Measurements as Enhancement of Numerical Simulation for Challenging Antennas

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***Abstract*— Computational Electromagnetics (CEM) solvers are important engineering tools in the characterization and optimization of antenna placement on large and complex platforms. The accuracy of the source representation has a strong influence on the simulation accuracy of such antenna systems. It is customary to use domain decomposition technique based on the near field description of the local domain in such cases. This allows a separate modelling of the radiating antenna with high level of detail. The source is subsequently used in the numerical simulation of the entire system. Due to the conclusiveness and high data reliability, measured antennas are attractive as accurate antenna model in numerical simulations.**

Inverse source or the equivalent current/source method (EQC) provides an accurate near-field representation of any radiating device in terms of equivalent electric and magnetic currents [1-8]. This technique establish accurate electromagnetic 3D models, maintaining the near-field (NF) and far-field (FF) properties of the measured device. The equivalent model of the measured device is importable in commercial CEM solvers in form of a near-field Huygens Box [1-3].

In this paper, applications of measured sources in complex scenarios are reported using commercial CEM solvers. Both free-standing and flush mounted antennas are investigated. The accuracy of the method is investigated by comparison with measurements and/or full-wave simulation of the full structure.

***Index Terms*— antenna, simulation, measurement.**

I. Introduction

Inverse source or the equivalent current/source method (EQC) as implemented in the commercial tool INSIGHT is as an efficient diagnostics and echo reduction tool in general antenna measurement scenarios [1-8]. EQC processing of measured antenna data originated as a numerical representation of antennas in the analysis of complex environment using CEM solvers [2-3]. The main obstacle for widespread use was the interface of the equivalent current to commercial solvers.

Commercial CEM providers use domain decomposition techniques based on the near field description of the local domain. This development also provides a direct link between INSIGHT processing of measured antenna data and numerical simulation using a Huygens Box surrounding the antenna. This development opens a range of interesting applications, using measurement as sources in commercial numerical simulation tools.

II. Validation Activity

Different applications of free-standing and flush mounted antennas in complex environments have been examined. The goal is to investigate the achievable accuracy of the link between INSIGHT processing [1-8] of measured source antennas and numerical simulation using commercial CEM solvers [9-13]:

- SR40-A reflector antenna fed by a SH4000 horn;
- SMC2200 monocone antenna on a rectangular plate;
- SM6000 monopole on a mock-up of a space plane.

The accuracy of the method is investigated by comparison with measurements and/or full-wave simulation of the full structure. Experiments have been designed to minimize errors, not directly related to the validation of the measurement/ simulation link.

III. SR40-A reflector fed by SH4000 horn @ 8GHz;

The test object is the SR40 reflector antenna fed by a SH4000 dual ridge horn @ 8GHz as shown in Figure 1. The offset parabolic reflector is precision machined from a single block of aluminum. The dual ridge horn is precision fitted to the mounting bracket of the reflector.

In this validation scenario, the SH4000 horn is measured separately and imported as source in numerical simulation of the entire antenna. The simulations are compared with reference measurements of the complete reflector antenna performed in the spherical near field, multi-probe systems, SG64 in Paris as shown in Fig. 2 (left).

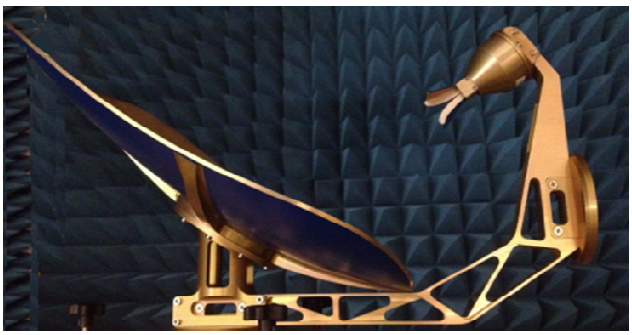

Fig. 1. The reflector antenna used in the validation experiment. SR40 offset reflector and SH4000 dual ridge horn, operating from 4-40 GHz from MVG.

The freestanding SH4000 dual ridge horn has been measured in the spherical near field, multi-probe systems, SL18GHz in MVG Paris as shown in Fig. 2 (right). Equivalent currents, constituting an accurate near field representation of the antenna have been computed by INSIGHT processing on a 90 x 102 x 113mm box fully enclosing the horn.

