MITIGATION OF ANTENNA POLARIZATION TRANSFORMATIONS CAUSED BYAIRFRAME REFLECTIONS

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ABSTRACT

The majority of aircraft telemetry antennas transmit a linearly polarized wave. These linearly polarized signals are often received by two orthogonal (left and right hand) circularly polarized receive antennas, each of which has 3 dB polarization loss. Under nominal conditions, a diversity combiner can be used to coherently add the two received signals, thereby restoring the 3 dB loss. Recent flight tests have revealed that the signals radiating from the aircraft are actually elliptically polarized or even circularly polarized, leading to degraded combiner performance. This paper describes how the transmit polarization can be transformed from linear to circular, why this degrades combiner performance, and how to mitigate this effect.

KEY WORDS

Polarization, Best Channel Selector (BCS), Data Quality Metric (DQM), Aeronautical Flight Testing

INTRODUCTION

An aeronautical telemetry system typically consists of a test article (aircraft), a tracking antenna, and a RF receiver. The modulated telemetry data is transmitted from the test article via RF, collected by a high-gain tracking antenna, and is output as left and right hand (LH, RH) circular components to a receiver that downconverts and demodulates the signals to recover the original source data. Since the transmit antenna is linear and the receive antenna creates both right and left hand circularly polarized outputs, it is assumed that both channels are approximately the same level and their combined output always provides the expected 3 dB gain along with the highest quality data output. The system diagram in Figure 1 illustrates a typical configuration. Figure 2 shows various polarization options for both the transmit and receive equipment and the loss associated with each pair. As previously noted, a linearly polarized transmission (vertical) experiences a 3 dB loss in power with circularly polarized reception unless both outputs are properly combined to recover the total transmitted power. Note that some incompatible polarization combinations can result in complete signal loss resulting in data link failure.

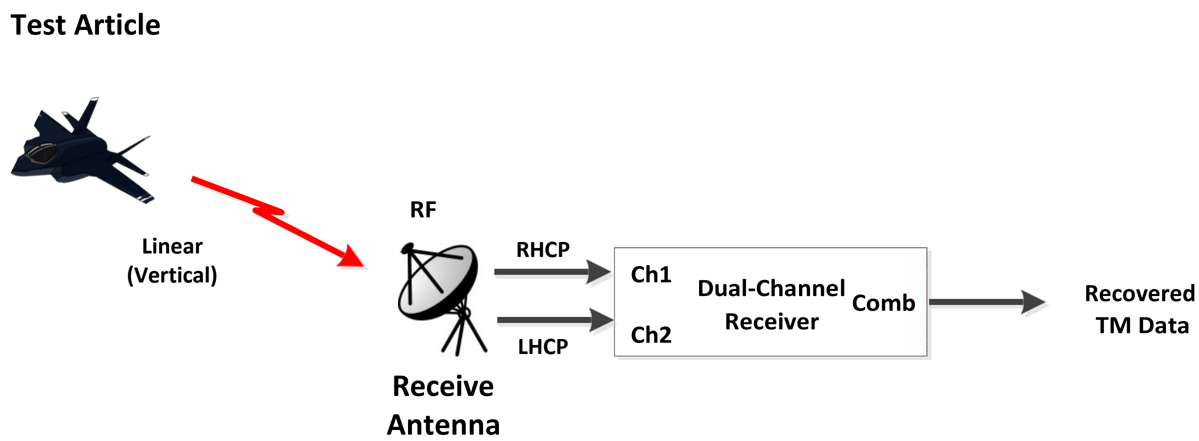


Figure 1: Typical Telemetry System Diagram

Tx \ Rx	V	H	LHCP	RHCP	Comb
V	0	-∞	-3	-3	0
H	-∞	0	-3	-3	
LHCP	-3	-3	0	-∞	
RHCP	-3	-3	-∞	0	

Figure 2: Polarization Loss Table (dB)

Although the telemetry scheme described above seems straightforward and robust, real-world field testing with a variety of test articles and receive equipment configurations have produced some unexpected results. These include large disparities between the left and right-hand signal level outputs, low combiner gain, and worse than anticipated link quality based on other observed receiver metrics. In general, poor telemetry link quality is often blamed on a variety of impairments with little quantative evidence. This paper investigates whether or not RF polarization transformations may explain many of these issues.

