Polarimetric Portraits

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Abstract “Fully polarimetric” in its original radio science usage denotes a receiving instrument’s ability to measure the four-parameter Stokes vector characterizing the polarimetric properties of an electromagnetic (EM) field. In contrast, radar remote sensing specialists use “fully polarimetric” to apply exclusively to radars that evaluate the four complex scattering matrix elements. To disambiguate, polarimetric portrait is suggested, defined to be the Stokes vector of an unbiased EM field. For a passive system, this new name applies without qualification to the four Stokes parameters seen through a passive dual-channel receiver. For an active system, the scene's illumination must have equal weighting between any two orthogonal polarizations to generate a polarimetrically unbiased reflected EM field. The suggested terminology is applicable to a variety of disciplines, including radiometry, alternative polarimetric radar architectures, radar astronomy, weather radar, and GPS/GNSS reflectometry. Polarimetric portraits obtained by dual-polarized and quadrature-polarized radars are shown to be equal.

1. Introduction

For half a century, the term “fully polarimetric” for radio astronomers (Cohen, 1958; Heiles, 2002) indicates an instrument from which sufficient data can be obtained to evaluate all four of the parameters that comprise the Stokes vector. Those parameters completely describe the polarimetric characteristics of an observed quasi-monochromatic electromagnetic field (Stokes, 1852). For radar remote sensing specialists, the term “fully polarimetric” applies exclusively to a polarimeter configured to measure the four (complex) elements of the scattering matrix, from which all 16 elements of the Stokes operator may be determined (Zebker et al., 1987). Within their respective disciplines, the prevalent terminology is well understood. However, outside of those virtual stovepipes, the double meanings intrinsic to that terminology—often unrecognized—are problematic.

“Full polarimetry” in remote sensing’s specific sense is a rich concept. When implemented—in a quad-pol synthetic aperture radar (SAR) for example—full polarimetry enables generation of polarimetric signatures (van Zyl et al., 1987) which represent—through vector-matrix calculations on the 4 × 4 Stokes operator—the ensemble of responses of an observed scene to all combinations of transmitting and receive polarizations. Retrieval of geophysical parameters from quad-pol SAR data usually entails matrix decomposition methodologies (Cloude & Pottier, 1996) applied to the scattering matrix, or to the associated coherence or covariance matrices. The success of quad-pol SARs, supported by their elegant mathematical framework, has given rise to an ethos that suggests to a nonspecialist that a fully polarimetric radar (in remote sensing’s sense) is the only acceptable approach to measuring a scene’s inherent polarimetric characteristics. This commonly held belief is not true.

The currently ambiguous terminology obscures a fundamental difference between two alternative representations of polarimetric measurements. Full polarimetry in the remote sensing sense is designed to evaluate the four elements of the scattering matrix. In contrast, full polarimetry in the classical sense is based on measuring the four Stokes parameters of the observed EM field. This measurement needs only half as much data as the scattering matrix element measurements require. Knowledge of the scattering matrix is sufficient to evaluate the Stokes parameters, but the scattering matrix cannot be recovered from knowledge of the Stokes vector. In spite of that difference, polarimetric characterizations of the EM field by either the scattering matrix or the Stokes parameters are equivalent (Born & Wolf, 1959, p. 552).

The fully polarimetric capabilities represented by a quad-pol SAR may exceed the requirements of users. Quad-pol radars have inherent disadvantages which may be avoided if the objective is recognized at the outset simply to be the polarimetric characterization of the observed EM field (Raney, Brisco, et al., 2021).
In a variety of applications, the objective is to measure a scene’s polarimetric properties in order to enhance the successful retrieval of geophysical parameters. To do that, the full four-parameter Stokes vector is sufficient. It is at this level that damage follows from the ambiguity inherent in the term “full polarimetry”. Polarimetric measurements that are fully responsive to the needs of a variety of applications may be made by alternative instrumentations that have no capacity to include quad-pol’s deeper capabilities.

