OFFICE MEMORANDUM ◊ STAR LABORATORY

February 7, 1998

To: Diane Shankle

From: Tony Fraser-Smith Electromagnetics

Subject: Ph.D. Quals Question, 1998

Question: When we look at our AM/FM radio dials we find that the frequency range for the various AM stations is 500–1600 kHz. In addition, typical frequencies in the shortwave range, where radio signals from most of the countries in the world can be picked up, are 3 – 30 MHz. Despite the great numbers of stations operating in these frequency bands, the US operates a radio station that transmits at a center frequency of 76 Hz and Russia operates a similar station at 82 Hz. These are the only two such radio stations in the world. At these low frequencies it is very expensive to build and to operate transmitters, so why would the US and Russia bother?

Answer: There are many different ways to answer this question. An ideal answer would include most or all of the following: (1) Recognition that the US and Russia must use their low-frequency radio stations to communicate with their submarines (they have to use low frequencies for the signals to penetrate deeply enough into the sea water to reach the subs). (2) A brief discussion of how sea water is a good conductor, and that a measure of the ability of an electromagnetic wave to penetrate a good conductor is given by the skin depth δ, where $\delta = [2/(\omega\mu\sigma)]^{1/2}$, where where ω is the angular frequency, μ is the permeability, and where σ is the electrical conductivity. (3) The student should demonstrate some knowledge of how the wave is exponentially attenuated (with attenuation constant $\alpha = 1/\delta$).

At or around this stage the instructor gives the student the representative skin depth of 250 m for a 1 Hz electromagnetic wave penetrating sea water, and asks what the skin depth is for the US and Russian low-frequency radio signals.

Using the above information, the ideal answer would then include the following: (4) assuming a typical frequency of around 80 Hz, the skin depth is found to be $250/\sqrt{80} \approx 28$ m. This is probably not a very great depth for a submarine, so the 76 Hz and 82 Hz radio signals must be attenuated quite strongly as they penetrate the sea water down to the submarines. (5) Further, attenuation in the water is not the only loss mechanism – there will be substantial energy loss simply getting the signals into the sea water, due to reflection from the surface. (6) Another disadvantage would be the inability to send much information over a 76/82 Hz data link. In particular, it would not be possible to send a voice signal (in real time). The final conclusion is that the 76 and 82 Hz transmissions must work, or the US and Russia would not use them, but they must be difficult to detect at submarine depths and their ability to transfer information must be extremely limited.

Skin depth $\delta = \left(\frac{2}{\omega\mu\sigma}\right)^{1/2}$

Good Conductor approximation $\frac{\sigma}{\omega\epsilon} >> 0$

Will it improve transmit range if transmitter tower is put under water?