AIRFRAME MODEL

Over the years, engineering flight tests have provided opportunities to collect detailed performance data on various telemetry systems. Both single and dual transmit antenna setups have been tested with measurements from the field commonly showing large differences in the received signal levels between the left and right-hand polarization antenna outputs. This seems odd since the transmit antenna is linearly polarized. However, this would be expected if the aircraft was transmitting a circular polarization that matches only one of the two receive antenna polarizations. Polarization anomalies could explain some of the combining and link degradation issues that have been previously observed.

In order to determine whether or not there is a viable mechanism to explain how a linearly polarized transmission can appear as being circularly polarized at the receive antenna, an electromagnetic model was constructed to investigate the propagation effects. The airframe is simulated as a cylinder with two wings, and the transmit antenna as a small dipole below it as shown in Figure 3. This model should give the curved and flat surfaces that may produce a circularly polarized signal at the receive antenna. The real aircraft has more structural surfaces which would produce a wider array of polarization reults, so this model illustrates the simplest situation.

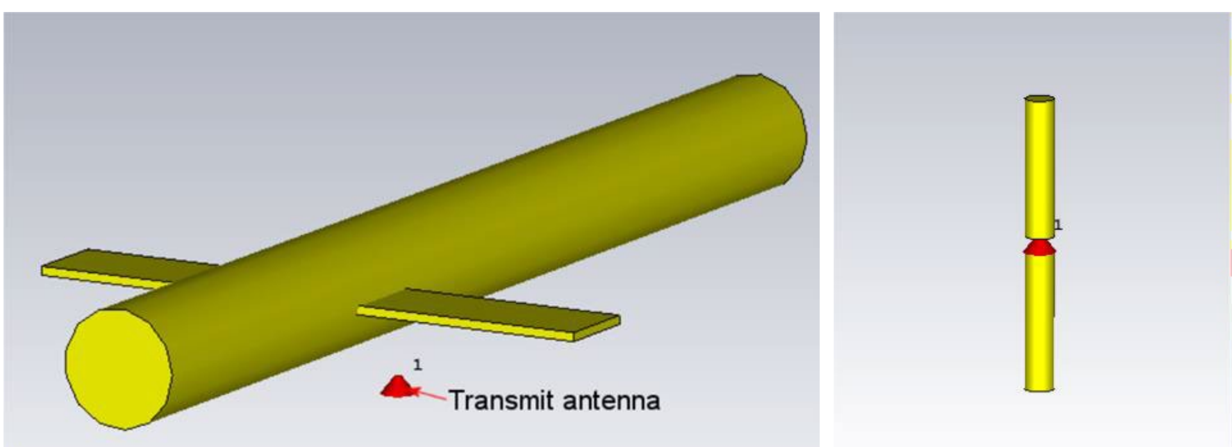


Figure 3: Airframe Model

One measure of RF polarization is the axial ratio which measures the difference between vertical and horizontal polarization components, usually in dB as a power ratio. In practice, axial ratios above 10dB or 20dB (depending on the individual requirements) are regarded as linear. In designing filters that reject one polarization, this number may be set to more than 20dB. For our purposes 20dB is a good figure of merit. As the axial ratio decreases, the polarization becomes more elliptical in shape, until it becomes circular when the axial ratio is zero as illustrated in Figure 4. This simple metric is a good basis for interpreting the type and levels of polarization transformations that take place as the observation angles between an observer and the airframe change.

