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Coherently Speaking….

I was reading with interest the debate over LiDAR, LiDAR, LiDAR and so forth in the previous issue of *LIDAR News*. I am not sure it much matters about the capitalization but I think we need to change the meaning of the acronym. There are several variants with the most popular seeming to be "Light Detection And Ranging." I think (seriously) that it should be "Laser Imaging, Detection and Ranging." Thus, in honor of this new meaning, I will revert to all capital letters, LIDAR. The meanings of these terms are:

- Laser—LIDAR systems always use laser light (as opposed to, say, incandescent lights).
- Imaging—this is the part of LIDAR that is often ignored. A LIDAR provides a pretty terrific grey scale image based on the intensity return of the near-infrared illuminating laser (see **Figure 1**). The best part about this is that it is a 3D true ortho.
- Detection—I am not sure how this got into the LIDAR name to begin with. I think simply to use as many of the letter meanings in Radio Detection and Ranging (RADAR) as possible. The original meaning of Detection was the ability of radar to detect an object in the air such as an incoming airplane.
- Ranging—this is the original true value of LIDAR (before the Imaging part got so good). This is the ability of LIDAR to do single, active pulse direct distance measurement.

Figure 1: Intensity return from an Airborne Laser Scanner

So the question may come to mind as to why the light part of LIDAR is laser? What is so special about a laser that we use it to the exclusion of all other potential "light spectrum" radiation sources? I want to examine this remarkable light source a bit in this article.

In spite of what you may have read to the contrary, the idea of a laser was conceived by Albert Einstein in 1916 in a paper entitled "Strahlungs-emission und -absorption nach der Quantentheorie" ("Emission and Absorption of Radiation in Quantum Theory"). This seminal quantum theory paper postulated a remarkable property of the (then) newly discovered quantum light particle, the "photon." Let's look at an ocean wave analogy to understand this phenomenon.

Imagine that I build a device to "magnify" an ocean wave. I build a series of towers that start 1 kilometer from shore and extend in a line spaced 10 meters apart from my starting location 1 km out to the shore. Each tower is 50 meters above the water and holds a big rock. I have a clever mechanism on each tower that allows the rock to drop at exactly the right time. We'll see what this time is in just a moment.

I first load up this set of towers by having the rocks hoisted from the sea bed to the top of the tower. In laser terms, this is called "pumping." (in a laser, I use some sort of mechanism to raise electrons from a "rest" orbit to an excited state orbit). All of the rocks and distances to the water are the same. This means (ignoring all sorts of other factors such as water depth, wind and other problems that reality causes) the waves generated by each dropping rock are identical in wave length (the distance between wave crests) and amplitude (the height of each wave). In optics, we call this property of identical wavelength "monochromatic." This term comes from the fact that we humans perceive differing wavelengths of light as different colors. If all of the light is at the same wavelength, we perceive the light as a very narrow, single color. Hence "mono" (one) "Chromatic" (color).

Anyway, back to our experiment. To start this whole thing going, I drop the rock that is at the farthest tower. When it hits the water, a circular wave is formed. This wave radiates outward from the point of impact. A super clever device on each tower looks for a wave "front" that is headed toward shore. At precisely the right instant, it drops its rock in a very special sort of way. The rock is dropped such that the crest of the wave it forms precisely aligns with the oncoming wave from the prior dropped rock along the line formed by the towers. This means that, along our line formed by the towers, the crest of this just dropped rock adds to the crest of the incoming wave, increasing the overall height of the wave (the waves are said to be "in phase"). This adding of waves such that they are precisely aligned is called *constructive interference.* The result is an *amplification* of the wave. Of course, away from the line of the towers, the waves are all scrambled up and tend to cancel one another out. This cancelling effect is called *destructive interference.* When waves from multiple emitters are precisely in step with constructive interference as we have with our rock dropping towers, we call the phenomenon *coherence.* Thus we would call our wave front moving toward shore a *coherent* wave.

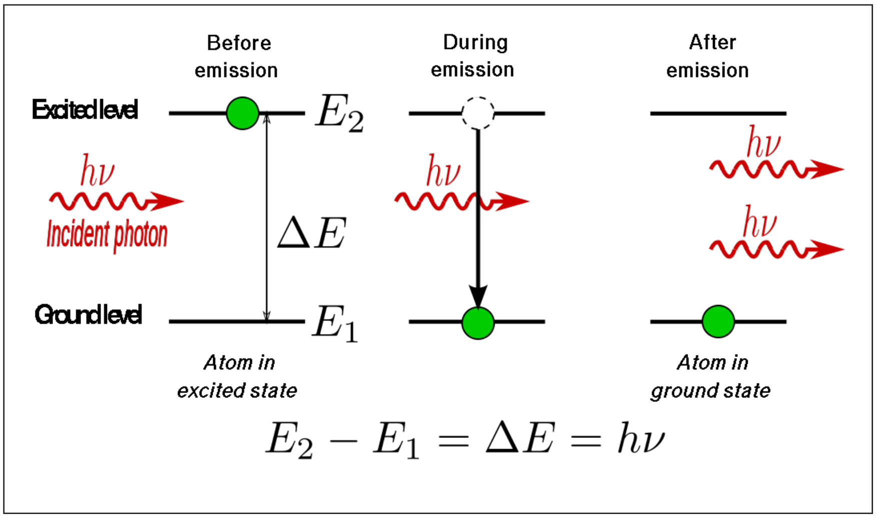

Figure 2: Stimulated Emission of Photons

Thus you see that in our experiment, the wave gets *amplified* by the rocks dropped at each tower. The rocks are *stimulated* to drop by our very clever mechanism that sees the oncoming wave front and drops the rock with precise timing such that it adds *coherently* to the wave front. Of course, each rock has to produce a wave that is identical to all other waves in terms of wavelength or the waves cannot stay lock-stepped together. This means that all *coherent* waves must be monochromatic.

In a laser, the medium is light rather than water. The amplification is the addition of waves from falling electrons rather than rocks. The electrons are stimulated to fall in lock step with the impinging electromagnetic wave by a quantum mechanical phenomenon called "stimulated emission" (as previously mentioned, postulated by Albert Einstein in 1916). When the stimulated electron "falls" from its excited orbit to a lower orbit, it emits an electromagnetic wave ("radiation") that is in lock step with the incoming wave. This is illustrated in **Figure 2**.

Thus the acronym Light Amplification by Stimulated Emission of Radiation fully explains all of the phenomenon that are occurring. Of course, we are ignoring some additional details such as reflecting our wave back and forth multiple times with mirrors to build up the amplitude, the quantum mechanical description of waves as photons and a few thousand other sundry details but what is described here should give you a basic feel for the terminology used in laser physics and how a laser works.

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