Development of the HEMP Propagation Analysis and Optimal Shelter Design, Simulation Tool "KTI HEMP CORD"

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Abstract

*High Altitudes Electro-Magnetic Pulse (HEMP) caused by nuclear bomb explosion had been tested during last 1960-1975 by the USA, Russia and other countries. But all of related simulation tools and documents are strongly classified and impossible to use it even, thus IEC and ITU had published the related standards and recommended its protection against HEMP and HPEM. Also, Middle East countries and Far East countries including South Korea are directly vulnerable against HEMP threat. Now we, KTI had developed the HEMP simulation and optimal shelter design tool named by "**KTI HEMP CORD**"*

Keywords: HEMP (EMP): *High Altitudes Electro-Magnetic Pulse, High Power Electro-Magnetic (**HPEM**), Height of Blast (**HOB**), Ground Zero (**GZ**)*

1. Introduction

The HEMP threat [1] may have acquired new, urgent and relevance as the proliferation of nuclear weapons and missile technology accelerates of the North Korea, for example, is assessed as already having developed few atomic weapons, and is on the verge of North Korea already has missiles capable of delivering a nuclear warhead over the South Korea. ITU K.78, K81 and IEC recommended its counter-measuring for the industrial facilities. HEMP test and estimation must only be done by the computer simulation which was studied on the 1960-1990 years USA/AFWL papers. This result has significant activities to the South Korea, Japan and China being under the North Korea nuclear bomb threat because all of HEMP related products was strongly limited for export. This KTI newly developed HEMP cord included the HEMP generation & propagation analysis, optimal shelter design tool, essential EM energy attenuation in multi-layered various soils and rocks with HEMP filter design tool of considering the high frequency equivalent circuits. Specially, these study adapted the least square fitting method for the EM energy attenuation in the soils and rocks because it has a various characteristics so, it based on many times field test reports. This paper were proven with the EXEMP CORD developed at 1992 by K.D. Leuthâuser [2] and other verification test done by ourselves and developed the HEMP filters.

2. General of the developing procedure

2.1 HEMP generation and propagation

This study needs a variety of HEMP test report with theories [2, 3, 4, 5] and papers to understand the HEMP generation, propagation and the coupling mechanism analysis. Specially, we had fallen in difficulties and muddle through the bitters on the unit unification of the mathematical formulas from the atom engineering, physics, aerology, electron mobility, earth magnetic field, vector direction to the Maxwell equations.

HEMP generation and propagation theories were based on the Ref. [2-5] and HEMP wave form adapted DEXP. Simulation and analysis were done by following procedure Figure 1.

2.2 Analysis of the EM energy attenuation in the multilayer soils and rocks

It has a following functions and applied theory;

- Computer simulation of EM energy attenuation in the multilayer soils and rocks.
- Very high accuracy for computer simulation using the statistical least square methods.

Table 1. HEMP analysis procedure

Key applied theories	Main analysis procedure
γ ray average energy and yield amount per kiloton(4 x10[19] ergs)	Gamma yield(kT) & average gamma energy(MeV)
Equation of Motion of Compton electrons, fist and secondary	Time variation of the first electrons number at time t, distance r
Gama ray mean path and energy	Secondary electron rate calculation by Karzas-Latter theory
Larmor frequency, small angle approximation.	Compton current and conductivities
Particle densities of atmosphere	Coordinate system in the static earth field
Current and conductivity of atmosphere	Spherical earth surface and atmosphere
Vector unit and space analysis	High frequency approximation of Maxwell equation
Static magnetic field of geomagnetic latitude	Dipole approximation and vector cross product of the Earth magnetic field
Jefimenko's equations Maxwell equation Field strength mapping on the map.	Field calculation at the observing point Field strength mapping

2.3 HEMP Shelter Design Tool

This simulation tool can calculate the effective shield effectiveness based on the following algorithms;

- Shielding effectiveness calculation without slots and holes for the welding type shielding cavity using pure material constants
- Shielding effectiveness calculation with gap for the PAN and panel type shielding cavity.
- Shielding effectiveness calculation with various waveguides and pin holes on the shielding wall considering the filter attenuation characteristics.
- Considering the shielding cavity resonant.