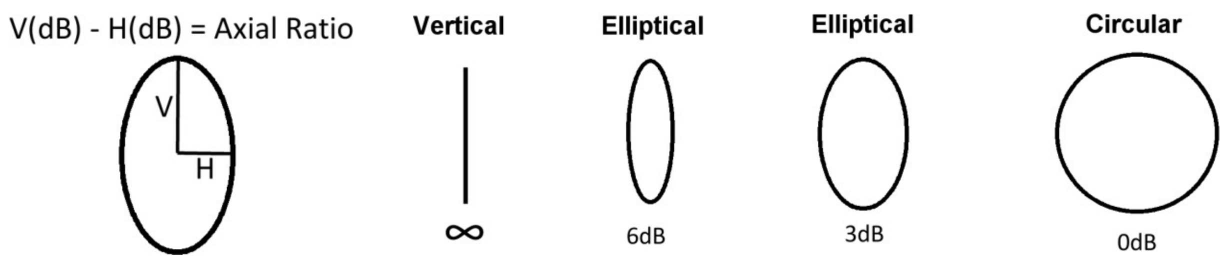
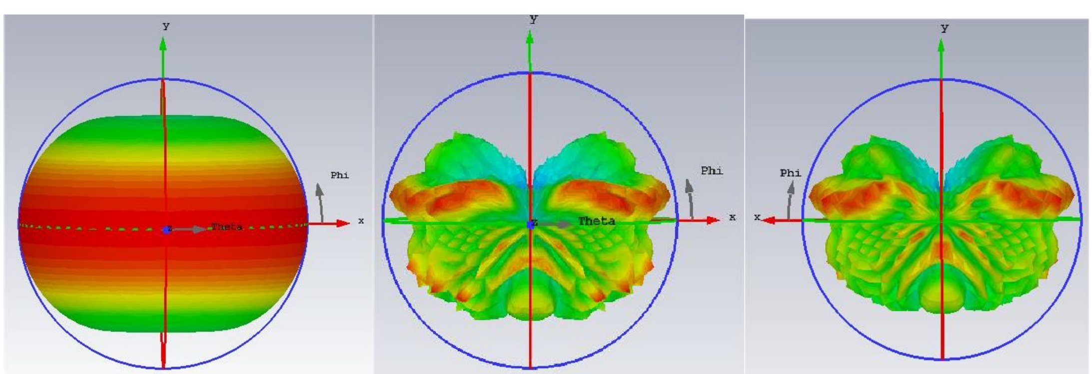


Figure 4: Axial Ratio Examples

SIMULATION RESULTS

Simulations were performed for frequencies ranging from 1485MHz (L-band) to 5100MHz (C-band) and we highlight three examples at 1485MHz, 2000MHz and 5000MHz. Examples of the radiation patterns for the transmitter dipole alone and with the "aircraft" are shown in Figure 5. As expected, the radiation pattern is fairly symmetric and is directed away from the aircraft body. The magnitude response seems to be consistent across the various aircraft orientations.



