



15 Critical Measurements for Power Beaming Links

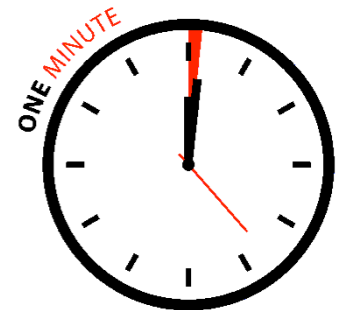
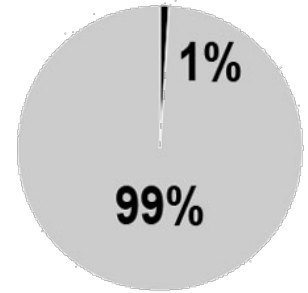
Paul Jaffe

202-767-6616

paul.jaffe@nrl.navy.mil

An Arbitrary Human-Scale Definition of “Power Beaming”

- Demonstrated end-to-end transmission efficiency of at least **1%**
- Spanned a distance of at least **1 m**
(where 1 m is beyond the reactive near field of the transmitter)
- Met the conditions above for at least **1 minute**

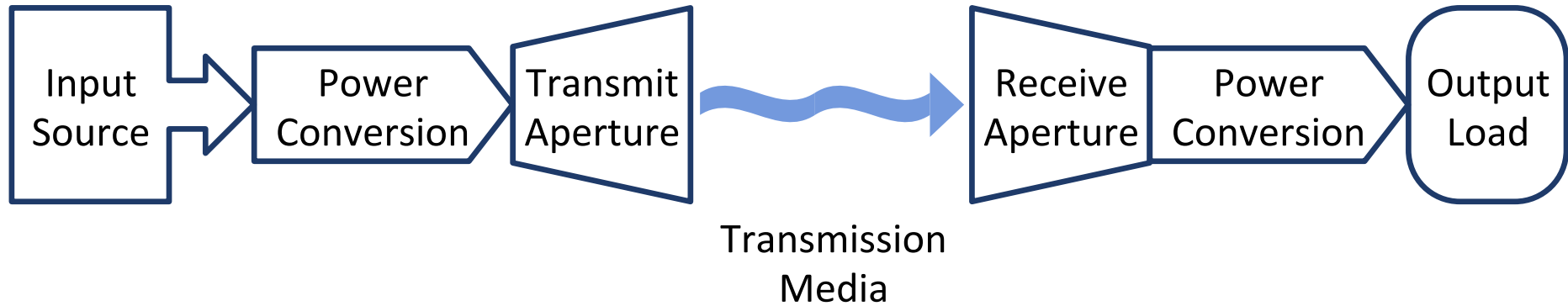


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Power Beaming Measurements

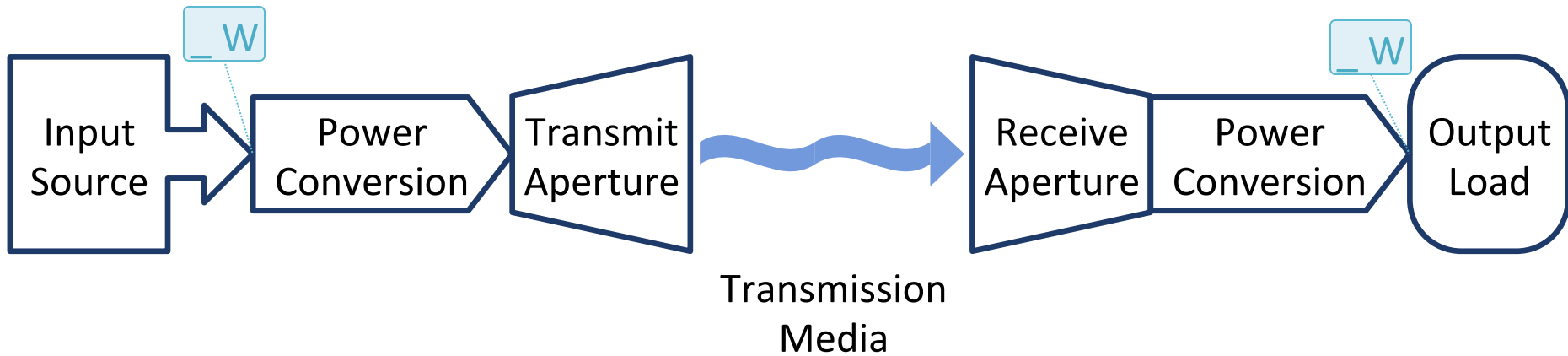
- Historically, power beaming link documentation has not always included all the pertinent information for meaningful comparisons
- The 15 critical measurements outlined herein form a basis for allowing for useful comparisons between power beaming systems
- Many derived quantities of interest can be calculated from the 15 measurements
- Other information may also be of interest: parameters related to cost, What, Where, When, Who, Why, How, etc.
- Guides for making accurate measurements to account for uncertainty and other factors:
 - “Introduction to Measurements & Error Analysis”
<https://users.physics.unc.edu/~deardorf/uncertainty/UNCguide.html>
 - “ISO Standards Catalog 17.020 - Metrology and measurement in general”
<https://www.iso.org/ics/17.020/x/>

