Design, construction and validation of a mobile test facility for high intensity radiated fields

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Abstract: The testing of platforms and equipments in their operational conditions and the understanding of their behaviour when they are exposed to high intensity radiated fields requires availability of highly versatile facilities. This presentation will focus on the design, integration and first operations of such a new facility devoted to generate fields and waveforms representing what could be experienced by platforms flying in front of modern radars.

Keywords: HIRF testing – HERO testing – Radar waveforms – Beam agility.

1. Introduction

Qualification of aircraft and their equipments requires verifying their compliance with various standards. For military vehicles and platforms, DGA is responsible in France for such trials, and its technical center CTSN in Toulon is in charge of testing the behaviour of electro explosive devices (EED) and related electronics. The stability of such devices under exposure to HIRF (high intensity radiated fields) corresponding to scenarios in which the platform flies nearby radar transmitters is a key aspect of personnel safety and material reliability. Related studies and measurements are known as HERO (Hazards of Electromagnetic Radiation to Ordnance).

CTSN operates a first "Modulateur d'Impulsions Radar" (MIR) since 1980's. Magnetron transmitters allow to deliver radar waveforms in various frequency bands with typical parameters:

- Pulse duration: 1 µs
- Pulse repetition frequency: 1000 Hz
- Duty factor: 1/1000

Horn antennas are connected to the transmitters through flexible waveguides, allowing the target to be illuminated at very short distances. Operators protected by radiation-proof clothes have to handle the horns. Such equipment is able to create mean electric fields of the order of 200 – 1200 V/m and peak values of 6 – 36 kV/m at 1 m in front of the horns.

To cope with the more recent radar threats to be considered, the new facility MIR2 was specified and commissioned in 2000, the major improvements with respect to the previous one being:

- The capability to reproduce pulse compression waveforms with long pulses and high duty factors, resulting in much higher mean fields
- The capability to scan mechanically the radiated beam across the target.

The team built by the aerospace research center ONERA with two SMIs was awarded the design and integration contract. One of the industrial partners, SCLE, was skilled in the delivery of instrumented shelters, and the other, CIRTEM, in the setting up of microwave power tubes corresponding to transmitters of modern radars. ONERA was in charge of coordinating the design and construction phases, and to study and procure, among others, critical elements like the antennas and microwave links from the power amplifiers.

2. Transmitter technology and reliability issues

The waveforms to generate could only come from high power wide instantaneous bandwidth amplifier tubes like travelling wave tubes (TWTs) and klystrons.

The following 4 tubes were selected according to their main characteristics:

- L band TWT amplifier, 170 kWp, duty factor 5%, HV power supply: 33 kW at 43 kV.
- S band klystron amplifier, 1,3 MWp, duty factor 0,5%, cathode modulator peak power : 5,9 MWp at 90 kV.
- C band TWT amplifier, 70 kWp, duty 2%, HV power supply: 11 kW at 40 kV.
- X band klystron amplifier, 100 kWp, duty 6%, HV power supply: 17 kW at 38 kV.

The high integration level of these four amplifiers required new designs from latest high voltage technology:

- Using of only one high voltage power supply for the four bands, with an automatic commutation to the band into service.
- New design of current absorption collector power supplies.

The high voltage power supply is composed of a full bridge IGBT high frequency converter working between 50 and 100 kHz, and a high voltage transformer with a ferrite magnetic circuit and a multi-stage secondary.
Series and parallel switches for grid or cathode modulators are built with matrix structures of MOS-FETs.

Identical structures compose the protection crowbar.

Safety circuits were designed according to the analysis of the various potential failures. The high voltage storage capacitors are discharged by the crowbar circuit in less then 5 µs.

The crowbar is triggered by any of the following faults, reported from specific detectors:

- Maximum body tube current exceeding threshold.
- Waveguide breakdown.
- Power supplies regulations loop error.
- Maximum ion pump current exceeding threshold.
- Focalisator power supply fault.
- Input RF overdrive.
- Reflected microwave power level exceeding threshold.

The various thresholds are automatically switched to the safe values according to the frequency band in use.

An illustration of the power tube and waveguide assembly is given below.

Figure 1: L and C frame

The protection of the power tubes from any accidental or operation induced mismatch (i.e. a target reflecting most of the received power back to the antenna) resulted from a combination of various waveguide devices:

- a breakdown detector with a photodetector looking at the EM window of the tube;
- a ferrite 3- or 4-ports circulator;
- a bi-directional coupler at the connection of the waveguide line inside the shelter with the outside line towards the antennas.

Dry air has to be blown in the waveguides for avoiding water condensation and potential breakdown; a mylar film was therefore sealed at the aperture of the radiating horns, with a controlled air leakage to provide continuous air flow.