Section 2 describes the relevant background of this issue, culminating in a discussion of the suggested updated terminology, polarimetric portraits. Section 3 reviews selected applications for which an unambiguous understanding of polarimetric measurements should be helpful. Section 4 offers proof of the equivalence of the full Stokes vector when evaluated by either a quad-pol polarimeter or a comparatively simple dual-polarized radar. The paper closes in Section 5 with concluding comments.

2. Background

2.1. Stokes Parameters

A powerful framework for the modern exploitation of polarimetric data was anticipated nearly two centuries ago (Stokes, 1852). To paraphrase the kernel of that contribution, the polarimetric characteristics of any quasi-monochromatic electro-magnetic (EM) field may be fully described by four real numbers. The Stokes parameters—often treated as a logical vector—may be determined by measuring the (averaged) values of any two orthogonally polarized constituents (including their complex cross-products) of the observed EM field. This principle applies to emanations from a natural source such as a quasar (Myserlis et al., 2018) or the ocean’s surface (Coriolis, 2003), as well as to reflections from an object or scene illuminated by a known radio wave source, for which radars or navigation satellites are topical examples.

2.2. Synthetic Aperture Radar (SAR)

One method of determining the polarimetric properties of a scene observed by a radar polarimeter such as a SAR (Curlander & McDonough, 1991; Moreira et al., 2013) is to collect sufficient data to evaluate all four of the complex elements of the Sinclair scattering matrix (Burkowitz, 1967). These elements are comprised of two pairs, each pair having two orthogonal received polarizations in response to one (of the two) orthogonal transmitted polarizations (van Zyl et al., 1987). In the event that the transmitted and received polarization bases are the same (Emmons & Alexander, 1983)—which in conventional remote sensing radars are the linear polarizations (H, V)—those data may be compressed by exploiting reciprocity between orthogonally cross-polarized counterparts (Dubois and Norikane, 1987; Zebker et al., 1987). The resulting quadrature polarized (quad-pol) data products are set up for analysis by users in either a coherence or covariance matrix, each derived from the scattering matrix (Cloude & Pottier, 1996), or the Stokes (Kennaugh) 4 × 4 matrix operator (van Zyl et al., 1987). The remote sensing SAR community uses the term “fully polarimetric” to apply exclusively to this special class of radar polarimeter.

2.3. “Fully Polarimetric”: Two Conflicting Meanings

In its original use in radio science (Cohen, 1958; Hull & Plambeck, 2015; Robishaw & Heiles, 2018), the term “fully polarimetric” is the accepted adjective for a receiving system whose data are sufficient to evaluate the full Stokes vector. To meet that standard, the receiver must be coherently dual-polarimetric, and retain the received signals in a complex form sufficient to evaluate the real and the imaginary parts of their cross-product. The terminology carried over into the field of radar astronomy in response to circularly polarized transmissions (Green, 1968; Ostro, 2002). In contrast—as noted in Section 2.2—since the mid-1980s the same words have been adopted by the (Earth-observing) SAR community, but the new meaning in that specific remote sensing context is more restrictive than its original use. The resulting ambiguity is problematic.
2.4. Troublesome Ambiguity

As an illustration, remote sensing specialists consider any polarimetric sensor that is not configured as a quad-pol radar to be inferior, hence incapable—according to their specialized definition—of supporting fully polarimetric data products. Within that community, the conflicting ambiguous meanings of “fully polarimetric” have contributed to controversies surrounding alternative “compact” approaches to quad-pol methodologies (Nord et al., 2009; Raney, 2016; Souyris et al., 2005). In other fields, the implied exclusivity of the SAR-specific sense coupled with its impressive reputation has dissuaded consideration by non-SAR experts of potentially valuable polarimetric system initiatives. Such unfortunate consequences of that ambiguity should be mitigated by the new terminology herein suggested.

