WORKING NOTE

Evanescent Waveguides as Test Systems for Topological Spacetime Modulation

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Scope: Phenomenological test protocol for evanescent microwave waveguides
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Goal: Definition of a measurable signature of the TopMod approach in evanescent zones.

1 Standard waveguide barrier (classical reference)

In a rectangular metallic waveguide, the propagation of an electromagnetic wave in the fundamental TE_{10} mode is described by the longitudinal wave number k_z

$$k_z^2 = k_0^2 - k_c^2 \tag{1}$$

with $k_0 = \omega/c$ and $k_c = \pi/a$ the cutoff wave number of the TE_{10} mode. Below the fundamental cutoff frequency, one has $k_0 < k_c$. In that case, k_z becomes imaginary:

$$k_z = i\kappa, \quad \kappa = \sqrt{k_c^2 - k_0^2}. \tag{2}$$

The corresponding segment of length L is then non-propagating and evanescent. In the reference description, the transmitted power T scales exponentially with barrier length:

$$T(L) \propto e^{-2\kappa L} \tag{3}$$

2 Phenomenological TopMod correction term

The TopMod minimal model postulates an effective direction-dependent modulation of photon propagation. In the present waveguide scenario, no claim is made that the microscopic metallic boundary conditions are derived or altered. Instead, a small anisotropic correction term δ_{TM} is introduced purely phenomenologically into the effective dispersion relation:

$$k_z^2(\theta) = k_0^2 - k_c^2 + \delta_{TM}\cos(2(\theta - \theta_0)). \tag{4}$$

Here, δ_{TM} has the same physical dimension as k^2, namely $[L^{-2}]$, for example m^{-2}. If the phenomenological correction term δ_{TM} is attributed to the same dimensionless anisotropy parameter as in the main model, a scaling of the form $\delta_{TM} \sim \epsilon\chi k_0^2$ is suggested; however, the precise mapping remains model-dependent. The angle θ describes the orientation of the setup relative to the preferred axis θ_0. In accordance with the addendum, one must distinguish experimentally between two cases:

- **Case A:** laboratory-fixed structure; modulation generated by active rotation of the setup.
- **Case B:** inertial preferred structure; modulation generated by Earth's rotation relative to the preferred axis.

In the evanescent regime, this yields the effective damping constant

$$\kappa_{eff}(\theta) = \sqrt{k_c^2 - k_0^2 - \delta_{TM} \cos(2(\theta - \theta_0))}. \tag{5}$$

For sufficiently small $|\delta_{TM}|$, one may linearize. With $\kappa = \sqrt{k_c^2 - k_0^2}$ this gives

$$\kappa_{eff}(\theta) \approx \kappa - \frac{\delta_{TM}}{2\kappa} \cos(2(\theta - \theta_0)). \tag{6}$$

This linearization is physically valid only within the window $|\delta_{TM}/(2\kappa^2)| \ll 1$, defining a strict operational limit for the permissible approach to the cutoff.

3 Concrete measurement signature

The primary observable is the transmitted power T at the end of the evanescent barrier. If an anisotropic TopMod correction term exists, it induces an angular modulation of the transmission. Inserting the linearized form of κ_{eff} into the exponential damping yields, for small modulations, a leading fit form

$$T(\theta) \approx T_0[1 + A_2 \cos(2(\theta - \phi_0))]. \tag{7}$$

Here, T_0 is the isotropic background signal, A_2 is the amplitude of the twofold modulation, and ϕ_0 is the experimentally extractable phase offset. In the linearized regime, the signal amplitude scales at leading order as

$$A_2 \propto \frac{L\delta_{TM}}{\kappa} \tag{8}$$

as long as the linearization remains valid.

