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MEMORANDUM

To: First Three Minutes Class

From: Peter

Subject: Memo #86: Waves and photons

Date: January 19, 2021

Electromagnetic radiation consists of particles, called photons, that carry energy. As a particle, a photon has a length and Fig. 1 shows this length comes from adding up waves of different wavelengths. The top five panels of Fig. 1 show waves of different wavelengths and the lowest panel shows the sum of the top five panels forming a pulse with a length of about 1 second. The center wavelength is 5 cm, corresponding to a frequency of 6 GHz. This shows a radiation pulse is a bundle of waves of different frequencies travelling together.

Fig. 2 shows three radiation pulses computed by summing over five waves with different ranges of frequencies. This figure shows the time duration of the pulse gets smaller as the frequency range of waves gets larger. Since radiation pulses always travel at the speed of light, the length of the pulse is proportional to the duration of the pulse. Fig. 3 shows a more realistic pulse with 200 waves added up to make the pulse. The center frequency is 10 MHz and the range of frequencies making up the wave varies from 320 kHz to 80 kHz. For a bandwidth of 320 kHz, the width of the pulse is about 5 μ seconds.

In information transmission, each pulse could be one bit and with a bandwidth of 320 kHz, about $1/5\mu$s=200,000 bits/second could be transmitted. As the bandwidth decreases, the bit transmission rate decreases. We hear about the value of high bandwidth so much because that means faster information transfer.

A pulse of electromagnetic radiation is a mass of photons all travelling together. The energy of each photon is proportional to its frequency. A pulse composed of different wave frequencies is a group of photons travelling together, each one having a different frequency distributed as the strength of the waves making up the pulse.

The pulse picture is the only picture of the photon — sometimes it matters that the photons travelling together make a wave and sometimes they can be thought of as particles.

The mathematics behind summing waves is called Fourier Analysis and is not much more complicated than the treatment here.

