Mitigating Fading at the Antenna

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Presented at the Pacificon ARRL Pacific Division Conference, Antenna Forum, San Ramon, California, October 2024

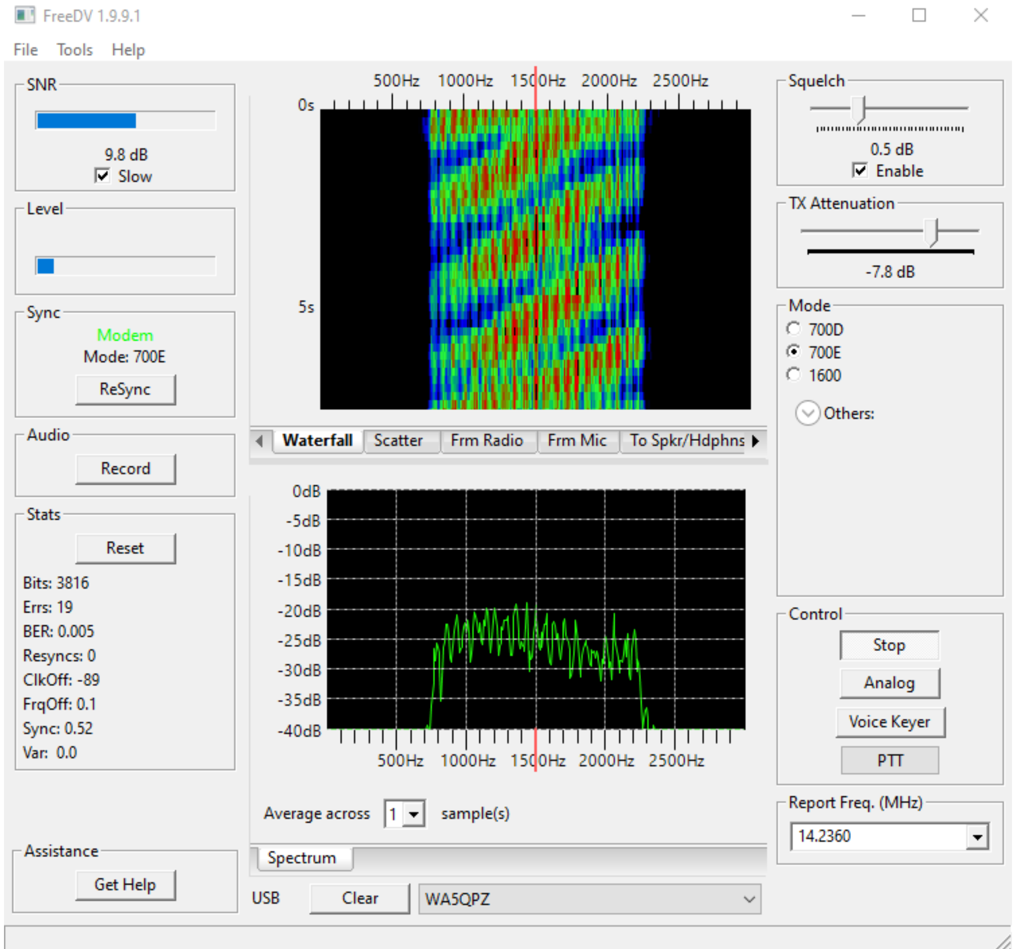
Photo: AI Generated, after Hieronymus Bosch.

What is Fading?

- Amateurs deal with fading all of the time.
- How often do you think about what fading *is?*
- *Where* is it happening?
- *Why* is it happening?
- Can we *do* anything about it?
- Why is it more important *now?*

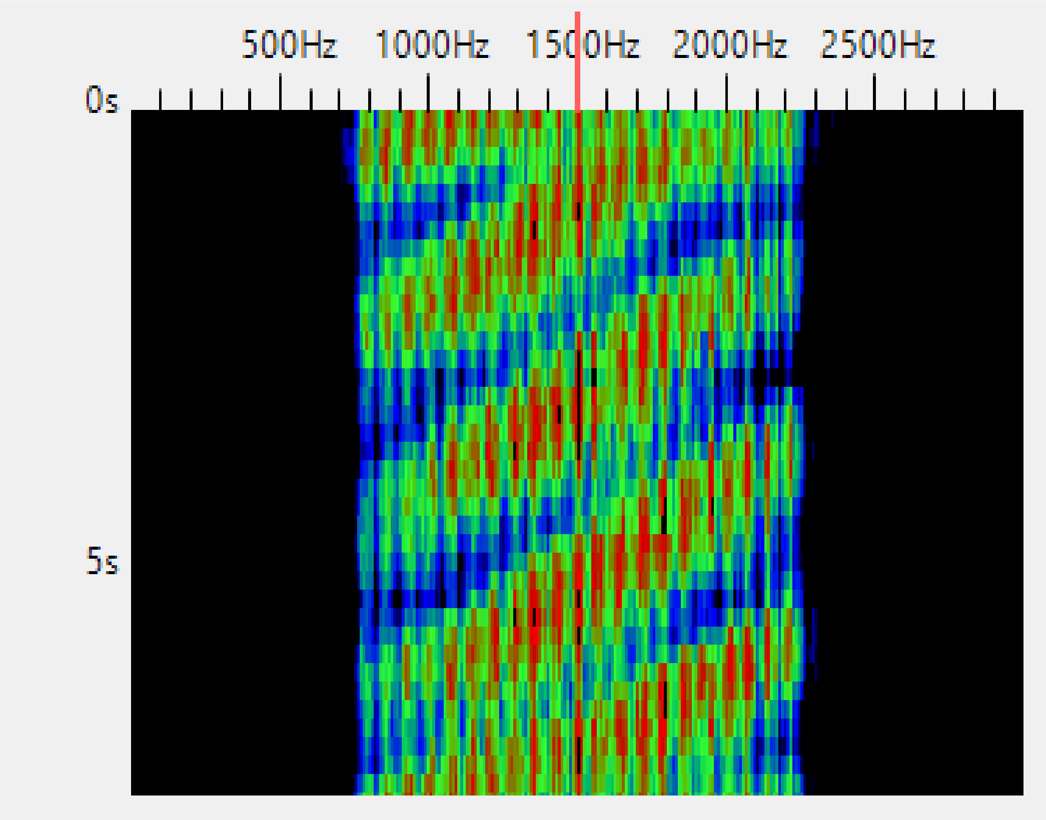
Let’s Look at Fading

- This is FreeDV, a digital voice system, on 20 meters. It uses multiple carriers, the overall signal is 2.4 KHz wide.
- The blue bands on the waterfall display are *RF fading.*
- We can see more about fading on this constant, wide signal than we could see easily on SSB or keyed CW.
- What can you tell about this fading?