2.5. Polarimetric Portraits

A polarimetric portrait is defined to be the Stokes vector of an observed EM field when that field’s polarimetric characteristics are unbiased. That is the natural condition for radiation passively observed, as is the case with radio science. For active polarimetric systems, unbiased polarimetric observations require that the illuminating field must be balanced, hence having equal weighting between any two orthogonal polarizations. Such balanced illumination is provided for example by a sequence of interleaved H and V polarizations having equal intensities (e.g., quad-pol SAR), or by a circularly polarized transmission (e.g., radar astronomy). In response to balanced illumination, the resulting polarimetric portraits embrace all of the backscattered polarimetric information unique to the observed scene. This condition satisfies the original sense of “fully polarimetric” while leaving space for the radar remote sensing system-specific sense for that terminology which is focused on evaluating all four of the scattering matrix elements.

3. Relevant Applications

The disambiguation theme of this paper is relevant to a wide variety of disciplines for which geophysical properties of an observed scene may be retrieved through analysis of polarimetric measurements. Specific disciplines include:

3.1. Radio Astronomy

Radio astronomy was the first polarimetric remote sensing discipline to produce Stokes vectors of unbiased EM fields (Cohen, 1958). The technique has proven to be a rich source of unique information from single-dish radio observatories such as Arecibo and the Greenbank Radio Telescope (Heiles, 2002). Polarimetric measurements require the instruments to be well calibrated (Myserlis et al., 2018). Large arrays—of 27 and more individual dishes—when calibrated and cross-correlated, have achieved remarkable measurements of polarimetric phenomena at multi-million light-year distances (Paré et al., 2019). “Full polarimetry,” the primary polarimetric product from this class of instruments, is a well established precedent.

3.2. Space-Based Radiometry

Decades ago, the remote sensing community recognized the value of measuring the Stokes vector of an unbiased EM field by passive means. An early pivotal contribution (Yueh, 1997) highlighted the value of such measurements to derive certain geophysical parameters from the full Stokes vector. Following thorough verification demonstrations, the jointly sponsored Coriolis mission (Coriolis, 2003) was launched in 2003, whose primary instrument, WindSat (Gaiser et al., 2004)—still operational as of this writing—includes the full Stokes vector among its primary data products. Oceanic geophysical data retrieval from space-based radiometric observations continues to mature (English et al., 2020). The European Space Agency’s requirements document for the Copernicus Imaging Microwave Radiometer (CIMR) (ESA, 2019) includes the specific terminology “full Stokes,” a noteworthy upgrade from the first version of that document in which full polarimetry was not a featured requirement. This illustrates the ambiguous pitfall: leading polarimetric radar remote sensing experts do not accept that the full Stokes vector obtained from radiometric observations qualifies as a fully polarimetric measurement.
3.3. Weather Radar

There have been decades of research and development on polarimetric radar techniques applied to weather radars as reviewed by Bringi and Zrnic, two of the leading pioneers in this field (Bringi & Zrnic, 2019). That work led to the Doppler upgrade operationalized in the NEXRAD system, based in part on the clever use of interleaved H and V transmissions. Circular transmissions were investigated, including extraction of Stokes parameters (Moran et al., 1998). More recently, there have been demonstrations of full polarization—in radar remote sensing’s special sense according to which H and V linearly polarized transmissions are interleaved—leading to estimates of the scattering matrix values (Ryzhkov et al., 2002). The problem is important for weather applications, but challenging, largely due to the short coherence time sustained by the dynamic hydrometeors of central interest in weather radar observations. Transmitting a circularly polarized EM field while reflections are measured by a coherent dual-polarized receiver supports polarimetric portraits with no requirement for sustained pulse-to-pulse coherent correlation.

3.4. Radar Astronomy

Inspired by radio science, radar astronomy relies on the polarimetric information embedded in the backscatter from objects in the solar system in response to circularly polarized transmissions. Data from the Arecibo Radio Telescope (1964–2020) when it was operated in its radar mode provide excellent examples (Heiles, 2002). A radar astronomical observatory transmits circular polarization. The backscattered signals are received on two mutually coherent orthogonal channels, usually circularly polarized at the same and opposite sense with respect to the transmitted field, although any pair of orthogonally polarized received constituents would serve the same purpose (Green, 1968). Such data are sufficient to evaluate the full Stokes vector of the observed field (Hull & Plambeck, 2015; Jackson, 1999; Ostro, 1993) providing a polarimetric portrait of the observed object.