2.4 HEMP filter design tool

Basically, we adapted the normal low pass filter design concepts even, thus it has specialties to consider a contact resistance, stray capacitance, stray inductance and the conductivity of inductor of a high frequency equivalent circuit.

3. Related Theories

3.1. Brief theory of the E_1 generation, smile diagram.

According to the Karzas-Latter-Longmire theory and K.D. Leuthâuser, gamma (γ) ray be assumed to be produced at approximately an exponentially increasing rate after the course of the nuclear explosion.

When a gamma ray of energy E_γ emitted by nuclear burst interacts with an electron of the air molecules in a Compton collision, Compton recoil electrons is created at an angle Θ with respect to the direction of the incident gamma ray. So we called the E_1 field for the first electrons creation, E_2 field created by the gamma ray n^{th} scattering collision and E_3 field created by the geomagnetic field stabilization which was disturbed by E_1 and E_2. If $l = 0$ is the time at which the explosion starts, then the number of gamma rays produced up to time l which is given by $e^{\alpha l}$, where α called by a shake is about 10^{-8} sec . If gamma ray reaches to maximum, it decreases to zero exponentially as a slower rate than starting built up, $\sigma\beta e^{-\beta(t-T)+\alpha T}$ on condition($\alpha \gg \beta, \sigma \lesssim 1$). HEMP pulse waveform was defined on the IEC 61000-2-13 and MIL STD 188-125.

Gamma rays have an average energy of about 1Mev, and there are 7.5×10^{21} gamma rays produced per kiloton (4×10^{19}ergs) of yield.

$$(1+\sigma)e^{\alpha T} = 7.5 \times 10^{21}\, Y \tag{1}$$

Here, Y= Total yield of the explosion in the form of gamma rays expressed in kTon, E is the mean gamma rays and $f(t)$ is a expression the time variation of the gamma rays.

According to the Ref. [4], the number of gamma rays emitted by a nuclear explosion per unite time is

$$\dot{N}(t) = \frac{Y}{E} \cdot f(t) \tag{2}$$

If we normalized expression of the $f(t)$

$$\int_{-\infty}^{\infty} f(t)dt = 1$$

The rate at which primary Compton recoils electrons are produced at a distance r in direction θ, φ from the explosion is

$$\dot{n}_{pri}(r,t) = g(r) \cdot f(t - \frac{r}{c}) \tag{3}$$

Term of $\tau = t - \frac{r}{c}$ is known as a retarded time and it is related with the electron traveled time since the creation of the Compton electron. Understanding of the retarded time from the source to observer locations described more details on Ref. [6] using the Jefimenko equation [6].

Here, new important function $g(r)$ is a number of gammas which interact to produce Compton electrons,

$$g(r) = \frac{Y}{E} \cdot \frac{exp[-\int_0^r \frac{dr'}{\lambda(r')}]}{4\pi r^2 \lambda(r)} \quad (4)$$

Where, $\lambda(r)$ is the mean free paths of gamma rays to produce Compton electrons, Y has a actual meaning, the gamma yield of the weapon in electron volt (eV), E is the mean gamma energy in eV and $\boldsymbol{c}$ is light velocity.

Equation (4) may also be called the radial distribution function or an attenuation function for interacting gamma rays. The $\frac{Y}{E}$ term is the total number of gamma rays available from the nuclear burst.

$4\pi r^2$ term accounts for the divergence of the gamma rays as the radius $\boldsymbol{r}$ is increased while the remaining term account for the reduction in gammas due to the air absorption in the atmosphere based on the mean free path.

Applying a small angle approximation by the Taylor series expansion; sin $\omega\tau = \omega\tau$, cos $\omega\tau = 1 - \frac{\omega^2\tau^2}{2}$ and high frequency condition, then we could find a simplified equation. Also we could get the electric field strength from the relation between current density and medium conductivity of the air density in the height of the atmospheres. Our basic model of the analysis underlying on the Karzas-Latter-Longmire theory and K.D. Leuthâuser's EXEMP. There are many limitations to describe on these papers for all of them, so refer to the references for the more detailed theories. Finally, we calculate the electric field strength at the observer location as a following procedure in order to find out the field distribution on the earth without HEMP test.

