

A REVIEW OF IONOSPHERIC EFFECTS ON EARTH-SPACE  
PROPAGATION

John A. Klobuchar  
Ionospheric Physics Division  
Air Force Geophysics Laboratory  
Hanscom AFB, MA 01731

ABSTRACT

Radio waves undergo several effects when they pass through the earth's ionosphere. One of the most important of these effects is a retardation, or group delay, on the modulation or information carried on the radio wave that is due to its encounter with the free, thermal electrons in the earth's ionosphere. Other effects the ionosphere has on radio waves include: (1) RF carrier phase advance; (2) Doppler shift of the RF carrier of the radio wave; (3) Faraday rotation of the plane of polarization of linearly polarized waves; (4) angular refraction or bending of the radio wave path as it travels through the ionosphere; and (6) amplitude and phase scintillations. With the exception of scintillation, all the other effects listed here are proportional, at least to first order, to the total number of electrons encountered by the wave on its passage through the ionosphere or to their time rate of change. In fact, phase scintillation also is merely the short term time rate of change of total electron content (TEC) after the longer term variations have been removed.

In this review, a short description will be given of each ionospheric TEC effect upon radio waves, along with a representative value of the magnitude of each of these effects under normal ionospheric conditions. This will be followed by a discussion of the important characteristics of average ionospheric TEC behavior and the temporal and spatial variability of TEC.

This paper was not received for publication.

## QUESTIONS AND ANSWERS

JULES SCHLESINGER, HAZELTINE CORPORATION: Obviously, to get a high confidence level, I can't use every reading that's coming down from a group of satellites. Is that correct?

MR. KLOBUCHAR: Yes, I would assume so.

MR SCHLESINGER: Going from that, in your best judgment, how many readings would I probably have to take to make sure that I am in good shape?

MR. KLOBUCHAR: Do you have to have this time continuously? You must have some sort of an oscillator there that's fairly stable that you can rely upon for seconds, or tens of seconds, of time.

MR. SCHLESINGER: Yes, that's correct. However, we are planning -- and this is in the planning stage -- some sort of an algorithm to use the GPS system as a master to keep updating the ground station flywheel.

Now, if I were to use every measurement in my algorithm, on occasion, during fading, my algorithm would indicate a failure. So, somewhere in my algorithm, judging from your information, I must put in some coefficient which says I have to use "x" number of readings rather than a single reading. What would this number "x" be in your best estimate?

MR. KLOBUCHAR: Well, I don't know whether I brought any with me, but we have various power spectra of the simulation fading. I guess that's really what you are asking.

Does most of it occur within the first tenth of a second, or one second? The answer is yes, a second let's say. None of the deep fades have occurred with any length of time, duration, longer than something on the order of half a second to a second.

Now the question is: How are you going to know when you have a bad reading? Just by the AGC on your receiver channel? Because that's what we are measuring, in effect.

MR. SCHLESINGER: What will happen in this proposed system is that there will be an error generated because the signal coming down from the satellite will be probably markedly different from that originating, or being kept in the flywheel system. From what you just said, it appears that if I were to do two measurements every two seconds I wouldn't see an error, because the fading would be less than a second long. Isn't that correct?

MR. KLOBUCHAR: That's right. You can measure that by just using the AGC on your receiver, and know whether you have that sort of problem or not.

MR. SCHLESINGER: Would that be indicated in this "quality" signal that comes from the GPS?

MR. KLOBUCHAR: Nothing in the telemetry coming down from the GPS is going to tell you that there is anything in the intervening

atmosphere. It's the ionosphere itself, from your particular direction, that you will have to measure in one way or another to tell you whether you have a problem.

MR. SCHLESINGER: I think that you have answered the question. If I use not every reading, but perhaps every two, I will probably be safe anywhere in the world most of the time. Is that a correct assumption?

MR. KLOBUCHAR: If you can integrate for a second, I think that you will be in good shape.

DAVID ALLAN, NATIONAL BUREAU OF STANDARDS: When you have a large deviation, 1 to 3 sigma, what is the extent of that? Is it worldwide?

MR. KLOBUCHAR: No. In fact, from Colorado, back in the early or mid-seventies, we were making measurements -- "we" meaning not me, but some ionospheric people -- were making measurements in two directions; one station near Boulder, and one near Fort Collins, and we were looking at two different satellites. One of them saw a big increase, and one of them didn't. That happened to be the demarcation line, because all of the east coast stations did see a big increase, and all of the west coast stations, from the one looking westward in Boulder, to the ones at Stanford and other places in the west, only saw a decrease.

No, it's not a worldwide phenomenon, and it will be later in time, generally, the lower in latitude you go, because these things propagate from the higher latitudes.

MEL BUCHWALD, LOS ALAMOS NATIONAL LABORATORY: Ionospheric people have been looking at simulations and the effects of simulations on the disturbing radio transmissions for localizing electromagnetic pulses using the W sensors on these GPS satellites, and we wonder where the body of data on simulations exist, and is it measured only through this Rayleigh fading data?

MR. KLOBUCHAR: We can probably talk privately in more detail about this, but I can answer that. There is a lot of empirical data, that is, fading data of the occurrences of different depths of fade versus time for different stations.

There is at least one group that is trying to make a model based partially on this empirical data, and partially on some theoretical work. They are making good progress in that. This is all for the background natural ionosphere, however.

There are also groups who are making extrapolations to the nuclear disturbed ionosphere. We probably deal with the bulk of the statistics on the natural ionosphere in our group, on the naturally occurring ionosphere measurements, at least.

MR. BUCHWALD: All we are interested in is the range of naturally occurring simulation.

MR. KLOBUCHAR: Well, the worst is Rayleigh fading. You can't get worse than that. Everything gets better from there, but I don't

know what percentage of the time you have Rayleigh fading at different locations. That's a function of a lot of things: time of day, season, solar geodetic activity, where you are located, and those kinds of factors.

MR. BUCHWALD: Thank you.

MR. KLOBUCHAR: On that general subject, I have one more view graph, and that is to show you about the solar cycle. This is the last of twenty-some odd solar cycles. It is a bit out of date now, because we are well down on this present solar cycle. If you look carefully, the highest solar cycle recorded according to sunspot number, was recorded in 1958.

The second highest was the one that we have just completed. It hadn't passed that point at the time this graph was made. The third highest was the one back in the forties. The one that peaked in 1968 or 1969 was a good average cycle.

We have been on a roll, then, during the last four cycles, if I may use that expression. We have had either an average, or well above average cycles. We have been well above the average for the last four cycles.

Who is to say what we are going to get in the future? We are now nearing the minimum of the present cycle. Those of you who are going to try to make measurements tomorrow, or for the next few years, here is a curve and we are about here on the curve (indicating). The first seven cycles are left off this curve because the optics and the quality of the data are suspect. You see that we have been at the mean or higher for the last several cycles. In the next few years, we are going to be down in the minimum, and who knows what will be the maximum for the next cycle. If I had to bet today, I would bet on the average, not above or below it. I attended, in June, a meeting in Paris of solar forecasters, among other ionospheric forecasters, and you can flip a coin and come up with a better approximation.

This is what they predicted for the present cycle (indicating). The prediction, the guy's name and the date of the prediction. You can see from the actual maximum and the range of the guesses that they are all over the ballpark. Things are improving, but it's really empirical.

If anyone has any predictions they want to add to this, it was done by Jerry Brown. I grabbed it from him just to show the futility in trying to look a few years in advance for solar cycles.