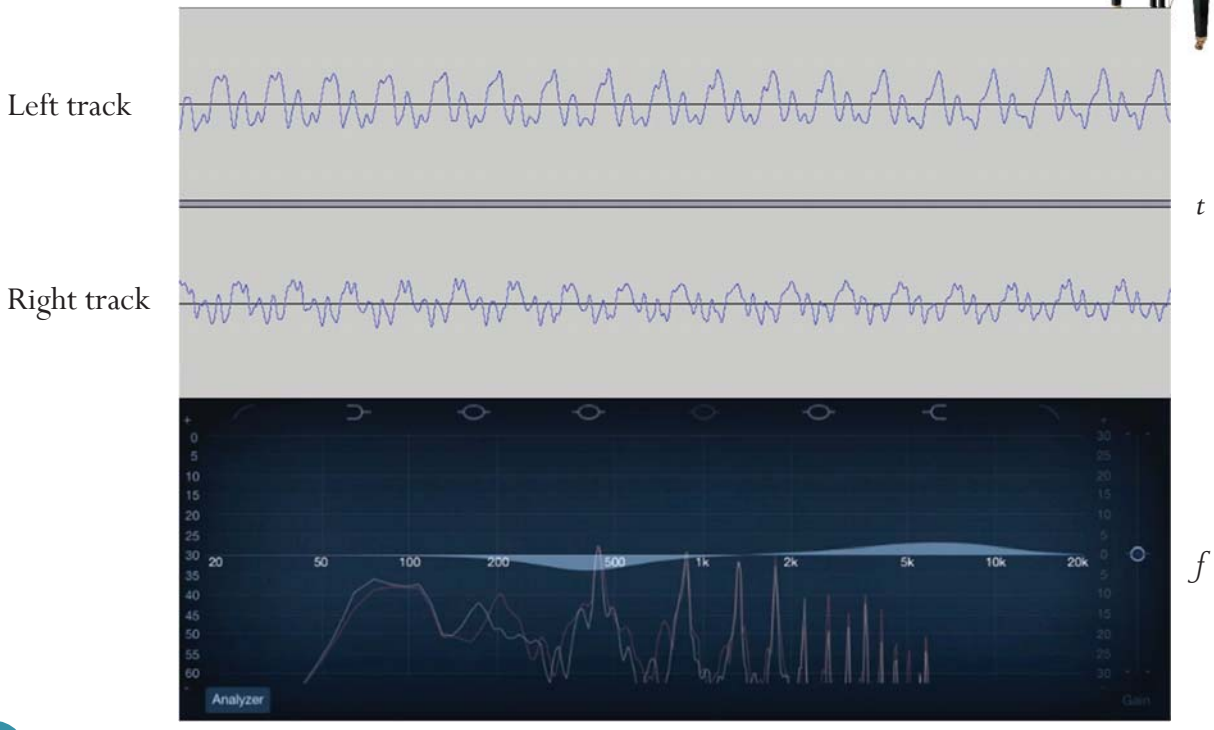
[https://www.youtube.com/watch?v=9iGjo2cd69s]
[http://www.philvarner.com/2015/01/27/why-does-a-tuning-fork-sound-different-than-a-piano-even-if-theyre-playing-the-same-note/]

Ex.1: A440 on a Cathedral Organ



[http://www.philvarner.com/2015/01/27/why-does-a-tuning-fork-sound-different-than-a-piano-even-if-theyre-playing-the-same-note/]

Ex.2: A440 on a Grand Piano



[http://www.philvarner.com/2015/01/27/why-does-a-tuning-fork-sound-different-than-a-piano-even-if-theyre-playing-the-same-note/]

Tone Dialing

- Most modern telephones use a dialing system known as **Touch-Tone**.
  - **Dual-tone multifrequency** (**DTMF**) system.
- Use **pairs of audio** (voice-frequency) **tones** to create signals representing the numbers to be dialed.
- First developed in the **Bell System** in the United States, and became known under the trademark **Touch-Tone** for use in push-button telephones starting in 1963.
  - Replace the use of **rotary dial**.
- Standardized by ITU-T Recommendation Q.23.
  - Also known in the UK as MF4.

[http://samanthanyers.typepad.com/photos/telephones/b1964_touch_tone_telephone.html]

Pushbuttons replace dials on telephone

Tests in regular service last winter at Carnegie and Greensburg, Pa., suburbs of Pittsburgh, have shown it's easier and more than twice as fast to press buttons for a phone call than it is to twirl a dial. As each "touch-tone" button is pushed, it sounds a pleasing musical tone.

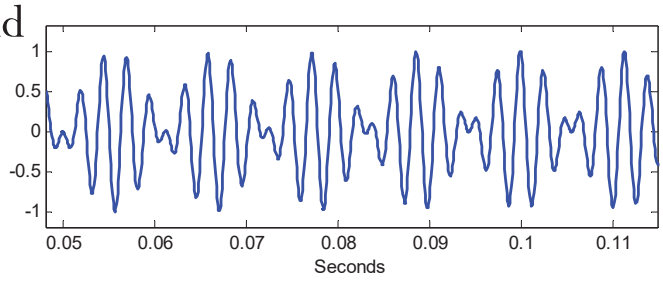
Bell is introducing the phone area by area, will have it in general use within the next 10 years.