4 Experimental significance

The working note does not claim a microscopic derivation of the correction term from the metallic boundary conditions. Rather, it defines a clean test channel:

- Evanescent waveguide barriers serve as sensitive detectors for small anisotropic correction terms in photon propagation.
- The primary search signature is a $\cos(2\theta)$ modulation of the transmitted power.
- Sensitivity increases as the setup approaches cutoff, but in laboratory practice it remains limited by losses, mode purity, and finite bandwidth.
- Secondary observables such as resonance shifts or phase modulations may also be investigated, but they are not central here.

5 Classification

This note is not a derivation of the main TopMod model in the strong microscopic sense. It is a phenomenological bridge between the existing minimal model and an alternative experimental test system. For the underlying minimal phenomenology and the reference-frame separation motivating Cases A and B, see the Main Paper and Technical Addendum of the TopMod package.

6 Appendix: Experimental protocol and systematics budget

As a concrete reference platform for the experimental test (Case A), we consider a rectangular microwave waveguide in the GHz regime containing a narrowed barrier section operated below cutoff (TE_{10} mode). The setup is mounted on a precision rotation stage in order to allow active rotation by the angle θ in the laboratory frame. Since the sought TopMod signature δ_{TM} is extremely small, the experimental protocol must be designed specifically to isolate the 2θ signal quantitatively from instrumental systematics.

A. Ratiometric measurement and fit procedure

To suppress source noise and input-power drift at an early stage, the transmission is measured ratiometrically, for example as the normalized transmission coefficient $|S_{21}|^2$ on a vector network analyzer (VNA). The rotating signal $T(\theta)$ is not merely filtered for a 2θ component, but must be fitted using the full harmonic quadratures:

$$T(\theta) = T_0 + C_1 \cos\theta + S_1 \sin\theta + C_2 \cos(2\theta) + S_2 \sin(2\theta) + \dots \tag{9}$$

The candidate signal amplitude is then extracted as $A_2 = \sqrt{C_2^2 + S_2^2}$. This full decomposition is essential in order to quantify and bound leakage of large 1θ systematics into the 2θ channel, and to correct for it only where an independent calibration of the detection chain is available. The protocol further requires an explicit upper bound for $1\theta \to 2\theta$ leakage, which must be derived quantitatively from the measured non-linearity of the detection chain and the observed 1θ component of the rotation signal.

B. Dominant systematics and error budget

1. **Geometric and stress artifacts (flange stress):** Since $\kappa = \sqrt{(\pi/a)^2 - k_0^2}$, even a microscopic bend of the waveguide width a changes the damping constant substantially. If such mechanical stress, for example from co-rotating RF cables, appears periodically with 2θ, it mimics the TopMod signal.

2. **Gravity sag:** Deformation of the waveguide under its own weight varies during rotation. Although this effect modulates primarily with 1θ, nonlinear detector response can up-mix it into the 2θ quadratures.

3. **Thermal drift:** Temperature fluctuations change both L and k_c. The rotation period must therefore be chosen much shorter than the thermal time constant of the setup, complemented by active temperature stabilization.

4. **Mode contamination and reflections:** Geometric steps can excite parasitic higher-order evanescent modes. The structure therefore requires adiabatic transitions as well as a full VNA characterization of the S-parameters in advance, in order to demonstrate that the measurement window is dominated exclusively by the intended TE_{10} coupling.

C. Null channels (falsification condition)

An extracted A_2 signal is to be regarded as a TopMod candidate only if the corresponding control-channel amplitudes are consistent with zero within experimental uncertainties in two independent control measurements:

- **Electrical null test:** A measurement with a waveguide operated entirely above cutoff, i.e. without evanescent sensitivity enhancement by the factor $1/\kappa$.

- **Mechanically matched null test:** The control setup must reproduce the rotational, flange, cable, and mass loading of the main apparatus without providing the evanescent sensitivity enhancement. The specific realization must be chosen to ensure that no dominant additional material or thermal systematics are introduced.

Closing remark

The working note with appendix is thereby frozen as a phenomenological test approach and as an experimental work-level specification. It is not a microscopic derivation, but it is a cleanly structured, testable, and HF-compatible test channel.