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ORAS : opérateur rapide d'analyse spectrale

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► **To cite this version:**

P. Gille. ORAS : opérateur rapide d'analyse spectrale. [Rapport de recherche] Centre de recherches en physique de l'environnement terrestre et planétaire (CRPE). 1981, 22 p. hal-02191543

HAL Id: hal-02191543

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RP

82 (49)
CENTRE NATIONAL D'ETUDES
DES TELECOMMUNICATIONS

CENTRE NATIONAL DE LA
RECHERCHE SCIENTIFIQUE

CENTRE DE
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EN PHYSIQUE DE
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TERRESTRE
ET PLANETAIRE

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NOTE TECHNIQUE
CRPE / 106

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123
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ORAS : Operateur rapide d'analyse spectrale

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Centre National de la Recherche Scientifique
Département de Physique



12 JAN. 1982

RP 182 (49)

CENTRE DE RECHERCHE EN PHYSIQUE DE
L'ENVIRONNEMENT TERRESTRE ET PLANETAIRE

NOTE TECHNIQUE CRPE/106

ORAS : OPERATEUR RAPIDE D'ANALYSE SPECTRALE

par

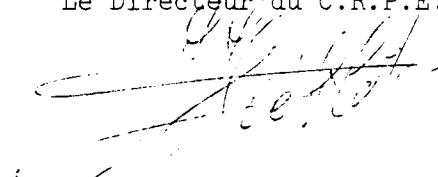
P. GILLE

C.R.P.E./P.C.E.

45045 - ORLEANS CEDEX

(Août 1981)

Le Directeur du C.R.P.E.



J. HIEBLOT

ORAS : OPERATEUR RAPIDE D'ANALYSE SPECTRALE

RESUME

L'interprétation des mesures géophysiques peut être réalisée avec efficacité au moyen d'un mini-ordinateur conversationnel associé à un périphérique spécialisé dans les opérations de traitement de signal : fonctions scalaires ou vectorielles, réelles ou complexes, calcul de spectres directs et croisés sur un nombre variable de signaux numériques.

L'ORAS a été notamment conçu pour doter un calculateur HP 1000 F d'une capacité de calcul rapide des matrices spectrales relatives aux mesures d'ondes TBF à 9 composantes. Par exemple, le calcul d'une transformée de Fourier complexe avec accumulation sur 1024 échantillons s'effectue en 20 millisecondes.

Le logiciel de l'ordinateur assure la gestion des opérations et des transferts de données qui s'effectuent au rythme maximum de 1 million de mots par seconde. L'utilisateur a la possibilité de définir son application de façon interactive sous la forme d'un macroprogramme.

L'ORAS pourra être utilisé à différentes fins, telles que l'étude des bruits électromagnétiques et il pourra servir de prototype à un dispositif fonctionnant en temps réel.

Ce texte a été présenté à la XXème Assemblée Générale de l'U.R.S.I. à Washington le 11 Août 1981, au cours de la session C2 ("Telecommunications and digital signal processing"), sous le titre : "Fast processor for spectral analysis".

II

PROPOSED PAPER TO U.R.S.I., XXth GENERAL ASSEMBLY

Washington, August 1981

Commission C : Signals and Systems

Author : P. GILLE, C.R.P.E. Orléans, France

Subject : Fast Processor for Spectral Analysis

Summary

Interpretation of geophysical measurements may be efficiently achieved with the help of an interactive mini computer coupled to a fast processor devoted to signal processing operations : linear/vectorial, real/complex functions, auto/cross-spectra of an adjustable number of channels. The ORAS ("Opérateur Rapide d'Analyse Spectrale") has been mainly designed to give a HP 1000 F computer the capability to quickly calculate and integrate the spectral matrices of VLF satellite data with 9 (or less) components. For instance, the complex Fourier transform with summation takes 20 ms for 1024 samples. The computer software controls the sequence of operations and the data transfers (up to 1 M w/s). It allows the user to interactively define his application as a macroprogram. The ORAS will be used for different purposes, such as electromagnetic noise analysis and could lead to a real time device.

