SuperDARN HF Radar

By

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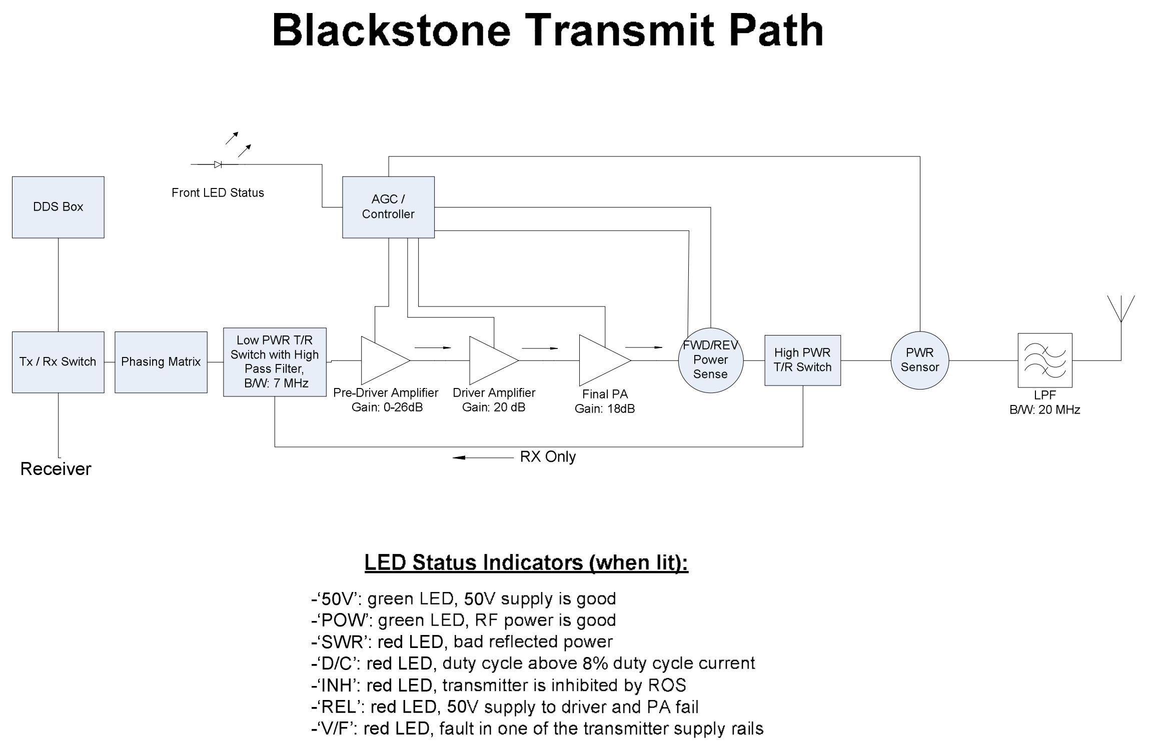
Introduction

SuperDARN is a research group that studies the motion of plasma in the ionosphere in cooperation with several other space weather and space science organizations. The motions of plasma are studied to make inferences about the Earth's magnetosphere and ionosphere and how they react to solar activities. The motion can also be used to study the coupling between the magnetosphere and the ionosphere. In order to monitor the motion of plasma in the ionosphere, SuperDARN uses high frequency (HF) radars which are equipped to monitor phase shifts of autocorrelation functions among pulses sequences. While there are several versions of the SuperDARN radar, this report examines from a system perspective how the radar at Blackstone, Virginia works.

Transmit Path

The pulse sequence is generated in a computer called the DDS Box. From there the signal passes through the first of many T/R switches. Next, the pulse sequence is formed into 16 phase delayed signals in order to form the desired beam direction. The phase delay of each of the signals is generated in the phasing matrix which will be discussed later in this report. Next, the signals are sent to a combiner and if stereoscan in enabled, the signal is combined with the other channel. Stereoscan is a special type of scan in which the radar generates signals at two different frequencies and beam directions. The combiner unit acts as a splitter on the receive side which will be mentioned later.

