2018 MCM
Problem A: Multi-hop HF Radio Propagation

Background: On high frequencies (HF, defined to be 3 – 30 mHz), radio waves can travel long distances (from one point on the earth's surface to another distant point on the earth's surface) by multiple reflections off the ionosphere and off the earth. For frequencies below the *maximum usable frequency* (MUF), HF radio waves from a ground source reflect off the ionosphere back to the earth, where they may reflect again back to the ionosphere, where they may reflect again back to the earth, and so on, travelling further with each successive hop. Among other factors, the characteristics of the reflecting surface determine the strength of the reflected wave and how far the signal will ultimately travel while maintaining useful signal integrity. Also, the MUF varies with the season, time of day, and solar conditions. Frequencies above the MUF are not reflected/refracted, but pass through the ionosphere into space. In this problem, the focus is particularly on reflections off the ocean surface. It has been found empirically that reflections off a turbulent ocean are attenuated more than reflections off a calm ocean. Ocean turbulence will affect the electromagnetic gradient of seawater, altering the local permittivity and permeability of the ocean, and changing the height and angle of the reflection surface. A turbulent ocean is one in which wave heights, shapes, and frequencies change rapidly, and the direction of wave travel may also change.

Problem:

Part I: Develop a mathematical model for this signal reflection off the ocean. For a 100-watt HF constant-carrier signal, below the MUF, from a point source on land, determine the strength of the first reflection off a turbulent ocean and compare it with the strength of a first reflection off a calm ocean. (Note that this means that there has been one reflection of this signal off the ionosphere.) If additional reflections (2 through n) take place off calm oceans, what is the maximum number of hops the signal can take before its strength falls below a usable signal-to-noise ratio (SNR) threshold of 10 dB?

Part II: How do your findings from **Part I** compare with HF reflections off mountainous or rugged terrain versus smooth terrain?

Part III: A ship travelling across the ocean will use HF for communications and to receive weather and traffic reports. How does your model change to accommodate a shipboard receiver moving on a turbulent ocean? How long can the ship remain in communication using the same multi-hop path?

Part IV: Prepare a short (1 to 2 pages) synopsis of your results suitable for publication as a short note in *IEEE Communications Magazine*.

Your submission should consist of:

- One-page Summary Sheet,
- Two-page synopsis,
- Your solution of no more than 20 pages, for a maximum of 23 pages with your summary and synopsis.
- Note: <u>Reference list and any appendices do not count toward the 23-page limit and should appear after your completed solution.</u>

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问题 A：多跳 HF 无线电传播

在高频（HF，定义为 3-30 mHz）区域，通过电离层和地球外的多重反射,无线电波可以传输较远距离（从地球表面上的一个点到地球表面上另一个遥远的点）。对于低于最大值（MUF）的可用频率，来自地面源的 HF 无线电波通过电离层反射到地球，在那里他们可能再次反射回电离层，或许也可能会再次反映回到地球上，等等，每一个连续的跳跃都会使得电波传输的更远。**除其他因素外，反射面的特性决定反射波的强度以及在保证有用信号完整性的同时如何最大程度的传输信号。**另外，MUF（最大可用频率）随季节、一天中的时间及太阳能条件而变化。高于 MUF 的频率不会反射/折射，而是穿过电离层进入太空。**在本问题上，重点关注在海洋表面的电波反射**。根据经验性发现，**在动荡海域表面电波的反射衰减程度会比平静海域大很多**。海洋湍流会影响海水的电磁梯度，改变海洋的局部介电常数和渗透率，并改变反射面的高度和角度。动荡海洋表面的波高、形状和频率迅速变化，且波浪的运动方向也可能改变。

问题：

第一部分：为通过海洋表层反射的信号建立一个数学模型。 对于一个 100 瓦的 HF 恒定载波信号，其值低于 MUF，从陆地上的一个点源，确定在动荡海域的首次反射强度，并将其与在平静海域的第一次反射强度相比较。（请注意，这意味着这个信号的有一个反射会从电

离层进行。）如果从平静的海洋发生附加的反射（2 到 n），在其强度低于可用信噪比（SNR）阈值 10 dB 之前该信号所能采取的最大跳数为多少？

第二部分：第一部分的研究结果如何与通过山区的 HF 反射进行比较？或者崎岖的地形与光滑的地形之间如何比较呢？

第三部分：在海上旅行的船舶将使用 HF 进行通信、接收天气及交通报告。你的模型如何改变，以适应在动荡的海洋上移动的船上接收器？当使用多跳路径时，船还能保持联系多久？

第四部分：准备一份简短的（1 到 2 页）结果摘要以方便在 IEEE 通信杂志上出版。