ORAS at a glance
 ^ ^ ^ ^ ^ ^ ^ ^ ^ ^ ^ ^ ^ ^ ^

WHAT ?

1. meaning: ORAS = Operateur Rapide d'Analyse Spectrale
= Fast Processor for Spectral Analysis
2. definition: digital peripheral for a mini-computer
micro-programmed and macro-programmable
dedicated to signal analysis operations

WHY ?

3. purposes:
 - linear operations with blocks (or vectors)
 - handling of both complex & real data
 - handling of multi-component digitized signals
 - fast Fourier transform
4. typical application: 6 component electromagnetic field
telemetered from Geos satellite
 - reorganization of data channels
 - weighted FFT with sliding window averaging
 - complex auto & cross-spectra
 - phase & spin corrections

HOW ?

5. typical performances
 - processing unit cycle time: 200 ns
 - memory access to complex data (2x24 bits): 1000 ns
 - FFT with square mod. and summation: 20 ms for 1024 samples
 - FFT butterfly :5500 ns
 - data transfer: 16 M bits/sec
6. present limitations
 - memory core: 16 K complex data (2 x 24 bits)
 - vector size: 8 to 8096 (32 to 1024 for FFT)
 - number of vectors: 1 to 256 according to size
 - number of signal components: 1 to 16
7. possible extensions
 - new macro-instructions ,e.g. correlation
 - amount of memory core
 - development of real-time or on-board version

WHO ?

8. CRPE (CNET+CNRS): specifications & acceptance
software for interfacing, tests & applications
9. LETI (CENG): hardware design & firmware

WHEN ?

10. kick-off :sep 76 ,study :77-78 ,development: 78-80
interface:may 80 ,delivery:jan 81 ,extensions:aug 81

ORAS typical Functions

1. Block handling

- operations performed item to item , data replaced by result
- arithmetic mode : floating point per block on 24 bit mantissa
- automatic normalization after most signif. bits in the block
- automatic adjustment of "block factor" : 8 bit common exponent

2. Fourier transforms & spectra

options: real/complex , direct/reverse , fft/spectrum

3. Arithmetic vector operations

3.1 Real block & real block

- addition, subtraction, multiplication, division
- scalar product $(X_k) = (X_k * Y_k)$
- (coherence) $(X_k) = (X_k / Y_k)$
- weighted summation $(X_k) = (U_k * X_k) + (V_k * Y_k) + \dots$

3.2 Real block & real constant

- addition, subtraction, multiplication
- sum of block items $s = S[X_k]$
- linear operations $(X_k) = a * (X_k) + b * (Y_k) + \dots$
- multidimensional rotation
- translation, centering $(X_k) = (X_k - a) * b$

3.3 Signal analysis

- correlation $(X_k) = S[X(k) * X(k+j)]$
- power, density $a = S[X_k * X_k]$
- cross power $a = S[X_k * Y_k]$

3.4 Statistical moments

- average $a = S[X_k] / N$
- deviation $d = S[(X_k - a) * (X_k - a)] / N$

3.5 Smoothing, derivatives $(X_k) = a * X[k-1] + b * X[k] + c * X[k+1]$

4. Complex operations

4.1 Complex block & complex block

- addition, subtraction, direct mult'n , conjugate mult'n
- square module $(X_k, 0) = (X_k, Y_k) * (X_k, -Y_k)$
- 2-dimens. rotation correction $(X_k, Y_k) = (X_k, Y_k) * (\cos[a*k], \sin[a*k])$

