

# RECOGNIZING, ANALYZING AND INTERPRETING MODE INFORMATION IN STANDING-WAVE CAVITIES\*

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## Abstract

Efficient operation of cavities in any accelerator is an important criterion. In order to achieve this requirement, an understanding of cavity performance under different constraints is necessary. Such information is necessary when designing, constructing and commissioning cavities, whether they are normal conducting or superconducting. Two tools, the programs DISPER and LOOPER available from the Los Alamos Accelerator Code Group, are used to describe how to obtain useful information from cavities throughout their lifetime in an accelerator facility.

## 1 INTRODUCTION

Equivalent circuit theory [1-5] has been used for many years to understand and predict, in simple rf terms, the behavior of standing-wave coupled-cell cavities. This theory is a powerful tool in construction and operation of accelerating structures. Plotting passband mode resonant frequency data and determining relative cell-to-cell field distributions for such structures must be done carefully in order to extract necessary information and to use this information for predictions as described in the following sections. DISPER [6] and LOOPER [7] use equivalent circuit theory information to assist users in recognizing, analyzing and interpreting mode information in standing-wave cavities. These codes are available from the author via the Los Alamos Accelerator Code Group [8].

The two programs are improved from earlier Fortran-based versions [9]; now in Excel format driven by macros written in Visual Basic. Macros are password protected at present, to make enhancements/improvements available to users in a uniform format and to maintain consistency.

## 2 DISPER

DISPER is an Excel-based program for weighted, non-linear, least-squares fitting of an ordered set of resonant frequencies belonging to a particular passband (such as the  $TM^{010}$ ) of a coupled-cell cavity to an equivalent-circuit dispersion relationship (such as that described in Ref. [2]). The fitting process provides the user with up to five parameters describing the cavity and, if requested, the termination phase value (hence type of termination; half, full, etc.). The parameters are the usual cell frequencies ( $f_1$  and  $f_2$ ) and coupling constants ( $k_1$ ,  $k_2$  and  $k_3$ ) for singly or doubly periodic systems. The user can specify different end-cell terminations including combinations of half-cells, full-cells, circular structures, and end-cell

tuning for flat fields of a  $0$ -mode or a  $\pi$ -mode cavity. In addition,  $\chi^2$  for best fit and the passband gap (for split passband systems) are given.

Excel spread sheets used by the program are *Fits* (for inputting the type of fit and associated parameters), *Data* (for inputting the ordered set of resonant frequencies and for the calculated results of the best fit), *Results* (for calculated results from each iteration of the fitting process), *Diagnostic* (for diagnostics of the program), *Guidance* (for information on operation of the program, definition of the parameters and the logic used) and *Working Sheet* (exclusively for the program to invert and multiply matrices).

Figure 1 shows results of a five-parameter fit to a cavity with large coupling constants, completing the fit process within four iterations. Note that data error bars are not uniform and the existence of a large passband gap. This example is used to show program flexibility for data fits.