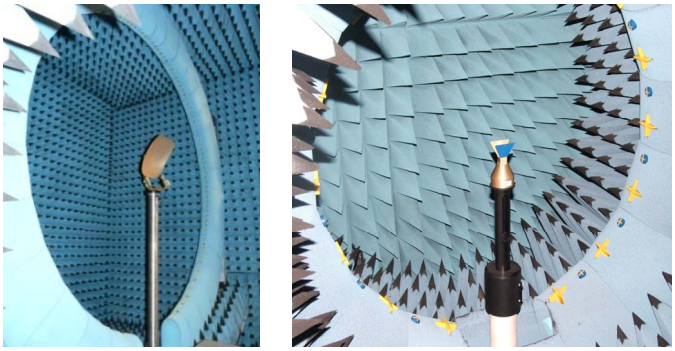

Fig. 2. Reference measurements of the reflector antenna and feed in the MVG SG-64 spherical near field facility in Paris (left). Measurement of the isolated SH4000 dual ridge fed in the MVG SL18 GHz facility. (right).

Following the procedure in Fig. 3 the Huygens Box representation of the measured SH4000 has been determined and imported in different CEM tools [9-12]. The complete reflector antenna has been simulated using a CAD model of the SR40 reflector and the Huygens Box fed. The participating CEM vendors were responsible for generating a suitable mesh, the import of the measured source in the Huygens Box format and controlling the numerical stability of the simulation.

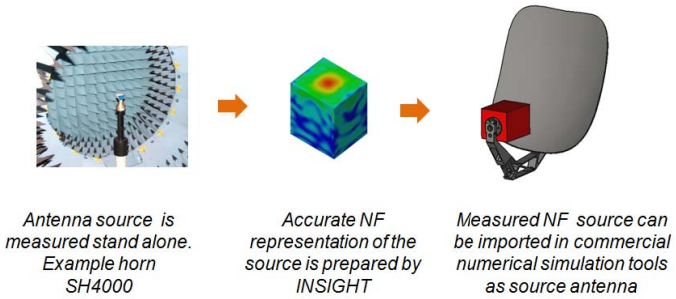

Fig. 3. Use of a measurement of a SH4000 horn as feed in the simulation of a reflector antenna.

The measured and simulated peak directivity values of the SR40 reflector with the SH4000 dual ridge horn @ 8GHz are reported in Table I. MEAS is the measured reference from MVG. The simulated results are from CST, FEKO ADF and HFSS [9-12]. Results from [13] are on-going. The table confirms the very good agreement between measurements and simulations.

TABLE I. PEAK DIRECTIVITY – REFLECTOR ANTENNA @8GHZ

	MEAS	CST	FEKO	HFSS	ADF
Peak Directivity [dBi]	27.42	27.69	27.83	27.51	27.60

The measured reference is compared to the simulated co-polar patterns from simulation using the measured source in Fig. 4. The forward hemisphere pattern has been used in the comparison. The different simulations of the SR40 reflector with the SH4000 dual ridge horn as measured source are in excellent agreement considering differences in numerical method and internal treatment of the imported feed pattern. The agreement between simulation and measurements is very good considering the approximation due to the feed representation and uncertainties arising from measurement, manufacturing and simulation.

