THE STORAGE STORY

Breakthrough in cathode-ray tubes gives a new dimension to scopes—and a new dimension to Tektronix

I. THE STORAGE MARKET: HOW WE GOT THERE

The development of the laboratory oscilloscope has been marked by a handful of major breakthroughs. Of these, Tektronix probably can claim more than its share—no matter whose list you look at.

And almost every list will include practical storage.

The storage cathode-ray tube not only has added a new dimension to our oscilloscopes—the ability to retain a waveform display—but also has triggered our first product diversification, and the formation of a new division to produce information display and large-screen monitors.

The storage tube may not, as some claim, open the door to a market as large as the conventional oscilloscope market itself. Then again, it may. At any rate, it offers extremely interesting possibilities.

Storage, in an oscilloscope, is the ability to retain the image of an electrical event after that event ceases to exist. This description, while technically adequate, still fails to capture the excitement caused by our development of what we have chosen to call "practical" storage.

Bob Anderson (Advanced Engineering), soft-spoken inventor of the storage tube which bears his name, points out that the tube, although a technical contribution to the state of the art, can be better understood as primarily an economic breakthrough.

For storage, as a phenomenon, has been recognized a long while. Storage tubes of various kinds existed, and some functionally similar to our own were on the market, for years before ours. Our contribution was a tube that was easier to build, sturdier and cost less. So it is that Tek, a latecomer facing a competitor with a virtual storage monopoly, has in less than three years become the leader in that highly promising field.

A storage tube is a cathode-ray tube with special features that let it retain the displayed waveform.

Like any CRT, it has a gun that "writes" the waveform on its fluorescent screen with a hard-hitting electron beam. A second gun then floods the screen with slow-moving electrons, holding the written areas bright and the unwritten areas dark.

(The target is erased by writing the whole screen bright with a positive pulse, then dark with a negative pulse, and the reuseable "blackboard" is once again ready.)

This characteristic—the bright trace and the dark background both being maintained by a single flood current—is called bistability; tubes with only two levels of brightness—dark and light—are called bistable tubes.

Conventional (that is, non-storage) oscilloscopes give you a visible graph of any repetitive electrical event. But one-shot events (like phenomena relating to bomb bursts) generally happen too fast for the eye to see well enough to retain more than a few bits of information. To capture these single transients without storage, you'd have to photograph them as they zipped across the CRT screen.

That used to be the industry's only answer. Thus the storage tube competes with the oscilloscope camera. It has several advantages; one is that you don't have to buy the camera and film; another is that it's reuseable. Also, with a camera you waste a lot of pictures in order to get one you can use.

Not only does the storage tube provide an inexpensive way to retain displays of single transients; it also is useful in studying waveforms of very slow events. For example, a scope display of a loudspeaker's output, graphing loudness against pitch, might require several minutes to draw. On a standard oscilloscope, the slow-moving dot would be hard to interpret, because it leaves no trail; with a storage instrument, the dot draws a graph that stays put.

Of the earlier storage tubes, some merely stored an electrical signal but produced no image you could see. Others did make a visible image, but it was temporary and in halftones—shades of gray. The bistable (black-and-white) tube came later.

In 1947, Dr. Andrew Haeff, working on US Naval research, developed a tube that in many respects was the forerunner of our own.

Haeff's tube had three of the features that ours has: A writing gun, a flood gun and a phosphor screen. It produced only a dim image and it operated at a very limited range of voltage. It wasn't any great shakes, but it encouraged Haeff to go on to more elaborate tubes.

He soon noted this problem:

Flooding the phosphor target with low-energy electrons would store the written waveform — but the image tended to spread across the target face, much like ink spreads on wet paper.

To prevent this spreading Haeff used, in his later tubes, a criss-cross mesh in front of the phosphor and touching it. Each small square of the mesh acted as a barrier to image spreading.

Haeff, working in an industrial laboratory, went on to more and more sophisticated storage tubes, eventually developing a commerical tube with three meshes and two non-conductive layers in the target (one of which was the phosphor). It was highly complex and took painstaking care and many steps to manufacture. But it gave the company he worked for a practical monopoly on bistable storage for about eight years.