Traditional analysis methodologies for such data are based on certain child parameters such as the degree of polarization, the circular polarization ratio, and the degree of linear polarization (Campbell et al., 2004; Carter et al., 2004; Ostro, 2002). Practitioners in this field are encouraged to take advantage of the larger scope of information retrieval tools enabled by polarimetric portraits (Hickson et al., 2021; Raney, Brisco, et al., 2021).

3.5. Two Lunar Satellites

More than a decade ago the payloads of two lunar missions included imaging radars that transmitted circular polarization and coherently received a pair of orthogonal linear polarizations (Raney, Spudis, et al., 2011). These were the first space-based implementations of hybrid compact polarization (HCP) SAR architecture (Raney, 2007). That radar mode replicated—in miniature—the well-established method of Earth-based radar astronomy, so the ensuing Stokes vectors obtained from lunar orbit supported radar astronomical information retrievals as traditional precedents together with providing polarimetric portraits (Raney, Cahill, et al., 2012; Spudis et al., 2013). The success of those lunar radars should encourage consideration of future planetary missions that would take advantage of the ×4 increase in coverage and the ×2 reduction in per-pixel data burden enabled by the HCP approach relative to an otherwise equivalent quad-pol instrument (Raney, Brisco, et al., 2021).

3.6. Earth-Observing Radar Satellite Polarimetry

In contrast to a quad-pol polarimeter, an HCP radar is a relatively simple dual-pol SAR, albeit a special case since it transmits circular polarization. This architecture is one example of compact polarimetry (Nord et al., 2009; Raney, 2016; Souyris et al., 2005), a term that encompasses dual-pol radars and their subsequent data processing methodologies. Compact polarimeters as a group are viewed by theoretical experts in the conventional radar remote sensing establishment as underperforming alternatives—hence unacceptable substitutes—for traditional quad-pol SARs. Whereas such a critical view is justified in general, it is not applicable to the HCP architecture, in which (i) the polarization of the transmitted field is circular (hence polarimetrically balanced) and (ii) the resulting backscatter is processed through methodologies that are...
not compromised by missing or approximated data (Charbonneau et al., 2010). Unlike conventional quad-pol systems whose data are processed using vector-matrix decomposition methods that require knowledge of all four of the scattering matrix elements, the HCP method circumvents the scattering matrix entirely, as the quantities measured by an HCP’s dual-polarized receiver are sufficient to evaluate the full Stokes vector.

### 3.7. Bistatic Radar

Two years into the Lunar Reconnaissance Orbiter (LRO) mission the on-board radar’s transmitter failed (Patterson et al., 2017). In the wake of that setback, valuable polarimetric information continued to be provided from the same instrument. The LRO Mini-RF radar—built and operated as a SAR but after that failure comprised of only a coherent dual-channel receiver and its supporting electronics—was used (2012–2015) in the bistatic configuration, a radar mode in which the transmitter and receiver are not co-located. The LRO’s Mini-RF in orbit at the Moon received signals reflected from the lunar surface in response to circularly polarized transmissions from Arecibo, Puerto Rico. Those data were sufficient to evaluate polarimetric portraits (Patterson et al., 2017; Wahl et al., 2012). The same principle applies to any bistatic illumination and reception geometry.

### 3.8. GPS/GNSS Reflectometry

Navigation satellites flood the Earth with circularly polarized transmissions. The detailed structure of the forward scattered EM field conveys geophysical information about the reflecting surface. Since the concept was first proposed and demonstrated (Martin-Neira, 1993), data from systems that exploit the forward scatter from navigation satellites have been applied to physical oceanography (Clarizia et al., 2009), and, in recent years, to terrestrial observations as well (Calabia et al., 2020). To date those missions have exploited only elementary like- and cross-polarized measurements. As suggested in this paper, the reflected EM field—when observed by a pair of mutually coherent orthogonally polarized channels—is sufficient to evaluate the full Stokes vector (Hull & Plambeck, 2015) comprising a polarimetric portrait of the observed scene. A GPS/GNSS reflectometry mission upgraded or newly designed to implement this latent capability would be a significant step forward, enabling new science from these ubiquitous platforms.