No airframe Front view with airframe Rear view with airframe

Figure 5: 3D Pattern without Airframe and with Airframe

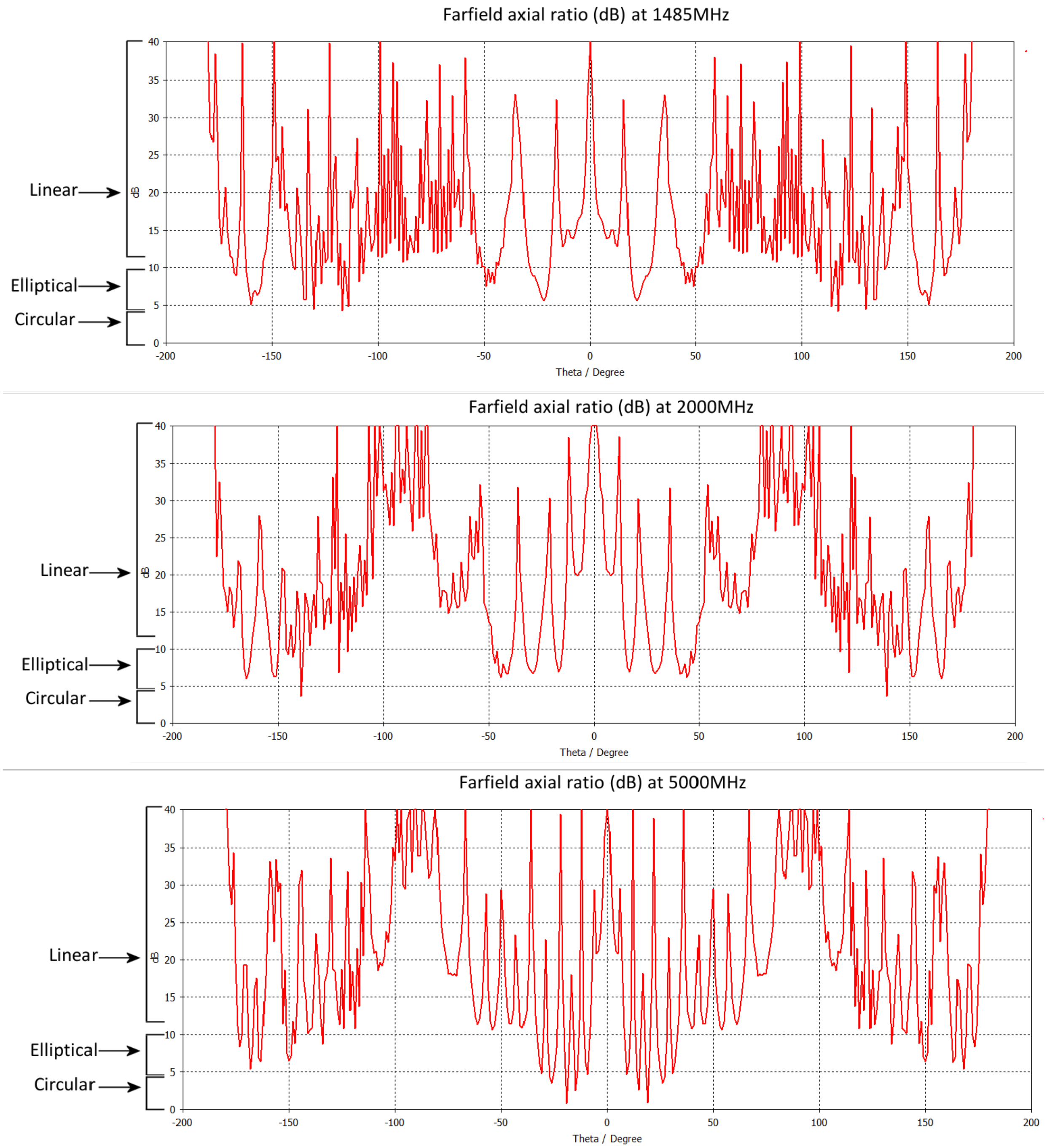


Figure 6: Axial Ratio Results

In contrast, the axial ratio results show large and rapid variations in polarization makeup versus attitude. Looking at Figure 6 it is clear that at 1485MHz and 2000MHz there are a number of look angles that result in elliptical polarization with axial ratios around 6 or 7 dB. At 5000MHz axial ratios of less than 5dB can be seen, with some look angles resulting in axial ratios of less than 2dB. This shows that a transmitted vertical signal can be received as circular (or nearly circular) from this simple aircraft model. The real aircraft will have more surfaces and angles, as well as contoured wings and a tail, so more opportunities exist for this phenomenon to occur.

Figure 7 shows the cumulative distribution of the simulated axial ratios for 5000 MHz. At high ratios, the signal polarization is approximately linear and will be present in both the antenna outputs. However, at low ratios, the signal will favor either the LH or RH receive antenna circuit and may show up almost exclusively in one or the other receiver channels. Although the received signal will appear to be linearly polarized as intended the majority of the time, there is a significant fraction of the observation angles that appear circular.

