# This Week: rf

## It's what makes the protons go 'round. The latest in a series explaining particle physics in everyday language.

Photo by Jenny Mullins

Author Pat Colestock is shown here accelerating past the rf building at FZero in the proton direction. He accelerates $10^{27}$ protons around the ring daily at considerably higher efficiency and lower cost than is achieved in the Tevatron. However, at his mean energy level, the probability of a collision is remote.

*by Pat Colestock, Accelerator Division*

All particle accelerators start from the principle that electrically charged objects experience a force in an electric field. An electric field exerts a force on a charged particle such as a proton, giving it a boost in energy. Electric fields can be steady, like those produced by a battery, or they can oscillate, like the alternating currents that power the electrical machinery around us. Electric currents at higher frequencies generate radio or television waves, as well as microwaves like those that heat food in a microwave oven.

A major accelerator breakthrough in the 1920s came with the introduction of alternating electric fields in the ***r***adio ***f***requency range, making possible the first high-energy circular accelerators. Since then, rf power has been at the heart of virtually every accelerator.

We can produce an electric field simply by connecting a battery to two electrodes. Charged particles between the electrodes will accelerate to the voltage of the battery; a 1.5 volt battery producing 1.5 electron-volts of energy, and so on. However, an accelerator based on this concept would be prohibitively large and costly. For instance, the Tevatron would require nearly a trillion batteries, at a cost approaching the national debt. Instead, accelerator physicists conceived the clever idea of making charged particles travel in a circle, experiencing a relatively small electric field at one point in the circle many times over, receiving a boost in energy with each revolution.

However, we can't use a steady electric field to accelerate the particles in a circular accelerator, because a steady electric field would necessarily point in the wrong direction for part of the particles' circuit—producing no net acceleration. Instead, accelerators use an alternating electric field, with oscillations precisely timed to the revolution of the particles around the ring. Thus, each particle feels only an electric field pointing in the right direction for acceleration.

As a consequence of this alternating field approach, only part of the circumference of the ring at any point in time has the electric field pointing in the right direction. This is why we must accelerate protons not in continuous streams but in bunches, and we must precisely time the bunches to be in phase with the oscillating electric field.

In the Tevatron and Main Ring, the rf systems are all located at the FZero service building. It houses the radio transmitters that produce the rf power that we apply to the beam. To produce the highest possible electric fields for a given available rf power, we use a highly evolved device called an rf cavity—typically a copper, barrel-shaped box with dimensions precisely chosen to exactly confine a radio wave between its walls. As the radio waves bounce back and forth between the walls of the box, the electric fields build up with each reflection, producing voltages up to 120 KV (120 thousand volts) across a short space that intersects the beam particles. Typically we use a series of these cavities, adjusting the timing of the oscillating electric fields in each cavity to coincide with the arrival of a proton bunch, producing an effective electric field wave traveling along with the protons, as surfers ride a wave.

We use a complex network of signal processing to maintain precise timing between the arrival of the beam and the cavity electric fields. Antennas installed near the passing beam sense the location of the protons, sending signals to adjust the timing of rf oscillations in the cavities. Such feedback loops, essential to every rf system, ensure the required precision for acceleration in the Tevatron. Much of the complex nest of equipment that confronts a visitor to the rf building belongs to a series of interrelated feedback loops for the rf systems.

In the future, pushing the energy frontier of high-energy physics will require the development of new methods to generate intense electric fields, to achieve higher energies with more compact, less power-consuming devices. Research on these new ideas has begun at Fermilab, and elsewhere, in the hope that at least one of them will someday usher in a new age in particle acceleration. ■