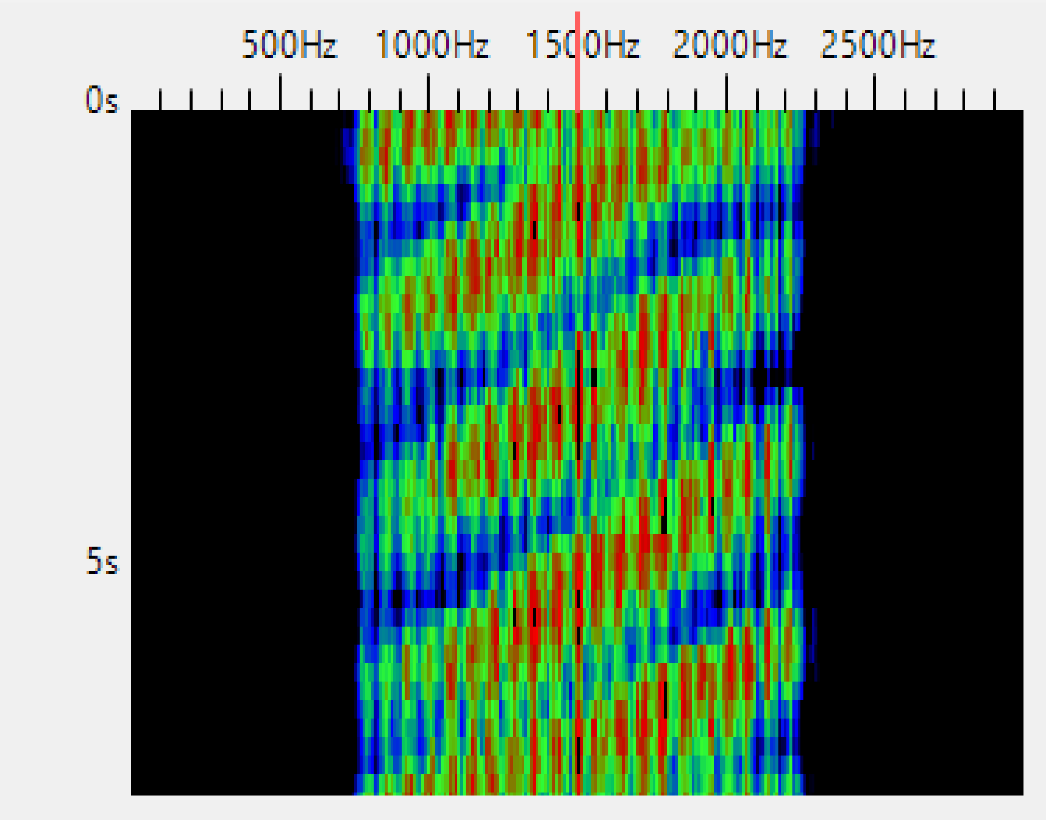
Let’s Take a Closer Look

- Again, the blue is fading of the digital signal. It has about 14 coherent PSK (phase-shift-keying) carriers.
- The fading is very narrow. Only about 200-300 Hz wide.
- Two of the carriers are severely attenuated by sharp fades at any time.
- The fading is very regular and periodic.
- The sharp fades diminish in frequency by about a KHz a second.



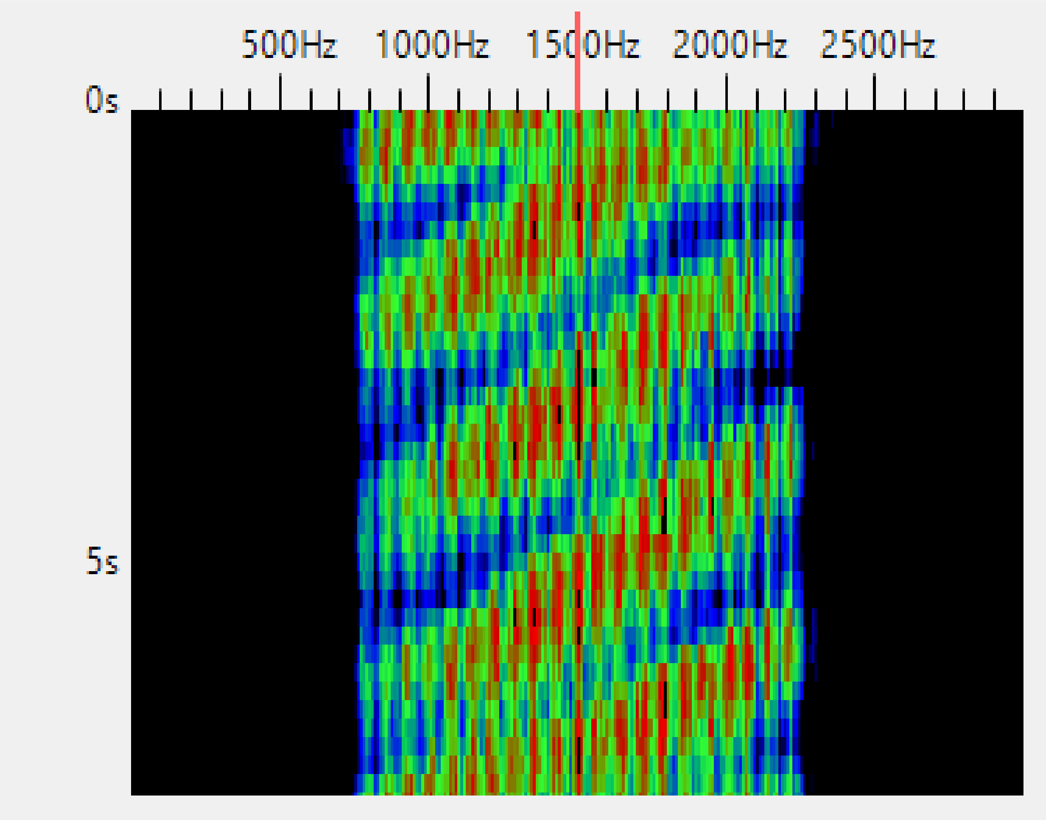
Digital vs. SSB

- On SSB, this would be heard as selective filtering of a voice frequency.
- You can generally still understand the voice, because voice has strong harmonic content, and the other harmonics aren’t attenuated.
- On the other hand, with a digital signal, we have to do something about this!