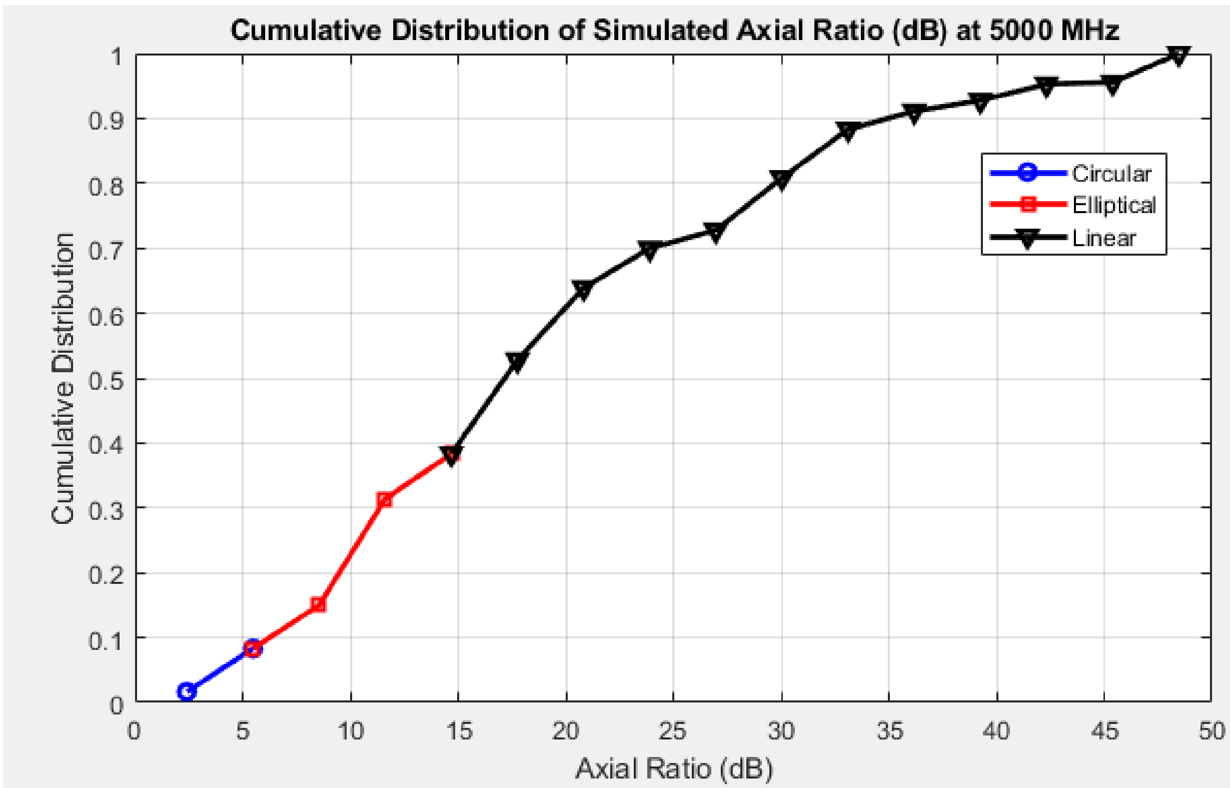


Figure 7: Distribution of axial ratio results (simulated)

POLARIZATION ISSUES WITH MULTIPLE ANTENNAS

Even though the transmit antenna is linear, it has been shown that the received signal can appear as elliptical or even circular. In systems with a single transmit antenna and a dual-channel receiver, a maximal-ratio combiner is typically used to efficiently combine the two channels and improve performance as compared to either of the individual channels. However, many test articles commonly use two antennas (top and bottom) to achieve better spatial coverage due to vehicle manuevering or airframe shadowing. In this case, polarization transformations can create conditions that seriously degrade combiner performance.

Figure 8 illustrates dual-antenna transmit examples with polarization transformations that can create issues with telemetry reception. The first situation is the normal case where both top and bottom transmissions are linear and both show up as similar signals in the LHCP and RHCP receive antenna outputs. The receiver combines these signals to optimally recover the telemetry data that was most likely transmitted. The second diagram shows what can happen if the top antenna transmission is transformed to LHCP and the bottom antenna to RHCP. In this case, the two inputs into the receiver are not necessarily versions of the same signal. The top and bottom transmission paths may have significantly different RF channel characteristics, or they may be completely separate signals such as is the case with Space-Time Coding (STC) modulation. Depending on the top and bottom RF channel conditions and the modulated waveform details, the two resulting dissimilar signals may cause the combiner to fail resulting in loss of telemetry data.

