Linear Technology Corporation (LTC) has an active Statistical Process Control (SPC) system. It operates via the interrelated mechanisms of: a structure, control charts with built-in contingency action plans, operational area documentation (flowcharts and control plan details), an SPC training program, each of which is defined in the Company's officially controlled SPC specification.

Structure

At the core of the SPC system are the Process (or Preventive) Action Teams (PATs). These cross-functional teams are comprised of individuals directly involved with a process element or problem. In a production operation, they typically involve production operators, lead operators, maintenance, engineering and/or supervision. In a nonproduction operation, the PATs are comprised of operating employees and representatives of related functions.

Each operating group (e.g., Wafer Fab) has a formal SPC presence in the form of an SPC Quality Control Team (QCT). These SPC QCTs are comprised mostly of the manager and staff of that particular operating unit bearing the responsibility to implement and maintain SPC within their respective areas.

This QCT structure is the leadership of that operating unit, and as such, sanctions the various PATs within its jurisdiction as they implement and maintain SPC and/or solve specific problems in their respective areas. In addition, the QCT conducts monthly reviews of SPC charts, action items and new programs.

The QCTs, in turn, report to the SPC Steering Committee. This body consists of the President, Chief Operating Officer, Vice President of Operations, Vice President of Quality & Reliability and the SPC Manager. Thus, it has the corporate leadership responsibility for SPC at Linear Technology.

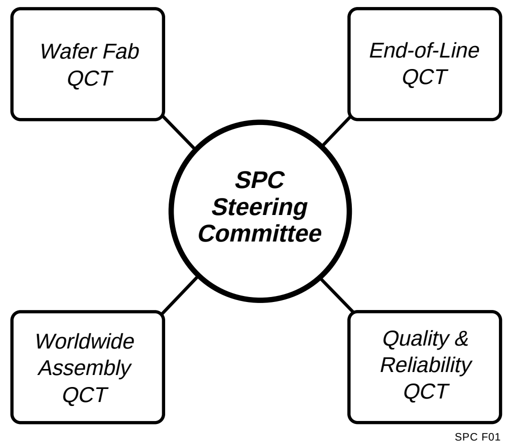

Figure 1. Linear Technology Corporation SPC Quality Control Teams

Control Charts

The control charts at LTC are manually charted by the operators to ensure that they are the custodians of the process, its trends, and defined corrective measures (as opposed to computerized SPC charting).

The contingency action plan, known as the Out-of-Control Action Plan (OCAP), defines the specific corrective actions when the process experiences out-of-control situations. No control chart is put in place without an OCAP. This strategy has in effect empowered the work force, while freeing the engineering staff for systematic and continuous improvement.

Flowcharts and Control Plan Details

The flowcharts serve to graphically display the flow of products in each operational area, as well as define and communicate the critical nodes of that operation. The details of each critical node are defined in the Control Plan Detail, which serves as a planning, reporting and communication tool.

An example of a flowchart and the related Control Plan Detail for one operational area (e.g., The Wafer Fabrication Area) Figure 2 and Table 1 follow:

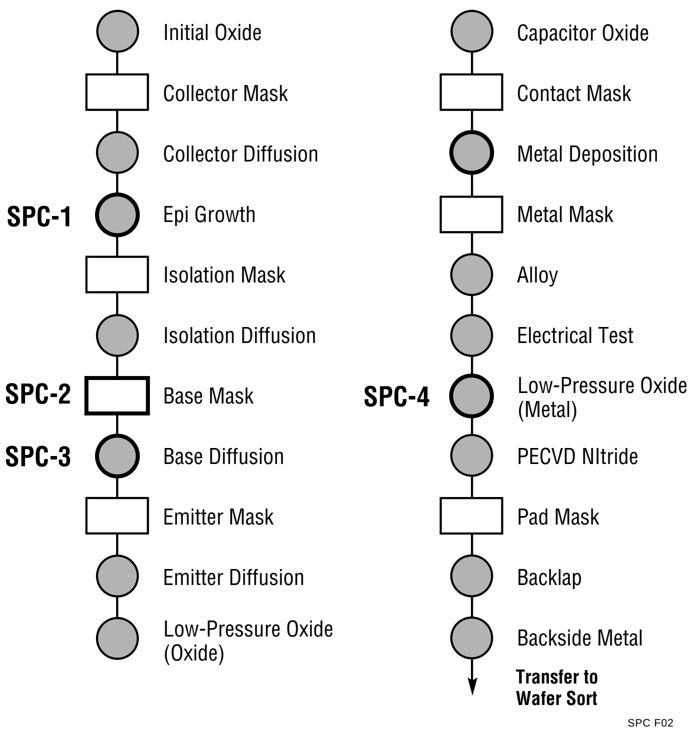

Figure 2. General Bipolar Wafer Fabrication Flowchart

Training Program

In order to pursue and continue the smooth operation of the SPC system within LTC, an all-encompassing instructional program for employees was initiated according to the following plan.

Each employee designated for SPC training is classified into one of three groups, and attends the specific classroom instruction for that classification. The courses and length of training (hours) for each group are designated in Table 2.