From the combiner/splitter, the signals enter their respective amplifier or transmitter at roughly 0 dBm. The first part of the transmitter is a low power T/R switch which allows the received signal to bypass the amplifier chain. The low power T/R switch also contains a high pass filter to clean up the signal coming from or going to the phasing matrix. Next, the signal is amplified up to the desired power output. The first stage, the pre-driver amplifier, sets the final output level as it is a variable gain amplifier from 0 to 26 dB. After the first stage, the driver amplifier and the final amplifier amplify the signal up to the final power output. With a 0 dBm input to the pre-driver amplifier, the maximum final output of this transmitter is around 2.5 kiloWatts. However, because of antenna coupling, the transmitters at Blackstone are typically set to output around 500-600 Watts.



From the final amplifier, the signal passes through a forward and reverse power sensor as seen on the figure above. This sensor is designed to sense forward power as it is transmitted toward the antenna to ensure the amplifier units are operating properly. The sensor also senses the reverse power in order to detect conditions in which the amplifier should be shut down. After this sensor, the signal passes through the final T/R switch and through another power sensor. The second power sensor in combination with the first power sensor can tell the controller unit if there has been a failure of the high power T/R switch. In the case of this switch failing, the controller would sense forward power being transmitted before the switch, but would not sense any power after the switch. Finally, each of the signals passes through a low pass filter to ensure higher harmonics are not radiated out of the antennas.

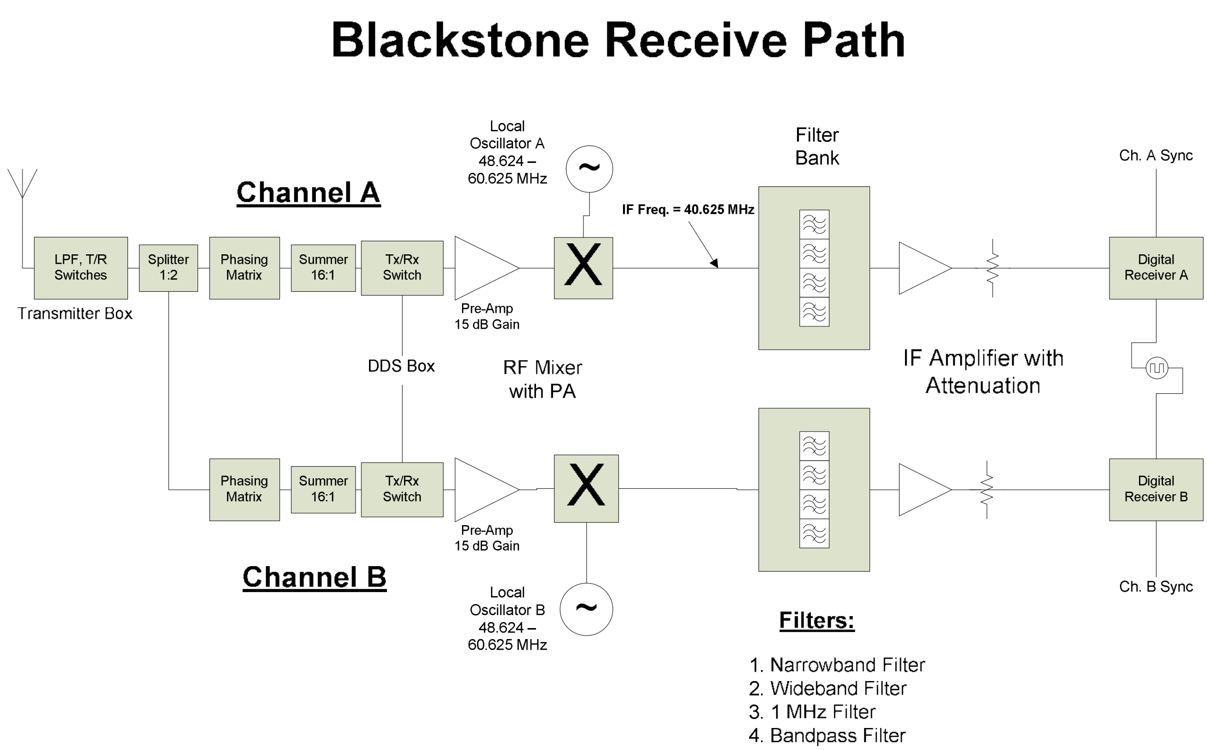
The controller unit also drives several other status lights that are indicated in the block diagram above. These provide for quick diagnostics of problems in the transmitter.