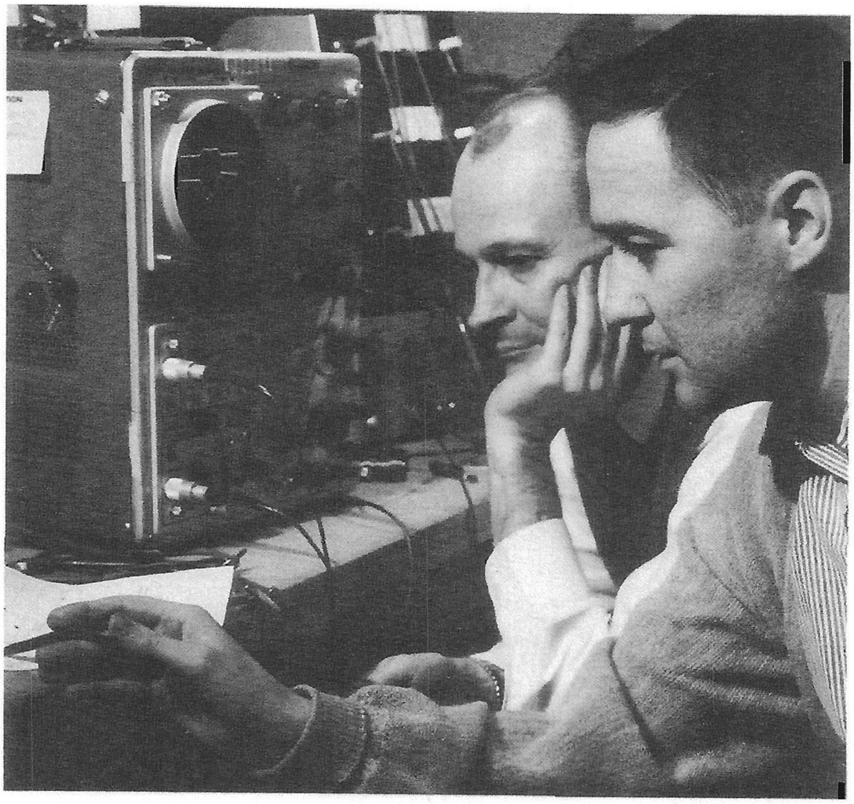
The market for costly, fragile storage tubes wasn't big. The need was for someone to come along with a better, tougher tube at far less money.

Bob, who came to Tektronix in 1959, felt that storage in oscilloscopes would be important, and that the black-and-white bistable tube was a "natural" for scope needs. Working largely independently (interest outside his department came only after he had a special instrument built using the tube), he began to simplify Haeff's tube.

It was then thought that any storage tube required a mesh, to keep the image from spreading.

Bob's early efforts were to place the mesh right on the phosphor target, but use one mesh instead of three. The tube stored, but the mesh was heavy, the image coarse and dim. The tube did, however, confirm the idea that a workable target must be noncontinuous. Bob set about making the tube easier to build by eliminating the mesh. Instead, he tried to build an interrupted, or broken, target surface.

INVENTOR BOB ANDERSON (Advanced Engineering) displays a tableful of storage tubes. Each one was a step in the evolution of what became the tube for the 564 oscilloscope.



JOHN MEPHAM discusses with Bob one of John's major experimental areas, improving the brightness of storage cathode-ray tubes. John developed the process that resulted in a uniform and higher-contrast phosphor target in the first Tektronix storage tube.

The resulting tube had no mesh, just dots of phosphor laid down in rows. This worked, and was simple to make. It might even have become the first Tek storage instrument, had not an even simpler tube been devised, thanks to a discovery made while observing a defect in manufacturing procedure.