Power Beaming Block Diagram



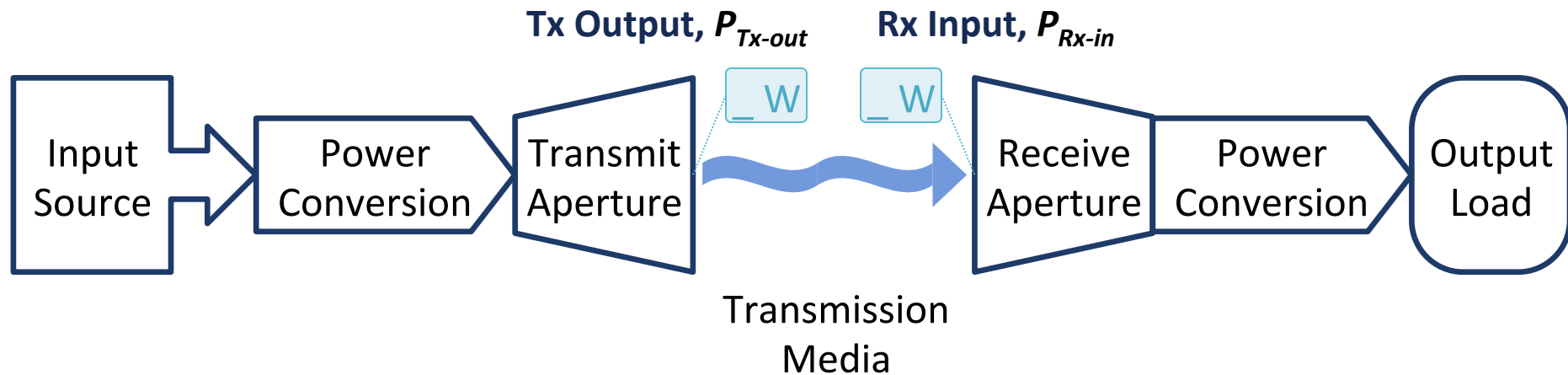
System Power Input and Output

Tx Input, P_{Tx-in}



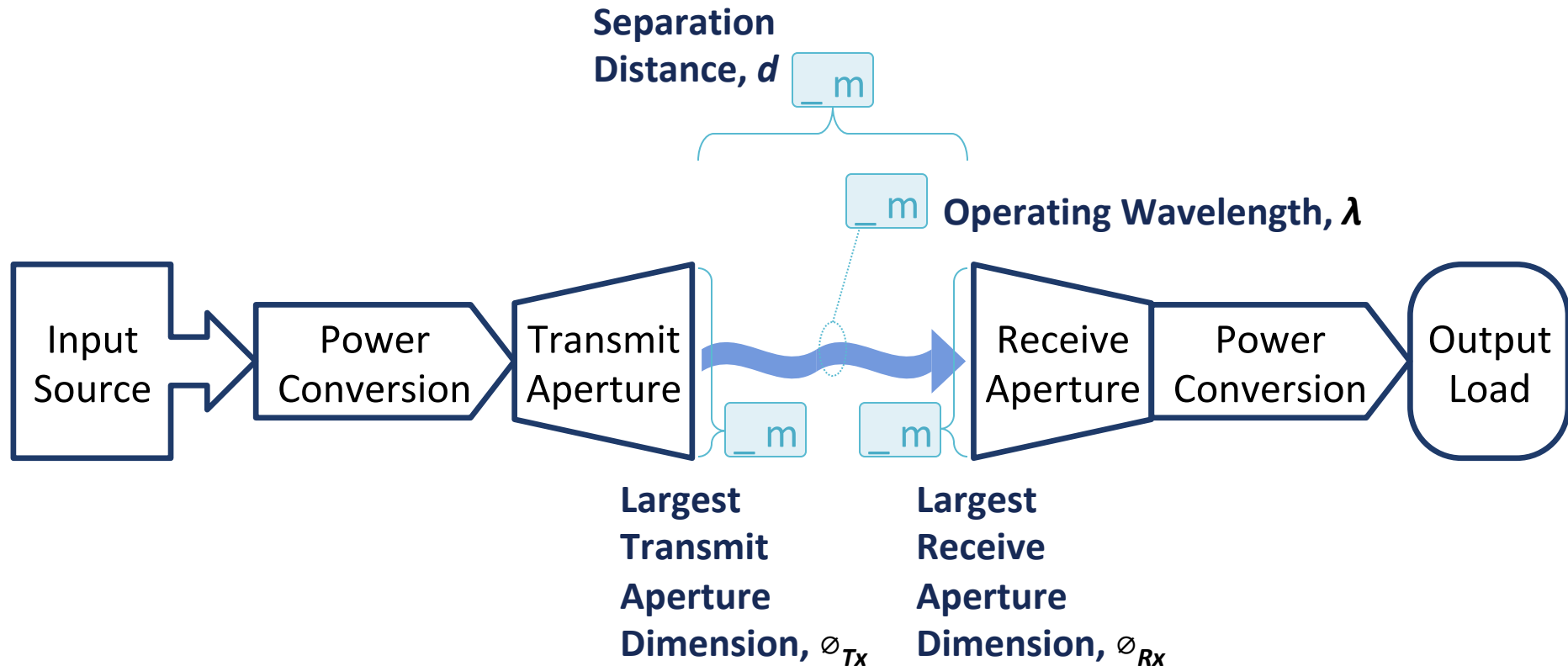
Input and output power of the system, measured in Watts. Mean, minimum, and maximum values may be appropriate to measure also.