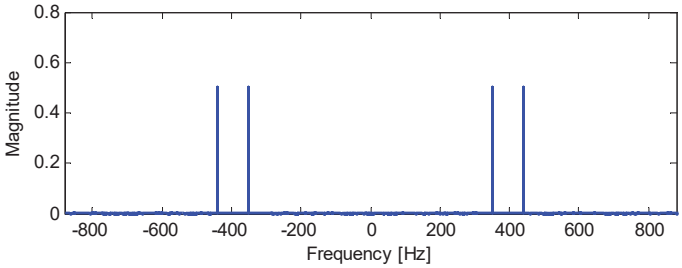
[http://blog.modernmechanix.com/pushbuttons-replace-dials-on-telephone/]

[Apr, 1964]

Dial Tone

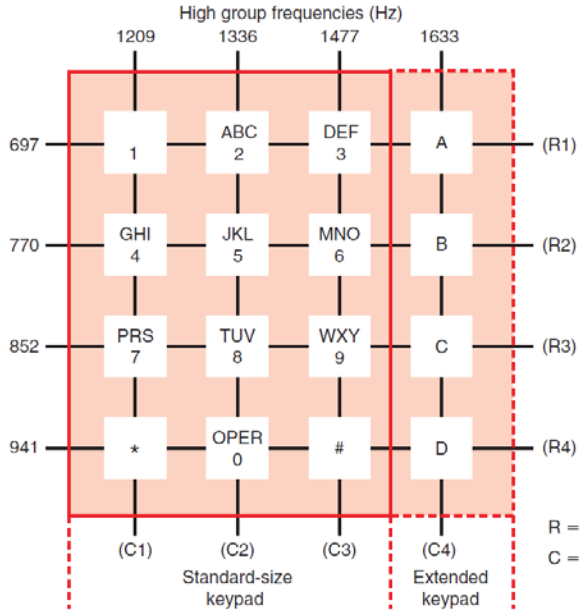
- North American and UK: A continuous mix of 350 Hz and 440 Hz
  - These two frequencies correspond to the standard concert pitch of A440, and approximately an "F".
  - @ -12dBm
- Most of Europe: constant single tone (425 Hz)





Encoding

- Each number corresponds to a mix of two audio frequencies associated with each row and column of the corresponding pushbutton.

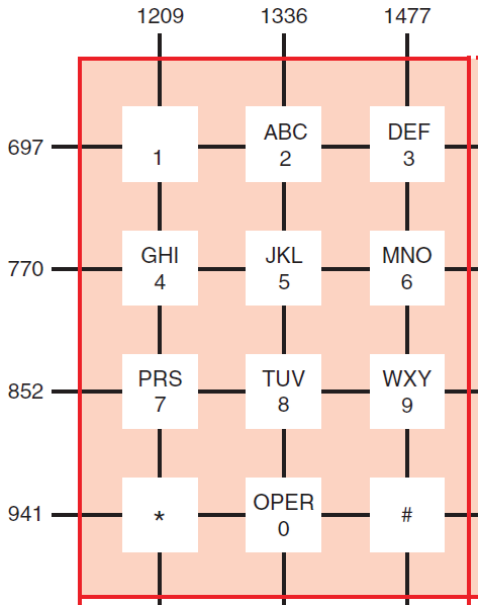


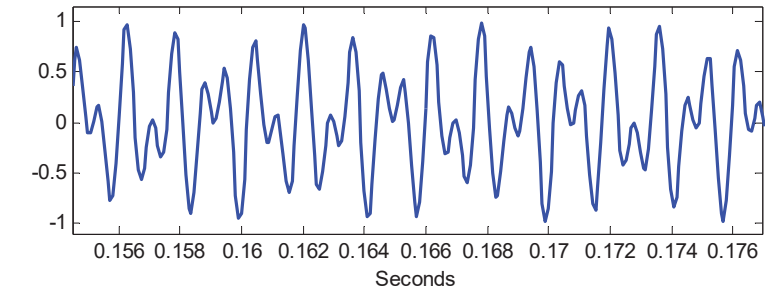
[Frenzel, 2016, Figure 18-5, p. 702]

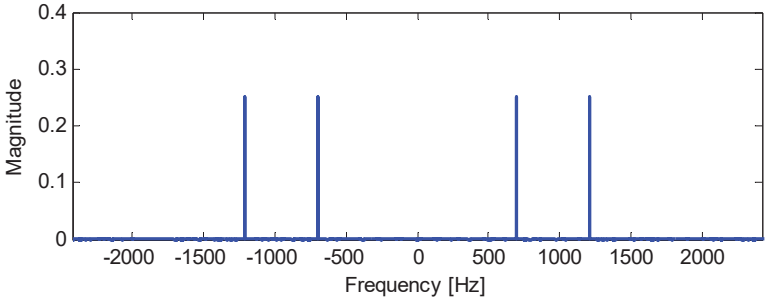
Most telephones use a standard keypad with 12 buttons or switches for the numbers 0 through 9 and the special symbols * and #.