A few of the status lights also work with the remote monitoring program so that the status of transmitters in remote locations can be monitored.

Receive Path

Once the signal is received on the antenna, the signal passes back through the transmitter on the receive path as indicated in the previous block diagram. Once the signal leaves the transmitter box, the signal is split into two channels as described before. Each of the channel's receivers is identical except for the local oscillator frequency. From the splitter, the signal goes back through the phasing matrix so that the phase delay of the signal can be stripped off. Once all the signals are in phase with each other, the 16 signals are combined into one signal. After being summed, the signal passes through a T/R switch which switches between the final parts of the receiver and the DDS box.

The signal then passes through a three-part modular section of the receiver that is made up of a mixer, a filter bank, and an amplifier. The mixer includes a pre-amplifier to overcome some losses in the mixer and other parts of the receiver. The output of the mixer is an IF frequency of 40.625 MHz which was chosen since a quarter wavelength at that frequency is roughly 6 feet.



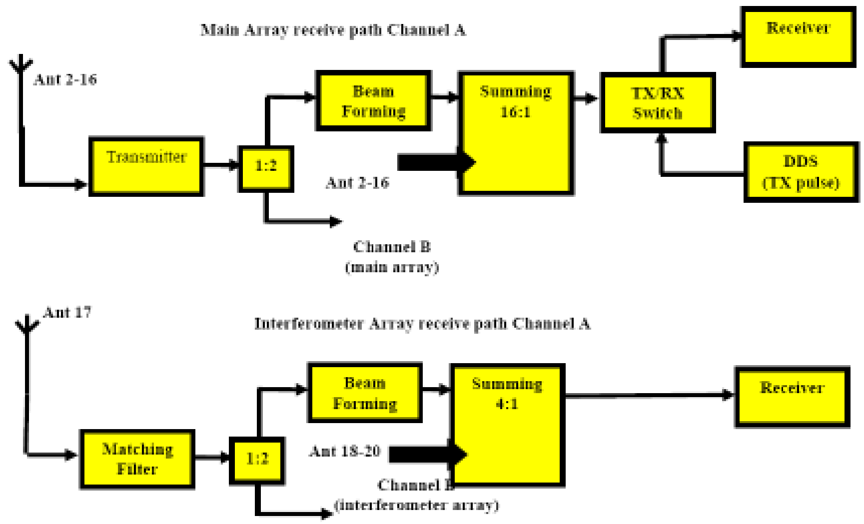
From the mixer, the signal then passes through a filter bank to eliminate unwanted mixing products. The filter bank has multiple filters since the electronics for this receiver are used for other applications than for SuperDARN. The narrowband and wideband filter have a bandwidth of 7 kHz and 20 kHz respectively. These bandwidths correspond to using a 100 microsecond and a 300 microsecond pulse width. The 1 MHz filter is used for the pulse sequence that SuperDARN radars employ. The last filter noted on the figure above is a 9 pole bandpass filter which is used for Doppler radar applications.

Lastly, before the signal goes to the receiver it passes through another stage of amplification in the IF amplifier. However, depending on the kind of application of the electronics, some attenuation may need to be added. The attenuator can be stepped from 10 dB to 70 dB in intervals of 10 dB. From there, the signal enters the digital receiver in which the signal is processed and information is extracted and saved to a hard disk.

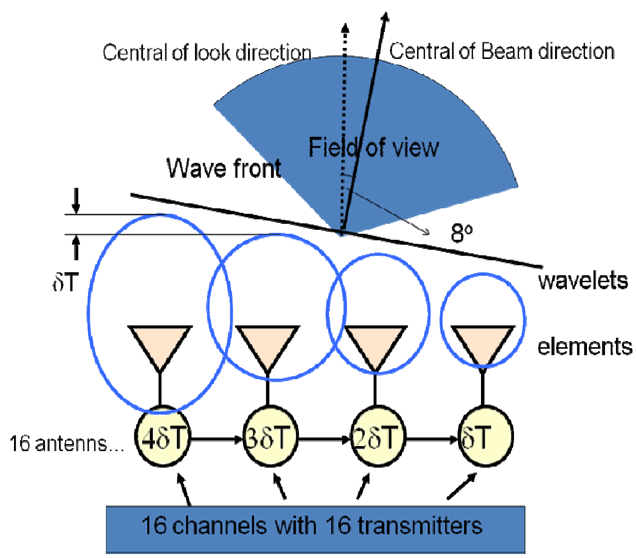
A similar receive path exists for the interferometer array at the SuperDARN radar at Blackstone which provides elevation angle information. However, in the interferometer array, the signal does not pass through a transmitter box since the interferometer array does not transmit. To compensate for this difference in phase length, the signal passes through a phase shifter. If all the other cables connecting the various parts of the system are the same length then the signal from the main array and the signal from the interferometer array will arrive at the receiver at the same relative phase. However, since the front array and interferometer array are separated by a couple hundred feet, the interferometer signal will lag behind the main array signal. The amount of phase difference can then provide elevation angle information.