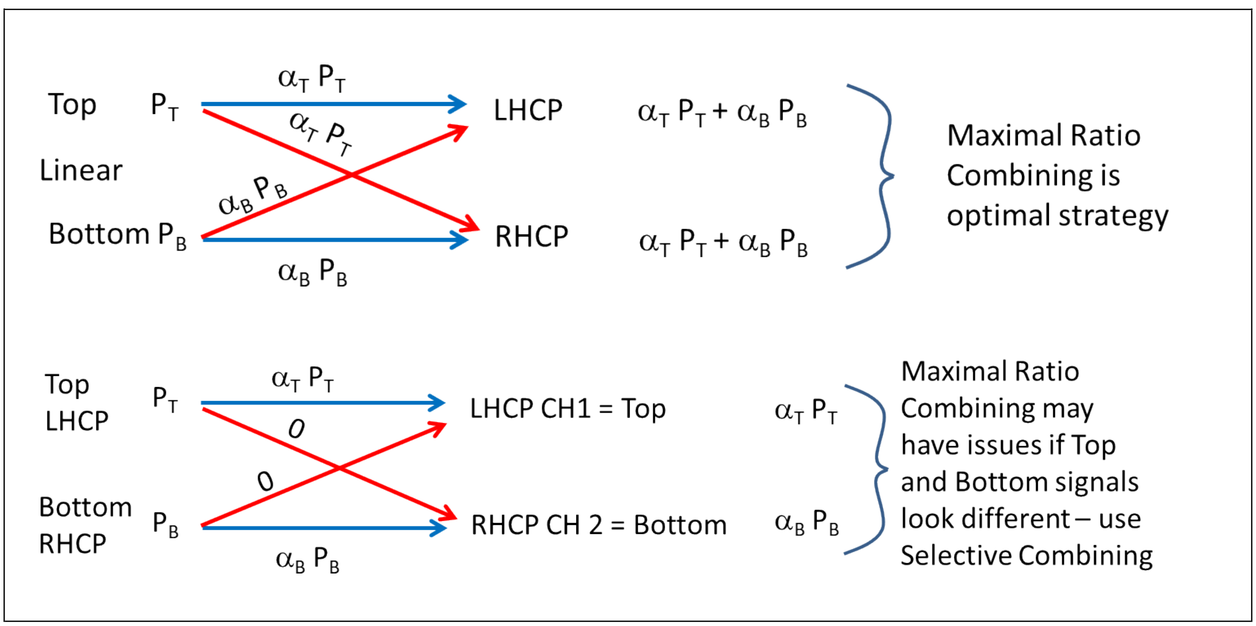


Figure 8: A dual-transmit antenna example with polarization related issues

FLIGHT OBSERVATIONS

Electromagnetic simulations have shown how a linearly polarized transmit signal can be transformed into circularly polarized receive signals. Figure 9 shows that these transformations are not only possible, but they are commonly experienced in real-world aeronautical flight testing. The received signal level of the two antenna RF outputs during a recent flight test clearly shows that the power in each polarization can be radically different over the duration of a mission. This is a strong indication that the received polarization is not linear and is indeed experiencing transformations as described in the previous simulation section.