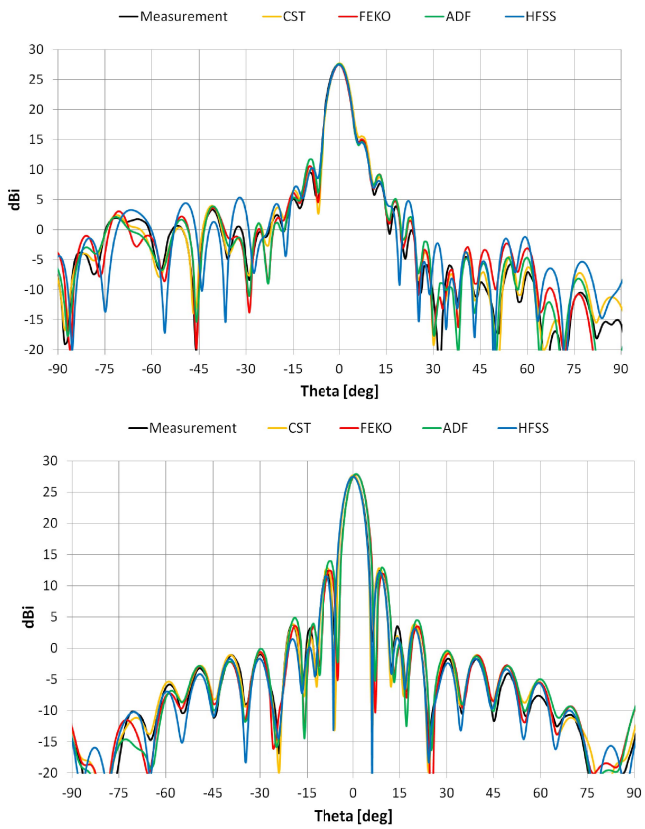

Fig. 4. Directivity pattern of the offset reflector antenna fed by the dual ridge horn at 8 GHz. E plane (top), H plane (bottom). Comparison between measurements and numerical simulation using measured source: CST [9], FEKO [10], HFSS [11] and ADF [12].

The agreement or correlation between simulations and measurements can be evaluated as the weighted difference between measured and simulated field using eqn. 1. The measured far field has been considered as reference field. The weighted difference for each simulation tool is overlaid with the measured, E-plane and H-plane patterns in the forward hemisphere in Fig 5.

$$e_i(\theta,\phi) = \left| \frac{E(\theta,\phi) - \tilde{E}(\theta,\phi)}{E(\theta,\phi)} \right| \cdot \frac{\left|\tilde{E}(\theta,\phi)\right|}{\left|\tilde{E}(\theta,\phi)\right|_{MAX}} \qquad (1)$$

$\tilde{E}(\theta,\phi)$ is simulated pattern, $E(\theta,\phi)$ is reference pattern

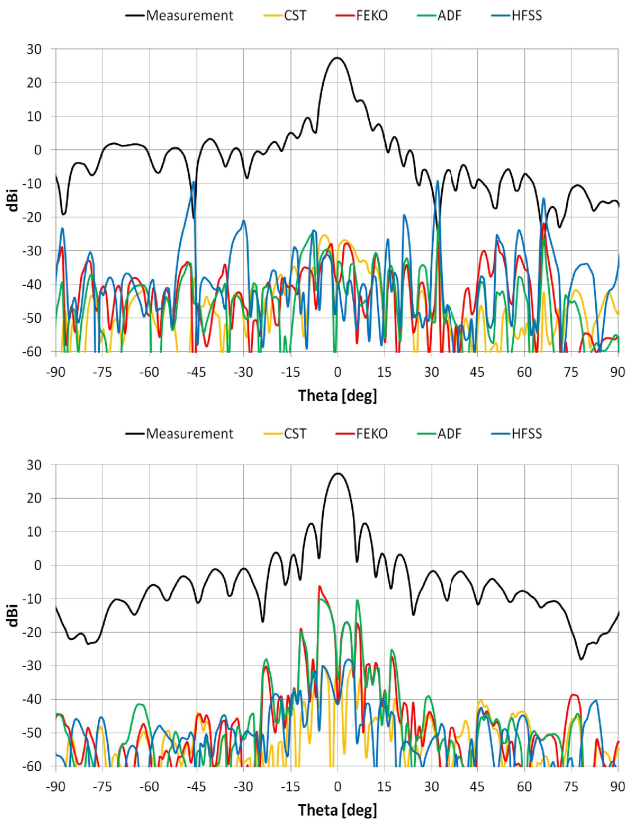

Fig. 5. Weighted difference between simulation and measurements in forward hemisphere. Simulation using measured source in different CEM tools CST [9], FEKO [10], HFSS [11] and ADF [12]. E plane (top), H plane (bottom).

The medium value of the weighted difference express the correlation in a single value as shown in Table II. This value is sensitive to depth and slope of side-lobe nulls as evidenced in Fig. 5. The general correlation between simulations and measurement is ~40dB, which is similar to what is obtainable with full-wave simulation of the antenna. This result is very encouraging confirming the accuracy of the measured source representation and the validity of the link between measurements and CEM tools.