### 4. Proof of Equivalence

In traditional Earth-observing remote sensing imaging radars, numerous comparisons of the performance of an HCP versus a quad-pol SAR (Brisco et al., 2020; Raney, 2016) have shown that the respective image classifications from these two different radar architectures are comparable. All known studies on this question are empirical; they are based on post-processing results from differing classification algorithms applied to observations from a variety of specific applications. In contrast to those empirical studies, this Section offers for the first time an equivalence demonstration that is based on a fundamental principle of physical optics.

#### 4.1. The Stokes Vector

The Stokes vector $S'$ of a reflected EM field (Green, 1968), evaluated using an orthogonal pair of linearly polarized received constituents $(H, V)$ is

$$
S' = \begin{bmatrix}
|E_H|^2 + |E_V|^2 \\
|E_H|^2 - |E_V|^2 \\
2\Re\{E_H^*E_V\} \\
2\Im\{E_H^*E_V\}
\end{bmatrix}
$$

(1)
Evaluation of $S'$ requires only two complex numbers, $E_t^r$ and $E_r^r$—four real numbers—to fully characterize the EM field set up by a transmitter’s illumination of the scene. Transformation of the transmitted EM field $E_t$ to the received field $E_r$ is described (Burkowitz, 1967; Sinclair, 1950; Zebker et al., 1987) by their interactions with the Sinclair matrix $[S]$ according to

$$E_r = [S] E_t$$

(2)

where the elements $S_{ij}$ of the $2 \times 2$ scattering matrix and the EM vectors are complex numbers.

The elements of the reflected EM vector $E_r$ are complex amplitudes of their respective polarizations. The same is true for the transmitted amplitudes $E_t$. The carrots ($\cdots$) denote ensemble averaging, a standard part of evaluating a Stokes vector (Jackson, 1999). $\Re e$ and $\Im m$ signify real and imaginary parts respectively. The asterisk denotes complex conjugate. Spatial averaging is equivalent to multi-looking in the SAR context (Curlander & McDonough, 1991; Moreira et al., 2013)—spanning several single-look resolution cells—to reduce the standard deviation of the measured data. Mutual coherence is required of the receiver to enable measurement of the relative phase between $E_t^r$ and $E_r^r$ and to get the values of the real and imaginary parts of their cross-product.

### 4.2. High-Level Observations

Equation 1 exposes three key principles: (a) a dual-polarized receiving system provides sufficient data to evaluate the Stokes parameters of the observed field, (b) the resulting Stokes parameters embody a polarimetric portrait of the observed scene if and only if the illuminating EM source is polarimetrically balanced, and (c) when the illumination source is constrained to provide balanced illumination with only one transmitted polarization, a circularly polarized transmission is the only option that gives rise to the scene’s polarimetric portrait. In particular, any single linearly polarized transmission, such as the $\pi/4$ mode (Souyris et al., 2005) or its equivalent in weather radar the slant mode (Bringi & Zrnic, 2019) do not satisfy that condition.

### 4.3. The Polarimetric Portrait: Part 1

Our first objective is to evaluate the Stokes parameters for the EM field reflected from a scene, in response to transmitted EM illumination using left-circular polarization

$$E_r = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ j \end{bmatrix}$$

(3)

where $j = \sqrt{-1}$. Using Equation 3 in Equation 2, the reflected polarized EM vector $E_r$ from $[S]$ is

$$E_r = \begin{bmatrix} E_h^r \\ E_v^r \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} S_{hh} + jS_{hv} \\ S_{vh} + jS_{vv} \end{bmatrix}$$

(4)

