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Joint Task Force: TEM Waveguides

The following is excerpted from [1].

EXAMPLE TEM WAVEGUIDE UNCERTAINTY BUDGET

There is still interest in the EMC community for alternative test facilities, including the free-space (FS) type fully-anechoic rooms (FAR), gigahertz transverse electromagnetic (GTEM) cells and other TEM waveguides, and reverberation chambers. GTEM cells are currently used as alternative test sites for both pre- and full-compliance radiated emissions testing. A GTEM does not directly measure an OATS-equivalent field strength at a distance, but it instead measures total radiated power from an equipment-under-test (EUT). It is useful to consider testing in alternative facilities in terms of "compliance uncertainty" [2]. Compliance uncertainty encompasses the usual measurement instrumentation uncertainty, e.g., [3] for OATS testing, but also includes other effects such as EUT-to-receive-antenna mutual coupling, cable layout sensitivities, and measurement system and EUT repeatabilities. The important condition, difficult to establish other than in terms of compliance uncertainty, is whether or not testing in an alternative facility will ensure electromagnetic compatibility in the final installation of the EUT.

The empty waveguide TEM mode is defined in [4] as -0/+6 dB variation in primary E-field component over a calibration area at each frequency, and secondary (cross-polarized) components less than at least 3 dB. Similarly, an emissions correlation is defined to be valid if the average is within –0/+3 dB and the standard deviation is within 4 dB over 10 or more EUT frequencies. In practice, uncertainties may affect whether this requirement of TEM waveguide correlation results overestimating OATS can be met.

Numerous uncertainty budgets for TEM waveguide immunity tests have been previously reported, e.g., [5,6]. However, only uncertainty components that are relevant for emissions testing are described here. Limited discussions on emissions uncertainty considerations appeared in [7-9], and relevant factors from those papers have been included here. EUT directivity effects in alternative facilities and in EMC testing in general are presently an active research topic [e.g., 10-12]. A view of the issues related to this influence quantity is given in [1].

POSSIBLE RADIATED EMISSIONS UNCERTAINTY INFLUENCE QUANTITIES

Table 1 gives an extensive but maybe not exhaustive list of uncertainty influence quantities for TEM waveguide radiated emissions testing. Several of these may overlap, and may or may not make a significant difference in any particular test. It is known that OATS or SACs usually correlate to each other within about 4 dB to 8 dB [e.g., 13], therefore uncertainty components of less than 0.5 dB or so can sometimes be neglected in favor of larger issues. Under current circumstances, in the end the proof of TEM waveguide efficacy is in the correlation. At present numerical estimates for several of these components are not available, so future discussion and research may be needed. Many of these are expected to be less than 1 dB and will not be discussed.

These influence quantities can be loosely categorized into effects due to the receiving system (1-4), correlation algorithm (5-14), TEM field distribution (15-24), and EUT (25-34). Discussion of any of these effects in the future can and should be done in terms of relative magnitudes in the uncertainty budget. The standard GTEM three-position electric field correlation equation is [14]

$$E_{\max} = S_{\max}\sqrt{30Pg} = S_{\max}\frac{20k_0}{e_{0y}}\left(\frac{3g}{Z_c}\right)^{1/2}\left[10^{\frac{V_{mx}-120}{10}} + 10^{\frac{V_{my}-120}{10}} + 10^{\frac{V_{mz}-120}{10}}\right]^{1/2},$$

which shows that GTEM *E*-field is a function of EUT radiated power P (related to measured voltages), EUT numeric gain g, frequency, site geometry factor $S_{\max}$, transmission-line impedance Z_c, and TEM mode field strength e_{0y}. The number of factors in the last square root term and the first numeric multiplier may differ among multi-position correlation methods. An uncertainty sensitivity analysis could be done using partial derivatives of this *E*-field equation. In the case that correlation data is available for a particular EUT type [15], nearly all components will be included in and can be replaced by a single TEM-to-OATS/FS correlation uncertainty component. For some EUTs, directivity and relative phase effects may be intertwined, so correlation algorithms tailored to account for either one separately may not show advantage if both effects are present.

Some of the main issues that are still under investigation fall within EUT mutual coupling, field distributions, and cable effects. A contribution on mutual coupling effects is given by the data later in this paper. Via an emissions field uniformity mapping with small dipole-like radiators, [16] shows that local cross-pol components do exist, but the effects for more realistic, larger EUTs are not described there. Reference [17] shows good correlation for various canonical EUTs, and points out that no pronounced effects are seen due to the main 130 MHz longitudinal component. Nonuniform waveguide effects [18], including higher-order modes, can have an influence on field distribution variations along the GTEM length. These are included in the field uniformity and correlation uncertainty components. Quadrupole effect [19,20] studies in one-port TEM waveguides have not been reported, probably because a revised correlation method would be required. Transmission between an antenna and EUT in the presence of a reflecting plane consists of primary and secondary rays, or direct and reflected. References [21,22] describe a third or tertiary ray or wave that is reflected from the EUT back to the antenna. This is a type of mutual coupling between EUT and antenna. Using an immunity-type setup, it was reported that in GTEM the tertiary wave can cause about ±3 dB response variations. However, results below with the slot- and plate-mode EUTs show less than 1 dB average variation for an EUT with size of 2/3 of the septum height.