Phasing Matrix

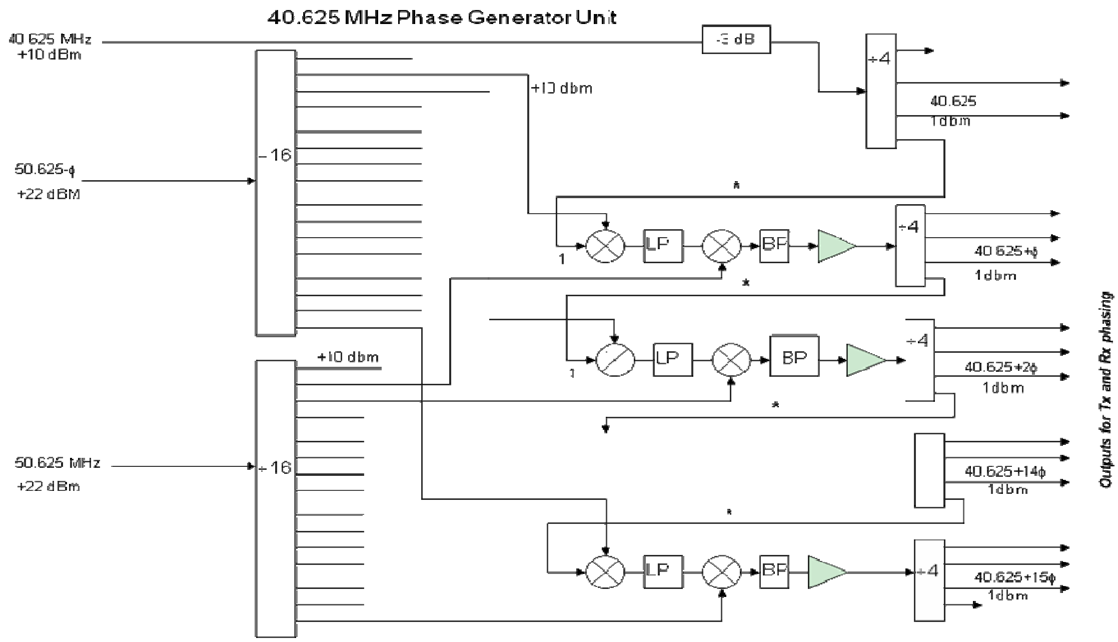
Blackstone HF radar is a linearly phased array radar, and consists of sixteen 600 W solid state transmitters that connect to 16 antennas, respectively. There are several reasons that linear phased array is used for the Blackstone Radar. First, an electronically steered beam can be created by changing of the current at each element. This beam can be rapidly (~ms) steered from one direction to another without moving the antenna mechanically. Second, 16 beam’s direction constitutes a large field of view. Third, there is large power for each element because each of them has a transmitter. Last but not least, compared with reflector antennas, phased arrays are more flexible and complex.



The phasing matrix, labeled beam forming above, provides the 16 antennas with desirable phases, one of which is shown in the figure. Those phases are sent to the antennas through their transmitter's and transmission lines respectively. The Blackstone radar radiates to 16 beam directions by changing the relative phases of those antennas. The way that beams are steered by phase delays is shown in the figure below. There is an 8^{o} squint angle between the central of the field of view and the direction that antennas look at.



