Frequency Augmentation of the WIS HPM Test Facility SUP.R.A

A. Kaiser, L. Meyer, B. Römer, U. Schenk
Armed Forces Scientific Institute for Protection Technologies and NBC-Protection
(WIS)
Humboldtstr.
D-29633 MUNSTER, GERMANY

ArnholdKaiser@BWB.ORG

ABSTRACT

The German High-Power Microwaves (HPM) test facility SUP.R.A - introduced in 2002 - is currently being upgraded in terms of its overall frequency coverage. After completion of the respective installation and integration of new hard- and software into the existing system at WIS, both vertically and horizontally polarized high-power microwaves from 675 MHz up to 3000 MHz will be offered for future HPM-tests, with no gap in frequency coverage.

Following an overview of the previous status and performance of SUP.R.A, this paper focuses on the new hardware especially designed and procured for the frequency augmentation. Initial performance data - acquired on site as well as in the US - is shown and is compared to the primary specifications, and to the initial goals, respectively.

Figure 1: HPM system with new tube 5 and shunt installed, and tube 3 (idle)

1.0 INTRODUCTION

The High-Power-Microwave test facility of the Federal Armed Forces Scientific Institute for Protection Technologies and NBC-Protection (WIS) in Munster was set up in the year of 2002 [1]. Currently, its overall frequency coverage is being extended.

Basically, the HPM-generator-system consists of a Thyratron-triggered, repetitive 1.4 Megavolt PFN-Marx generator and several High-Peak-Power Super RELTRON[1] tubes. Each tube is provided with stepping motors for precise and remotely controlled frequency- and output power tuning. With respect to its center frequency each tube allows an approximately ± 10 percent tuning. The pulse repetition rate (PRF) is adjustable, from single shot up to 10 pulses per second. A maximum of 100 pulses can be contained in one burst.

Individual pulses contain at least 300 cycles, and all pulse widths are at least 300 ns. For test frequencies in the resonance region of a device under test (DUT), in practice such relatively long pulse durations allow fields generated internally in the target to equilibrate (e.g., inside cavities with quality factors of 500 to 1000).

Utilizing different waveguide systems and horn antennas, the microwaves are radiated into an anechoic chamber (L x W x H: 20 m x 4 m x 4m) mainly furnished with non-combustible, pyramidal absorbers. Both vertical and horizontal polarization is provided. Two 10 dB waveguide attenuators for each different waveguide system can be inserted if field levels have to be reduced constantly, or minimized.

From a shielded control room, and via optical fibers, the whole system is remote-controlled and monitored by a computer. Data acquisition (8 channels), and data reduction and processing are automated.

2.0 BASIC PERFORMANCE OF THE PREVIOUS (2002) SUP.R.A

The basic system - as it was installed in 2002 - consists of four RELTRONS, two waveguide systems (WR 1150 & WR 770), and two matched horn antennas. The frequency coverage extends from 675 MHz to 1.44 GHz with no gaps in coverage. Electric field amplitudes of at least 50 kV/m (rms) can be achieved at a distance (far field) of 15 m from the respective antenna(s), both vertically and horizontally polarized. Two 10 dB waveguide attenuators can be inserted if field levels have to be reduced, or minimized. Then, minimum fields as low as 3-5 kV/m (rms) can be provided at a distance of 15 m from the antenna(s). At that distance, the illumination area is about 4 m x 3 m when the respective antenna is set for radiating vertically polarized electric fields.

[1] RELTRON: Relativistic Klystron

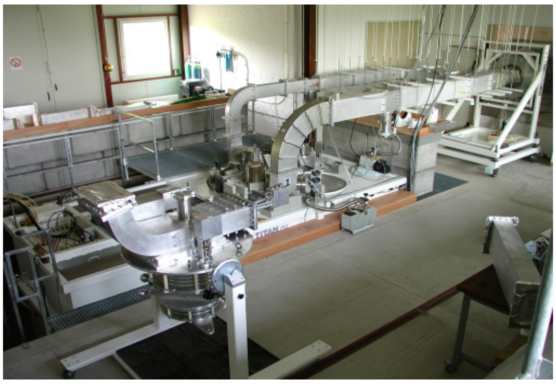

Figure 2: View of the 2002 HPM system (before augmentation)