1) Generation of the Compton recoil electrons and propagation analysis

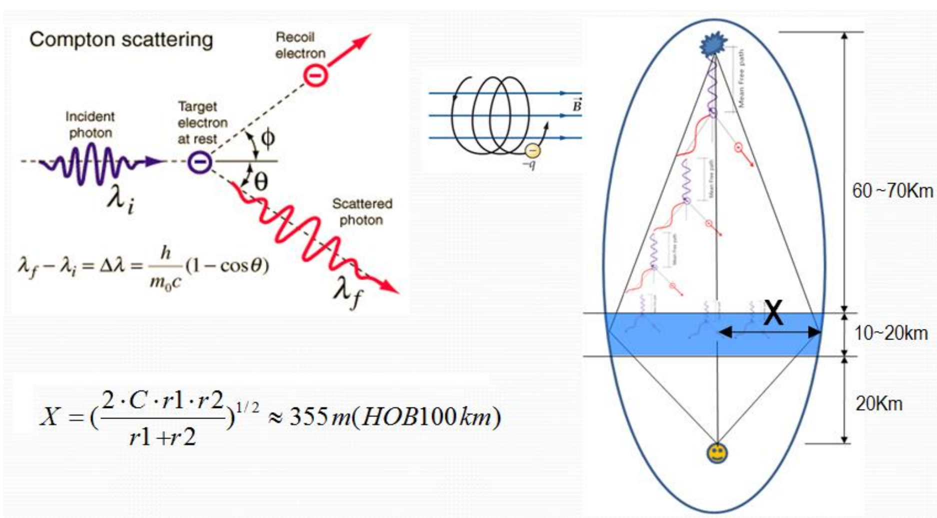


Figure 1. Gamma rays scattering and the elliptic analysis of the source range

2) Coordinate system change from the spherical coordinates to rectangular of the earth surface and atmosphere

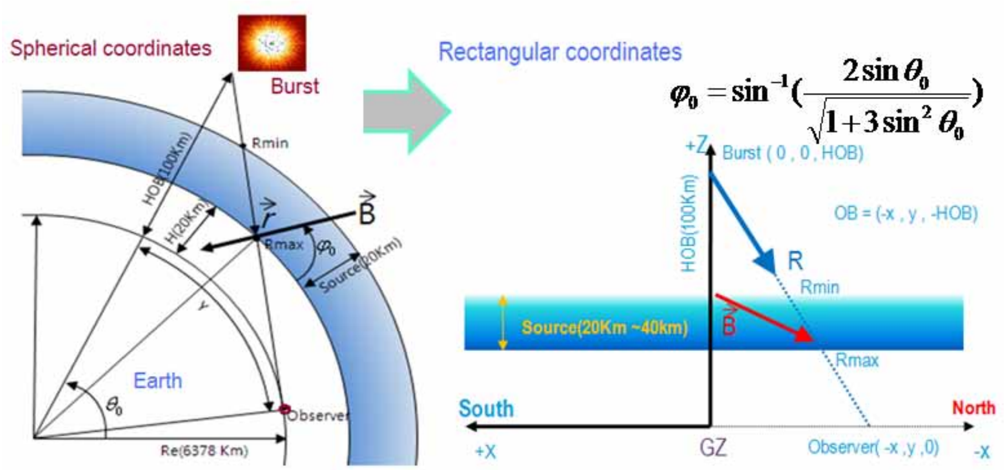


Figure 2. Coordinate system conversion and Earth magnetic field calculation at some location

3) Survival probability of the one gamma ray and electrons distributions depend on the height from the sea level.

