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Auroral backscatter with unequal propagation path lengths

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Abstract. In Aurora dx communication, the total propagation path length is the sum of the transmitter distance and the receiver distance to the scatterer. If the transmitter leg corresponds to, say, 30 percent of the total path length, the receiver leg is 70 percent and vice versa. This percentage may be considered the normalized position of the scatterer along the propagation path (at 50 percent, for example, the scatterer is located in the center of the propagation path and the length of the transmitter leg is equal to the length of receiver leg). Using the radar equation in bistatic scattering, the available received power is calculated as a function of the scatterer's normalized position. It is shown that the received power is minimum if the scatterer is located in the center of the total propagation path, i.e. scatterers displaced from the path center improve the signal level in Aurora dx communication. Independend from the scatterer's actual position, the reciprocity of the propagation path is maintained at all times, i.e. both stations receive equal power from the scatterer in a given Aurora QSO (assuming both stations operate the same transmitter output power).

1. Introduction

In Aurora dx communication, the propagation path separates into two legs, i.e. the uplink from the transmitter to the scatterer and the downlink from the scatterer to the receiver. The length of the uplink and downlink may differ considerably in practice. The red lines in figure 1 show an example where the scatterer's position separates the propagation path into a short and a long leg.

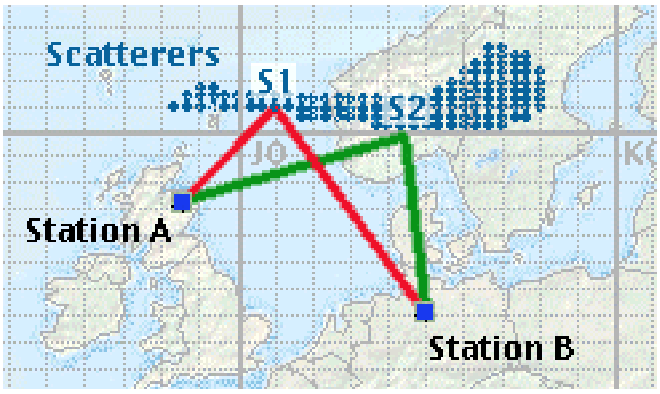

Figure 1. Red: Aurora propagation path which separates into a short leg (A-S1) and a long leg (S1-B). Green: propagation path with two legs of equal length, i.e. A-S2 and S2-B.

Assuming station A denotes the transmitter and station B the receiver, the path loss along the uplink A-S1 is relatively small resulting in a high field strength of the scattered radiowave at the position S1. However, the scattered radiowave must travel a long way from S1 to the receiver B corresponding to a high path loss along the downlink. If station B takes over the function of the transmitter in the Aurora QSO, we find a different scenario, i.e. the field strength of the scattered radiowave is relatively low at S1 because the incident radiowave must travel the long distance from station B to S1. However, the scattered radiowave travels only a short distance from S1 to station A, i.e. the downlink path loss is small in this case. In the following, we will discuss both scenarios in detail.

2. Radar equation

2.1 Radar equation in monostatic and bistatic scatter

In free-space radar applications, the radar target returns the power

(1) $$P_{monostatic} = P_{TX} \cdot \frac{\lambda^2}{4\pi} \cdot \frac{\sigma \cdot G_{TX} \cdot G_{RX}}{(4\pi \cdot d^2)^2}$$ (monostatic radar)

to the receiver where P_{TX} is the transmitter power, λ is the radar wavelength, G_{TX} and G_{RX} denotes the transmitter and receiver antenna gain, σ the target's radar cross section and d is the distance between the radar and the target (assuming $d >> \lambda$), see e.g. [1]. Eqn. (1) refers to the so-called monostatic radar where the transmitter location and the receiver location is identical.

However, in Aurora dx communication the transmitter location is independent from the receiver position, i.e. the uplink distance d_{TX} (transmitter – scatterer) must be considered separately from the downlink distance d_{RX} (scatterer – receiver). In this case, the radar equation is

(2) $$P_{bistatic} = P_{TX} \cdot \frac{\lambda^2}{4\pi} \cdot \frac{\sigma \cdot G_{TX} \cdot G_{RX}}{(4\pi)^2 \cdot d_{TX}^2 \cdot d_{RX}^2}$$ (bistatic radar).

2.2 Ratio of received power

Assuming the radar cross section is identical in monostatic and bistatic scattering, we may calculate the ratio of the available receiver power, i.e.

(3) $$\begin{aligned}\eta &= \frac{P_{bistatic}}{P_{monostatic}} \\ &= \frac{d^4}{d_{TX}^2 \cdot d_{RX}^2}\end{aligned}.$$

Using the quantity η, we may examine the influence of the transmitter and receiver target distance on the echo power. Note that the sum of the uplink and downlink distance is the total length of the propagation path, i.e.