Figure 3: Control room with control units and data acquisition system

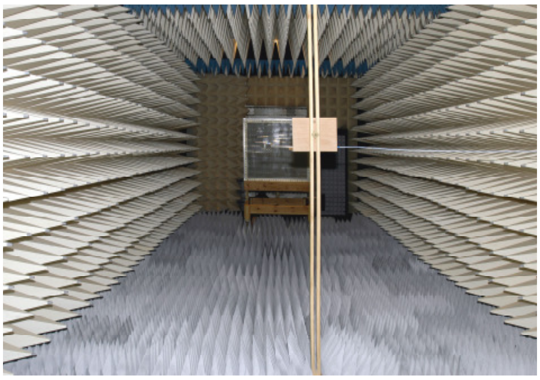

Figure 4: Anechoic chamber, matched Horn antenna (0.675 GHZ - 1.0 GHz)

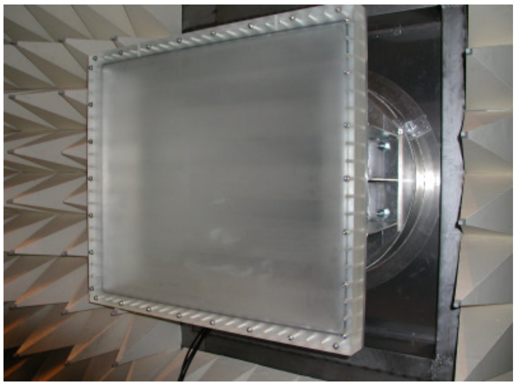

Figure 5: Matched Horn antenna with vacuum window (1.0 GHZ - 1.5 GHz)

So far, at three different distances from the antennas (4 m, 9 m, and 15 m) the electric field distributions have been completely measured for the respective planes (or cross sections) illuminated. For both waveguide- and antenna- systems field mapping data are stored with reference to the corresponding microwave power supplied to the respective antenna in use (see Equation 1). Therefore, simultaneously, electric free-field levels can be derived from the active RELTRON output power measured (by using directional couplers inside the waveguides) during real HPM tests, even in the presence of the device under test (DUT).

$$(1) \qquad \mathrm{Erel(P)}_{\mathrm{dB}} = 20 \cdot \lg\left(\frac{E}{1\,\mathrm{V/m}}\right) - 10 \cdot \lg\left(\frac{P}{1\mathrm{W}}\right) = 20 \cdot \lg\left(\frac{\frac{E}{1\,\mathrm{V/m}}}{\sqrt{\frac{P}{1\mathrm{W}}}}\right)$$