Four additional keys for special applications.

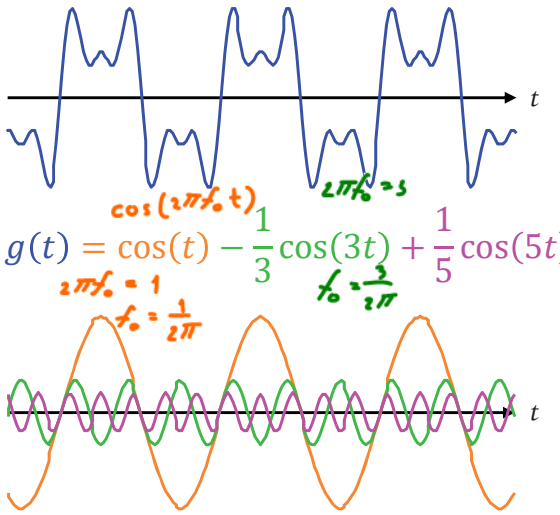
The "1" tone



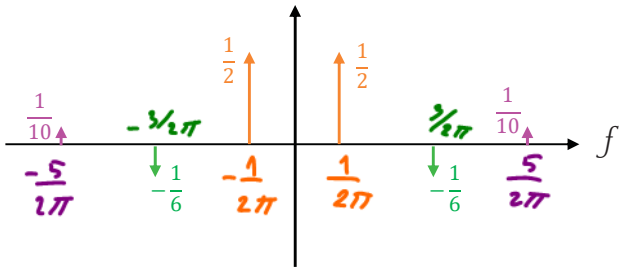




Fourier transform: Example

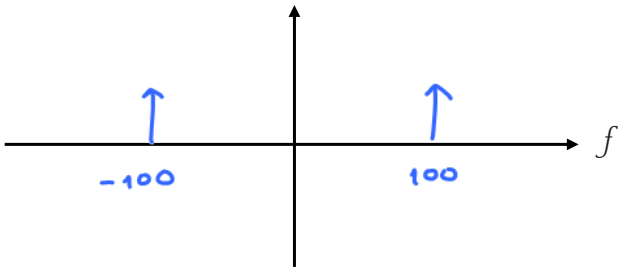


$$g(t) = \cos(t) - \frac{1}{3}\cos(3t) + \frac{1}{5}\cos(5t) \xrightarrow{\mathcal{F}}$$



Practice Problems

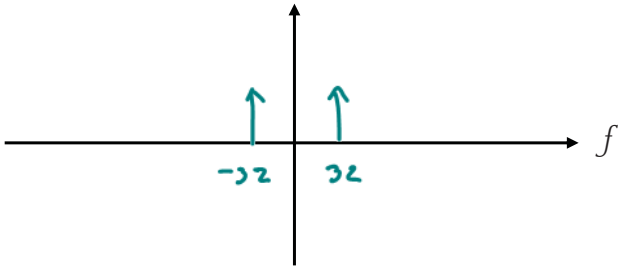
$$\cos(200\pi t) \xrightarrow{\mathcal{F}}$$