Transmitted and Received Power



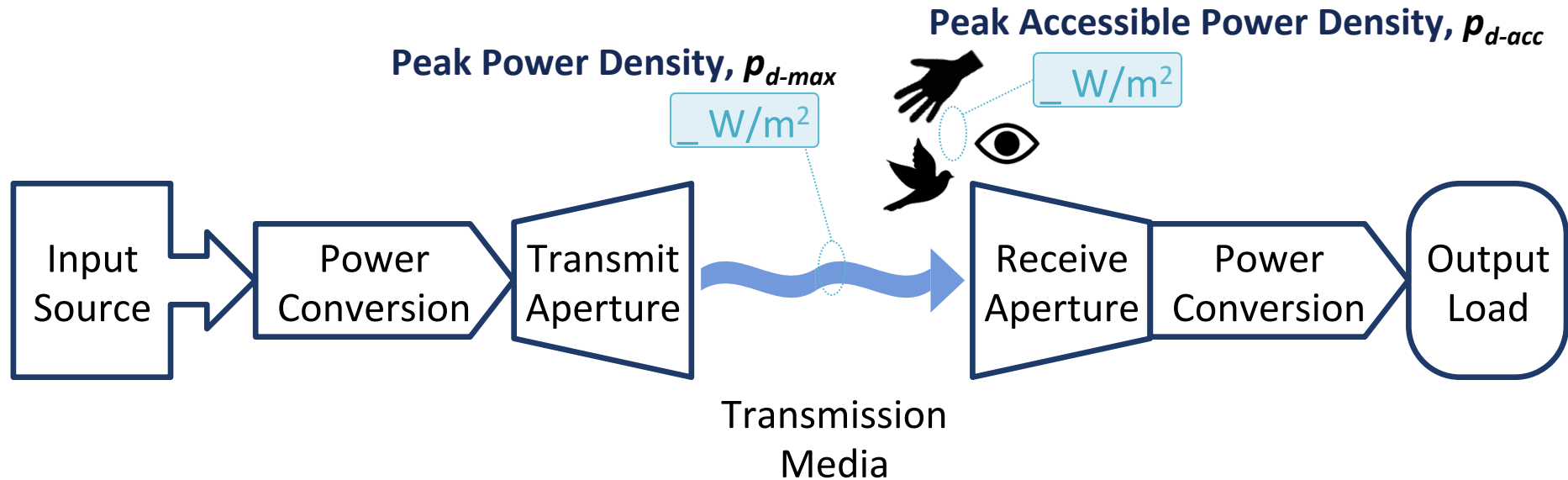
Power transmitted and received. The measurements will show loss in the link due the transmission media factors and low beam collection efficiency.