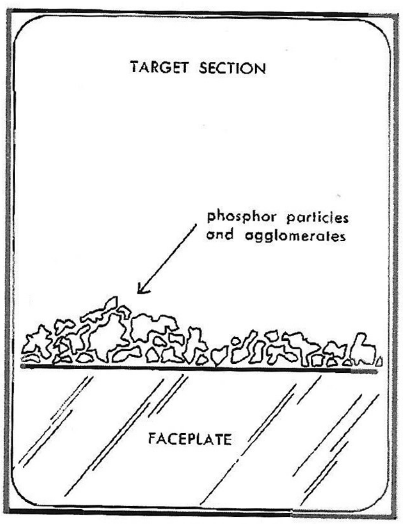
Many dot-pattern targets were made by standing a tube on its face, filling it with liquid and settling phosphor through a mask just above the faceplate. When the mask was lifted and broke the surface, some bits of phosphor would be knocked off and drift down among the dots. It was noted that this "defect" (the unwanted particles) stored a trace.

Experience had taught us that a thick continuous target wouldn't store; the trace kept spreading across the phosphor surface. Now we learned that a thin scattering of particles would store, but only a dim trace.

The ideal target seemed impossible to achieve by scattering: A target thick enough to store a bright trace, yet not continuous. We "knew" that once the scattered phosphor particles piled up thickly enough to store a bright trace they would form a continuous surface, and thus the image would spread.

But it turned out—and this is what made our tube possible—that we were able to build a scattered target that was more than one particle layer thick, but was not continuous.

(We know now that these scattered-phosphor targets are very porous. The particles are irregular in shape, and pack loosely. Thus, they don't touch each other very much. We refer to our target as semi-continuous.)



The range from the lowest to the highest target voltage at which a tube will store a trace is called its stable range. Our tube has considerably wider stable range than competing tubes do, and this is of great commercial importance.

The phosphor target, when written, charges up to the voltage of the faceplate (set on our tube at about 150 volts). In operation, however, faceplate voltage will fluctuate with the age of the tube and with drift in power supply—and target voltage will vary somewhat with position because the phosphor is thicker in some places than others.

If target voltage sinks too low, the written area remains dark. If it gets too high, the background lights up. The wider its stable range, the more likely the tube is to store in spite of unexpected voltage fluctuations.

Once we found that the scattered target could become a Tektronix product, hurdles still remained in the way of producing a phosphor screen that would store uniformly.

Bob credits John Mepham (Advanced Engineering) with a breakthrough in process technology (through use of a proprietary screening technique) that made our phosphor target more uniform, and improved the contrast. The breakthrough came at just the time it was most needed.

Another problem was that the conductive wall bands inside the glass CRT bottles tended to rob electrons from the edges of the screen, creating a dark halo around the target, unless an extra tube electrode was added. About this time, a breakthrough in a separate Tektronix technical area came to the rescue: Development of a flat-faced ceramic CRT bottle, under Bill Wilbanks's direction, which allowed changes in tube construction that eliminated the objectionable dark ring, without requiring the extra electrode. Orv Olson then designed and developed the finished product.

Later, still another vital concept was added by Chuck Gibson. He found a way to improve the writing speed of the dot target by using a new conductive structure near the phosphor. Interest in dot targets revived; it led eventually to development of our new 549, the highest-speed direct-viewing bistable storage oscilloscope on the market.

Our storage instrument has three special performance characteristics worth mentioning:

One, it can form a stored image by "integrating" a number of repetitive traces, each too fast to store by itself.

Two, it has a horizontally-split screen, allowing comparison of a stored and an unstored waveform, and separate erase of two stored traces.

Three, it makes it easy to repeat a stored scope trace at some remote location on an inexpensive monitor (a TV screen, for example.)