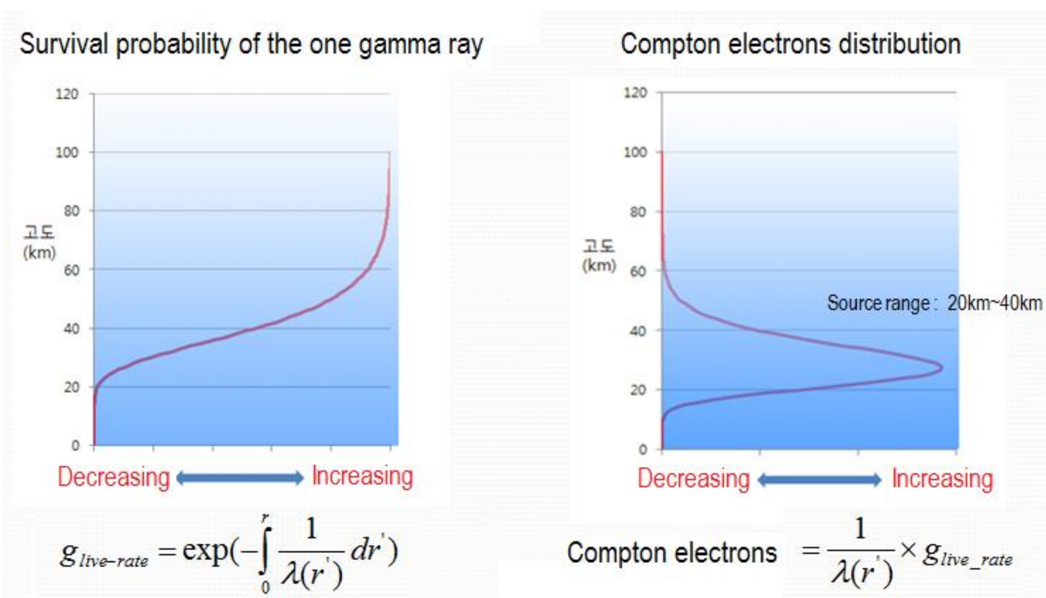


Figure 3. Variation of the gamma ray and Compton electrons depend on the height

4) Wave polarization

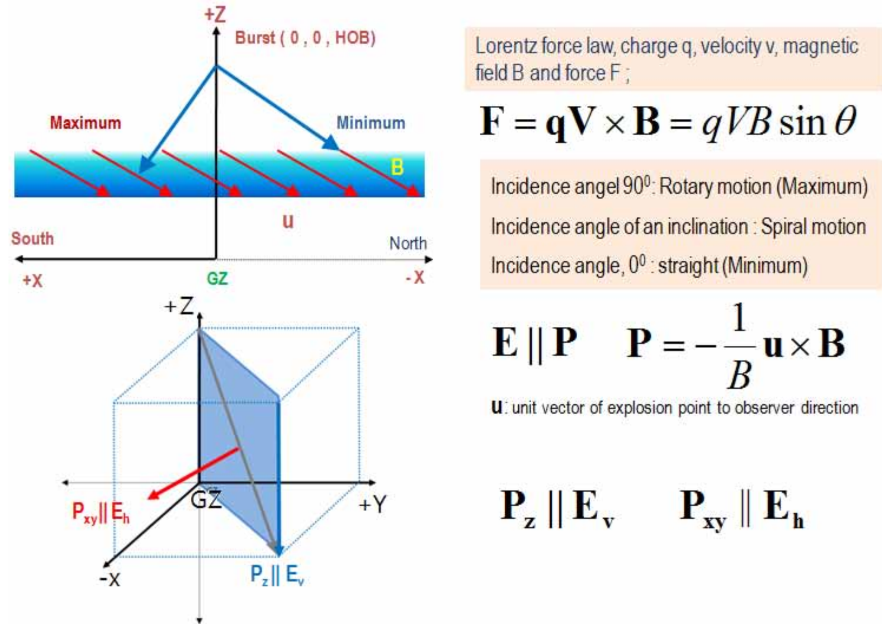


Figure 4. Wave polarization and unit vector

5) Contour plot of the electromagnetic magnitudes

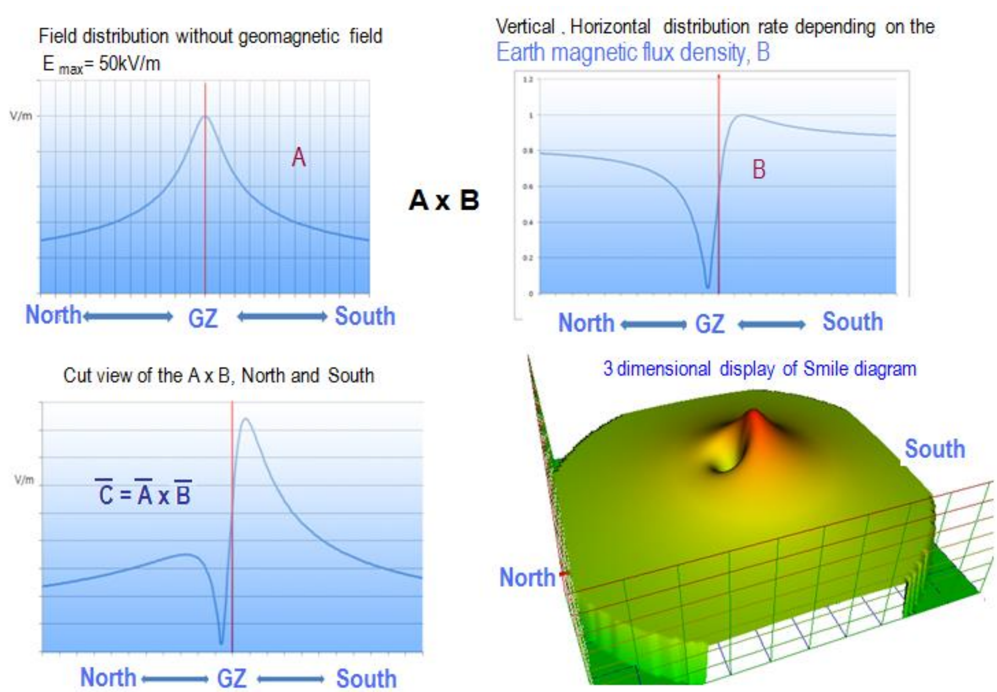


Figure 5. The electromagnetic field distribution on the earth

3.2. Brief analysis algorism of the EM energy attenuation into the soils and rocks.

We need to simulate the natural attenuation in the multi-layered soils and rocks when HEMP shelter is installed in the underground tunnel. In this case, finding the ideal material constants of the soils and rock are very important to decrease the uncertainty because these materials have a various characteristics. So this tool optimized its effectiveness using a least square method from the much field test result of the electromagnetic power attenuation in soils and rocks [7, 8].

3.3. Shielding effectiveness estimations of the HEMP shelter and HEMP filter design tool [9]