4.2 Complex block & real constant

- multiplication

4.3 Complex block & complex constant

- 2-dimens. phase correction $(X_k, Y_k) = (X_k, Y_k) * (\cos a, \sin a)$

4.4 Linear complex operations : similar to real ones

4.5 Processing 2 real vectors as one complex vector

5. Transfer operations

- Some data handling are performed via the interface in both trans'n & recep'n
- multi-component reorganization : exchange lines/rows (up to 16 rows)
 - combination of 2 real signals in one complex , & vice versa
 - binary inversion of addresses (before fft)
 - data word matching : 16/24/32 bits with 0 to 16 bits shifted

Short bibliography

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ORAS Hardware structure

3 printed circuit boards

1. Processing unit

1.1 Arithmetic & logic processor

- sliced microprocessor (AMD 2903)
- internal registers (ram): 2 x 16 words x 24 bits
- I/O registers : 24 bit input , 24 bit output
- bus 24 bits

1.2 Multiplier : special circuit

[TRW MPY16HJ or MPY24HJ ???]

1.3 Firmware

- microprogram rom : 1 K x 64 bits [extension to 2 K]
- microprogram sequencer (AMD 2910)
- micro-instruction register 64 bits
- instruction register: 24 bits

2. Memory

- memory core: 2 x 16 K words x 24 bits (dynamic memory)
- interface registers (AMD 2907) : 2 inputs, 2 outputs, 1 address
- processing registers (AMD 2907) : 2 inputs, 2 outputs, 1 address
- special multiplexer for binary inversion of addresses

3. ORAS interface to computer

- I/O registers : 24 bit input, 32 bit output
- transfer code reg. : 16 bits
- memory address reg. : 24 bits
- word counter: 16 bits
- status register: 6 bits
- logic for command & interrupt system

4. Computer connexion

- interface HP12930 with direct memory access facility (DCPC)
- data output reg.: 16 bits , result input reg. : 16 bits
- control output reg. : 6 bits , status input reg.: 16 bits
- transfer rate: 16 M bits/sec
- cable & connectors : 4x37 pins

5. Electrical & mechanical

- standard rack 19" , 5 U
 - power consumption : 90 watts DC (19 Amps x 5 V)
-

ORAS Memory organization

1. Principles

1.1 Different areas

- data & results (e.g. 30 K words) [see below]
- special tables or "system area" (e.g. 2 K words)
 - block factors or exponents
 - cosines for FFT
 - variables & indexes
 - parameters for configuration & run
 - macro-program

1.2 Flexibility & reconfiguration

- location & size of all areas are described in "parameter" table
- special tables (if needed) have to be reloaded from computer at every boot-up
- they may be checked or modified during real-time operations

1.3 Memory access

- word per word or direct memory access
- simultaneous sharing by ORAS proc'g unit & computer interface

1.4 Word length

- 24 bits in ORAS
- 16 bits (integer) or 32=24+8 (floating point) in HP computer
- matching is assumed by interface (missing or extra byte)

2. Data structure

2.1 Block organization

- internal references inside ORAS are block number counts
- one block (or vector) is a data set with same exponent
- all blocks at a given time have same length
 - power of 2, from 8 to 8096
- block length is imposed by a specific macroinstruction at any time (e.g. block split in sub-blocks)