$2\pi f_0 = 200\pi$

$f_0 = \frac{200\pi}{2\pi} = 100$

$$\cos(200t) \xrightarrow{\mathcal{F}}$$

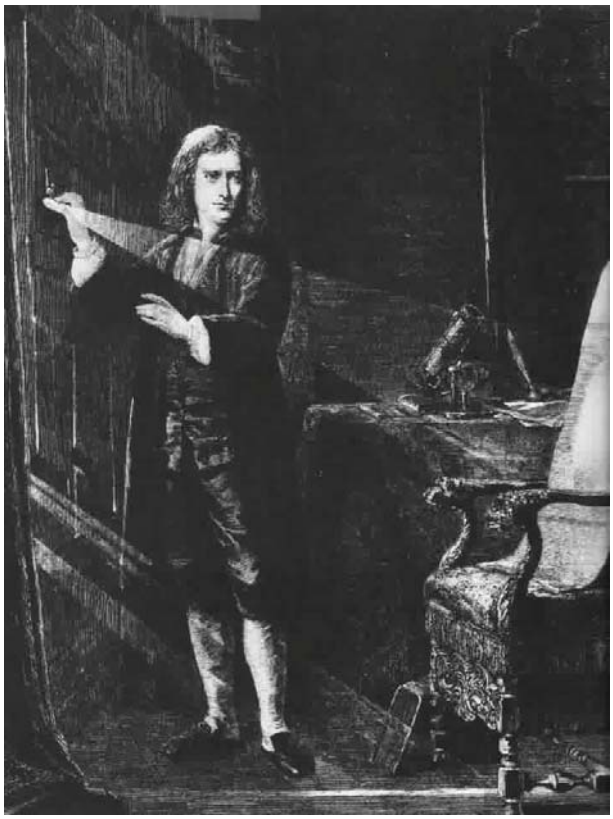


$2\pi f_0 = 200$

$f_0 = \frac{200}{2\pi} = \frac{100}{\pi} \approx 32\ \text{Hz}$

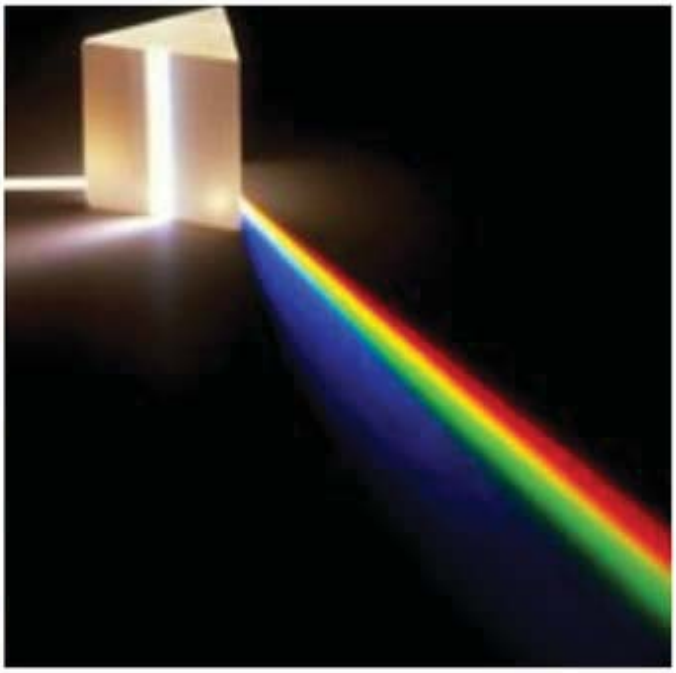
Sir Isaac Newton

- Our modern understanding of light and color begins with Isaac Newton (1642-1726) and a series of experiments that he publishes in 1672.
- He refracts white light with a prism, resolving it into its component colors.



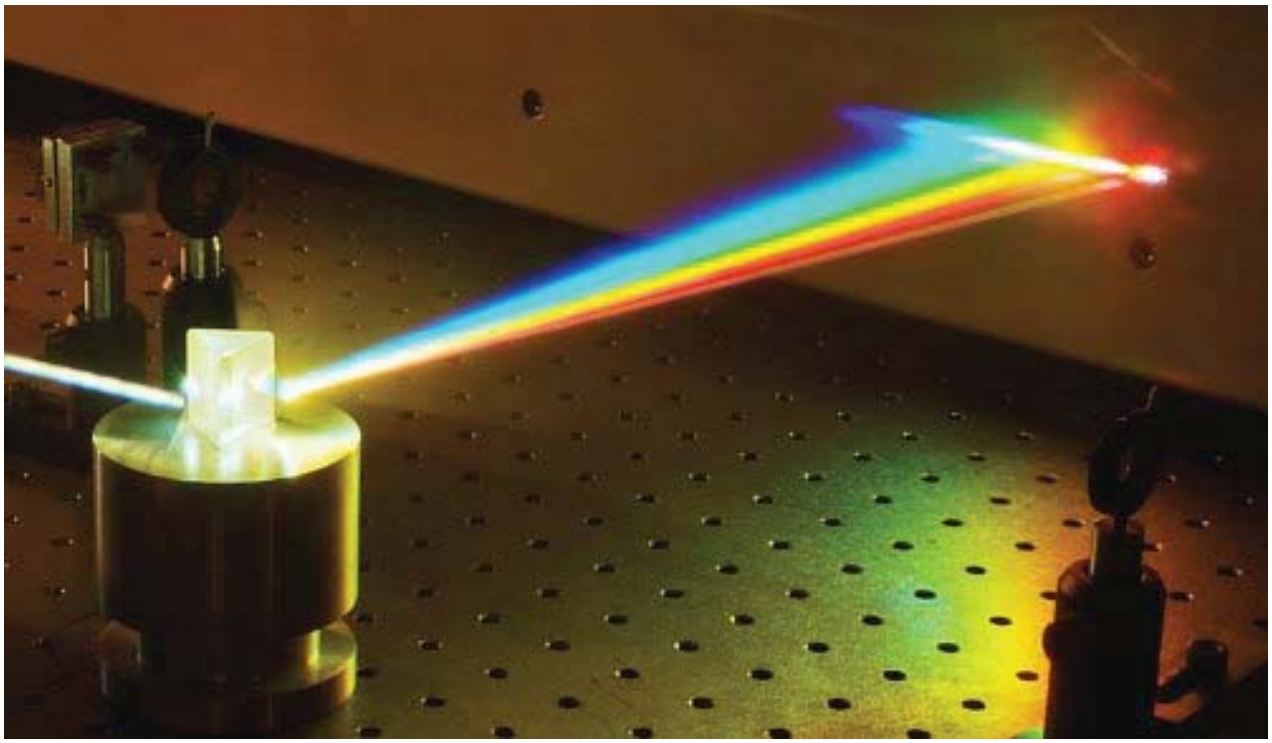
[https://www.britannica.com/biography/Isaac-Newton/images-videos/Sir-Isaac-Newton-dispersing-sunlight-through-a-prism-for-a/153369]
[http://www.webexhibits.org/colorart/bh.html]