Shielding effectiveness could be calculated if material constants was given as the well known theory [9, 10] but theoretically calculated result has not corresponded to the shielding effectiveness test on the site. So, this study proposed the ideal estimated solutions for the HEMP shelter design and construction by way of adapting a effective permeability, conductivity and a number of wave guides. Shielding effectiveness written in the text will be corresponding to the test result on the site for the perfectly welded shielding enclosure. But for the panel and PAN type shielding enclosure, it was constructed with gaps by panels or PAN jointing using the conducted gasket. Therefore, all of the jointing type shielding enclosure has discontinuities which is main reason to reduce the effective permeability and conductivity in the few MHz band. This study fully considered the effective permeability and conductivity to the simulation tool. Higher than about 100MHz, this tool handling the hardening shelter as a cavity with slot which consist of honeycomb, various wave guides.

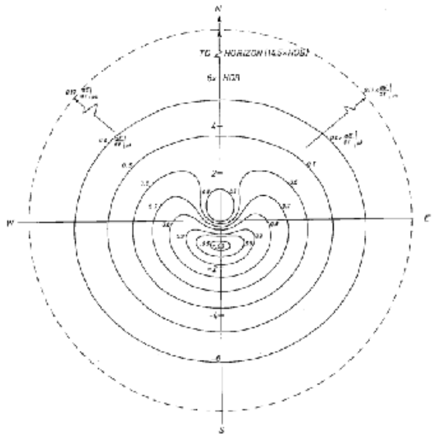
HEMP filter design tool is based on the normal low pass filter design theory but developed the simulation S/W considering the contact resistance, stray capacitance and stray inductance for the LPF passive components.