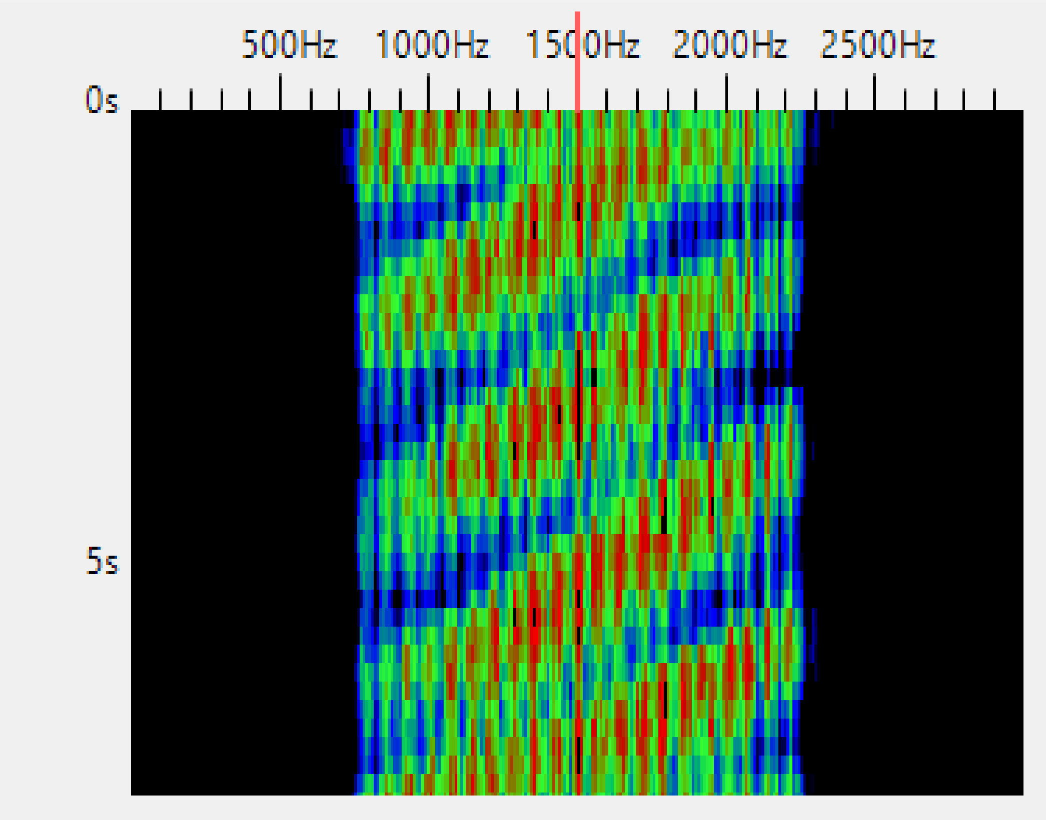
On a Digital Signal

- We're losing two carriers! That's a lot of information lost.
- We have to make up for this with *forward error correction* (FEC). FreeDV *duplicates* the most important information about the voice signal from the CODEC *into the other carriers.*
- Less important information about the voice is not duplicated. So, a fade tends to reduce fidelity first, comprehension only if it's really severe.
- But this means we lose overall data rate to FEC.



Can We Do Better?

- If we could get rid of the fading, we'd be able to recover more data from this signal.
- We might be able to hear other stations better.
- Can we do that?
- Yes! And there is more than one way!
- Then why haven't we been doing that? What has changed now?
- Let's learn more about fading, and see.



Where Does Fading Happen?

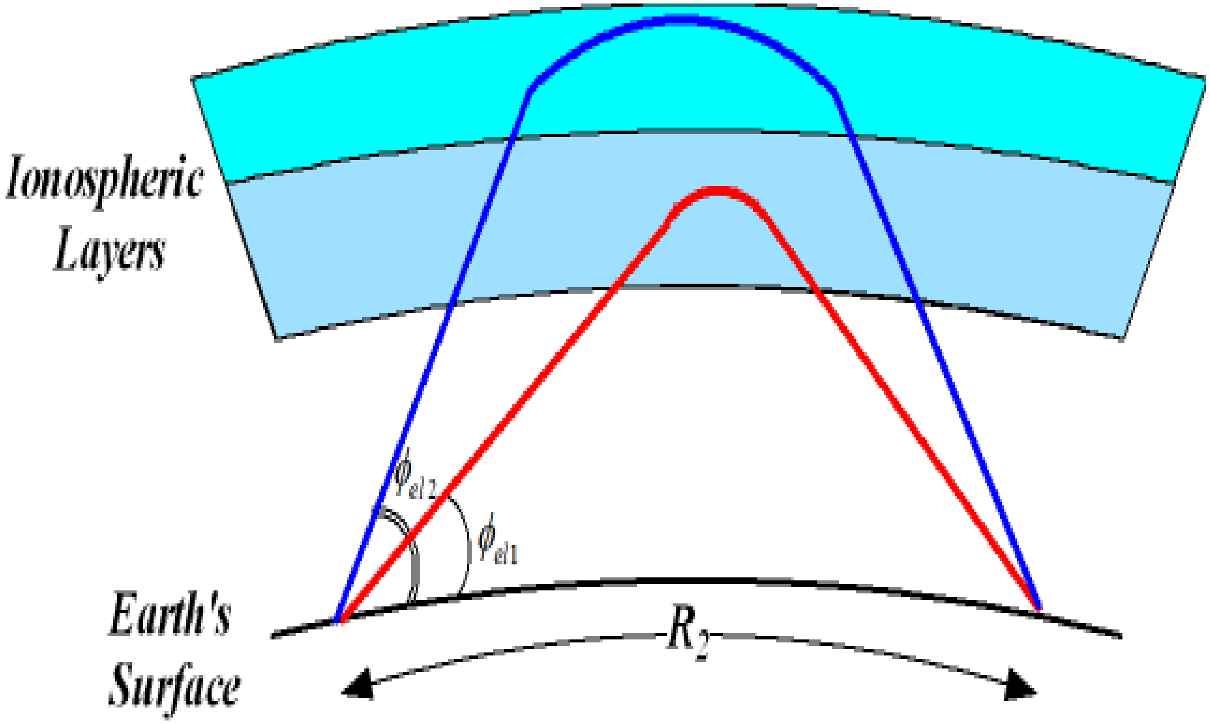
- You might imagine that it happens in the sky! Perhaps there are frequency-selective elements in the sky.
- There would have to be crystal filters better than the ones in our receivers. In the sky! And variable ones.
- A lot of this actually *does* happen in the sky. But the most important part happens *at your antenna.*
- Well, maybe then we can do something about it.

