An Introduction to Sub-Space Communication Systems

A Technical Overview of Metric Waveguides and Non-Local Phase Coupling for the Amateur Radio Operator

Technical Paper: N9OGL-2026-01-HAM

Author: Todd E. Daugherty (N9OGL)

Target Audience: Amateur Radio Operators, Digital Mode Experimenters, & RF Bench Builders

1. Abstract

For over a century, amateur radio experimentation has revolved around Transverse Electromagnetic (TEM) wave propagation across the ionosphere, troposphere, and space. Whether bouncing 20-meter signals off the F-layer or steering 10 GHz dishes for EME (Earth-Moon-Earth), radio operators are fundamentally constrained by the speed of light (c) and standard inverse-square space loss.

This paper outlines the practical theory behind a **Sub-Space Communication (SSC)** transceiver architecture. By stepping away from classic antenna radiation and utilizing non-linear dielectric material properties, asymmetric cavity resonators, and Generalized Orthogonal Frequency Division Multiplexing (G-OFDM), the SSC framework creates a localized metric phase coupling. For the ham builder, this system can be understood as an advanced digital mode stack operating through a non-local field gradient rather than an airborne transverse wave.

2. Moving Beyond Classic TEM Propagation

In traditional HF/VHF setups, an antenna acts as an impedance transducer. It converts fluctuating currents on a feedline into oscillating, orthogonal Electric (E) and Magnetic (H) fields that detach from the wire and radiate through space:

$$E_r \propto \frac{1}{r}, \quad P \propto \frac{1}{r^2}$$

[Traditional RF] ──> [Transverse E/H Wave] ──> [Ionospheric Bounce / Space Loss]
[SSC System] ──> [Non-Linear Cavity] ──> [Phase-Coupled Metric Corridor]

In an **SSC system**, energy is intentionally prevented from radiating as a standard TEM wave. Instead, the transmitter stores high-density reactive energy ($E_{reactive}$) inside a shaped, asymmetric resonant cavity containing high-permittivity dielectric media (such as Barium Titanate, BaTiO_3).

When driven with high voltage at exact resonance, the non-linear polarizability of the dielectric alters the local boundary conditions. Rather than broadcasting a wave *through* space, the cavity produces a **localized phase gradient** that couples non-locally to a matched receiver cavity.

3. The Digital Engine: G-OFDM & Raptor Coding

Phase coupling requires extreme signal structure to keep the metric corridor stable against thermal noise and local environmental phase jitter. The SSC protocol stack uses two core digital tools familiar to modern SDR experimenters:

[User Data] ──> [Raptor FEC] ──> [G-OFDM Modulation] ──> [High-Voltage Phase Driver]

A. Generalized Orthogonal Frequency Division Multiplexing (G-OFDM)

While standard OFDM (used in Wi-Fi, 5G, and modern HF modems like VARA or FreeDV) splits data across orthogonal subcarriers in a 1D or 2D plane, **G-OFDM** projects an N-dimensional constellation across all subcarriers simultaneously.

- **Why it matters for SSC:** If a localized phase disturbance degrades specific subcarrier frequencies inside the waveguide, the overall signal constellation suffers only minor distortion. The receiver recovers the full payload without dropping frame lock.

B. Raptor Forward Error Correction (FEC)

Raptor codes are rateless fountain codes. The transmitter continuously streams encoded parity symbols; as soon as the receiver collects *just enough* valid symbols to satisfy the mathematical matrix, it reconstructs the original frame instantly—regardless of channel dropouts or phase hits.

4. Hardware Architecture of an SSC Bench Node

For the homebrew operator, building an SSC node does not require a national laboratory. The hardware stack maps cleanly onto standard bench equipment and high-power digital experimentation:

```
                 [ SDR / FPGA Baseband ]
                 (G-OFDM Generator / DSP)
                          |
                          ▼
[ 10 MHz Master Clock ] ──> [ HV Driver Bridge ] <── [ High-Voltage DC Supply ]
  (GPSDO or OCXO)         (SiC / GaN MOSFETs)       (0 - 500V DC)
                          |
                          ▼
               [ Metric Waveguide Core ]
            (Tapered Brass + BaTiO3 Dielectric)
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1. The Phase Anchor (Master Timing)

Phase coupling demands picosecond-level stability. Standard internal crystal oscillators (TCXOs) drift too quickly, causing the receiver to lose cycle-lock.

- **Bench Requirement:** A **GPS-Disciplined Oscillator (GPSDO)** or a low-phase-noise **Oven-Controlled Crystal Oscillator (OCXO)** running as the 10 MHz master clock reference for both the SDR baseband and the phase drivers.

2. High-Voltage Phase Driver

Unlike a typical 50-ohm QRP transmitter outputting 5 Watts into a dipole, the SSC core requires high potential (V) to drive non-linear polarization in the dielectric.

- **Bench Requirement:** High-speed Silicon Carbide (SiC) or Gallium Nitride (GaN) MOSFET switching bridges powered by a variable 0–500V DC power supply, isolated from the control PC via high-speed optical couplers.

3. The Metric Waveguide (The "Antenna")

The "antenna" is a closed, tapered brass or copper resonant cavity lined with high-permittivity ceramic inserts (BaTiO_3). It acts as a high-Q LC tank circuit that traps the EM field, forcing it to interact continuously with the atomic lattice of the dielectric rather than escaping into free space.

5. Summary & Bench Setup Checklist

For ham radio operators looking to explore non-local phase coupling, the migration path mirrors the early days of digital mode development:

Component	**Standard Ham Rig**	**SSC Bench Prototype**
Propagation	Ionospheric / Line-of-Sight TEM	Non-Local Metric Phase Coupling
Antenna	Wire Dipole / Yagi Beam	Asymmetric Cavity + Dielectric Core
Modulation	SSB, FT8, VARA, AX.25	G-OFDM with Raptor FEC

Clock Source	Internal Rig TCXO	10 MHz GPSDO / Low-Noise OCXO
Power Output	RF Wattmeter into 50 Ω Load	High Voltage (V) across Cavity Field

By combining software-defined radio processing, precision OCXO/GPSDO timing anchors, and solid-state high-voltage switching, amateur operators can move beyond the limits of skywave propagation and actively participate in the development of sub-space metric communications.