(4) $$d_{TX} + d_{RX} = 2d\,.$$

Introducing the ratio of the uplink path length to the total path length, we can write

(5a) $$\varepsilon_{TX} = \frac{d_{TX}}{d_{TX} + d_{RX}},$$

and, analogous,

(5b) $$\begin{aligned}\varepsilon_{RX} &= \frac{d_{RX}}{d_{TX} + d_{RX}} \\ &= 1 - \varepsilon_{TX}\end{aligned},$$

In the case of identical distances (d_{TX} = d_{RX} = d), we obtain ε_{TX} = ε_{RX} = 1/2, i.e. the down-link and the uplink correspond to half the total propagation path length each. Evidently, the scatterer is located in the center of the propagation path in this case. The quantity ε_{TX} may be therefore interpreted the normalized position of the scatterer with respect to the transmitter, i.e. the scatterer may be shifted to any position along the total propagation path by varying ε_{TX} between 0 and 1.[1]

Introducing eqn. (4) to eqn. (5b) in eqn. (3), we obtain

(6) $$\begin{aligned}\eta &= \frac{1}{16 \cdot \varepsilon_{TX}^2 \cdot \varepsilon_{RX}^2} \\ &= \frac{1}{16 \cdot \varepsilon_{TX}^2 \cdot (1 - \varepsilon_{TX})^2}\end{aligned}.$$

3. Conclusions

3.1 Reciprocal radio propagation

Note the symmetry of eqn. (6) in respect to ε_{TX} and $\varepsilon_{RX} = 1 - \varepsilon_{TX}$, i.e. η is constant when exchanging the function of the transmitter and the receiver in an Aurora QSO and, as a consequence, the available received power of station A is always equal to station's B receiver input power (if both stations operate the same transmitter output power, of course).

Hence, the scenarios from above do not result in a non-reciprocal radio propagation as long as the radar cross section is independent from the direction and the magnitude of the incident

[1] It is however worth to mention, that zero distances are excluded practically as well as mathematically because d » λ is assumed in eqn. (1) and (2).

radio wave. It is in particular not true to assume that one station may benefit from closer position relative to the scatterer.

3.2 Gain by scatterers displaced from the path center

Note that η = 1 if ε_{TX} = ε_{RX} = 1/2, i.e. the available echo power in monostatic scattering is equal to the receiver input power in bistatic scattering if the length of the uplink is identical to the length of the downlink.

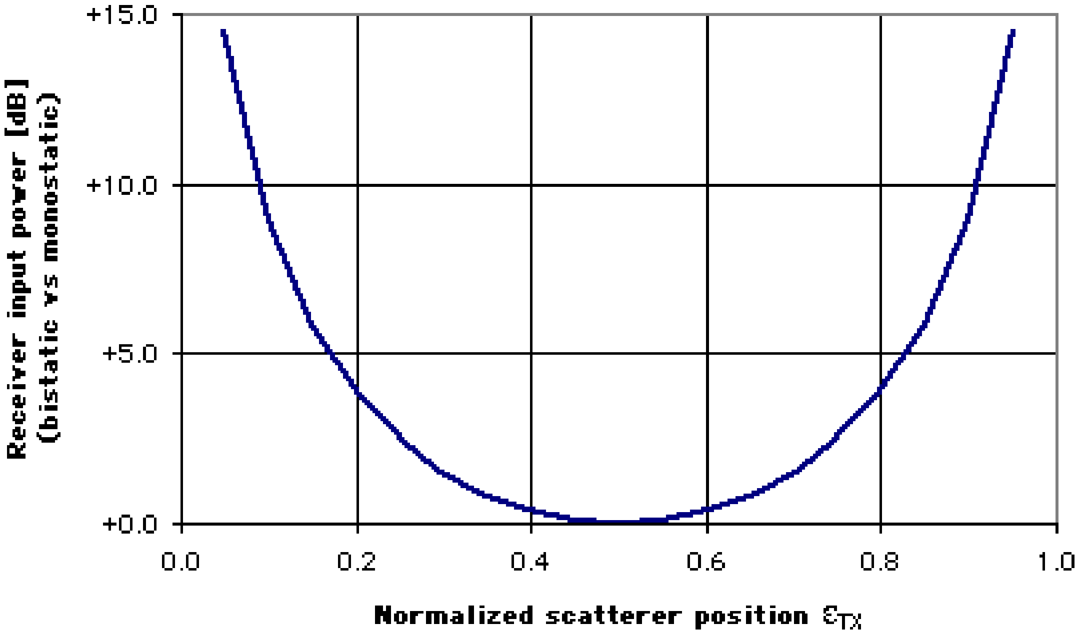

Figure 2. Variations of the available received power in Aurora dx communication.

However, in Aurora dx communication the uplink path length is generally not equal to the downlink path length. If, for example, radio stations in midlatitudes communicate with stations in polar latitudes (which is typical to many Aurora QSOs), then the station in the north is generally closer to the scatterer than the station in the south. Assuming the normalized scatterer position ε_{TX} = 0.2 (i.e. ε_{RX} = 0.8 or vice versa), the available received power is

$$10 \cdot \log\left(\frac{1}{16 \cdot 0.2^2 \cdot 0.8^2}\right) = 3.9 \text{ dB}$$

higher compared to the case where both stations have the same distance to the scatterer (ε_{TX} = 1/2), see figure 2.

The scatterer's displacement from the center towards one end of the total propagation path therefore results in a positive gain in Auroral backscatter propagation. The same result was already communicated in [2]. However, this gain cannot be explicitly measured in a given Aurora QSO because it is impossible to modify ε_{TX} from 0.2 (the true scatter geometry in this example) to 0.5 (the scatter geometry of reference). On the other hand, this effect might explain why north-south propagation paths seem to be more likely than east-west propagation paths in minor Aurora openings or when an Aurora opening starts to develop.

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4. References

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