What Happens in the Sky?

- Multipath
- Differences in delay
- Faraday Rotation
- Let’s look at all of these.

Multipath

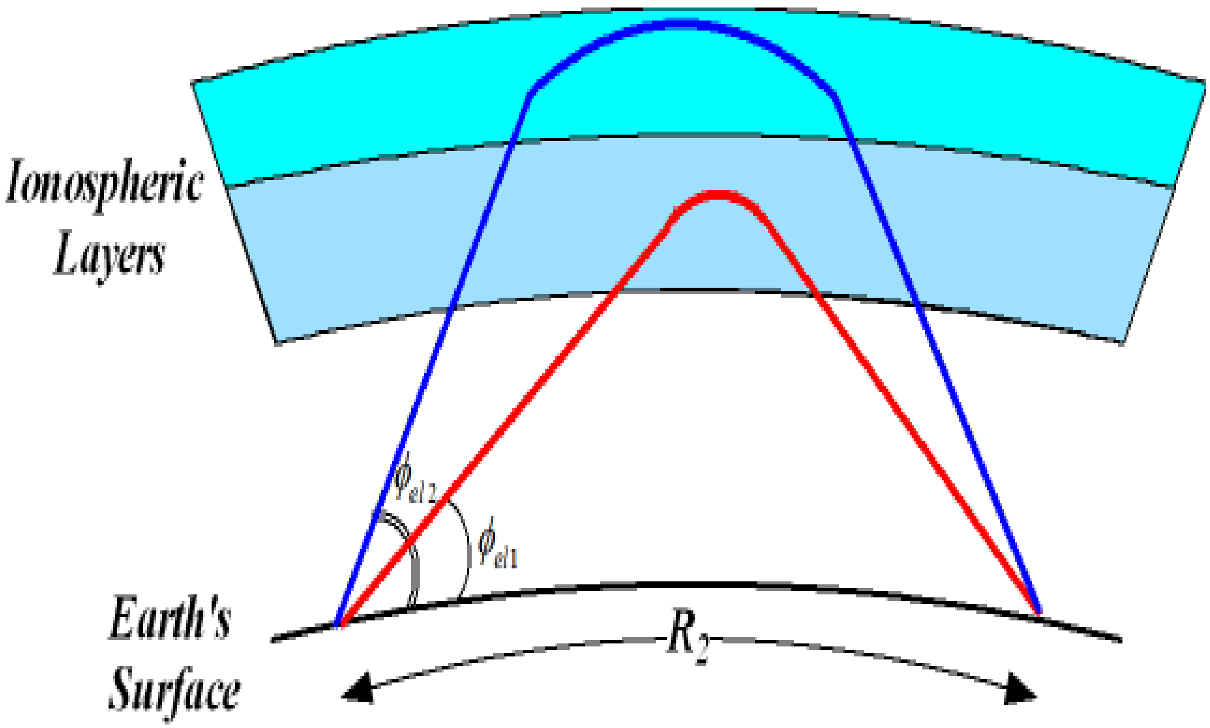
- This is a diagram of a signal between two stations being reflected by the ionosphere.
- But the ionosphere isn’t a nice solid mirror. It’s made of the thinnest clouds of ionized gas. It has different layers, and signals reflect and refract off of it at different angles.
- Signals also reflect off of the earth. And the earth is made of different materials, and isn’t smooth.
- So, this image is actually a lot simpler than what really happens!



From Sonia Tomei Ph.D. thesis on HF MIMO

What’s Happening Here?

- The same signal comes in from more than one reflection.
- The reflections are at different angles.
- The reflections have different amplitude.
- The reflections travel different distances, at the speed of light, so they have different delays.
- Reflection changes the polarization.
- The reflections are not in phase.
- **This mess is mixed together indiscriminately at your antenna.**



From Sonia Tomei Ph.D. thesis on HF MIMO

Faraday Rotation

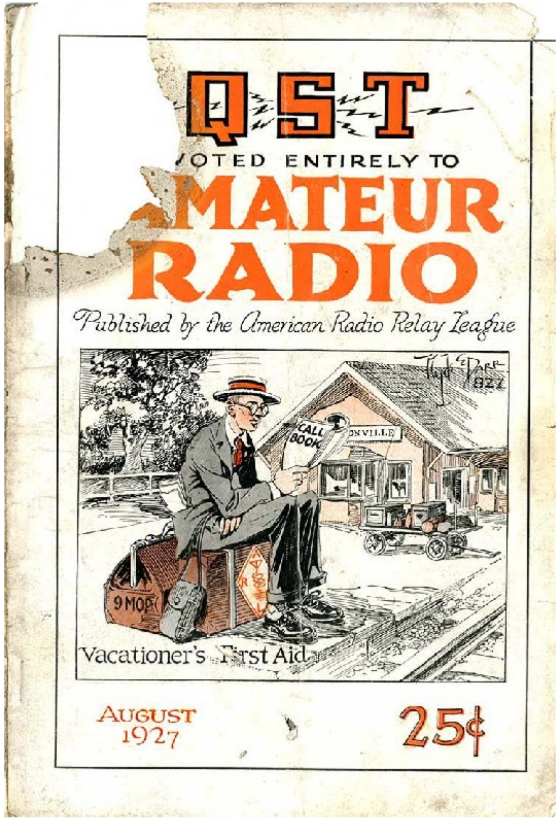
- The influence of the Earth’s magnetic field on the ionosphere causes polarization rotation.
- And rather than take a lot of time explaining that, people who can comprehend the math can see the Wikipedia.

So, Where Does Fading Happen?