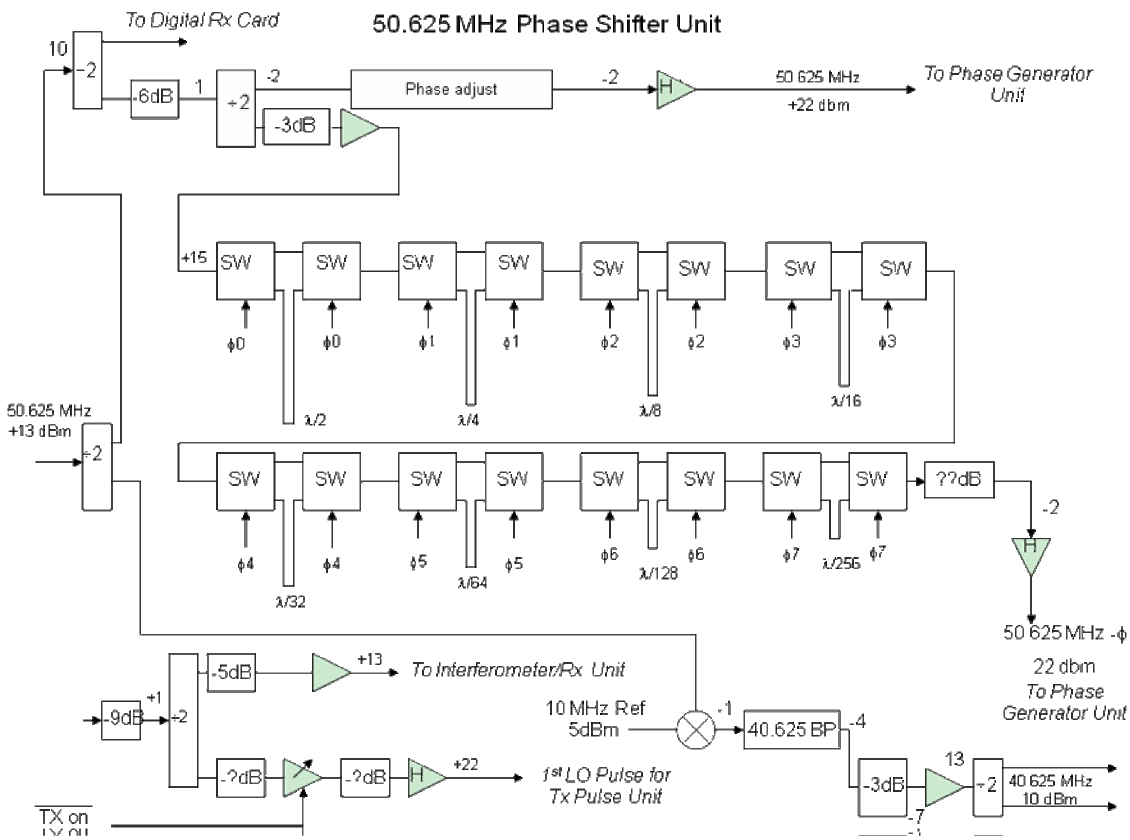
The following diagram is the part of phasing matrix, which is used to generate phase delay from 0 to 15Φ. The local frequency 50.625MHz is used because 10MHz carrier frequency (local frequency minus medium frequency) works best for the phase transmission among blocks. Here, the low pass filter has a central frequency at 21.4MHz, in order to filter frequency components except for 10MHz + (0 to 15Φ). The band pass filter has a central frequency at 40MHz in order to let the component 40.625 + (0 to 15Φ) pass through.