Sir Isaac Newton



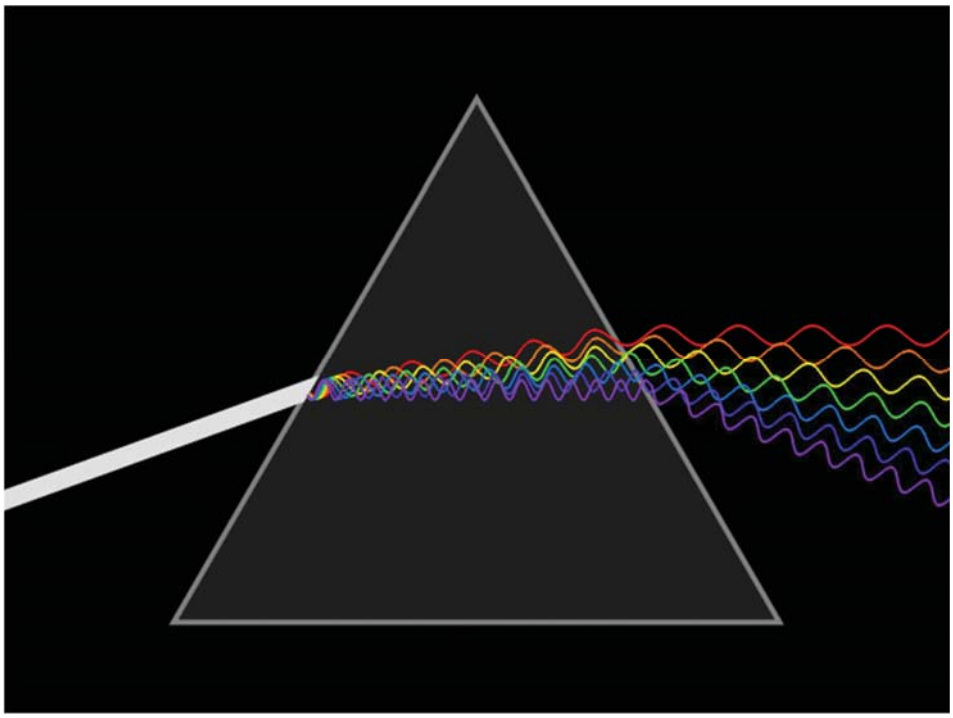
[http://sirisaacne.weebly.com/accomplishments.html]

A triangular prism, dispersing light



[http://www.astromia.com/astronomia/newtonluz.htm]

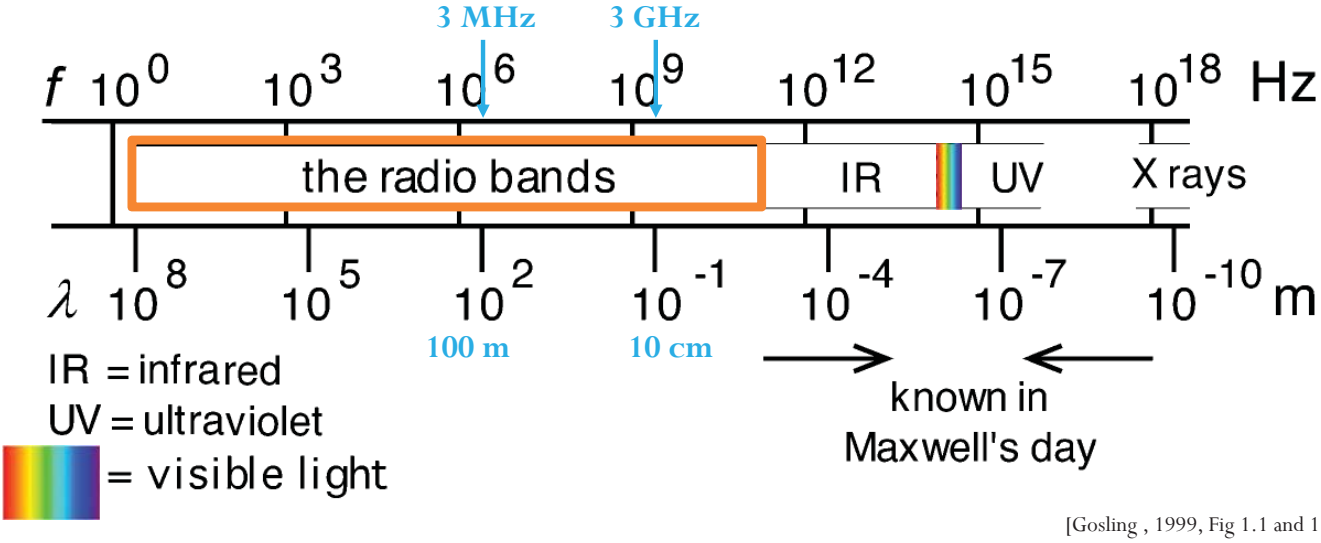
A triangular prism, dispersing light



Waves shown to illustrate the differing wavelengths of light.