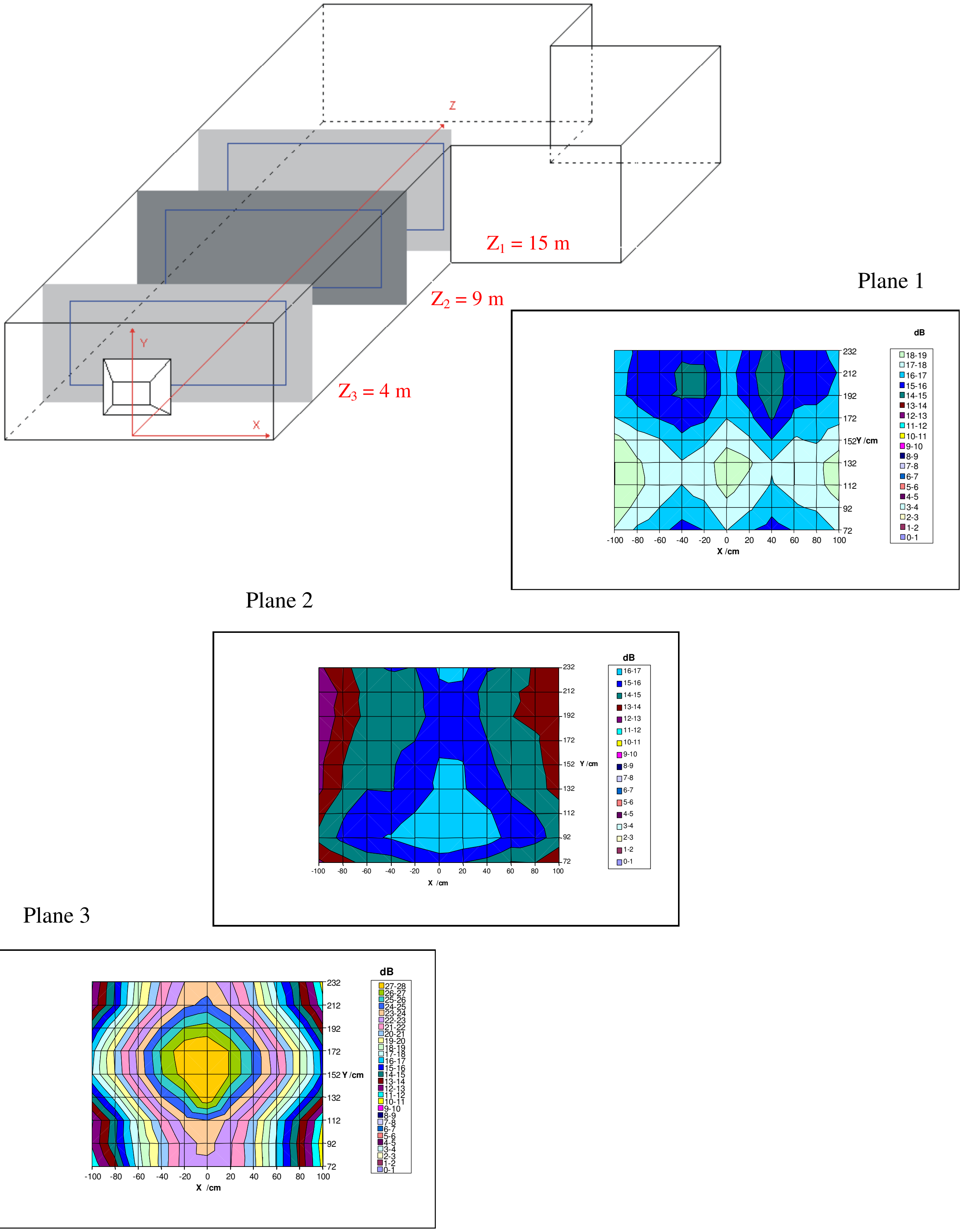

Figure 6: Introduced illumination planes and corresponding electric field distributions (e.g. at 700 MHz)

3.0 NEW SPECIFICATIONS FOR THE AUGMENTATION

The specifications for the HPM simulator previously had been defined for free space conditions. Lessons learned from both the development and the usage of the system led to a new set of specifications. Those new specifications have been considered to match WIS´s needs best with the performance the manufacturer [2] could guaranty, especially for the new RELTRON tubes to be developed.

Since the RELTRON cathode surfaces become smaller with increasing frequencies, cathodes´ current densities had to be limited by reducing the respective beam currents. Consequently, electric field strengths – as they had to be guaranteed at the 15 m distance – are now specified slightly lower for the augmented frequencies. To limit the cathode current densities a shunt (1200 Ohm) had to be added. With this liquid installed resistor (see Figure 7) about 60 % of the Marx current is delivered to any new RELTRON tube in use. A pump and heating/cooling system keeps the fluid at 20° C, constantly.

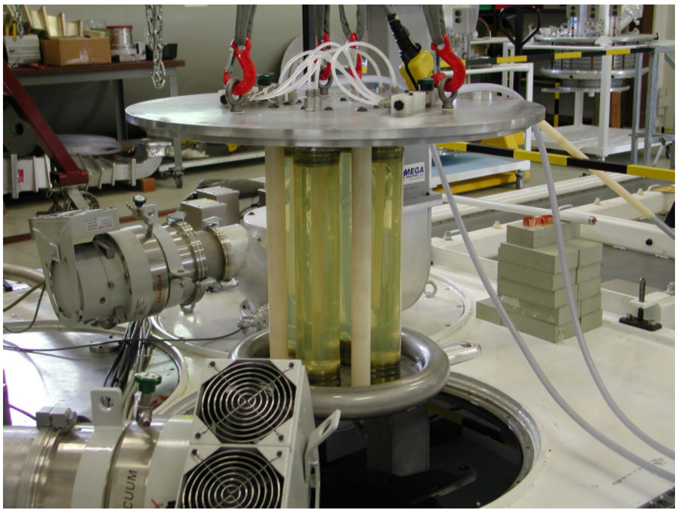

Figure 7: 1200 Ω shunt resistor (liquid: Sodium Thiosulphate)

The maximum repetition frequency also was specified differently compared to the 2002 system. Initially, the same material the “old” tube’s cathodes are made of (velvet or rayon) was considered to be used for the new tubes, too. To prevent grids and cathodes from early wear or damage during long bursts (especially for a maximum of output power), the new microwave tubes´ capabilities of running repetitively therefore was agreed to be 5 Hz, at least. On the other hand, for achieving higher repetition rates in the long run anyhow, additional research on new, less plasma producing cathode materials was done in parallel.