Separation Distance, Wavelength, and Largest Aperture Dimensions



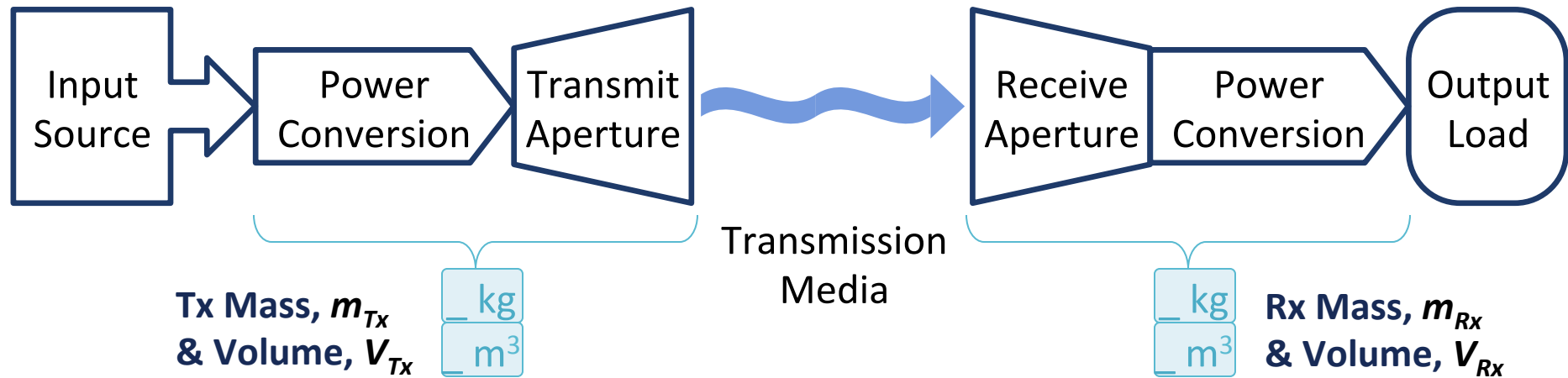
These linear measurements define the expected Beam Collection Efficiency (BCE), assuming no losses due to pointing or polarization mismatches.

Power Densities



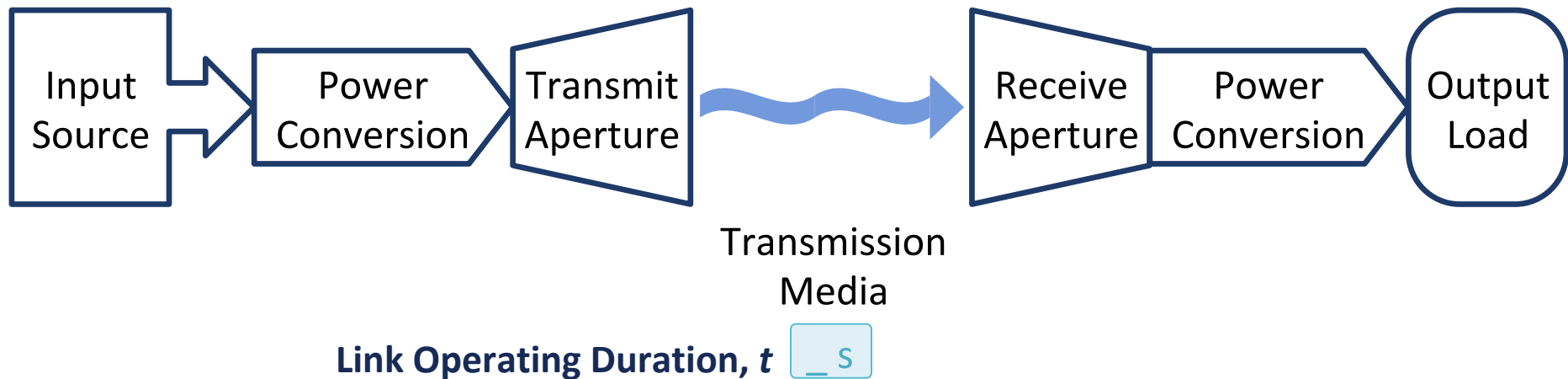
The peak power density along the beam gives an indication of the likelihood of effects resulting from power dissipation in the medium. The peak accessible power density (to people, animals, etc.) indicates if there may be a safety risk.

