OFFICE MEMORANDUM ◇ STAR LABORATORY

February 3, 1994

To: Gene Franklin/Diane Shankle

From: Tony Fraser-Smith

Subject: Ph.D. Quals Question, 1994

Electromagnetics

$\beta = \sqrt{\frac{\omega\mu\sigma}{2}}$

$v_{ph} = \frac{\omega}{\beta_{@\omega}} = \sqrt{\frac{2\omega}{\mu\sigma}}$

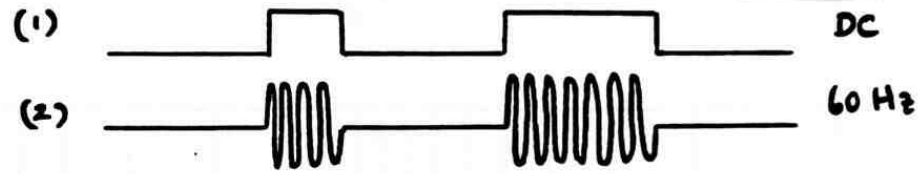
$v_g = \frac{d\omega}{d\beta} = \sqrt{\frac{4\omega}{\mu\sigma}}$

Following a brief review of the student's previous work on the propagation of electromagnetic fields in conducting media at low frequencies, in which it is established that both the attenuation and velocity (actually both the phase and group velocities) increase with increasing frequency, the following question is asked:

Question: You have gone down a deep mine and an accident has occurred in which a large amount of the overlying rock has filled up the elevator shaft and cut the telephone link with the surface. You want to send some kind of signal to the surface to let the rescuers know you are still alive. You look around and find (1) a considerable length of telephone wire strung along the side of the tunnel in which you are located, (2) a large battery (powering an emergency light), and (3) a light bulb that is still lit, indicating that some 60 Hz power is still available. What is the best way to send a signal to the surface with this equipment?

Answer: The wire first has to be arranged into some kind of antenna. Obviously doubling the wire back on itself and then connecting it to either the battery or the 60 Hz power will be ineffective, but a loop antenna or a straight dipole antenna configuration (the latter preferably with earthed ends) should be adequate.

The two ends of the wire can then be connected to either the battery or the 60 Hz supply. The student is advised to try generating a dot/dash pattern as is used in Morse code:



Concentrating first on the frequency content of the "DC" and "60-Hz" dot/dash patterns, we notice that the DC dot converts to a sinc pattern centered on a frequency of 0 Hz in the frequency domain, whereas the 60-Hz dot converts to an equivalent sinc pattern centered on 60 Hz. Knowing that the attenuation increases with frequency, and not knowing the depth, or the conductivity, of the conducting material above the tunnel, we decide that it is safer to work with the DC dot/dash pattern.

Concentrating now on the DC dot/dash pattern, we first notice that the sharp edges are associated with the highest frequencies, which will be attenuated most rapidly. The dot and the dash will be converted to rounded pulses as they propagate upwards toward the earth's surface. In addition, since the dash is longer and thus has lower frequencies associated with it, it will probably reach the surface with a somewhat larger amplitude than the dot (assuming the dot and dash initial amplitudes are equal). Dispersion also needs to be taken into account. The dot and the dash share some frequencies, which will reach the earth's surface at the same time. However, the dash has a lower average frequency content than the dot, so its shape will become distorted in such a way that the dot, which is assumed to be following the dash, will tend to catch up with it as time progresses. To keep the dot and dash clearly separate, their spacing needs to be increased.