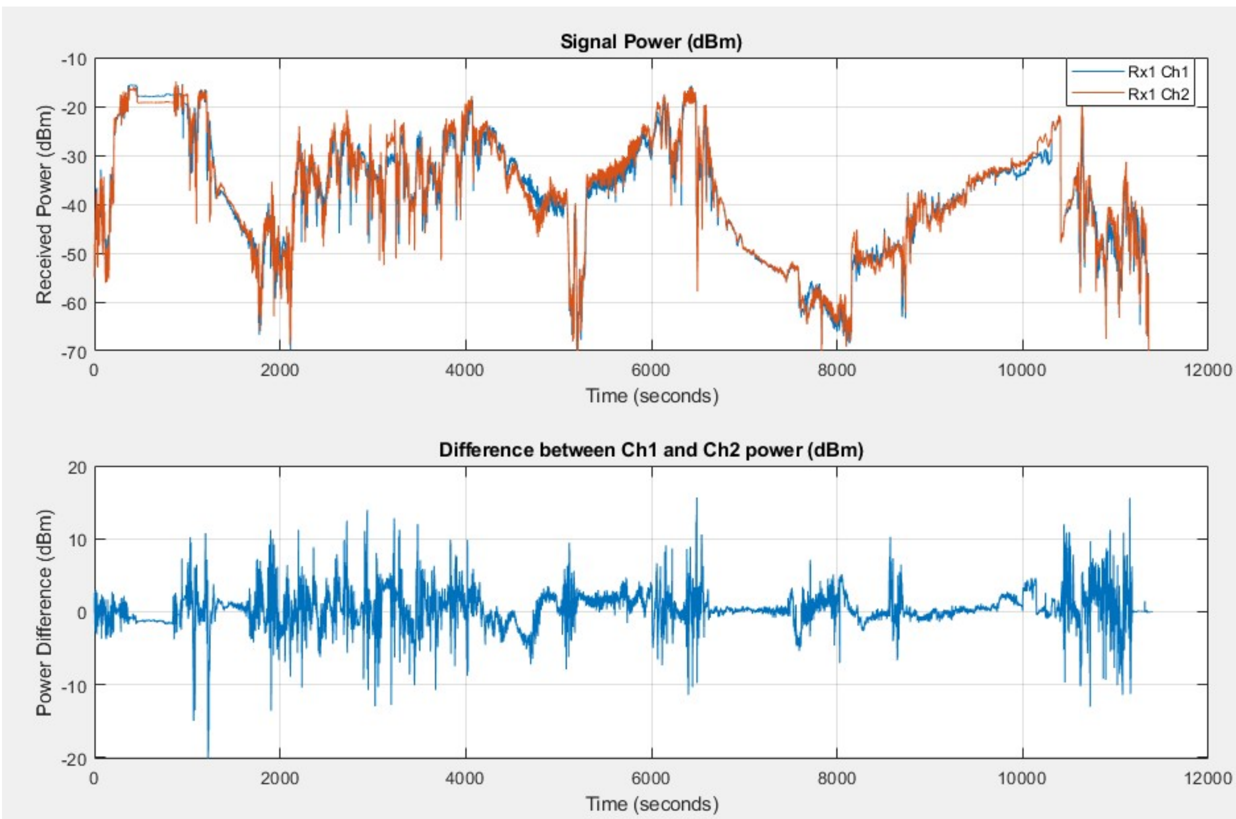


Figure 9: Example of RHCP vs LHCP Received Power Levels (absolute and difference)

Figure 10 shows a real-world example of the most extreme polarization transformation issue consisting of the bottom antenna signal showing up exclusively in Channel 1 (LH) and the top antenna signal in Channel 2 (RH). In this case, the top and bottom antenna contributions are independently resolved by the fact that the STC waveform [1] uses separate orthogonal pilot sequences for the top and bottom antennas. The white sticks indicate the presence of each sequence. Channel 1 only sees the sequence from the bottom antenna (bottom stick) while Channel 2 only sees the pilot sequence from the top antenna (top stick). Notice that the combiner attempts to fuse the two channels together resulting in a blend of the two channels. The pre-combined signal is actually very poor. However, by adding a post-combiner process which uses all of the outputs (Channel 1, Channel2, and the Combiner), data link failure can be avoided. This 'Best Channel Selector' (BCS) scheme [2] not only handles polarization related combining issues, but also addresses a wide variety of other channel impairments as well.