As far as the microwaves propagation is concerned, the focusing of the radiated HPM beam had to be increased to comply better with the very narrow shape of the anechoic chamber at WIS. To a considerable degree, a smaller beam width should reduce inherent [2] interferences (see Figure 6) occurring with

[2] L3-Communications Pulse Sciences (former TITAN PSD)

increasing distance from the antenna(s). Therefore, the size of the illumination area - within electric fields should not vary by more than 3 dB – was specified to be smaller than as it had been for the 2002 system.

For comparison, Table 2 contains both the main new requirements and the system's current (or previous) main characteristics and features, respectively.

Table 2: Characteristics of the HPM Simulator

	2002 SUP.R.A	2007 Upgrade
RF-Sources	**4 RELTRON Tubes**	**another 4 RELTRON Tubes**
Cathode Material	**Velvet, Rayon**	**Glass Fibers**
Frequency Coverage	**0.675 GHz – 1.44 GHz**	**1.4 GHz – 3 GHz**
Pulse Duration	**> 300 ns (and > 300 cycles)**	**> 300 ns**
E_{peak} @ 15 m (minimum)	**70 kV/m**	**45 kV/m (1.4 – 2.2 GHz) 30 kV/m (2.2 – 3.0 GHz)**
RF Peak Power	**400 MW – 200 MW**	**100 – 25 MW**
max. Pulse Repetition Frequency	**10 Hz**	**5 Hz (10 Hz goal)**
max. Shots / Burst	**100 (at 50% reduced power) 25 (at full power)**	**100**
3 dB - Illumination Area	**4 m x 3 x m (when vertically polarized)**	**3 m x 3 m (1.4 – 2.2 GHz) 2.5 m x 2.5 m (2.2 – 3.0 GHz)**
Horn Antenna Aperture (Diameter)	**1.6 m (Horn 1) 1.2 m (Horn 2)**	**1.0 m (Horn 5), 0.8m (Horn 6) 0.6 m (Horn 7), 0.55m (Horn 8)**
Far Field Distance[3] (for Center Frequency)	**14 m (Horn 1) 12 m (Horn 2)**	**11 m (Horn 5), 9 m (Horn 6) 7 m (Horn 7), 6 m (Horn 8)**

[3] Minimum distance R is calculated by **$R=2D^2/\lambda$**

4.0 PERFORMANCE OF THE AUGMENTED (2005) SUP.R.A

Besides the formal specifications, during the development it always had been goal to exceed the specified peak power and the resulting field strength, and the repetition rate, especially.

In fact, at WIS recently performed tests have proved that tube 5 in conjunction with the appropriate antenna (see Figures 8 and 9) actually is good for frequencies up to 1.9 GHz, and that it exceeds the field strength requirements by at least 25% within its specified bandwidth (1.4 – 1.8 GHz). Furthermore, now furnished with novel cathode material (glass fibres) tube 5 is capable of reliably running at a 10 Hz repetition rate for a 100-shot burst. For a test frequency of 1.44 GHz, a 30-shot burst is illustrated in Figure 10. The modulated beam current of tube 5 is represented by the green trace, the RF output measured inside the waveguide by the purple red, and the electric field measured inside the chamber by the olive brown trace. In Figure 11 a single shot is depicted.