TABLE II. MEAN WEIGHTED DIFFERENCE WITH MEASUREMENT

	CST	FEKO	HFSS	ADF
E-plane [dB]	-42.3	-39.7	-36.1	-41.5
H plane [dB]	-48.0	-34.4	-46.7	-34.3

The very good correlation on this test object encourage further investigation clarifying the possibilities and limitation of the measured source approach. Future investigation on the reflector and dual ridge feed should include the comparison of the measured source representation also with data obtained from full wave simulation of the antenna.

IV. SMC2000 ANTENNA ON A RECTANGULAR PLATE

The use of measurements in numerical simulation of flush mounted antennas on larger complex structures is illustrated by a relevant example as shown in Fig. 6. To minimize errors, pertinent to the validation of the measurement/ simulation link, a rectangular plate of 5λ x 10λ @ 5.28GHz has been used. The source antenna is a SMC2200, mono-cone antenna mounted in a corner of the plate at 1.5λ and 2λ distance from the nearest edges at the validation frequency. The validation structure is shown in Fig. 6 during measurements in the MVG, SL18GHz spherical near-field multi probe system [14].

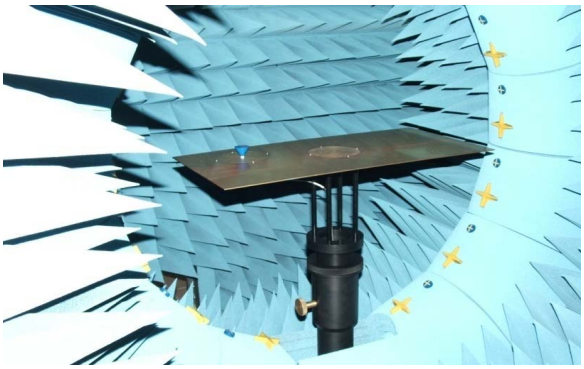

Fig. 6. Validation structure during measurement in the MVG Spherical Near Field antenna measurement system, SL18GHz [14].

The determination of the electromagnetic model of the source antenna for flush mounted applications is more difficult than situation where the antenna is detached from the scattering structure. The proximity of scattering modifies the current distribution on the antenna itself. An infinite ground plane boundary condition is a good approximation but such a condition cannot be directly obtained on a realistic measurement scenario. However, this condition can be emulated from measurements of the source antenna on a finite ground plane and the application of post processing as discussed in [15]. The post processing of the measured data eliminates the diffractive contributions from the edge of a finite ground plane creating the wanted infinite ground plane boundary condition. A circular ground plane with minimum 5λ diameter is considered adequate for most measurement source antennas.

In the validation example, the mono-cone antenna, has been measured on a circular ground plane of diameter 7λ in the MVG, SL18GHz spherical near-field multi probe system [14] as illustrated in Fig. 7. After post processing, to eliminate edge diffraction, the 3D electromagnetic model in the form of equivalent electric and magnetic currents associated to the source can be evaluated with INSIGHT. It should be noted that, since an infinite ground plane condition is considered, the image of the source antenna is initially included in the equivalent current computation and then removed when determining the Huygens Box representation of the measured source.

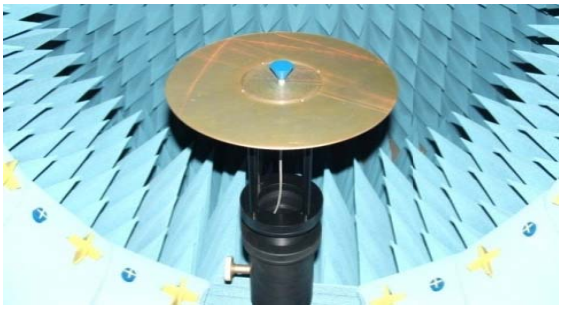

Fig. 7. Measurement of the mono-cone antenna on a limited ground plane in the MVG, SL18GHz spherical near-field multi probe system [14].

Following the procedure in Fig. 8 the Huygens Box representation of the measured SMC2200 monocone antenna has been determined and imported in different CEM tools [9, 13]. The participating CEM vendors were responsible for generating a suitable mesh, the import of the measured source in the Huygens Box format and controlling the numerical stability of the simulation.