Several standardized cable layouts, which essentially remain fixed throughout EUT rotations, are proposed in [4]. While these should provide repeatability and reproducibility advantages, results based on these setups will likely have systematic differences between each other and between the usual OATS and SAC cable layouts. These differences need more experimental investigation, after which their contributions can be included in compliance uncertainty budgets.

EXAMPLE UNCERTAINTY BUDGET FOR GTEM TEST

An example uncertainty budget is shown in Table 2 for a GTEM radiated emissions test. Typical element values are used for a setup with spectrum analyzer, external pre-amp, cables, and GTEM. First, combined standard and expanded uncertainties are computed for the GTEM using a template like Table 2. This GTEM contribution consists of a 4 dB field uniformity influence quantity with triangular distribution (weighting factor $1/\sqrt{6}$), and for example the correlation standard deviation σ =2.92 from typical GTEM data (Fig. 9 of [1]) with a normal distribution. (It is permissible to use the number of test frequencies to derive and use the standard deviation of the mean, but that will not be done in this example.) This gives an expanded uncertainty (k=2) of 4.381 dB for use as the GTEM component in Table 2. A zero weighting factor is shown for the comb generator amplitude tolerance because it is included in the GTEM correlation term. The final expanded uncertainty for the system is then 4.989 dB.

Table 1. GTEM and TEM Waveguide Radiated Emissions Uncertainty Influence Quantities

1	Input VSWR in termination transition-frequency range
2	Input VSWR other frequencies
3	Receive cable attenuation
4	Cumulative effect of 3 times (or 6, 9, 12, 15 etc.) - voltage measurement, receiver, pre-amp uncertainties
5	Noise/comb generator uncertainties, if used in correlation
6	Use of voltage-based versus power-based tests
7	Uncertainty in GTEM-OATS correlation – Type A
8	Uncertainty in OATS reference values for correlation comparison
9	All uncertainty components from OATS test will impact agreement with GTEM predicted field strengths
10	Correct rotation positions = EUT orthogonal axes permutations
11	Alternate correlation algorithms that may vary from any reference correlation algorithm results
12	Correlation routine coding, software bugs, or formulation errors
13	Directivity value used in correlation formula
14	Difference between actual ground plane parameters versus ideal ground plane used in most correlation algorithms
15	TEM waveguide characteristic impedance at EUT location
16	Septum height variation across volume occupied by EUT
17	EUT platform, turntable, manipulator, positioner dielectric perturbation, scattering, absorption effects
18	*xyz* positioning offset (e.g., in sensitivity of 3-position correlation)
19	Field uniformity – may be analogous to OATS NSA
20	Wave impedance – may be included in field uniformity
21	Deviation from theoretical 2D asymmetric TEM cell field distribution (e_{0y})
22	Field non-planarity – may be included in field uniformity
23	Energy loss in absorber or higher-order modes
24	Cross-polar or longitudinal-mode coupling
25	Polarization mismatch
26	Change in EUT coupling for alignment parallel to floor, septum, or in between
27	EUT loading, mutual coupling, surface-current perturbations
28	Radiation pattern peak location, interception
29	EUT equivalent-dipole moments relative phase uncertainty
30	Quadrupole effects=EUT phase center location offset uncertainty
31	EUT chassis or functionality variations throughout rotations
32	Cable routing
33	Cable length
34	Cable termination

Table 2. Example Uncertainty Budget for Slotted-box EUT 3-position GTEM-to-FAR Correlation

Component Source		Tolerance or σ		Max VSWR				Spec. U (k=2)			Dist.	Type Eval.	Weighting	u_s
#	Name	dB	%	In	Out	Γι	Γo	dB	%	n	(A,N,R,U)	(A, B)	Factor	dB
1	spectrum analyzer	1.049		1.5		0.2				1	N	B	1.0000	1.049
2	pre-amp			2	2.2	0.333	0.375	1.23		19	N	A	0.2294	0.141
3	GTEM				1.25		0.111	4.381		1	N	B	1.0000	2.19
4	cable1	0.277								1	R	B	0.5774	0.16
5	cable2	0.212								1	R	B	0.5774	0.123
6	comb generator ampl tol.							0.8165		1		B	0.0000	0
Mismatch Calculation		Γ1	Γ2	--				Tot. Err.			--	--	--	--
7	pre-amp : spec ana	0.375	0.2	--				0.65	--	--	U	B	0.7071	0.462
8	GTEM : pre-amp	0.111	0.333	--				0.32	--	--	U	B	0.7071	0.228
					Combined Standard Uncertainty, u(c):						N	A	--	2.495
							Expanded Uncertainty, U:				N	A	2	4.989

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