References

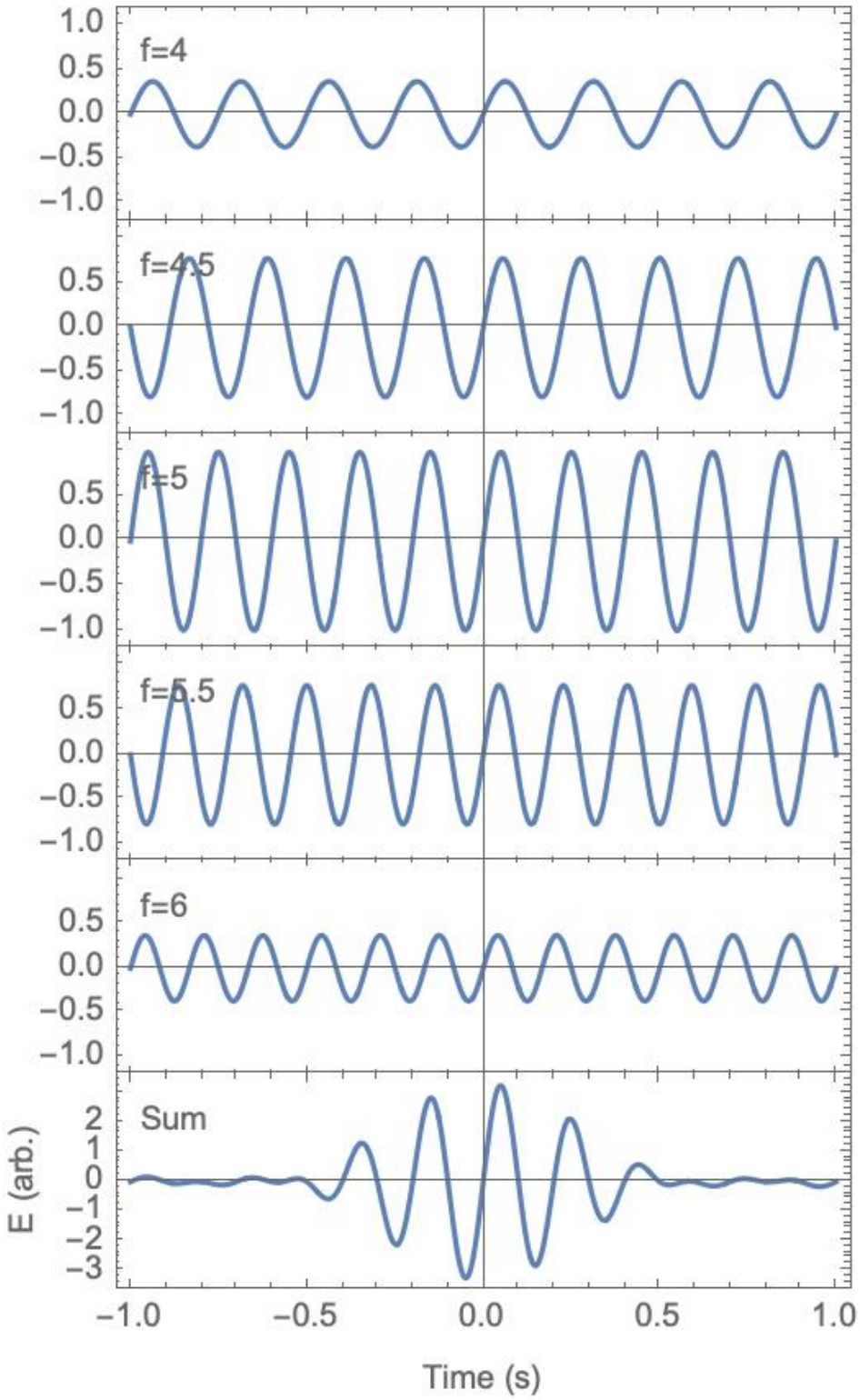

Figure 1: Five plane waves with wavelengths 4, 4.5, 5, 5.5, 6 cm are shown in the top five panels. The bottom panel shows the sum of the top five panels.

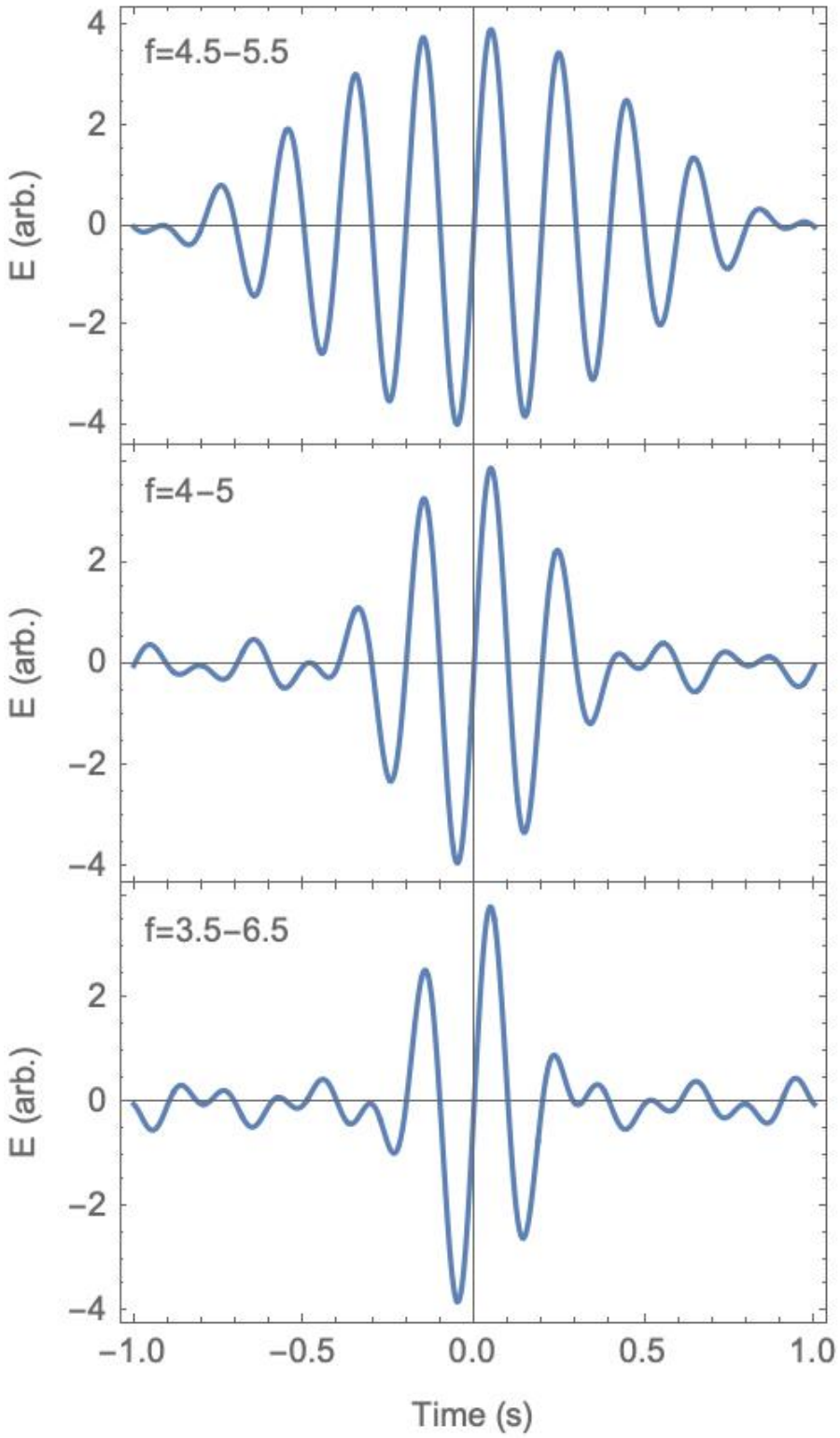

Figure 2: Pulses computed as in Fig. 1 with three different ranges of wavelengths. These figures show the wider the range of frequencies, the narrower the pulse.