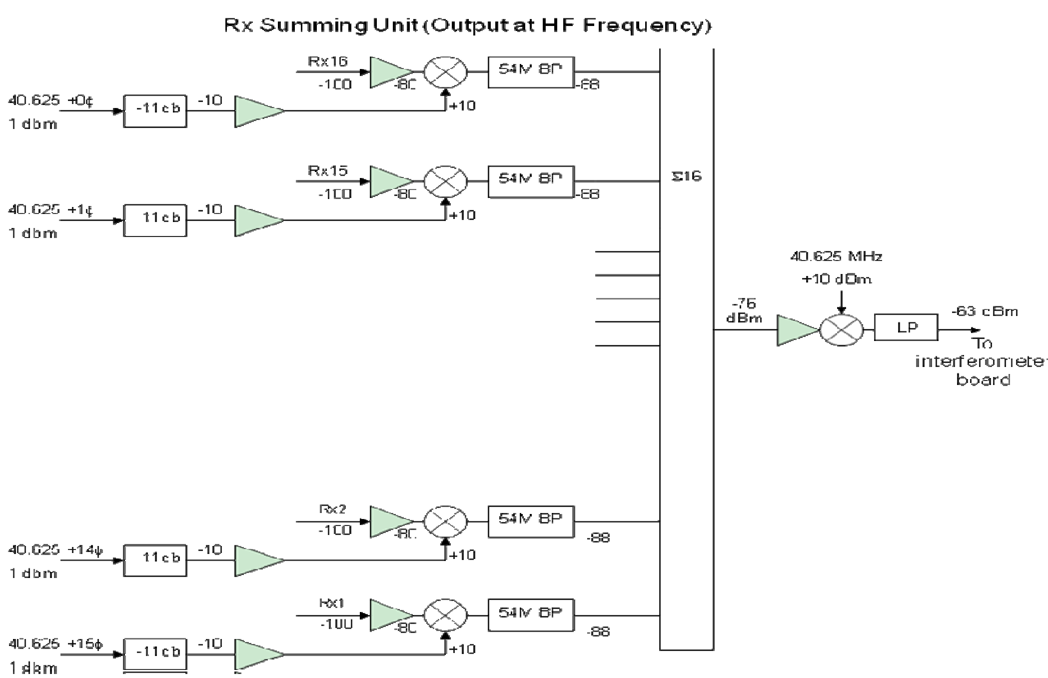
Cables indicated by * are cut to give in-phase outputs on all 16 ports, if ϕ = 0.

Before the utilization of 40.625MHz phase generator unit, a 50.625 MHz phase shifter unit is used to generate phase delay Φ. There are only two inputs to the phase shifter unit: a 50.625MHz signal and a 10 MHz signal. By turning on and off the switches, labeled SW, we are able to change the total length of transmission cables, and thus determine the value of Φ.

The transmitter pulse unit is used to transfer signals of f_{IF}(40.625MHz) + (0 to 15Φ) to f_{TX} + (0 to 15Φ), respectively, where f_{TX} is the transmission frequency in the range from 8MHz to 20 MHz. In this unit, the radar will first scan within this frequency range and then determine a transmission frequency which will cause lowest interference with the surrounding spectrum. As a result, the local frequency f_{LO} is selected from 48MHz to 60MHz to generate the optimum transmission frequency, since $f_{TX} = f_{LO} - f_{IF}$.



The RX summing unit is then transferred the signal with Doppler frequency from f_{TX} + (0 to 15Φ) to f_{IF}(40.625MHz) + (0 to 15Φ), based on which the signal is digitized and Doppler frequency is then picked up.



Autocorrelation Function (ACF)

We need a pulse sequence with fixed lag between every two pulses, in order to find out the phase of the Autocorrelation Function (ACF) and thus to determine the velocity of the targets.

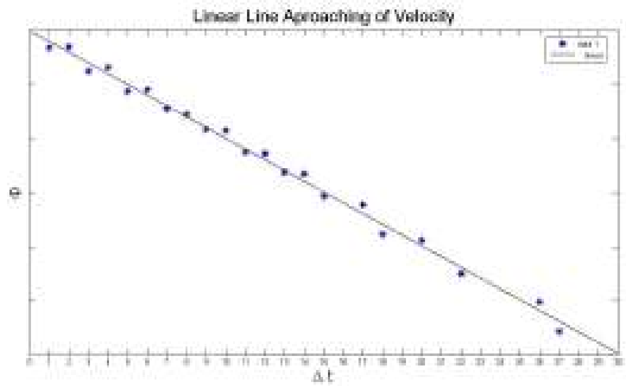
Radar transmitters send out a series of pulses, which are sampled by the receiver. By comparing the relative phase of the signal received at time t_0 with phase received at time $t_0 + \Delta t$, we can determine the average velocity for time Δt. Let S_{11} represent the complex signal received from pulse sequence #1, pulse 1 and S_{12} represents the signal received from pulse sequence #1, pulse 2.