2.2 Block exponent (or block factor)

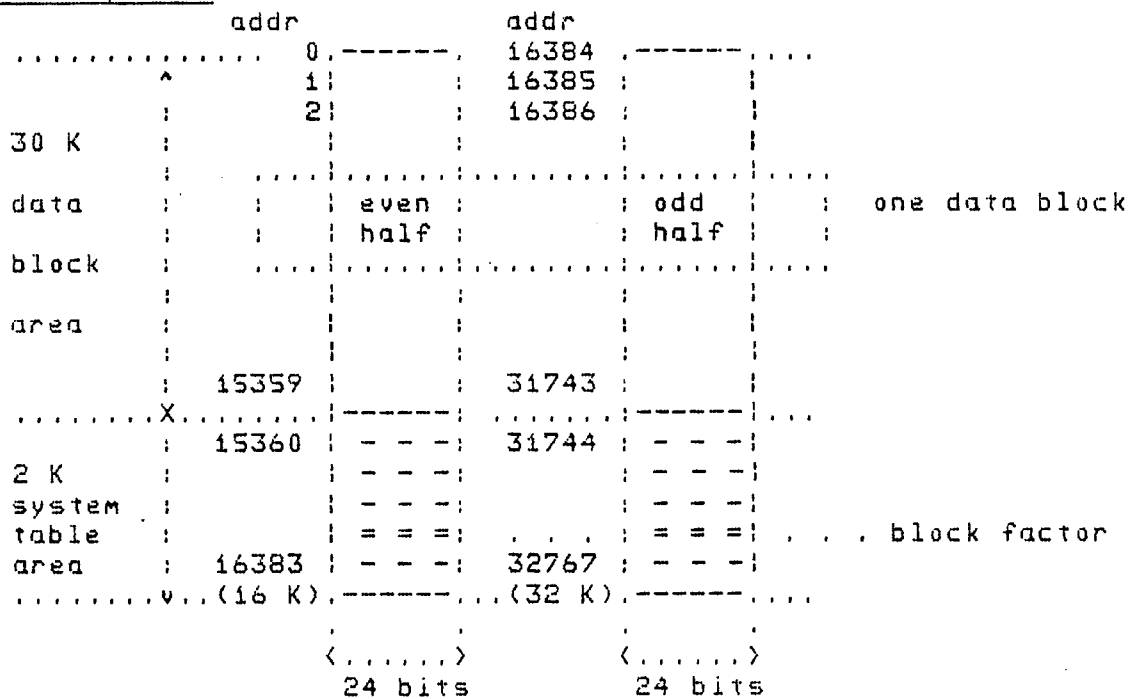
- one 8 bit byte is the binary exponent common for a whole block
- it is considered & updated by arithmetic operations on block
- the block exponent area has a special geometry
- number of blocks & block expo's is limited to 256

2.3 Data types & addressing [see figure].

- data are consid'd as "real" or "complex" according to the macroinst'n
- memory core is divided into 2 word sets:
 - first half (0-16K) or even part, or real part of complex
 - second half (16-32K) or odd part, or imag. part of complex
- the current block length corresponds to a number of double words
- "complex" (or double word) lay-out is the regular one
- "real" type data are put alternatively in both memory halves

ORAS memory layout

1. General lay-out



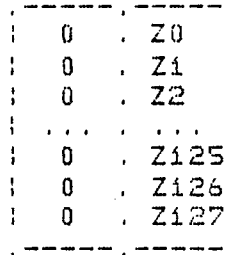
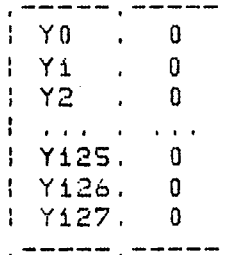
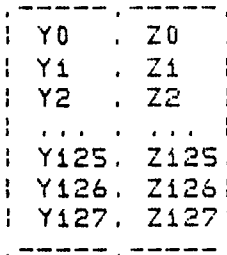
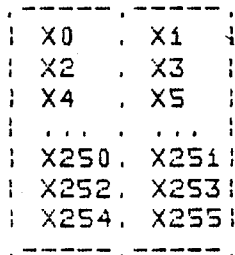
2. Data block types Example with block size = 128 double words

2.1 Real block

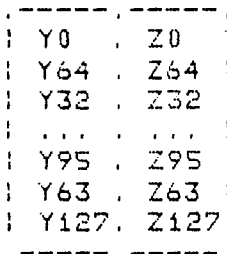
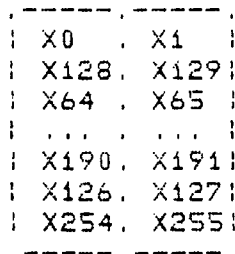
2.2 Complex block