The content of the training courses is as follows:

BASIC SPC: Philosophy of SPC, concepts of variation, control, capability; tools and techniques for control and capability, including histograms, capability studies, control charting; 8D problem solving, including normality, brainstorming, cause and effect diagramming, Pareto analysis, capability index/ratio.

ADVANCED SPC: Review of basic concepts, fundamentals of Measurement System Evaluation (Gauge R&R), process capability studies, determination and use of control charts, i.e., $\overline{X}$ & R, Median & R, X & Moving R, p, np, u, and c chart techniques. Chart interpretation and the basics of attributes sampling system.

Table 1. Linear Technology Corporation Process Control Plan Detail for Bipolar Wafer Fab

SPC Node and Process	Critical Features	Measurement Method	Sample Size	Sample Frequency	SPC Control System	MSE (Gauge R&R)	Process Capability		Status
							Cp	Cpk	
(SPC-1) Epi Growth	Resistivity	4-Point Probe	2	Batch	X & Moving R Chart with Adaptive Control	Acceptable	>2.0	1.9 to >2.0	On Line
(SPC-2) Base Mask	CDs	OSI-VLS1	1 Site/ 3 Wafers	Batch	$\overline{X}$ & R Chart with Adaptive Control	Acceptable	1.67	1.6	Out of Control*
(SPC-3) Base Deposition	Sheet Resistance	4-Point Probe	3 Sites/ 3 Wafers	Batch	$\overline{X}$ & R Chart	Acceptable	>2.0	>2.0	On Line
(SPC-4) LPOM	Thickness	Nanospec	5 Sites/ 3 Wafers	Batch	$\overline{X}$ & R Chart	Acceptable	1.8 to >2.0	1.65 to >2.0	On Line

* A Process Action Team (PAT) has been initiated to bring process under control.

Table 2.

Group #	Trainee Audience	Basic SPC	Advanced SPC	DOE	Team Org.	Total
1	Engineering (Technical)	15	20	24	4	63
2	Management/Supervision Technicians	15	20	—	4	39
3	Operators	15	—	—	—	15

DESIGN OF EXPERIMENTS (DOE): Philosophy and need of experimental design, experimental methodologies utilizing Fisher & Taguchi concepts. Response Surface Methodology for parameters and tolerance designs, including ANOVA and analysis of co-variance.

TEAM ORGANIZATION: An outline of the SPC organization within LTC, the concepts of the SPC Quality Control Teams (SPC QCTs) and Preventive/Process Action Teams (PATs). Strategies for Detailed Control Plans and Out-of-Control Action Plans (OCAPs). Concepts of team effectiveness.

Manufacturing Excellence

One of the LTC goals is *manufacturing excellence.* The traditional SPC techniques seek to produce processes that are capable and in control. To improve those processes and to determine rational parameters and specification tolerance of new products and processes requires the *Design of Experiments* (DOEs) methodology.

LTC actively pursues the screening techniques described by Fisher as well as the optimization techniques of Box and Taguchi. These latter techniques, known as *Response Surface Methodology* and *Taguchi Methods*, are particularly useful in developing robust products and processes, with a minimum of sensitivity to process variation.

Contribution to Quality

Contribution to quality improvement has evolved from one dominated by ATTRIBUTE INSPECTION (pass/fail) to one involving a mixture of SPC and attribute inspection. As we progress further, the contribution of Design of Experiments will become significant. Products and processes developed using the DOE tools will have the *quality built in*. The consequence of this built-in quality is predictable performance at the lowest possible cost.

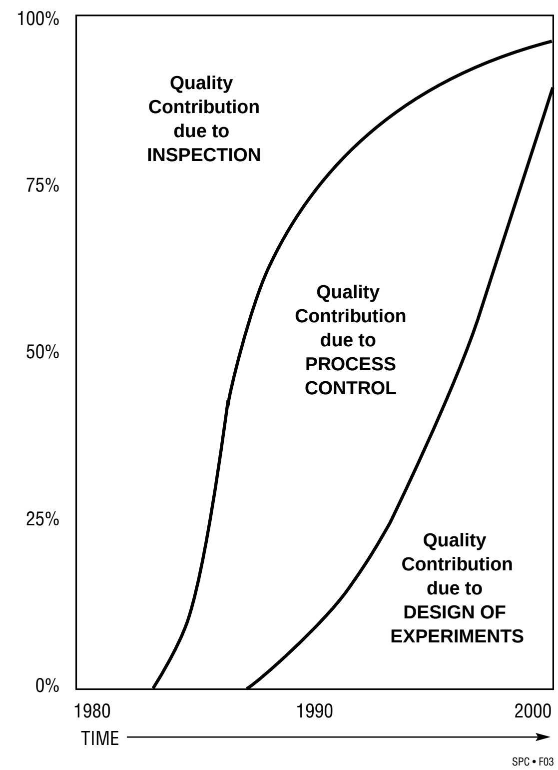

Figure 3. The Semiconductor Quality Evolution

The concepts of SPC and DOE have already been institutionalized within LTC and will provide the methodology to ensure a process of continuing improvement.