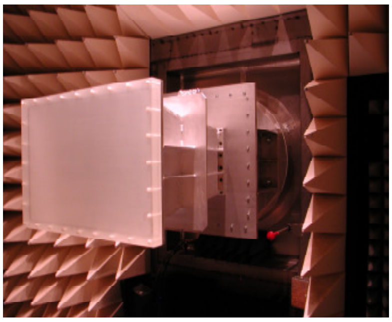

Figure 8: Matched horn antenna

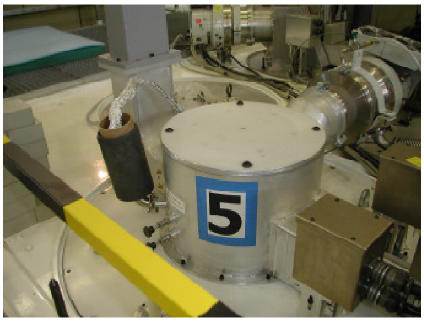

Figure 9: Tube 5 with vacuum pump attached

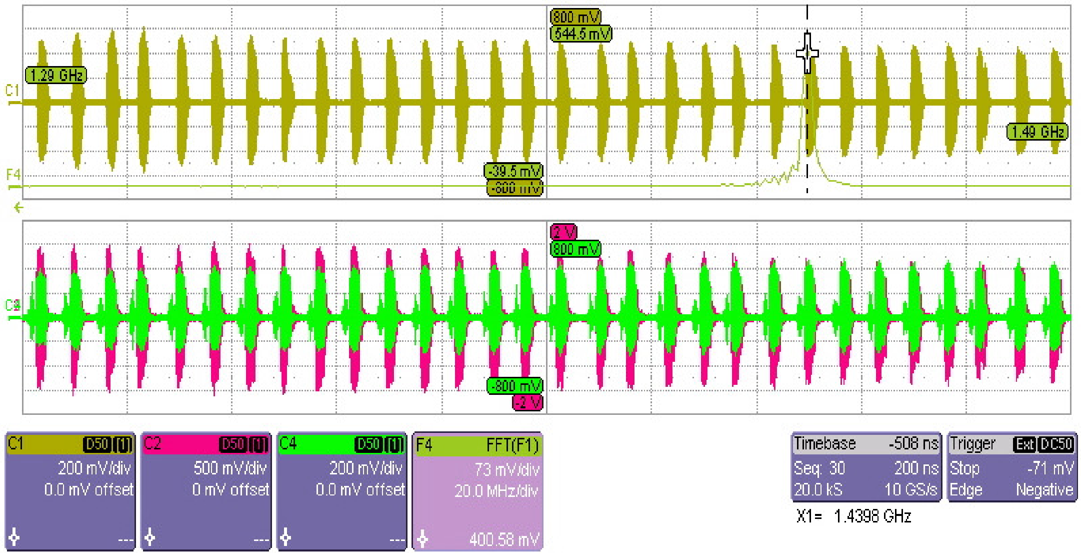

Figure 10: 30-shot burst at 10 Hz repetition rate

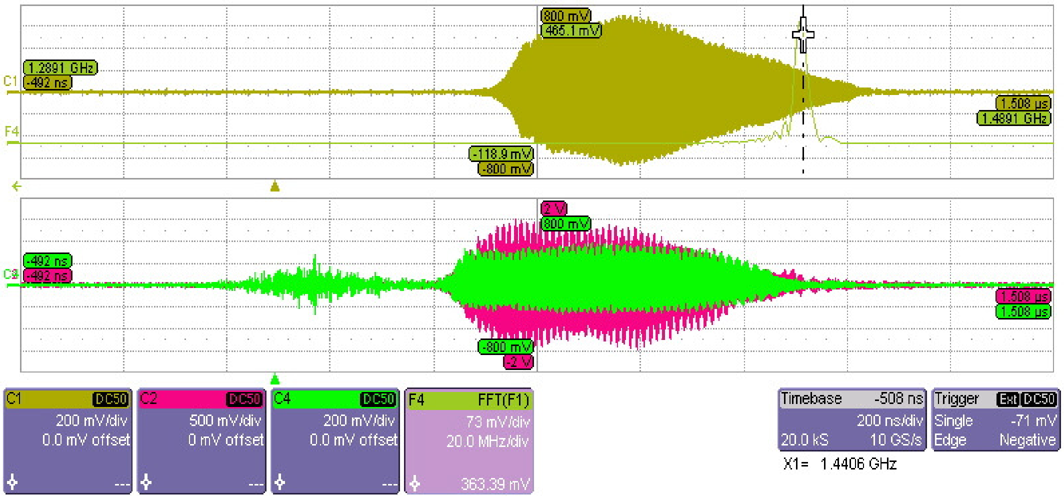

Figure 11: Single shot burst (1.44 GHz)

Scaled both to RF output power and to the corresponding electric field (for tube 5 only) measured in the centre of the 15 m location, the measurements conducted at WIS as well as data so far gathered in the US only is diagrammed in Figure 12.