Transmitter and Receiver Size and Mass



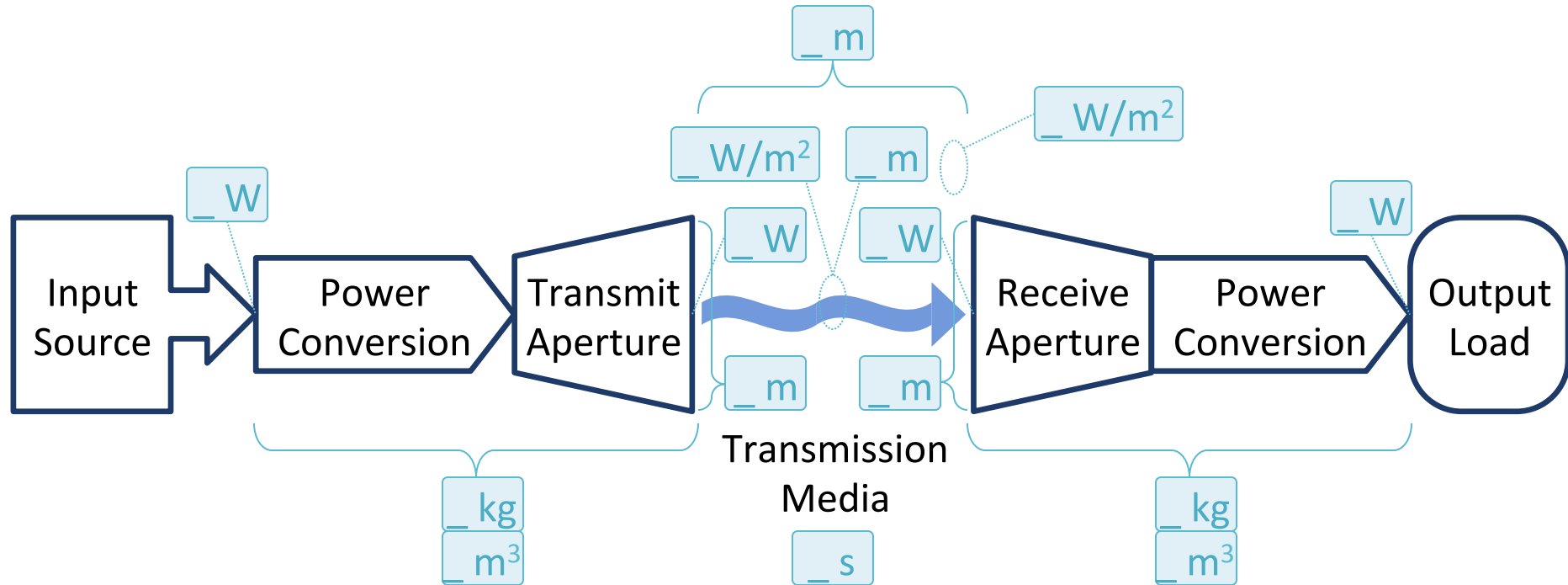
For nearly every application, there will be mass and volume constraints on either the transmitter, receiver, or both.

Duration of Link Operation



The time that the link can be active may be constrained by thermal management limitations or other factors.