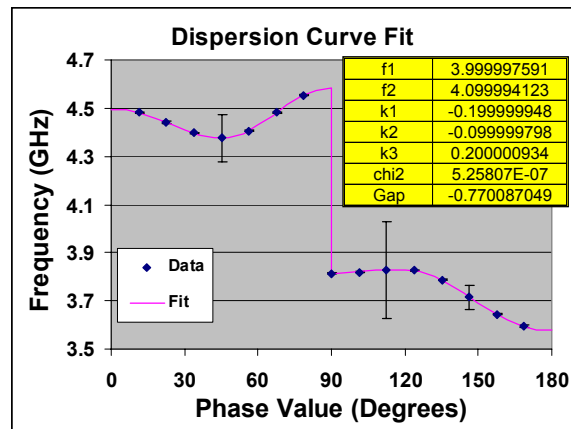


Figure 1: DISPER fit to backward-wave structure

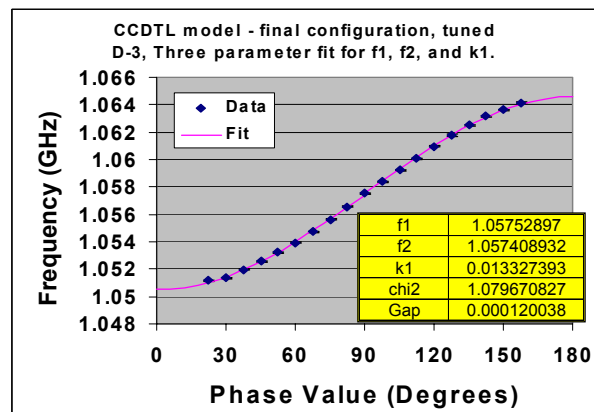


Figure 2: DISPER fit to CERN CCDTL data

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A three-parameter doubly-periodic fit to CERN CCDTL data [10] is shown in Fig. 2. The passband gap is only 0.00012 GHz indicating a very good tune for this complex structure.

Figure 3 shows determination of end phase value and phase separation between modes of a five-cell cavity with elliptically shaped cells [11]. Not surprisingly, the non-linear least-squares process determined that the fit was for a full-cell terminated cavity with end-cells detuned for a flat-field  $\pi$ -mode.

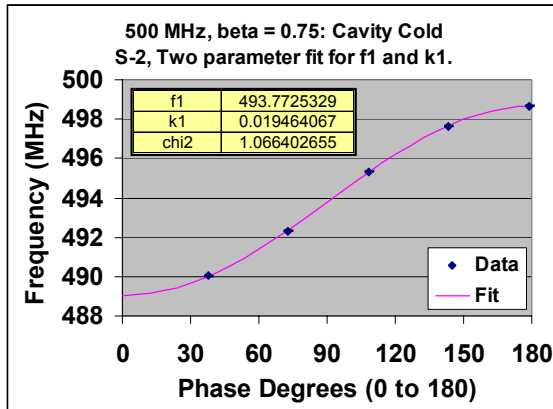


Figure 3: DISPER fit to FZ-Juelich superconducting cavity data

DISPER can be used to determine:

- parameters that best fit measured data allowing for sensitivity/tolerance determinations with LOOPER or methods similar to Ref. 5 descriptions,
- cavity tuning as shown above,
- end terminations as described in Ref. 12,
- “cold” relative field levels in superconducting cavities using DISPER fit parameters and procedures described in Ref. 13, and
- proper tuning of end cells [12].

### 3 LOOPER

LOOPER is an Excel-based program for solving coupled-loop average on-axis cell fields after finding resonances of multi-cell cavities with parameters that can be different for each cell and between adjacent cells. Characteristics of each resonance are determined from a best fit of the  $Q$  curve to the scanned data about the resonance peak. LOOPER uses the following information for each cell of the cavity: resonant frequency  $f$ , coupling constants  $k_i$  to neighboring cells, quality factor  $Q$ , effective  $ZT^2$ , length  $L$ , relative drive (phase and amplitude), and beam drive (phase and amplitude). In addition LOOPER accommodates random variables, specific changes in values, different terminations, bridges, phase shifts between cells because of geometry and operation, end-cell detuning corrections, and singly-doubly- or tri-periodic geometries.

LOOPER performs a frequency scan of the  $\Delta f$  region requested, finding resonant peaks that are analyzed for useful information. For each resonance within this

scanned region, LOOPER analyses the data for peak amplitude relative to the drive(s) and cavity impedance, rf powers in cavity cells,  $Q$  value,  $\chi^2$  fit of the  $Q$  curve to the data, relative fields and phases of cavity cells and the overall effective shunt impedance for the cavity.

Excel spread sheets used by the program are *Params* (for inputting the type of calculation and associated parameters), *Data* (for inputting individual cell data and for calculated results if corrections were requested: color coding is used to ease recognition of cell parameters), *ResultsOt* and *Resulters* (for calculated results of fields, phases and related information), *Diagnostic* (for diagnostics of the program), *Guidance* (for information on operation of the program, definition of the parameters and the logic used) and *Working Sheet* (exclusively for the program to invert and multiply matrices).

Figure 4 shows a typical resonance peak and a fit to the  $Q$  curve [5] including background from adjacent peaks. Fits are typically very good as shown in this example so calculated data from the resonance peak can be used effectively in determining properties of the cavity.