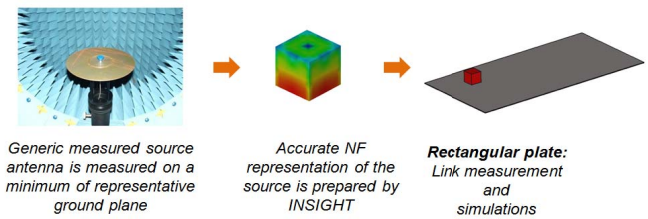

Fig. 8. Use of a measurement of a SMC2200 monocone antenna as flusmounted antenna on a rectangular plate.

The measured and simulated peak directivities @ 5.28GHz of the rectangular plate with SMC2200 mono-cone antenna are reported in Table III. MEAS is the measured reference from MVG. The simulated results are from CST, Savant (asymptotic technique, Shooting and Bouncing Rays – SBR), and Feko [9,10,13]. Results from [11,12] are on-going. The table confirms the very good agreement between measurements and simulations.

TABLE III. PEAK DIRECTIVITY @8GHZ – SMC2200 ON PLATE

	MEAS	CST	Savant	FEKO
Peak Directivity [dBi]	6.2	5.7	5.9	5.7

The measured reference is compared to the simulated co-polar patterns from simulation using the measured source in Fig 9. The agreement between simulation and measurements is very good considering the approximation due to the feed representation and uncertainties arising from measurement, manufacturing and simulation.

The agreement or correlation between simulations and measurements has been evaluated as weighted difference between measured and simulated field. The measured far field has been considered as reference field. The weighted difference for each simulation tool is overlaid with the measured, patterns @ phi = 90° in the forward hemisphere in Fig. 10.

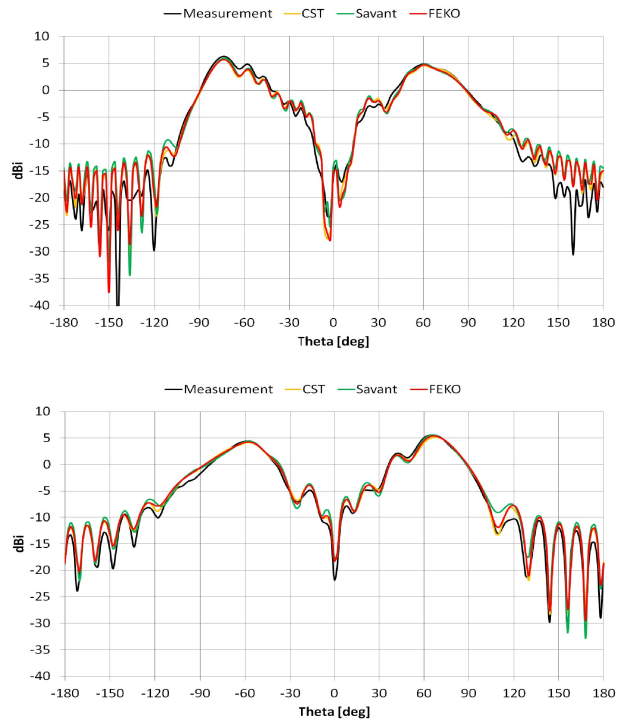

Fig. 9. Directivity pattern of SMC2200 monocone antenna on rectangular plate @ 5.28 GHz. phi=0° plane (top), phi=90° plane (bottom). Measurement and simulation using measured source: CST [9], Savant [13], FEKO [10].

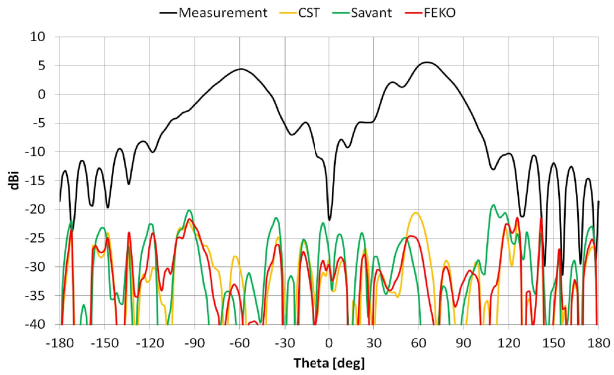

Fig. 10. Weighted difference of simulation and measurements, phi=90° plane. Simulation using measured source: CST [9], Savant [13], FEKO [10].