- *A lot of things happen in the sky.*
- We combine them all at our antenna, indiscriminately.
- Multiple, out-of-phase signals add together or cancel each other out, and that changes constantly.
- The ionosphere changes the polarization so that some of the time it doesn’t match our antenna. And it’s constantly changing.
- **Fading mostly happens at our antenna.**

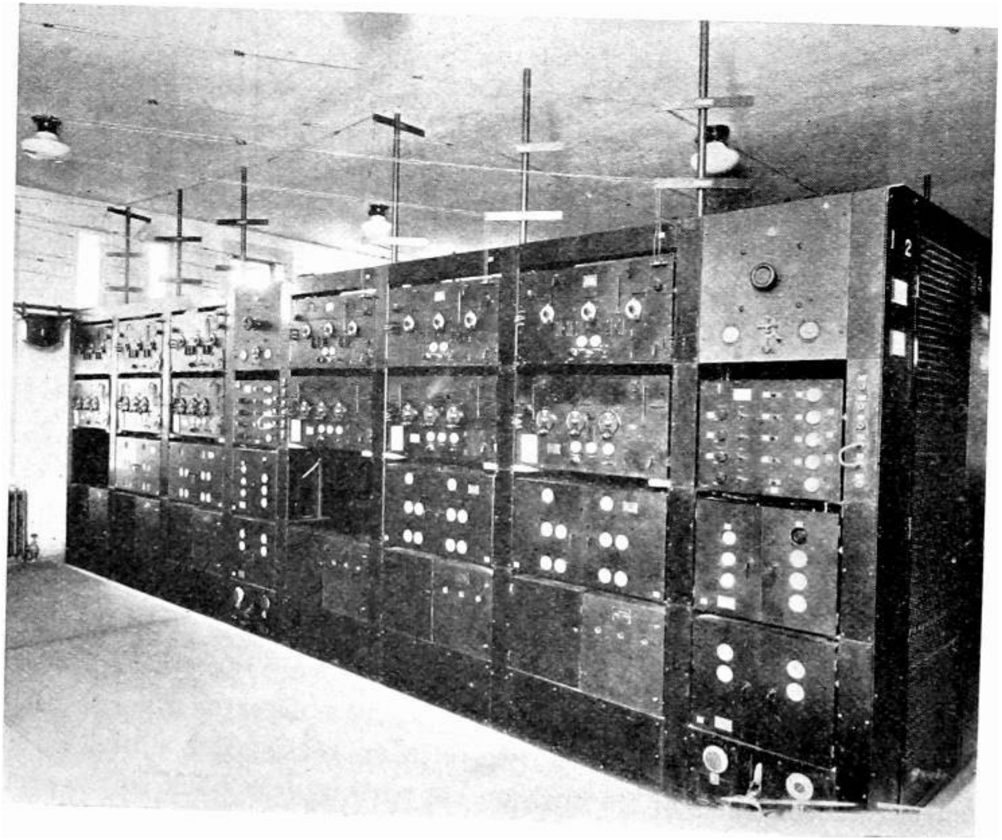
Hams Knew About This

- Back when we were still exploring the “useless” HF frequencies that the government let us use, the August 1927 issue of QST had an explanation of how ionospheric skip worked, including material on fading.
- A lot of the work came from RCA and shore stations.



RCA Space Diversity Receivers

- RCA, in 1927, published that they were using antenna-separation space diversity, 3 differently-positioned receivers per channel.
- They found that a **spacing of 1 wavelength** worked well
- The receivers each received different fading, at different times.



Hallicrafters Diversity Receiver, 1937

Hams experimented with antenna-separation space diversity in 1936. This diversity receiver was featured in a 1937 QST.

And Then We Forgot

- Shore stations abandoned space diversity as it became easier to receive signals.
- Space diversity was used commercially and in the military in the 1950’s.
- Since then, articles on ham diversity reception pop up once in a while, and are mostly ignored.

And Then Diversity Became Important Again

- But not for hams.
- For optical fiber communications, mitigating polarization fading and increasing bandwidth with polarization diversity.
- For HF RADAR.
- MIMO (multiple input, multiple output) is used on WiFi now.

So, Can We Do Anything About Fading?

- We can.
- Then, why aren’t we?
- Fading wasn’t enough of a problem to bother, back when all of our communications were analog.
- We didn’t have technology as good as we do today, especially computer processing power.

What Has Changed Now?

- Digital communications make looking at this issue relevant again.
- Good, cheap SDRs make diversity receiving affordable for the Amateur.
- You can afford CPUs that would have been considered supercomputers, not long ago.

Different Kinds of Diversity We Can Try

- Frequency diversity, as FreeDV uses.
- Antenna separation space diversity, as used by RCA in 1927, *but we have improvements today.*
- Polarization diversity.
- What can we try?

Space Diversity at Home

- 1-wavelength separation is possible on a residential lot for higher bands. Less may be useful.
- But today, we have easily-networked SDRs. Put one at a friendly neighbor’s home with a small receiving loop. We can avoid the Internet with wire or fiber, or a local WiFi link.
- Internet to another ham.

Polarization Diversity

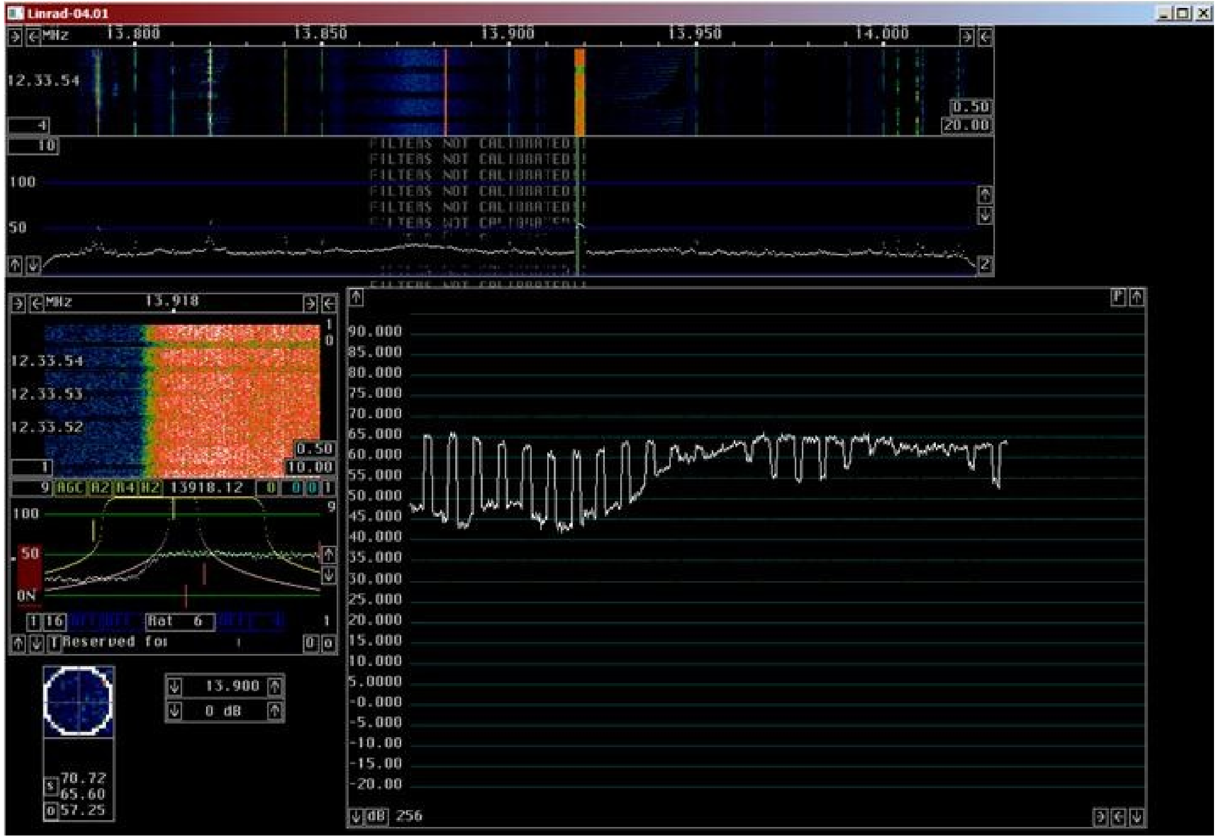
LZ1AQ mounted horizontal and vertical receiving loops on the same tower. What did he find?