- $S_{11} = A_1\exp(i\Phi_1)$; $S_{12} = A_1\exp(i\Phi_1+if_d\Delta t)$, where Φ is random phase and f_d is Doppler frequency during this time
- ACF between pulse 1 and pulse 2 is:

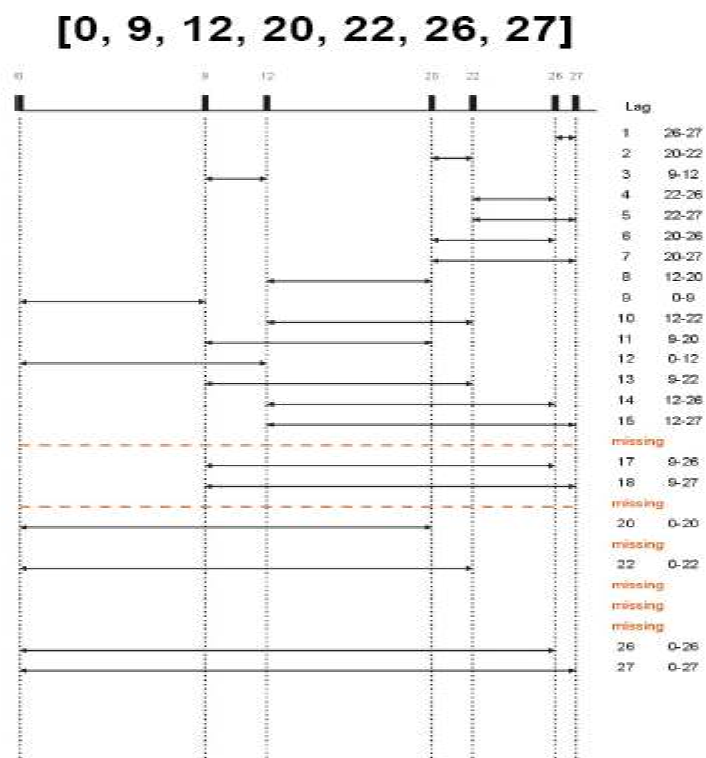
$$R_{1,1} = S_{12}(S_{11})^* = [A_1\exp(i\Phi_1+if_d\Delta t)] * [A_1\exp(-i\Phi_1)] = A_1^2\exp(if_d\Delta t);$$

The phase of the ACF is determined by looking at the real and imaginary components, in the way as follows: $\Delta\Phi = \text{atan}(\text{Im}/\text{Re})$. Since the random phase is canceled, the only phase in the ACF function is caused by the Doppler shift: $\Delta\Phi = f_d\Delta t$; and $f_d = \Delta\Phi/\Delta t$. The Doppler frequency f_d and relative velocity of target v_r has a relationship: $f_d = 2*v_r / \lambda$. Thus, according to the time lag between two pulses, Δt, the phase that the receiver measured ΔΦ and the transmission frequency we know f_{TX} (from 8 to 20 MHz), we are able to find the velocity v_r during Δt.

In order to find out a more precise velocity, transmitters choose various Δt and receiver measures corresponding ΔΦ, as a result. A computer does a curve approaching of the points and determines velocity. That is the reason why transmitters use certain pattern of time lag for one sequence of pulses. We assume the relative velocity does not change too much. For a sequence of [0, 9, 12, 20, 22, 26, 27], we can find various Δt by counting the time lag between any two pulses. An example of the relationship between phase difference and time lag is as follows:



If we look at the figure shown as follows you can see by using this pulse sequence with only seven pulses, we are able to count Δt from 1 to 27 ms, with only a few values missing. For example, we want to see what is the phase within 1ms, we look at the ACF between pulse 6 and 7, which happen at 26 ms and 27ms, respectively. The design of this pulse is intelligent in that, with only seven pulses, many variable time lags are produced to generate a precise velocity.



Conclusion:

The transmitter and receiver use the phasing matrix to form 16 beam directions and electronically steer the antenna array. Once the signal is received through the hardware of the system, the autocorrelation function is calculated to find the velocity of the return ionospheric backscatter.

Reference:

1. Presentation “FITACT: A SuperDARN Tutorial” by Kile Baker;
2. Presentation “SuperDARN Pulse Sequences-Optimization and Testing” by Kathryn McWilliams
3. http://ion.le.ac.uk/cutlass/stereo/stereo.html