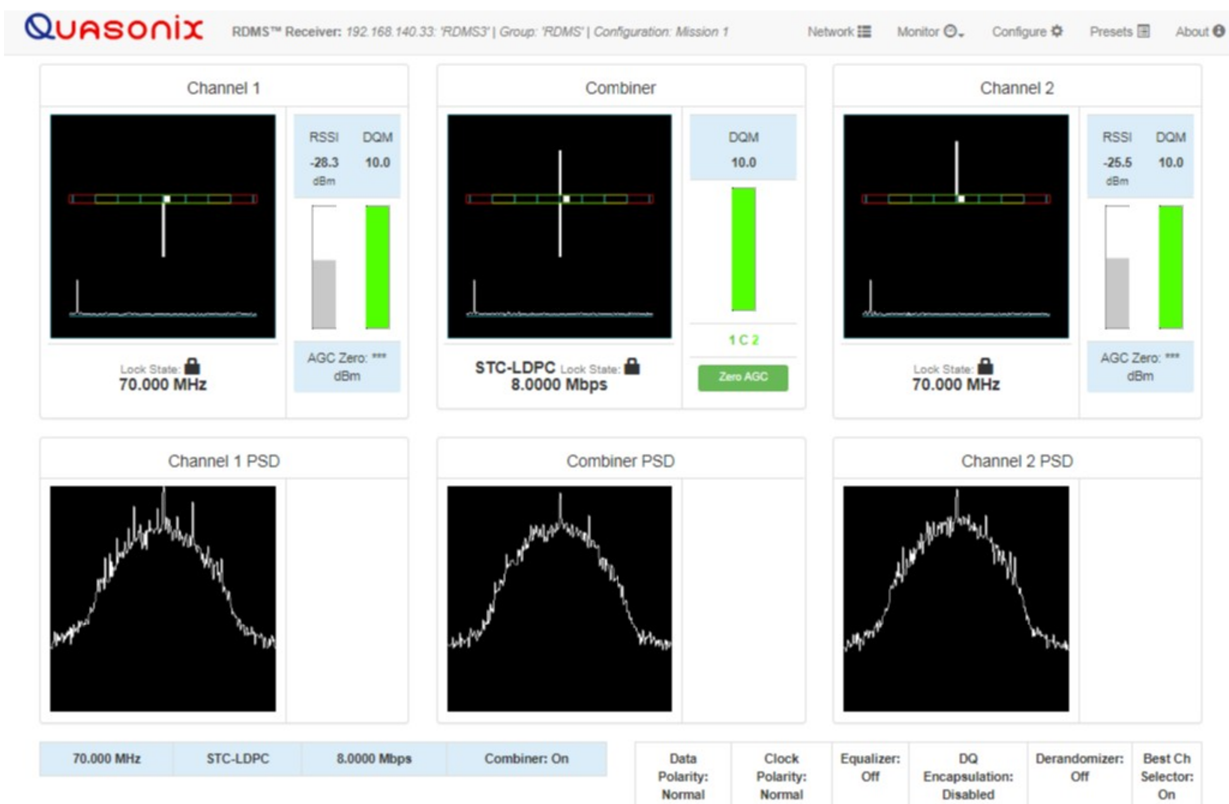


Figure 10: Dual-transmit antenna example with cross polarized bottom and top signals

CONCLUSION

This paper has addressed the question of how a linearly transmitted signal can appear to be circularly polarized at the receive antenna. These polarization transformations have been frequently observed in the field, but the underlying mechanisms behind them have not been well understood. A simple RF model was constructed and simulations were performed that reproduced these transformation effects. The results indicate that they are inherently present due to the interaction with the airframe and vary dramatically based on geometry, frequency, and observation angle. The simulated single antenna example was extended to show possible polarization transformation effects that can occur with dual-transmit antennas that are commonly used in practice. Combinations of top and bottom signals with various polarizations were shown to create 'uncombinable' received channels that have been observed in actual flight testing. Insights into these RF channel and combining issues have resulted in a new generation combiner approach that can address these polarization issues along with a host of other channel impairments.

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REFERENCES

[1] Telemetry Group, Range Commanders Council, IRIG Standard 106-17 Appendix 2G, Telemetry Standards, Secretariat, Range Commanders Council, U.S. Army White Sands Missile Range, NM, 2017.

[2] J. Uetrecht, "Dual-Channel Receiver Performance using Best-Channel Selection: Field Test Results," in Proceedings of the International Telemetering Conference, Las Vegas, NV, October 2019.