Notice that this is highly symmetrical but the loops aren’t concentric (don’t have the same center).

This is small enough to try anywhere. It’s even smaller if you make the loops concentric.

Polarization Changes Constantly At The Receive Antenna!

- This is switching between the H (horizontal polarization) and V (vertical polarization) antenna on the same tower, same receiver, 20 meters.
- The longer period is V, the narrower one is H.
- Note how the signal starts out stronger in H, and then becomes stronger in V. It’s rotating in polarization!
- So, you can use polarization diversity with small receiving loops spaced close together.
- Photo: LZ1AQ

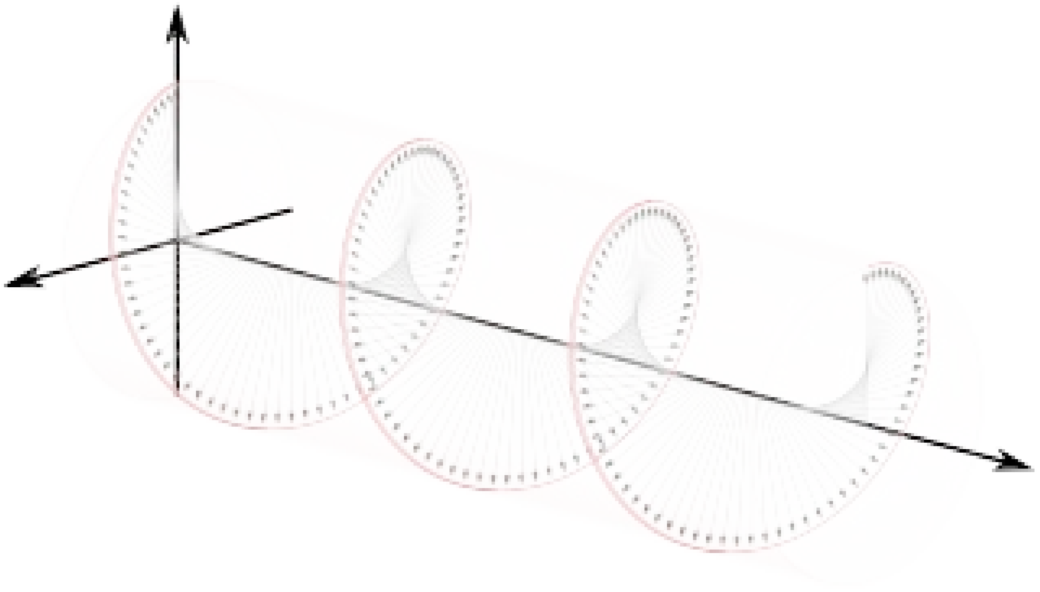


Polarization Diversity

- You can use polarization diversity with stereo headphones, one polarization to each ear.
- The psychoacoustic effect separates the signal, positionally, from the noise, and the signal moves around as polarization and delays change.

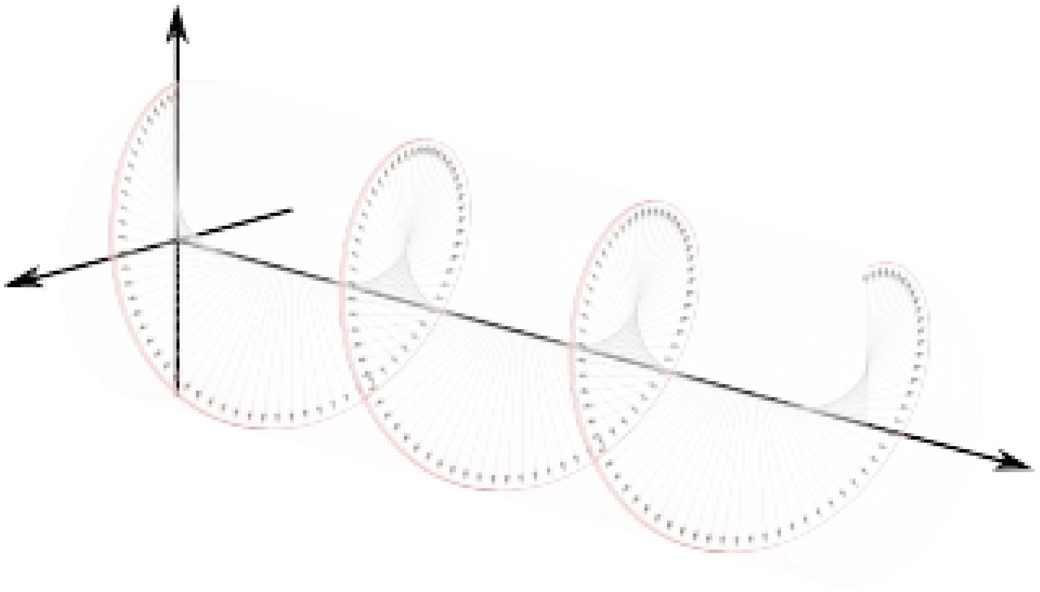
Circular Polarization

- Circular polarization combines horizontal and vertical, with a 90 degree phase shift, to create a rotating polarization. It is used with satellite communications because it is insensitive to the rotation of the polarized signal as the distance to the satellite changes.
- We can achieve the phase shift with a coax delay line.



Changing the Rotation

- If you combine crossed dipoles, one fed with a 90 degrees phase shift from the other, the wave spirals. Invert the phase fed to one dipole and the wave spirals in the other direction.
- Thus, we get LHCP and RHCP.