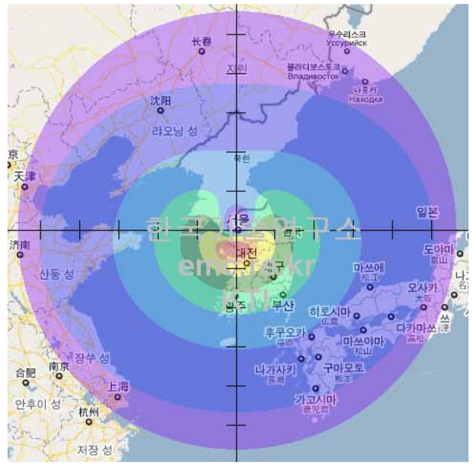
4. Verifications

4.1. HEMP simulation tool

Our simulation results come to have an exact consistency with the EXEMP CORD at the same geometric condition as shown on the Figure 6. Our main goal to develop the electric field distribution, smile diagram is just to know the field strength without actual HEMP test used for the optimal shelter design and provided the enough margins between HEMP field strength and EM sensitive system. Figure 7 is the electric field distribution diagram when burst at *GZ N37.56, E126.97 (Seoul, Gwoang whoa mum)* and *10kt, HOB 75km*.

We could get a field strength 2.60kV/m at Seoul, 48.22kV/m at Whoa sung, 28.82kV/m at Pyongyang, 17.74kV/m at Shanghai in China and 21.20kV/m at Hiroshima in Japan as shown Figure 7. Therefore, we realized that all of main cities in the Far East Asia should be threaten if North Korea carries out the HEMP test on the Korea peninsula. Here, HEMP is defined as nuclear bomb burst in the higher height than minimum 40km.





a) Contour plot of peak E-field, *EXEMP* at geomagnetic latitude $\theta_0 = 50^0$

b) Contour plot of peak E-field, *KTI-cord* at geomagnetic latitude $\theta_0 = 50^0$

Figure 6. Comparison between EXEMP cord and KTI- HEMP cord on same geo-condition

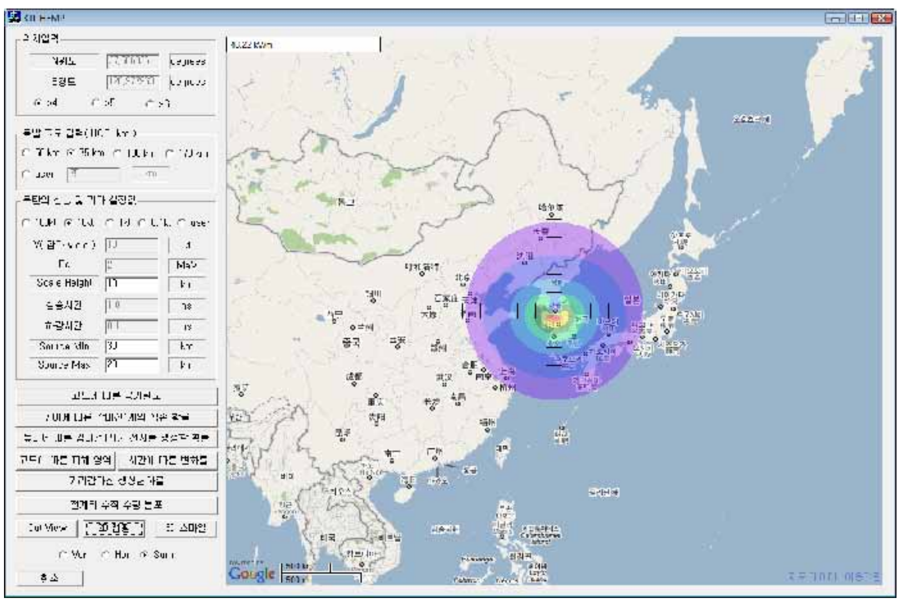


Figure 7. Field strength distribution burst at GZ N37.56, E126.97 and 10kt, HOB 75km

4.2. Estimation of the EM energy attenuation in the multilayer soils and rocks

Figure 8 showed some of simulation examples for the 4 layer soils and rocks.