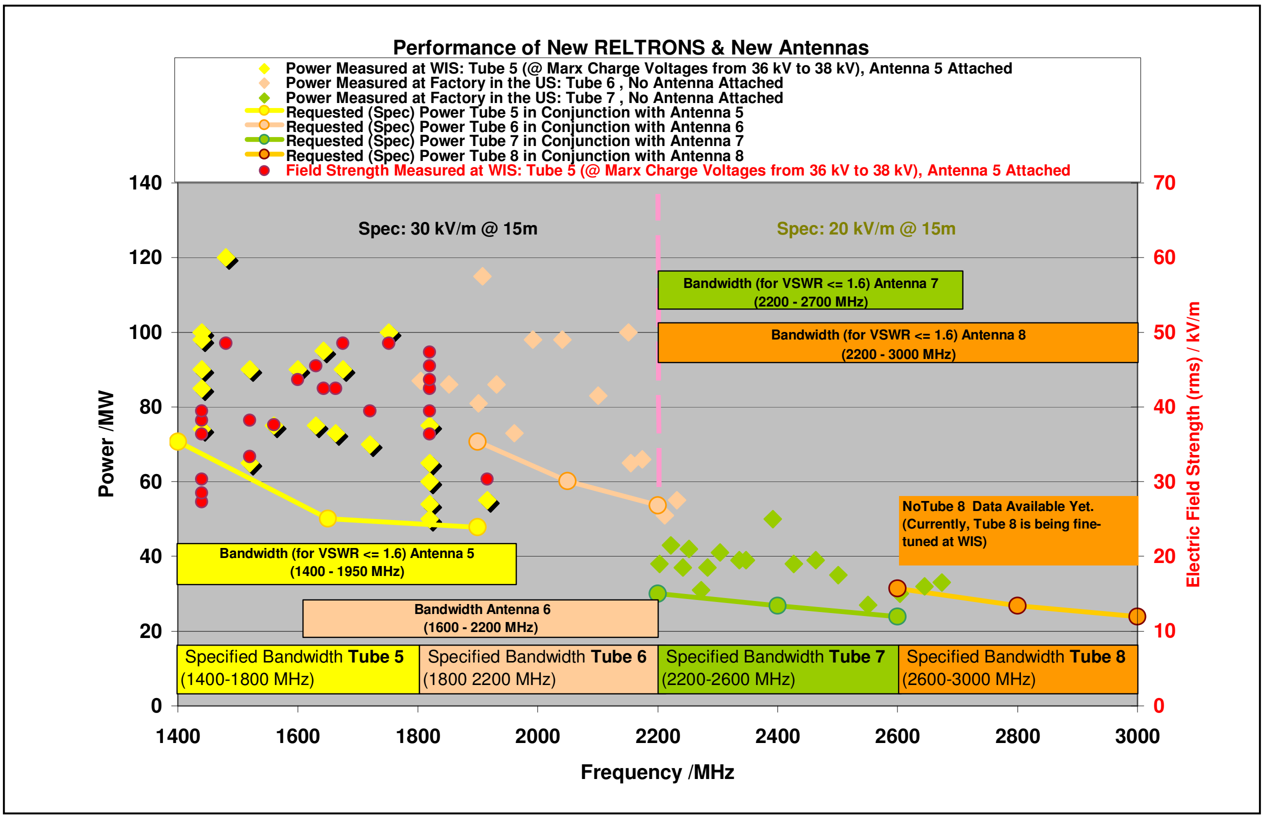

Figure 12: Power measured inside waveguide and corresponding electric fields @ 15 m

The gain of antenna 5 - calculated from the electric field measurements and the RF output power - is shown in Figure 13. For comparison, in both figures the respective requirements have been put, too.