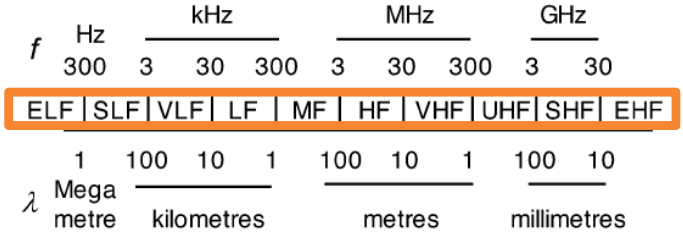
[https://en.wikipedia.org/wiki/Prism#/media/File:Light_dispersion_conceptual_waves.gif]

Electromagnetic Spectrum



IR = infrared
UV = ultraviolet
= visible light

[Gosling , 1999, Fig 1.1 and 1.2]



$$c = f\lambda$$

3×10^8 m/s

Wavelength

Frequency

(Discrete)

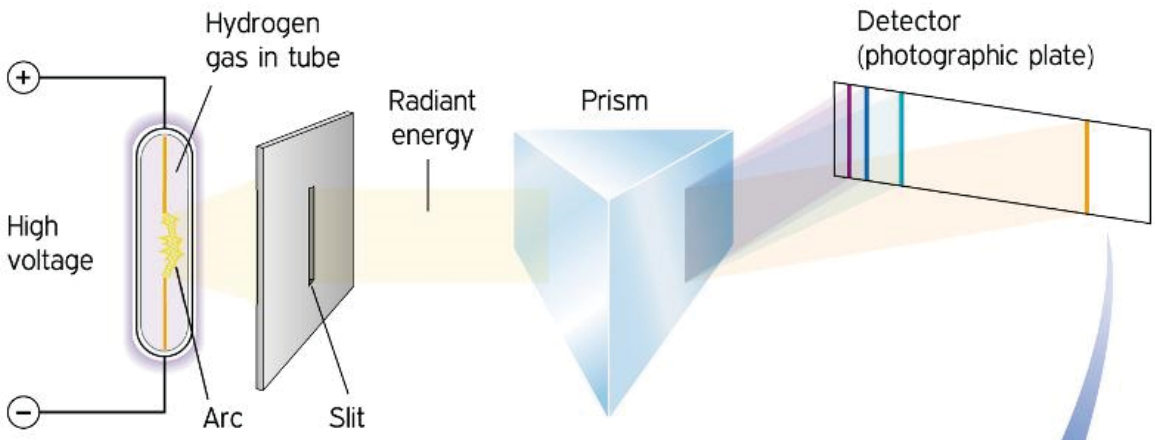
Continuous Spectrum vs. Line Spectra

Continuous spectrum of an incandescent lamp

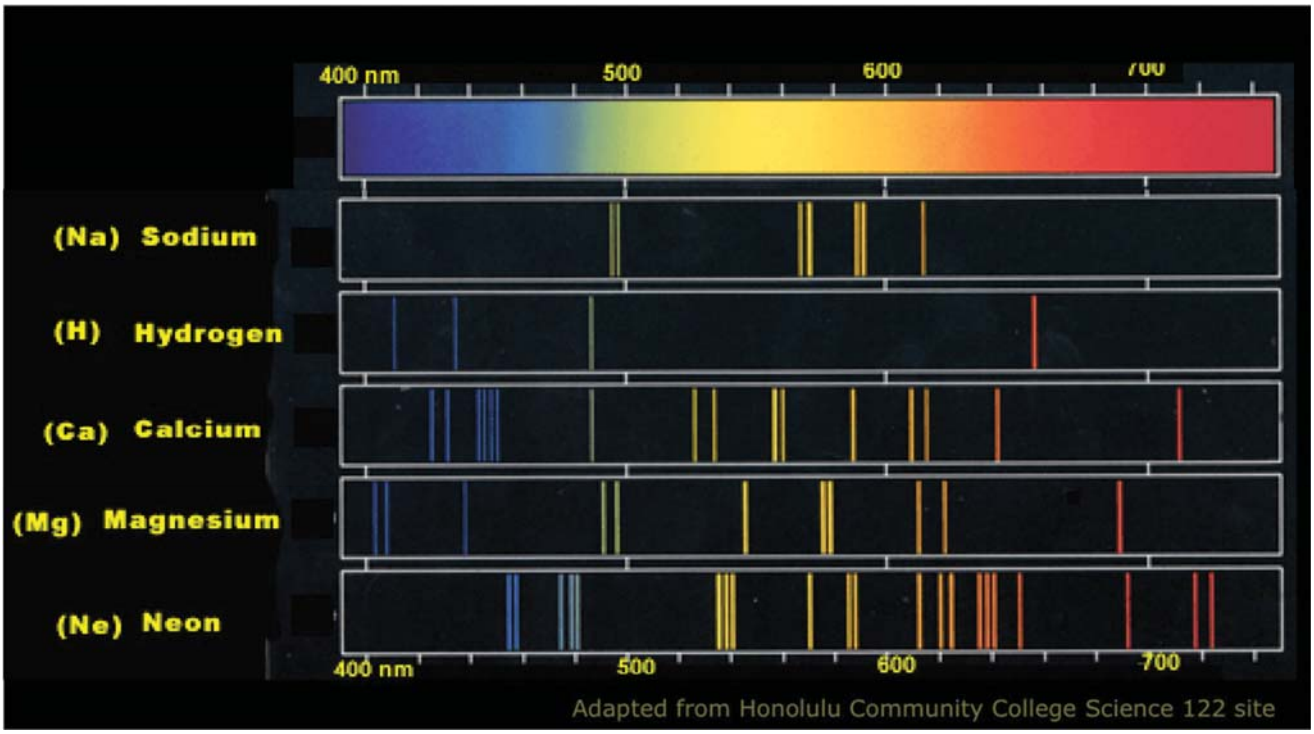
Discrete spectrum lines of a fluorescent lamp