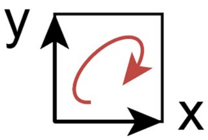
Combining LHCP and RHCP

- If you combine otherwise-equal LHCP and RHCP signals, they sum to a linear polarization, because one of the dipoles cancels out the corresponding one with a reversed orientation.
- You can synthesize any polarization (in one or two directions) by sending different amplitude and phase to each of the crossed dipoles.
- Later we will get to how to do this in multiple directions.

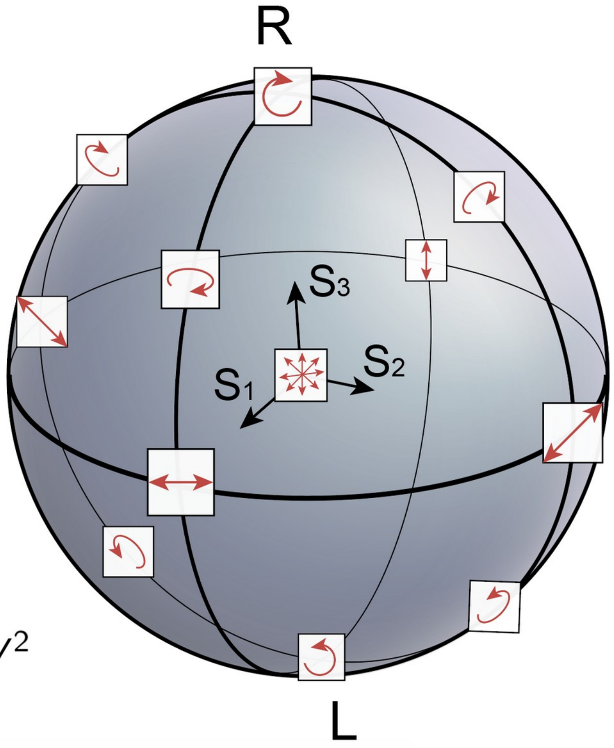
Synthesizing a Polarization

- The Poincare sphere describes how you can synthesize any polarization.

$$S_0 = I = E_x^2 + E_y^2$$
$$S_1 = Q = E_x^2 - E_y^2$$
$$S_2 = U = 2E_xE_y \cos\delta$$
$$S_3 = V = 2E_xE_y \sin\delta$$



$$radius = I^2 \geq Q^2 + U^2 + V^2$$



Why is This Important?

- We may be able to use processing to implement *polarization selectivity.*
- Track the signal polarization as it rotates.
- Separate out noise without the desired polarization.
- Separate multiple signals with different polarizations, *when they don't overlap.*
- We're getting to multiple directions later. Then this gets more interesting...

Receivers

- I found two commercial dual SDR receivers that were ready for polarization or space diversity.
- SDRPlay *RSPduo*. Comes with diversity software. ~$350 on Amazon.
- *Red Pitaya*, various models. Not sure about the software, but diversity is supported in the programming API.
- Both can be used in **phase-coherent mode.**

Phase-Coherent Receivers

- Phase-coherent receivers are two or more receivers with their internal oscillators locked in both frequency and phase, that preserve the phase of their input signals *to their output, relative to each other.*
- Consider crossed dipoles with a common center, each fed to a phase coherent SDR. You can very simply add or subtract the two received signals at the I/Q level (I/Q are *quadrature* so the delay is built-in) to derive the original polarizations, plus right-hand and left-hand circular polarization, and output all of them at once.
- With processing, you can synthesize additional receive polarizations, etc.

Synthesizers and Phase-Coherency

SDRs use a *fractional-N synthesizer* for their VFO. This means the synthesizer step is a fraction of the reference frequency. Consider a 10 MHz reference and 100 Hz steps.

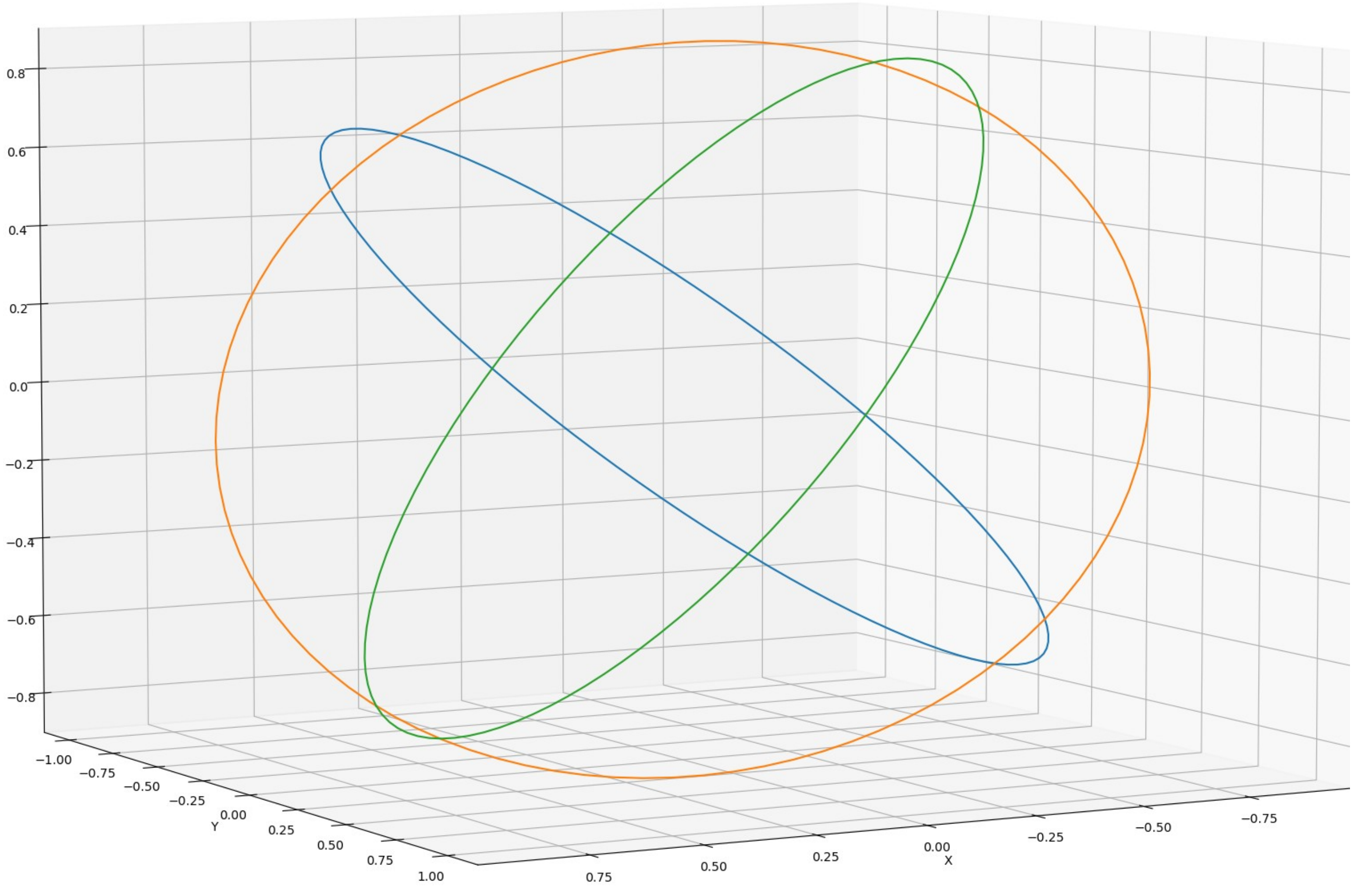
- The synthesizers start at a random phase difference, relative to each other, when programmed for a frequency. There is an extra step in the software to synchronize them with each other. For *RSPduo,* it’s a software button you push. On *Red Pitaya,* it’s an API call, I don’t know about the Red Pitaya apps.
- In software, you can manipulate phase with delay and/or inversion, rather than synchronize the actual synth