The medium value of the weighted difference express the correlation in a single value as shown in Table IV. The general correlation between simulations and measurement is ~30dB, which is similar to what is obtainable with full-wave simulation of the antenna. This result is very encouraging confirming the accuracy of the measured source representation and the validity of the link between measurements and CEM tools.

TABLE IV. MEAN WEIGHTED DIFFERENCE WITH MEASUREMENT MONO-CONE ANTENNA SMC2200 ON RECTANGULAR PLATE

	CST	Savant	FEKO
Phi=0°cut plane [dB]	-30.2	-30.1	-30.5
Phi=90°cut plane [dB]	-33.2	-32.4	-33.4

V. FLUSH MOUNTED ANTENNA ON A CURVED SURFACE

A flush mounted antenna on a curved structure has been investigated using a mono-pole like antenna mounted directly on the back of a space plane as shown in Fig. 11. The purpose of this investigation is to quantify the error deriving from the flat ground plane approximation employed in the measurement and processing of the measured source. To isolate this effect, the source is simulated on a ground plane and treated as an actual measured source following the procedure shown in Fig. 11.

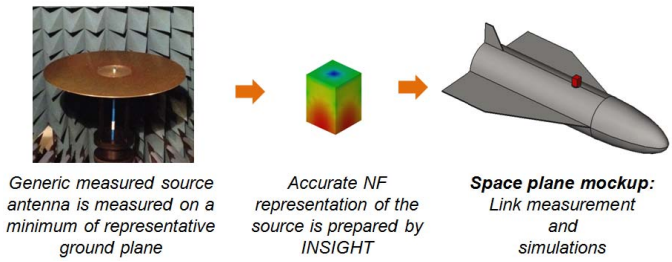

Fig. 11. Use of a measurement of a SM6000 monopole as fluhed mounted antenna on a mock-up of a space plane [6-18]MHz frequency band.

The pattern comparison between source antenna in the numerical simulation (EQC + CST, blue trace), CST full-wave simulation (Full wave -CST, red trace) is reported in Fig. 12 for two cuts, φ = 0° (top) and φ = 90° (bottom). Results from the other numerical tools [10-13] are on-going.

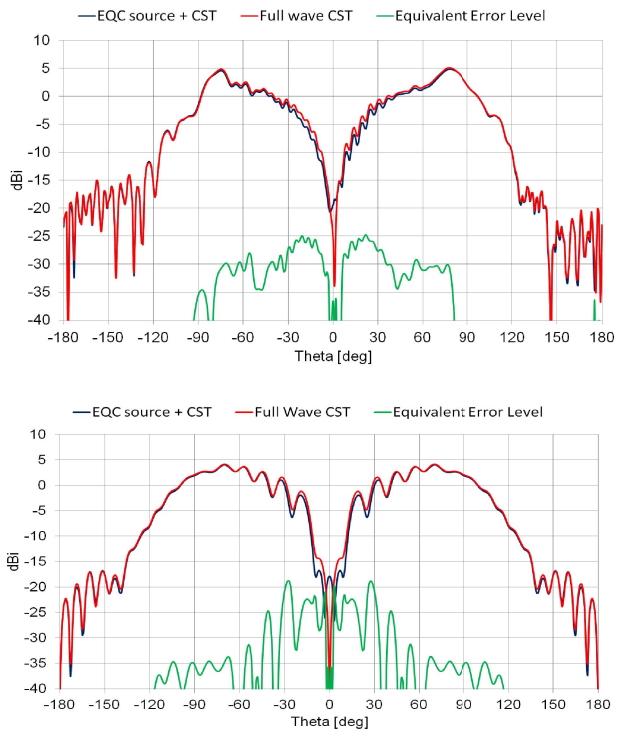

Fig. 12. Space plane. CST simualtion using EQC source (blu trace) and CST full-wave simulation (red trace). φ = 0° (top) and φ = 90° (bottom).

VI. CONCLUSION

A new method has been proposed as the missing link between numerical simulation and antenna measurements. Based on INSIGHT processing the equivalent model of a measured device is importable in commercial CEM solvers in form of a Huygens Box. The method has been validated on difference complex scenarios in the case of free standing and flush mounted antennas using different CEM solvers.

The validation activity shows that processed measurements of antenna can be conveniently applied in commonly used commercial numerical simulations tools with very good accuracy and no apparent limitation on simulation approach.

VII. ACKOLEDGEMNT

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