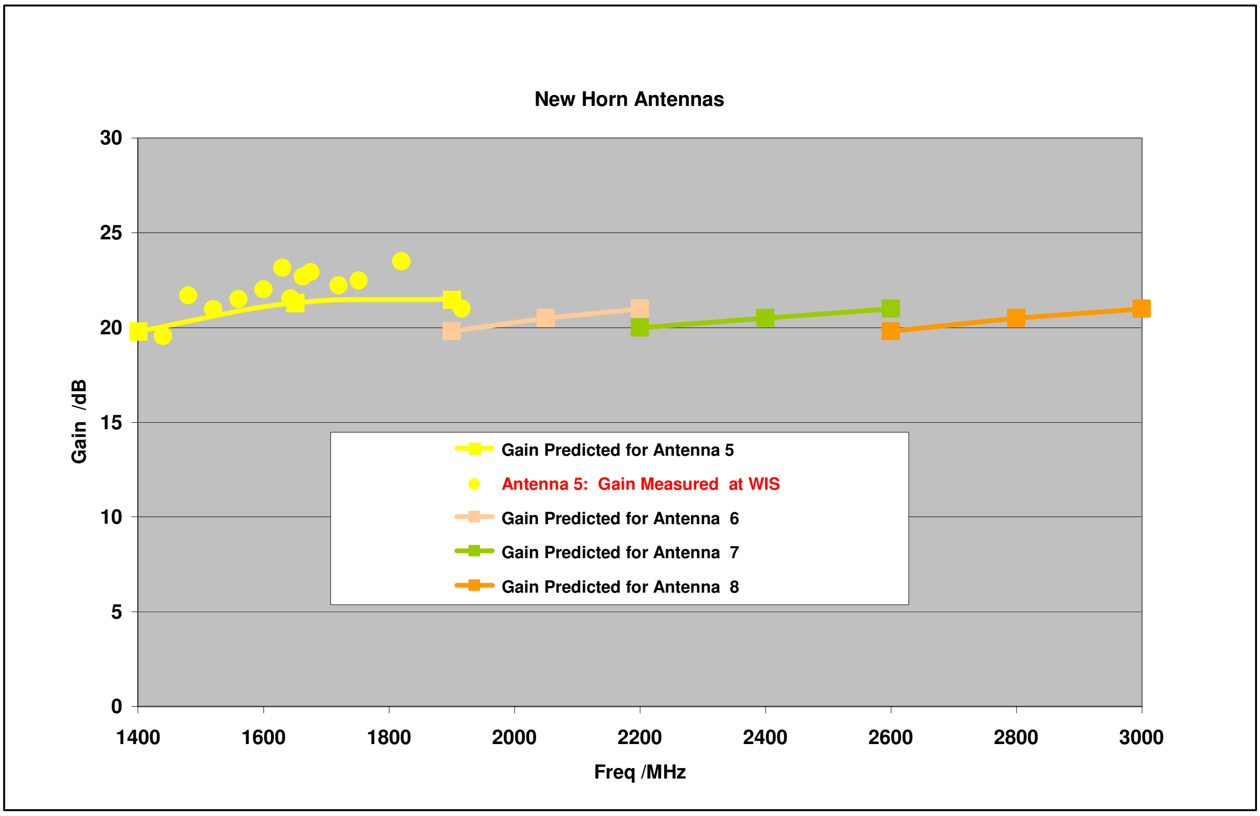

Figure 13: Antenna gains predicted (gain for horn antenna 5 vs. at WIS measured gain)

At WIS measured data confirms that RELTRON 5 - in conjunction with antenna 5 - meets and exceeds all the requirements both for field strength and RF output power. Also, tube 5 provides approximately 25% more bandwidth than initially specified (500 MHz instead of 400 MHz). The measurements (in the presence of WIS personnel) done in the US also indicate that tubes 6 and 7 will probably pass the tests when performed at WIS. So far, no data is available on tube 8. Both the new antennas and the antennas delivered in 2002 are designed[4] for best mode purity. Since antenna 5 could be proved to have the pre-calculated gain, and since the gain calculations include the effects of any vacuum-window mismatch, this can be anticipated for the yet to be tested antennas, too.

[4] Calabazaz Creek Research, Inc.

5.0 SUMMARY

The High-Power Microwaves (HPM) simulator (SUP.R.A) of the Armed Forces Scientific Institute for Protection Technologies – NBC-Protection (WIS) in Munster is being augmented for higher frequencies. By the end of this year (2007) the respective Installation will be completed.

Assuming that tube 8 is complying to the specifications also, the overall frequency coverage will extend from 675 MHz to 3.0 GHz with no gaps in coverage.

At far field distance field strengths exceeding 30 kV/m (peak field strength at 15 m distance) will be provided at all test frequencies, both vertically and horizontally polarized.

10 dB waveguide attenuators (2 for each wave guide system) can be inserted if field levels have to be reduced, or minimized.

6.0 REFERENCES

[1] S. Sabath, M. Bäckström, B. Nordström, D. Serafin, A. Kaiser, B.A. Kerr, and D. Nitsch.

Overview of Four European High-Power Microwave Narrow-Band Test Facilities

IEEE Tran. EMC, August 2004, Vol. 36(3)

[2] A. Kaiser, B. Römer, J. Büchling, L. Meyer

Calibration of the Horn Antennas of the HPM-Simulator at WIS

Internal Report, July 2005 (in German Language only)