3D Antennas and MIMO

- The Van Veen antenna is popular for measuring emitted RF in an RF anechoic chamber. It can receive from all directions.
- As you can see, it combines a horizontal and two vertical receiving loops.
- This would work with three phase-coherent receivers to isolate the vector (direction) and polarization of a received signal, with a lot of math.
- This is not, however, the right antenna for HF, because HF is mostly coming from the horizon, not any direction equally.
- Photo: Narda.

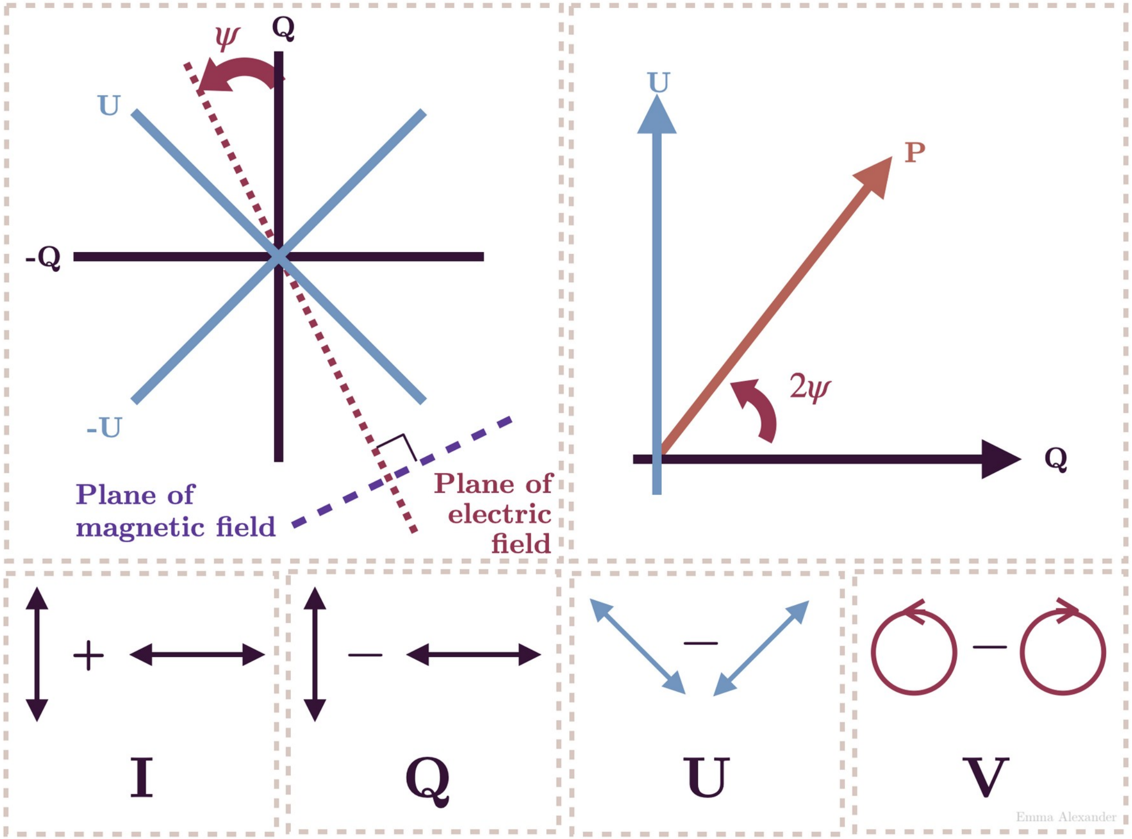
Triple Inclined Loop

- A triple inclined loop antenna would be best for HF, as it would be better able to discriminate near-horizon signals.
- Each of the three loops is inclined 45 degrees off of vertical.
- Each has an identical antenna pattern.
- You need *three* phase-coherent receivers for this. Commercial receivers are not available at ham-friendly prices today.



The Stokes Parameters

- The Stokes Parameters (or Stokes Vector) gives us a way to derive the actual polarization from the three antennas.
- This is just a hint of all the math we would need to do.



What Might You Do With Three Phase-Coherent Receivers, a Triple Inclined Loop Antenna, and a Ton of Math?

- If it works. There are papers on HF MIMO, but not enough to tell us if it’s worthwhile.
- Use all of the information your antenna throws out today!
- Achieve directional selectivity without a rotator! Receive a different direction “per receiver” (actually, per output of the math).
- Track polarization changes and achieve polarization selectivity.

Triple Loop and HF MIMO

We can see from LZ1AQ’s double-loop experiment that there are some conditions in which it *would* work. Enough to be worthwhile?

- Separate out one reflection, or combine several with appropriate delay.
- Pick different stations out of a pile-up on the same frequency?
- Separate out directional and non-directional noise.
- Some of the more powerful desktop CPUs could probably handle the math.

Opportunities for YOU

- RF MIMO for hams is a work in progress, and there are opportunities for **you** to be a pioneer.
- Lots of us could build the triple loop antenna.
- I’m the wrong person to do the SDR math or design a triple phase-coherent receiver that hams can afford.

Contact the Speaker

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