2.3 Even block

2.4 Odd block

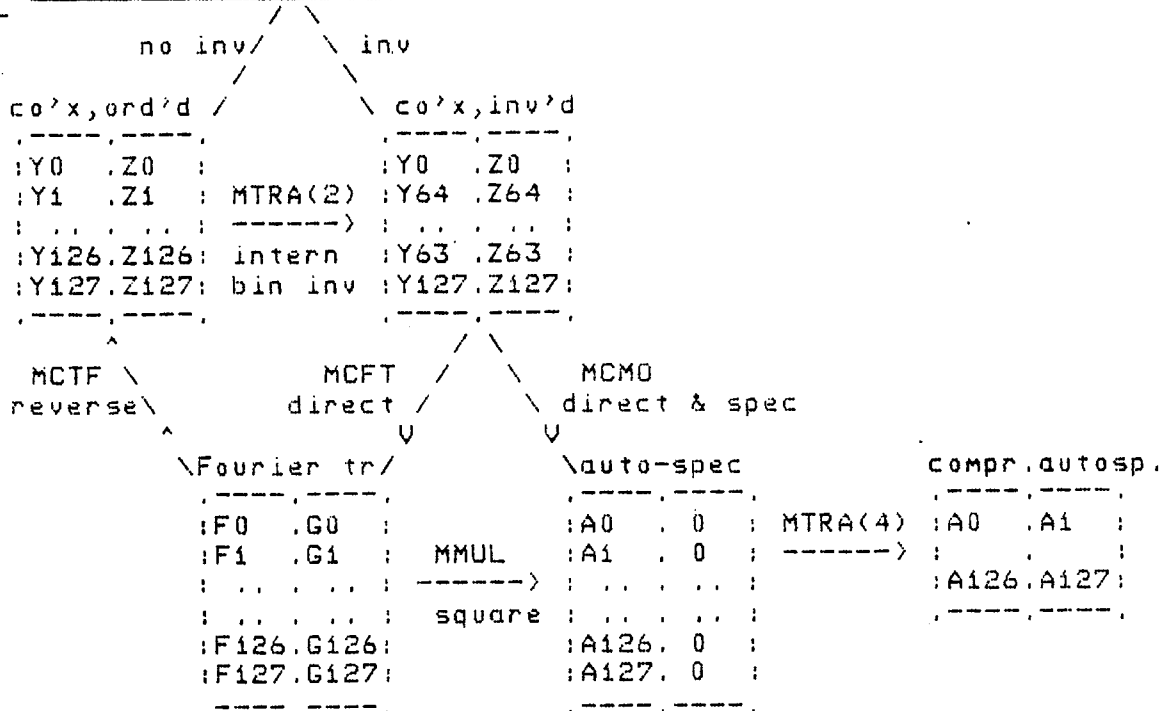


3. Binary inversion of addresses



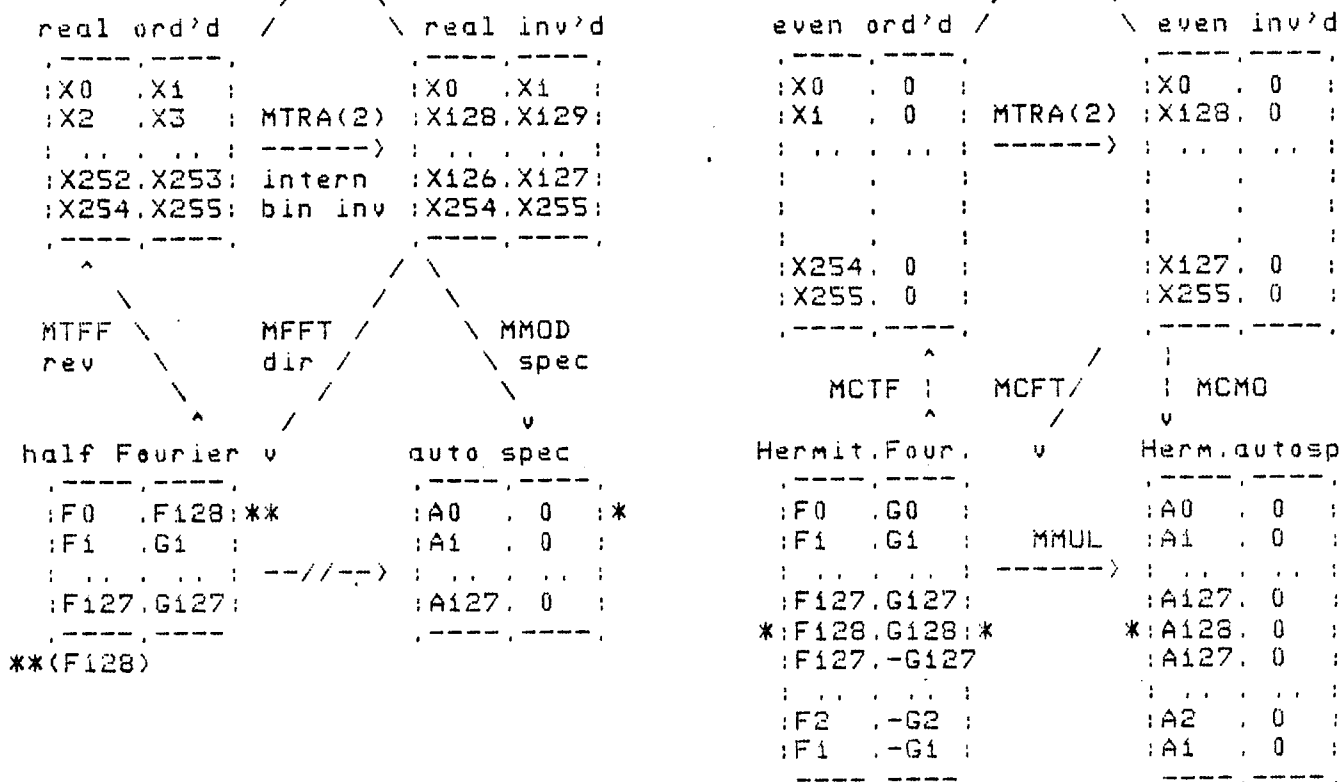
1. Complex data (Y0,Z0,Y1,Z1, ..., Y127,Z127)

transfer:



2. Real data

(X0,X1,X2, ..., X253,X254,X255)



ORAS & computer : task organization
 ^

1. General principles

- ORAS and HP1000 computer work simultaneously
- synchronization is made by means of interruptions and flags
- all data exchanges are computer-directed

2. Operations inside computer

2.1 Foreign relations

- external data management : disc, tape, etc
- auxiliary computations e.g. calibrations
- digital & graphic display
- interactive functions: start-up, break, etc

2.2 Preparation tasks

- building up auxiliary tables
 - configuration parameters
 - trigon. tables: cosines, weighting
- compilation of symbolic macro-program
- initializations, ORAS reset

2.3 Run time tasks

- control of all input/output op'ns
- control of task activation & completion in ORAS

3. Operations inside ORAS processing unit

- macro-instruction decoding
- micro-instr'n execution, management & arithmetic functions
- update of parameters, variables, status, error flag, etc
- (no I/O)

4. Operations performed by ORAS Interface

4.1 Bidirectional I/O general tasks

- data & result transfers , as required by computer
- emission & echo of interruptions

4.2 Special features due to data structure

- complex or real (double or simple) data addressing
 - word format matching : 16 or 32 bits in HP , 24 bits in ORAS
 - reorganization of up to 16 multicomponents per channel block
 - binary inversion of addresses (anticipation of next FFT)
 - word shift , 0 to 15 bits to the left (in data transm'n only)
-