When the transmitted and observed polarization bases are the same, the cross-polarization terms of the scattering matrix ($S_{hv}$, $S_{vh}$) have equal values—the reciprocity principle—which we use in the following calculation. The corresponding polarimetric portrait $S'_L$ is found by substituting the values of Equation 4 into Equation 1:

$$S'_L = \begin{bmatrix} \left\{ \frac{1}{2}|S_{hh}|^2 + |S_{hh}|^2 + \frac{1}{2}|S_{hv}|^2 + \Im m \left\{ S_{hh}S_{hv}^* + S_{hv}S_{hh}^* \right\} \right\} \\ \left\{ \frac{1}{2}|S_{hh}|^2 + \frac{1}{2}|S_{vv}|^2 + \Im m \left\{ S_{hh}S_{vv}^* - S_{hv}S_{vh}^* \right\} \right\} \\ \Im m \left\{ S_{hh}S_{vh}^* \right\} \\ \Re e \left\{ S_{hh}S_{vv}^* + |S_{hv}|^2 \right\} \end{bmatrix}$$

(5)
In response to single circularly polarized transmissions, the receiver measures only two of the four scattering matrix elements (Equation 1). That is of no consequence since the subsequent evaluations of the Stokes vector do not depend on knowledge of all of those elements. This fundamental fact is the source of much of the controversy in the remote sensing community surrounding “compact” polarimetric methodology. To emphasize: evaluation of the full Stokes vector does not require knowledge of the scattering matrix.

The HCP radar generates the four Stokes parameters (Equation 5) from the \((E'_h, E'_v)\) data measured through dual receiving channels (Equation 1). Although the value of each of those parameters depends on combinations of all four of the scattering matrix elements \(S_{ij}\), the numerical value of any one of the scattering matrix elements is not available. Each Stokes parameter as evaluated using Equation 1 leads to a single (real) number when measured in practice.

### 4.4. The Polarimetric Portrait: Part 2

Our objective in this context is to evaluate the Stokes parameters for the EM field reflected from a scene in response to transmissions from a quad-pol radar. Such a “fully polarimetric” SAR (van Zyl et al., 1987) is designed to evaluate all four elements of the scattering matrix—two in response to each of two orthogonally polarized illumination polarization, which requires two transmissions (Burkowitz, 1967, p. 565) per resolved pixel. Once the scattering matrix has been evaluated, then circular polarization may be emulated in the data processing stage by appropriate choice (mathematically) of the transmission vector. From that point, there are two ways to proceed (van Zyl et al., 1987; Zebker et al., 1987). One of those methods relies on the same Stokes vector formula (Equation 1) that an HCP polarimeter evaluates directly (Section 4.3). The other method generates the backscatter Stokes vector through the Kennaugh matrix-vector product. The Stokes vector of the observed EM field generated by a quad-pol SAR turns out to be identical to the result previously derived (Equation 5) for a dual-polarized receiver’s measurements of the same EM field in response to a circularly polarized transmission.

### 4.5. Comments on Equivalence

This result should not be surprising, because the full Stokes vector conveys all of the scene’s polarimetric information in like manner as the corresponding coherency matrix (Born & Wolf, 1959, p. 552) that would be measured by a “fully polarized” radar (in the narrow meaning of the SAR community) in response to the same transmitted sense of circular polarization. From the perspective of evaluating a scene’s polarimetric portrait, there is only one substantive difference between the two system architectures: virtual versus actual means of providing circularly polarized transmissions. In the traditional SAR remote sensing community, the conventional approach—which transmits interleaved linear polarizations—collects sufficient data so that a virtual representation of circular polarization may be invoked since all of the scattering matrix elements are measured. The same result is realized by actually transmitting circular polarization, either L-sense or R-sense, but in that case only one transmitted polarization—circular—is sufficient.

### 4.6. Comments on Calibration

Although both architectures produce equivalent polarimetric portraits, there is a significance difference. Evaluation of the Stokes vector—the EM field’s polarimetric portrait—is not sufficient to support evaluation of the \(2 \times 2\) scattering matrix or the corresponding \(4 \times 4\) Stokes (Kennaugh) operator. Since the scattering matrix cannot be fully evaluated by transmitting just one sense of circular polarization, polarimetric signatures are not available.

