STEP
Electromechanical Response Characterization Program

- Determine large field electromechanical properties of piezoelectric, ferroelectric, electrostrictive and anti-ferroelectric materials
- Four parameters of response are strain (S), stress (T), electric field (E) and polarization (P) where electric displacement is related to polarization as follows:
  \[ D = \varepsilon E + P \]
- In all measurements, one parameter is varied, the opposite electrical or mechanical parameter is fixed and the other two are measured
- Comprehensive data acquisition module allows automated control of electromechanical measurements to collect data sets including support of aging and temperature dependency measurements
- STEP HV provides all instruments, protection electronics and the enclosure necessary to perform comprehensive electromechanical measurements
- Runs under all Microsoft Windows operating systems

Analysis
- Rich set of fitting and graphic tools to manipulate and analyse results.
- The STEP non-linear regression engine simultaneously fits electrical/mechanical curves including hysteresis in those curves
- Results can be saved, printed or copied to the Windows clipboard
- Four analysis modules for four material types
  - Ferroelectric Module
  - Piezoelectric Module
  - Electrostrictive Module
  - Anti-Ferroelectric Module

Piezoelectric Module
- Assumes Rayleigh Models of piezoelectricity
- Assumes maximum field is well below coercive field
- As an example, for an unclamped sample (T=0), we might apply a known field (E) and measure D and S:
  \[ S_p = s_{pq}^T T_q + d_{pm}^T E_m \]
  \[ D_m = \varepsilon_{mn}^T E_n + d_{pm}^T T_p \]
  simplifies to
  \[ S = dE \]
  \[ D = \varepsilon^T E \]
Ferroelectric Module

- Ferroelectric response is characterized by a coercive field and saturation polarization
- A variety of models are supported, each optionally modified to support hysteresis if required
- Strain is modeled by applying the quadratic relation of electrostrictive to the models of ferroelectric polarization
- Terms are added to correctly model curves that do not saturate

Electrostrictive Module

- The quadratic relation between strain (S) and electric displacement (D) seen in most materials is termed electrostriction
- A general relationship between S, T, E, and D was derived by Mason:
  \[ E_i = -2Q_{klij}T_{kl}D_j + \left[ \beta_{ij}^T + R_{ijmnkl}T_{mn}T_{kl} \right]D_j + \sum_{ijkl}D_j D_k D_l + \sum_{ijklmn}D_j D_k D_l D_m D_n \]
  \[ S_{ij} = [s_{ijkl} + R_{ijmnkl}D_m D_n]T_{kl} + Q_{ijmn}D_m D_n \]
  where Q is the coefficient of electrostriction, subscripts represent anisotropy, and superscripts represent boundary conditions.
- In addition to a variety of other specialized models of electrostriction, these models are applied in several forms according to measurement boundary conditions

Instrumentation

- A comprehensive instrument abstraction layer allows acquisition of electromechanical curves from virtually any set of polarization and strain measurement systems
- Quasi-static and dynamic measurements supported
- Modules available for collecting single, aging, temperature dependence, and transient response data sets

STEPHV

- Measurement hardware, enclosure and protection electronics for performing large signal electromechanical measurements
- Basic system supports up to a 20 kV field and 1 kHz quasi-static waveform. Displacement resolution is 10 nm using contact DVRT
- System components can be exchanged on request to modify specifications
- STEP and STEPHV work together to provide the complete solution for turn-key large signal electromechanical measurements