Line spectra

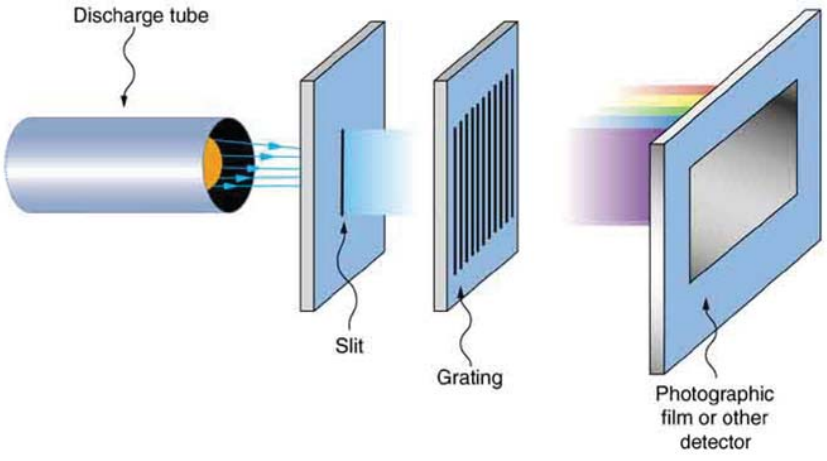
Remember those flame experiments from your high school chemistry class?



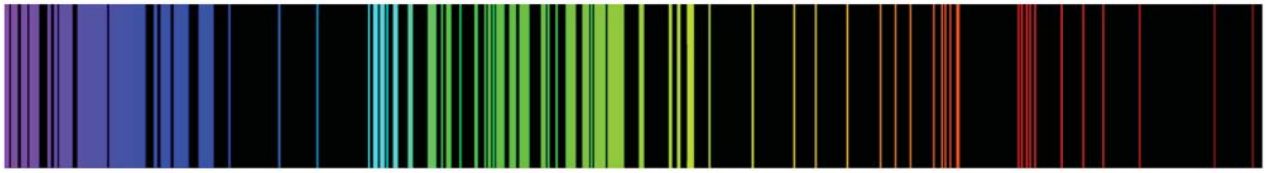
Line spectra



Line spectra



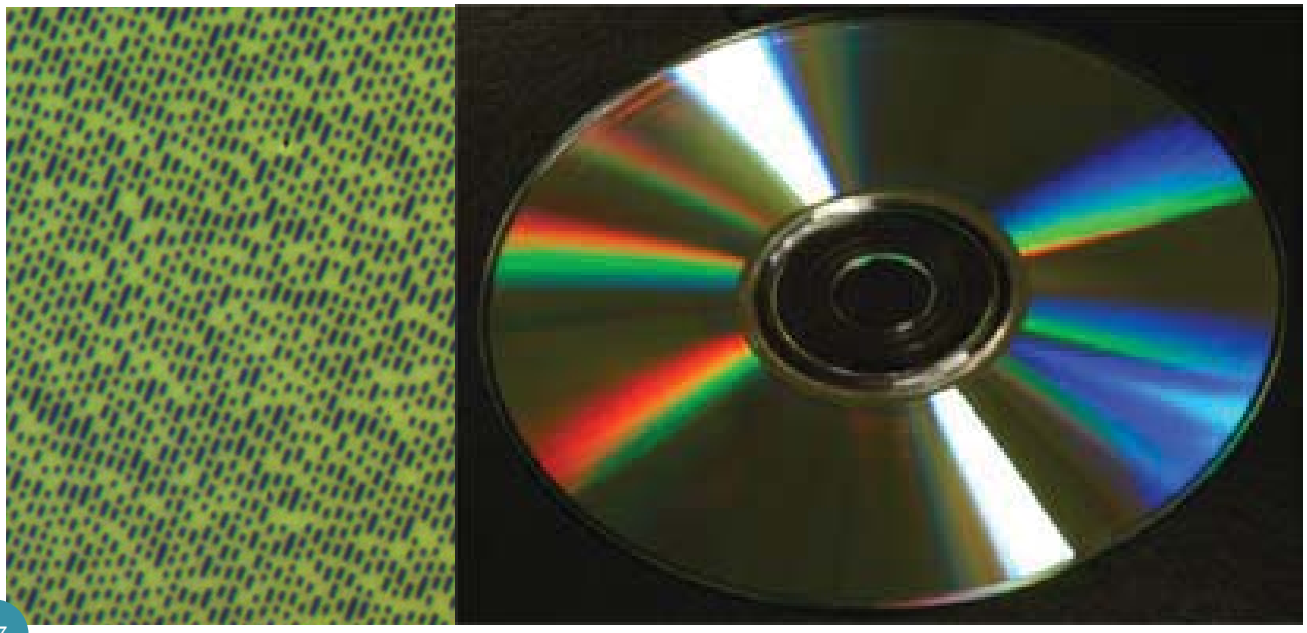
(a)