3. Beam scanning and control

Various antenna options were considered for meeting the specification of a focused beam (-3dB beam width of 10 wavelengths 15 m in front of the shelter) to be scanned across a target within a scene 8 m wide by 4 meter high.

A 2-axis rotating parabola was first considered, but not selected due to the cost and limited reliability of rotary joints; in addition, replacing the primary feed and waveguides at each change of frequency band would have been tedious.

The preferred solution combines steady horns illuminating a translatable parabola. At the penalty of a slightly larger reflector, this solved completely the waveguide feed issues. For cost reduction, the offset parabola of a Ku band Satcom mobile ground station was purchased, with diameter 2.80 m, and primary horns were designed to optimise illumination of the parabola and limit beam distortion at extreme scan. The horn phase centres were positioned behind the focal plane of the parabola in order to achieve a better beam focussing at 15 m.

The problem of an efficient man-machine interface for positioning the beam on the target during operations requested also innovative solutions. The image of the target taken by a video camera is transferred to a desktop computer and displayed together with a computed representation of the beam. The beam position can be derived from the position of the parabola –its motors being controlled through a joystick by the operator and position known from optical coders- taking mostly into account following effects:

- focussing properties of the parabola illuminated by the primary feed, including aberration effects;
- magnification and aberration of the lens of the video camera;
- parallax effects, the camera and parabola axis being different for obvious reasons.

These effects combined with residual uncertainties in the position and orientation of the parabola with respect to the other steady reference objects (horns, camera) made it difficult to predict perfectly the transformation formulas between the displayed image and the real beam position on the target.

The alternative solution we chose was a careful global calibration, for which we erected a metallic frame having the 8 m by 4 m dimensions at a 15 m distance, parallel to the shelter. We prepared 24 points equally spaced in this reference plane for positioning a field probe.

At each position of the probe, seen on the video display as pixel (X, Y), the parabola was moved until a maximum radiated field was detected by the probe meaning the beam was centred on it, and the corresponding (x, y) parameters coding the parabola position were recorded.

Assuming a generic polynomial formula X(x,y) and Y(x,y) for the 24 positions of the probe allowed to derive the various coefficients of the polynomials. First order would read $X = ax + b$, $Y = cy + d$ meaning that a translation of the parabola would create a proportional translation of the beam across the scene, the displayed image being itself linearly linked to the positions in the scene. The various effects mentioned above made of course a more complex reality, and 3rd order polynomials proved useful. The full calibration process had to be repeated for each of the 4 frequency bands, since the horn positions and focussing properties were different.

Figure 2: Beam control display

The calibration frame and field probe could then be used to compare real beam and predicted positions, and the rms error through such method was found of the order of 5 cm.

Figure 2 is a picture of the beam control display taken during test operations with a fighter aircraft as target. The cross wire on the tail of the aircraft is the predicted position of the beam centre, the circle indicates the estimated -3dB beam width at C band.

4. Integration and mobility issues

The equipments described above were integrated in a 25 feet wheeled shelter with EMC shielding. Another wheeled shelter is used for storage of various spares, accessories and external parts like the parabolic reflector (which can be split in 2 parts), its motors and the horn feeds when shipping the facility.

The RF signal generation comes from a microwave synthesiser with external pulse modulation, switched to the selected one out of 4 preamplifiers according to the frequency band. One cabinet contains this hardware.

Each power tube is housed in a specific frame, with its high voltage supply and modulator close-by. A cabinet houses the generation of the various command signals and processes the different controls to and from the RF cabinet and the high voltage supplies.

Waveguide routing between the power tubes and a common interface plate to the external antenna feeds had to be optimised in order to reduce losses at X and C band, and to limit volume at S and L band. The insertion of the waveguide couplers and circulators made it more difficult.

Important ancillary functions integrated also in the main shelter are:

- water de-ionizing, cooling and distribution to power tubes, circulators, X-band waveguides and some of the high voltage cabinets
- air drying for the waveguides
- air-conditioning

For safety of operations, a surveillance camera is provided for operators inside the shelter to inspect the safety limits around the antenna and target zone. Indication is also made available by sound and flashing lights when the facility is emitting.

Figure 3: The MIR2 mobile test facility with L band feed during integration at CTSN proving range

5. Conclusions

After some months of operations, the MIR2 facility has demonstrated its capacity to fulfil the requirements and improve from what was previously available with respect mostly to:

- Accurate control of the transmitted power
- Wide agility of all parameters of the waveform
- Direct display of the transmitted waveform, control of reflected waves
- Easy-to-use command and control of the beam position on the target.

The trials made recently on a fighter aircraft allow a better understanding of the coupling mechanisms, identification of the critical parameters, and therefore a reduction (up to a factor 3) of operational constraints such as safety distance between the platform and a given radar transmitter.

Further improvements are likely to be added to the MIR2 facility in the near future, like longer pulses for higher energy density on target, or wider instantaneous bandwidth for better *analysing* the effects.