Application to GEOS Survey data

1. Purpose

A contribution to study of power-line radiations after spectral analysis of VLF magnetic field via eigen-values of spectral matrices
This is the first operational use of ORAS system although it needs some additional computations (eg eigen-values)

2. Characteristics of data

- origin: GEOS.1 satellite , "Survey mode" , recorded on magnetic tape
- total bandwidth : 9335 Hz , swept in 31 steps with frequency overlay
- step bandwidth : 744 Hz , of which 296.16 are undependant
- one "high speed format" (hsf) = 128 samples with constant gain per antenna
- one step = 688 ms = 8 hsf = 1024 real data * 3 antennae

3. Task summary

3.1 Data selection

- select the 3 magnetic components (Bx,By,Bz) from the tape
- gain correction for the 8 hsf
- averaging to zero : suppression of DC component
- rotation correction on X and Y axis (Z has a fixed attitude)

3.2 Spectral analysis (via ORAS)

- sliding window per step for each of the 3 real channels ,ie:
split the 1024 in 5 segments of 256 ,with overlay of 64
- weighting of each data segment (Parzen window)
- 3 real direct fft per segment : 128 Hermitian complex
- calculate 3 real auto-spectra and 3 complex cross-spectra
- correction of antenna phase on 2 cross-spectra
- accumulation of the 6 corrected spectra for the 5 segments

3.3 Eigen-values

- select useful bandwidth : 51 of 128 frequency points
- re-arrange the spectral matrices in triangular real array (6*6/2)
- compute eigen-values by pair : 3 free E.V. per frequency

3.4 Graphic display

options: raw data, fft, spectra, eigen-values

5. Performance

timing : 360 ms per step of spectral analysis (see above 3.2)
compatible with the real-time sampling (688 ms)
i.e. conversion of 3*1024 real data into 128 spectral matrices * 9 items
this includes mainly 15 weighted FFT and spectrum calculations
all information transfer ORAS-computer
the task synchronization is not optimized (no parallelism)

4. Possible extensions & improvements

- handle the 6 electromagnetic components
- accomodate the sliding window inside ORAS via block shifting
- build a flip-flop processing : transfer parallel with computation

ORAS command file

```

*** #POWEL:OR:12 oras-command file 30.6.81
TRFA,TRVA,TRPA reset parameter area
TRFE build & transfer weighting block (15)
  256,1, 15
TRRO rephasing blocks (16,17,18)
  128,2, 16, 0, 186,3600
    , , 17,-450,2011,
    , , 18,-675,1825,
FATA specify data block size (0 to 14)
  128,2, 0,15
COMA compose macro program
  ORG,0
  MTAI,120,128,2 block size
  MRAZ,3 reset before accumulation
  MRAZ,4
  MRAZ,5
  MRAZ,6
  MRAZ,7
  MRAZ,8
  MCHV,1,999,0 iteration index
COM loop beginning
  MSYN send sync signal ,ready for new data
  MSSY wait for ACSY ,data transferred
  MTRA,0,12,0 internal data copy
  MTRA,1,13,0
  MTRA,2,14,0
  MMUL,12,15 weighting
  MMUL,13,15
  MMUL,14,15
  MFFT,12 real fft
  MFFT,13
  MFFT,14
  MTRA,12,9,0 duplicate before spectra
  MTRA,13,10,0
  MTRA,14,11,0
  MMCC,9,13 complex cross spectra
  MMCC,10,14
  MMCC,11,12
  MMCC,12,12 even auto spectra
  MMCC,13,13
  MMCC,14,14
  MMCC,13,17 phase corr yz,zx
  MMCC,14,18
  MADD,3,12 sum 6 spectra
  MADD,4,13
  MADD,5,14
  MADD,6,9
  MADD,7,10
  MADD,8,11
  MCAL signal end of iteration
  MBRA,1,-60 end of loop
  MEND signal end of oras processing
  FIN end of symbolic macropgm
TRMA,ACMA load & start macropgm
TRIN end of command file

```