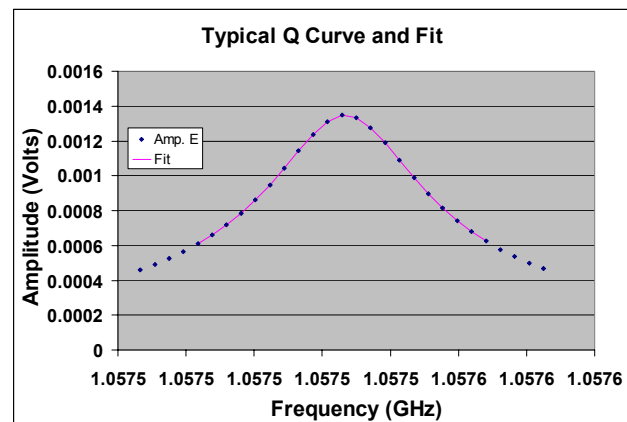


Figure 4: Typical  $Q$  curve and the fit to the scanned data

Examples of calculated mode spectra for different terminations and for different end-cell detuning were described in Ref. 12. These showed the usefulness of understanding mode spectra shapes as well as the relative peak heights of the passband resonances.

The measured spectrum [10] for the CERN CCDTL is shown in Fig. 5. Note the ends of the passband and the significantly larger  $Q$  for the main middle mode (the operation mode). The results from LOOPER simulating the CERN CCDTL are shown in Fig. 6 using five parameters for the calculation based on measurements at CERN:  $f$  and  $Q$  for the DTL cells and the coupler cells,  $k$  between the DTL and coupler, and reasonable random errors in these parameters based on lab measurements. Agreement between the two figures is remarkable considering the simplification of a 23-cell system with many individual parameters into a five-parameter analog based on equivalent circuit theory.

LOOPER provides relative fields and phases cell-to-cell for each resonance identified as well as the mode  $Q$  value.

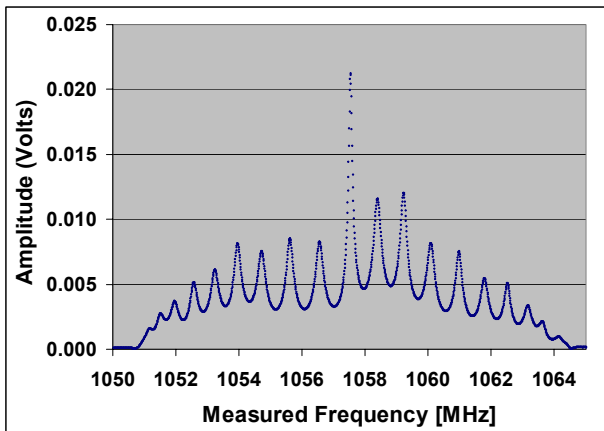


Figure 5: CERN CCDTL frequency scan data [10]

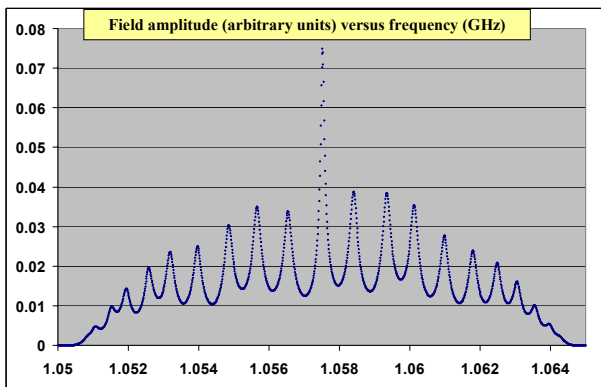


Figure 6: LOOPER results simulating CERN CCDTL

LOOPER can be used to:

- locate passband resonances and determine their characteristics,
- determine cavity sensitivities and tolerances for the operating mode of interest,
- identify modes within the passband,
- investigate cavities with multiple drive cells and heavy beam loading,
- investigate end-cell detuning effects,
- determine design parameters for complex systems, and
- verify operational parameters of multi-cell cavities.

## 4 SUMMARY

The practical use of two programs suitable for analyzing and interpreting data from rf structures has been

demonstrated with examples. The programs show excellent agreement with experimental data and can be used in many different applications.

## 5 ACKNOWLEDGEMENTS

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