(b)

CD Tracks as Diffraction Gratings

- The tracks of a compact disc can act as a diffraction grating, producing a separation of the colors of white light.



[http://3.14.by/en/read/cd-dvd-microscope]

CD Tracks as Diffraction Gratings

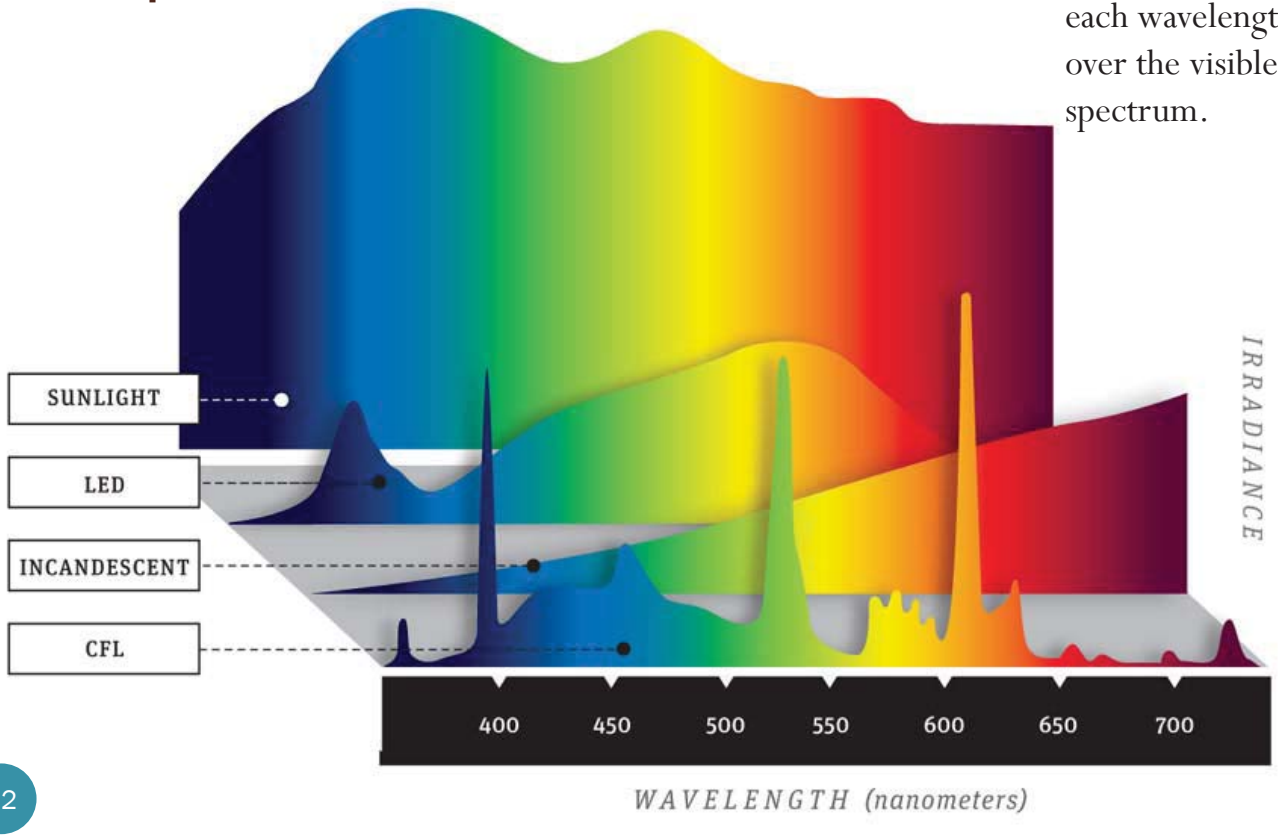
Sunshine

Compact Fluorescent Lamp

CF vs LED

Spectral Power Distribution

Plot of the relative power emitted by the light source at each wavelength over the visible spectrum.



Spectral Power Distribution