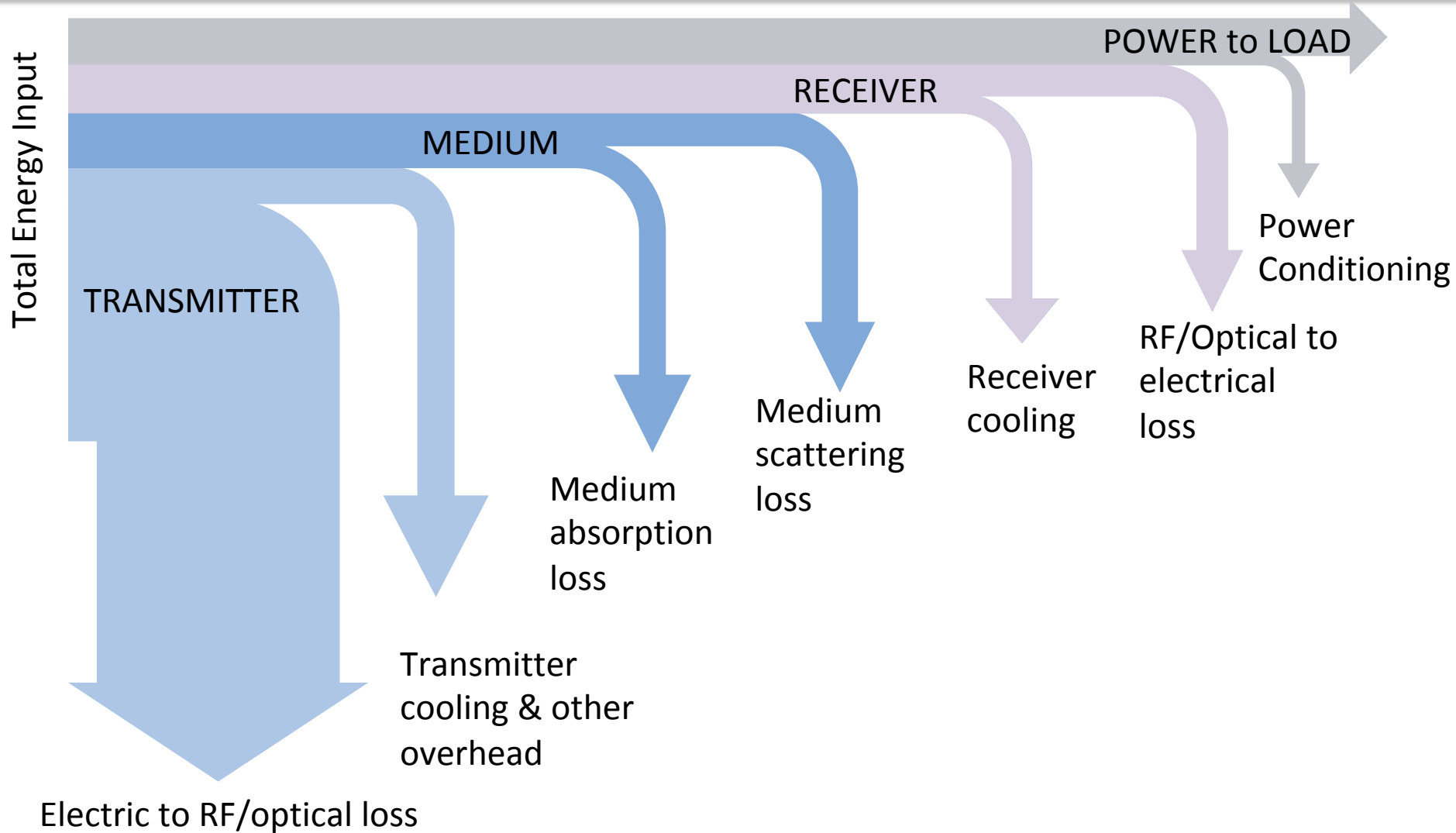
Critical Power Beaming Measurements



Power Beaming Link Measurement Summary

Power Beaming Link Measurement Summary		
Parameter	Recorded Value	Description
Date		The date the demonstration occurred. For multi-day demonstrations, the first day of operation.
Location		The location the demonstration occurred.
Title		A short, descriptive title to distinguish the demonstration from others
λ (m)		The wavelength corresponding to the frequency of operation (or operating frequency in Hz)
ϕ_{Tx} (m)		The largest dimension of the transmitter aperture, typically the diameter
m_{Tx} (kg)		The mass of the transmitter, including power conversion elements and the transmit aperture
V_{Tx} (m ³)		The volume of the transmitter, including power conversion elements and the transmit aperture
ϕ_{Rx} (m)		The largest dimension of the receiver aperture, typically the diameter
m_{Rx} (kg)		The mass of the receiver, including power conversion elements and the transmit aperture
V_{Rx} (m ³)		The volume of the receiver, including power conversion elements and the transmit aperture
d (m)		The distance between the transmit and receive apertures
P_{Tx-in} (W)		The input source power to the transmitter
P_{Tx-out} (W)		The power output of the transmitter at the frequency of operation
p_{d-max} (W/m ²)		The peak power density anywhere along the beam's path
p_{d-acc} (W/m ²)		The peak power density accessible to people, animals, aircraft, etc.
P_{Rx-in} (W)		The power incident on the receive aperture
P_{Rx-out} (W)		The average power from the receiver to the output load during the demonstration
t (s)		The duration over which the power link was active
Add'l References		Additional data sources

Notional "Sankey" Diagram Loss Depiction



Key Concluding Points

1. Past power beaming demonstration reports have lacked key details
2. Making the 15 measurements described will allow for meaningful comparisons of future demonstrations and assessments of technology readiness