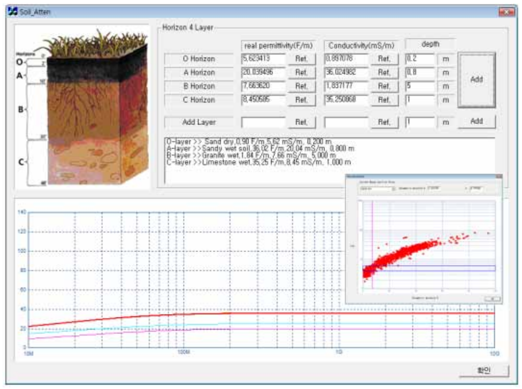


Figure 8. EM attenuation in the multilayer soils and rocks

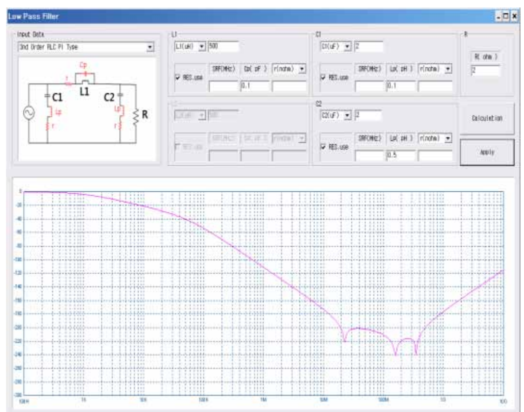


Fig.9. HEMP filter design tool

4.3 HEMP shelter Design Tool [11, 12]

On the view of our experience, the shield effectiveness written in the text is not corresponding to the shielding room site test. It could come to the well corresponding result between the simulation and site SE test when we consider the effective material constants and shelter with slot. Fig.8 is a normal simulation results using our simulation tool and Figure 9 is a shielding effectiveness test results on the site. Point A on the Figure 9 is a cavity resonance frequency.

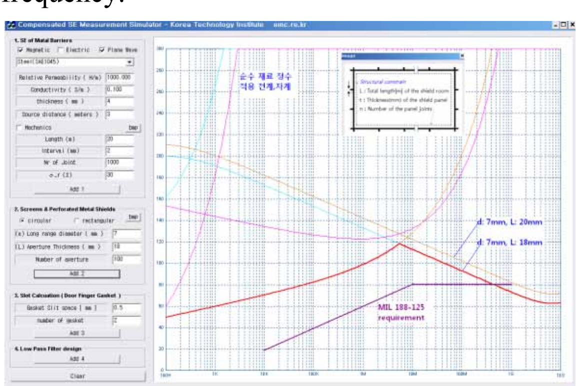


Figure 10. SE simulation result by KTI' S/W   Figure 11. SE test result on the site

4.4 HEMP filter design tool

Figure 9 shows the simulation results when π type filter consist of 500uH inductor with stray capacitance 0.1pF, the feed through capacitor 2 uF with the stray inductance 0.1pH and load resistance is a 2Ω. This tool is very useful to confirm important of the contact resistance, stray capacitance and inductance, load impedance and to choose the optimal LPF components.

5. Conclusion

This tool provided the estimation of the HEMP field distribution on the earth, Analysis of the EM energy attenuation in the multilayer soils and rocks, optimal HEMP hardening shelter and filter design in accordance with the commercial standard ITU, IEC recommendation and MIL STD 188-125. All of the simulation cord and tools related to HEMP are strongly classified by all the countries that already had high altitude test experiences. Also, very few papers are available in the open literature to the 3rd countries.

Now, we are getting in the new nuclear cold threat since North Korea has successed to develop the nuclear bomb and long distant missile over the Far East Asia and Middle East area. So, we are looking forward to using this study result for the improving the nuclear hazards without classified notice in future.

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