

# Appendix M – Energy and Safety Limits for UBT Experiments

## M.1 Purpose

This appendix specifies energetic and safety envelopes for laboratory tests of Unified Bi-quaternion Theory (UBT) using standing/modulated EM modes (cf. Appendix L) and their phase-sector coupling through  $\psi$ . Where  $\psi = 0$  (or averages to zero), UBT reduces to GR/Maxwell and remains consistent with existing experiments.

## M.2 Scaling Relations (Stored Energy, Drive Power)

For a cavity mode with angular frequency  $\omega = 2\pi f$ , volume  $V$ , effective permittivity  $\epsilon_{\text{eff}}$ , rms electric field  $E_{\text{rms}}$  and quality factor  $Q$ ,

$$U \approx \frac{1}{2} \epsilon_{\text{eff}} E_{\text{rms}}^2 V, \quad P_{\text{in}} \approx \frac{\omega U}{Q}. \quad (1)$$

The fractional frequency shift of a metrological probe by a weak metric perturbation  $h_{\mu\nu}$  is

$$\frac{\Delta f}{f} \simeq -\frac{1}{2} \langle h_{00} + n^i n^j h_{ij} \rangle_{\text{mode}}, \quad (2)$$

with  $n^i$  the local propagation direction. In GR alone, EM  $T^{\mu\nu}$  yields negligibly small  $h_{\mu\nu}$  for lab powers; in UBT, the effective source is

$$T_{\text{eff}}^{\mu\nu} = T_{\text{EM}}^{\mu\nu} + \lambda_\psi \Psi^{\mu\nu}(\psi, F) \Rightarrow h_{\mu\nu} \propto \int \frac{T_{\text{eff}}^{\mu\nu}}{|\mathbf{x} - \mathbf{x}'|} d^3x' \quad (\text{Appendix L}). \quad (3)$$

## M.3 Numeric Envelope (Indicative Values)

Assuming  $V = 1.0 \times 10^{-3} \text{ m}^3$ ,  $Q = 10^6$ ,  $\epsilon_{\text{eff}} \approx \epsilon_0$ , two drive levels give:

$f$ [GHz]	$E_{\text{rms}}$ [kV/m]	$U$ [J]	$P_{\text{in}}$ [W]
2.4	50	0.011	0.17
5.0	50	0.011	0.35
10.0	50	0.011	0.70
2.4	200	0.18	2.7
5.0	200	0.18	5.7
10.0	200	0.18	11.3

These are order-of-magnitude targets; thermal management and breakdown thresholds must be respected (Sec. M.5).

## M.4 Detectability Window

Let  $\Delta f/f \geq \sigma_f$  be the instrument sensitivity (e.g.  $\sigma_f \sim 10^{-8}$ ). Writing

$$\frac{\Delta f}{f} \sim \mathcal{K}_{\text{UBT}} U, \quad (4)$$

the minimum stored energy is  $U_{\min} \approx \sigma_f/\mathcal{K}_{\text{UBT}}$ . In GR one expects  $\mathcal{K}_{\text{GR}} \ll \mathcal{K}_{\text{UBT}}$ ; thus any detection at lab powers constrains  $\lambda_\psi$  and  $\Psi^{\mu\nu}$ .

## M.5 Safety Limits

- **Dielectric breakdown (vacuum):** avoid peak fields  $\gtrsim 30$  MV/m at surfaces; smooth geometry, proper conditioning.
- **Heating/Quench:** keep surface losses below cryostat capacity; derate for seams and couplers.
- **Exposure/EMC:** enclose in Faraday cage; comply with local RF exposure limits; interlocks and E-stop required.

## M.6 Control and Modulation of Hopfions & Psychons

UBT links hopfion topology and psychon excitations through the phase sector  $\psi$ . A practical loop: EM field pattern  $\rightarrow T_{\text{eff}}^{\mu\nu} \rightarrow \Delta g_{\mu\nu}$ , while  $\psi$  modulates both  $T_{\text{eff}}^{\mu\nu}$  and the metric response (Appendix L). Below is a *self-contained TikZ* block diagram (no external file).

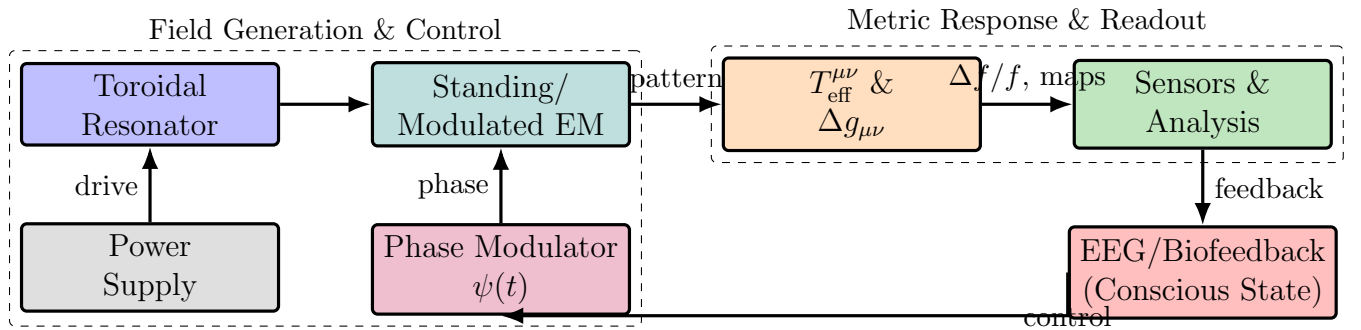


Figure 1: Closed-loop control of hopfion/psychon dynamics via phase modulation  $\psi(t)$  and standing/modulated EM fields. Diagram is drawn with TikZ (no external image).

## M.7 Summary

UBT-compatible operation keeps EM powers in safe ranges while seeking a measurable metrological signature ( $\Delta f/f$ ) mediated by the  $\psi$ -sector. The TikZ control diagram specifies a practical loop for hopfion/psychon modulation without external figures.