One practical consequence is that calibration methodologies that have proven their worth in the quad-pol context are not applicable to the HCP radar architecture in spite of the efforts to do so (Chen & Quegan, 2011). These methods rely on clever adjustments to the values of the four scattering matrix elements to offset imbalance, cross-talk, and co-phase issues in the transmitted fields and the receiver channels.
an HCP radar evaluates only two of those elements, matrix manipulation methods—including in particular calibration—that have their roots in a fully evaluated scattering matrix lead to unsatisfactory results.

Calibration of an HCP radar (monostatic or bistatic) is more effectively approached through methods developed for radiometric systems, such as reliance on known external illumination sources (Myserlis et al., 2018). The LRO lunar radar was calibrated through illumination from Arecibo’s circularly polarized EM field (McKerracher et al., 2010). In response to a known near-perfect illuminating source, such reference data observed in the range/Doppler domain (a natural stage inherent to a SAR’s image retrieval algorithm (Curlander & McDonough, 1991)) conveys the polarimetric properties of a two-dimensional section of the receive channels, including the receive antenna’s elevation/azimuth (El, Az) angular coordinates. In practice, that field is likely to have a detrimental “polarimetric structure” (Heiles, 2002) which can be observed, quantified, then compensated. Effecting these compensations—which are a function of the (El, Az) — is more comprehensive than the scattering-matrix-based approach which has no ability to offset Doppler-dependent polarimetric perturbations. After the receive channels have been calibrated, the remaining calibration task for this class of polarimeter is to characterize the polarimetric properties of the transmitted field.

5. Conclusions

The original meaning of “fully polarimetric” as used in the radio science and radar astronomy communities is that all four of the Stokes parameters (which are sufficient to fully characterize the polarimetric properties of an observed EM field) are measured by a suitably configured dual-polarized receiving instrument. In the mid-1980s the same term was repurposed by the remote sensing community to a narrower specific technical scenario, restricted exclusively to a radar polarimeter designed to measure all four of the complex elements of the Sinclair scattering matrix, hence sufficient to evaluate all 16 of the elements of the Stokes operator. Those two meanings of “fully polarimetric” are mutually inconsistent, leading to ambiguities, misunderstandings, and missed opportunities when applied to alternative radar architectures, or to entirely different—for example, bistatic or radiometric—scenarios. To mitigate those ambiguities and their ensuing problems, the new term “polarimetric portrait” is suggested as an alternative to “fully polarimetric” for all scenarios other than quad-pol synthetic aperture radar.

The unifying technical theme that emerges for active systems is that an unbiased polarimetric characterization of an observed scene requires that the illumination must be balanced. Given the constraint of transmissions comprised of only one polarization, the resulting backscatter is unbiased if and only if the transmitted polarization is circular. Circular polarization is realized by a single linearly polarized wave whose orientation sweeps through 360° at the wave’s frequency. When illuminated by such a wave, all possible in-scene scatterers no matter their innate preference enjoy their instant of favored incoming polarization. The clockwise or anti-clockwise direction of that sweep has no practical consequences in applications. The receiver must be coherently dual polarized, for which any pair of polarizations is sufficient. The principle that follows is that any situation in which a scene of interest is illuminated by a circularly polarized EM field is open to investigation and classification by its polarimetric portrait.

The disambiguation of “fully polarimetric” has significant consequences. The central tenet—proven in this paper through a physical optics calculation—is that a relatively simple coherent dual-polarized receiver is sufficient to provide polarimetric portraits in response to observations of an unbiased polarimetric EM field. That is a high-level generalizable property. It is directly applicable to hybrid compact polarimeters (an on-going controversial topic in the radar remote sensing community), certain bistatic radar astronomical opportunities, future satellite based planetary imaging radar observations, sounding radars (either atmospheric or terrestrial), radiometers, and GPS/GNSS reflectometry.

Conflict of Interest

The author declares no conflicts of interest relevant to this study.

Data Availability Statement

There are no data files associated with or referenced by this paper.
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