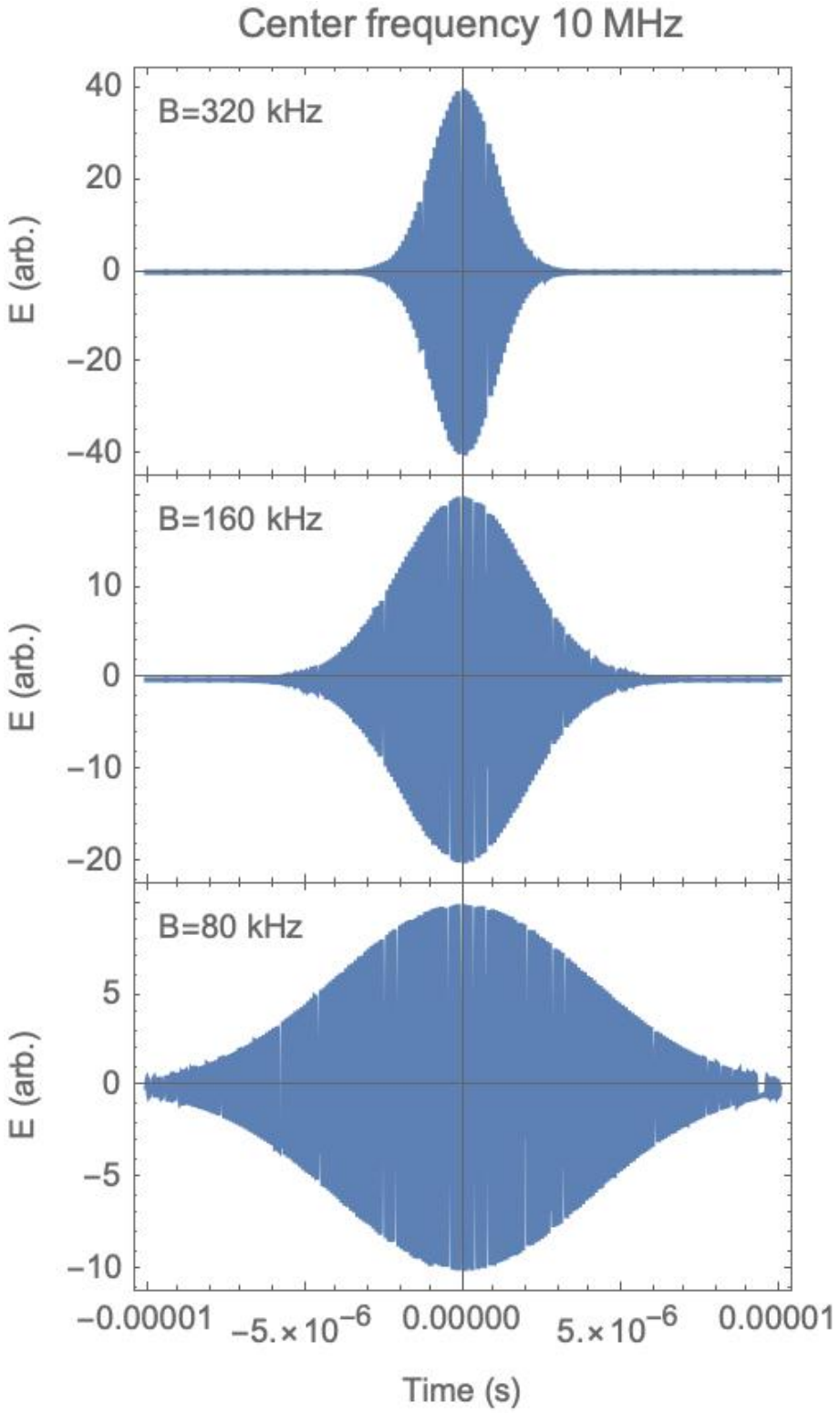

Figure 3: Pulses computed with a 10 MHz center frequency with bandwidths of 320, 160, and 80 kHz around the center frequency.