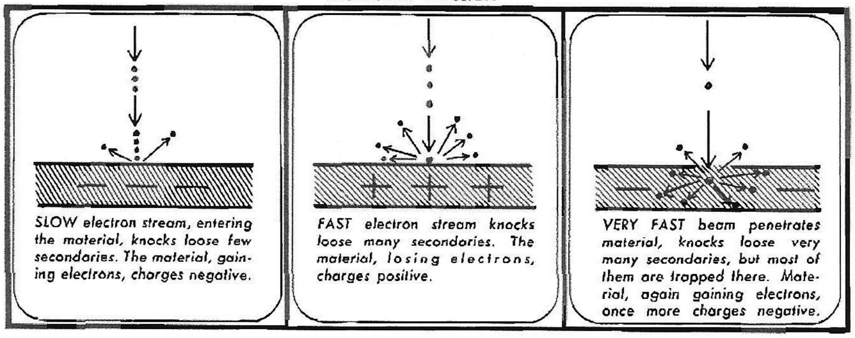
These features, plus the tube's simplicity and low cost, open the door to a wide variety of possible applications, within and outside the scope industry. These possibilities (some of them described in Part III) are as varied and as far-ranging as the imagination of the engineer.

II. THE STORAGE TUBE: HOW IT WORKS

(To understand storage, it's well to remember these electronic principles:

1. A surface with too many electrons (called **negatively** charged) tends to repel electrons.
2. A surface with too few electrons (said to be **positively** charged) tends to attract electrons.
3. Electrons flow from the more negative to the more positive area, at a velocity determined by the difference in voltage between the two areas.)

SECONDARY EMISSION



SLOW electron stream, entering the material, knocks loose few secondaries. The material, gaining electrons, charges negative.

FAST electron stream knocks loose many secondaries. The material, losing electrons, charges positive.

VERY FAST beam penetrates material, knocks loose very many secondaries, but most of them are trapped there. Material, again gaining electrons, once more charges negative.

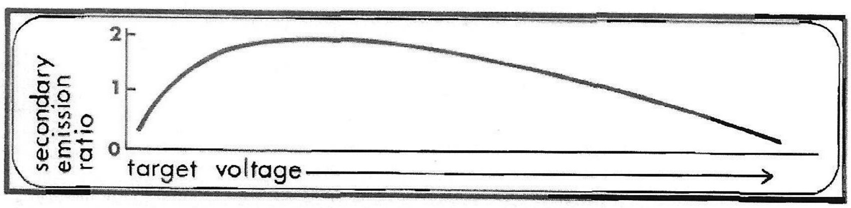
Storage occurs because of **secondary emission,** the effect of a stream of electrons (called **primary** electrons, or primaries) striking a material and knocking loose other electrons (called **secondaries**) from the surface.

At low velocities, few secondaries are thus emitted. But if velocity increases, the incoming stream hits harder. When it is so fast that each primary knocks away more than one secondary, the material—now losing electrons—charges positive.

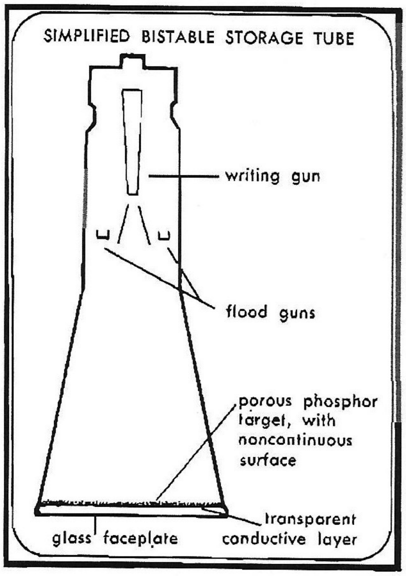
You might expect this to go on and on—the harder each primary hits, the more secondaries it discharges. But somewhere around the point that each primary is knocking two secondaries away, the ratio (2:1) begins to diminish.

Why? Because the primaries now hit so hard that they dislodge secondary electrons deep within the material. Unlike those on the surface, these secondaries can't escape. Past this point, voltage increases mean more secondaries trapped, fewer emitted. When voltage is high enough, the material once more is gaining electrons, and again charges negative.

This secondary emission curve, when plotted, looks about like this: It shows that electrons striking a surface, over a range of voltage, will drive it negative at low voltage, then positive, then negative again at high voltage. The fact that they will do this, is a prime reason why a storage tube stores.



Our storage tube looks like this:



It's much like a conventional CRT, with these special features and added parts:

1. A flood gun that covers the entire phosphor screen with a slow stream of electrons.
2. A phosphor layer that (unlike the phosphor on a standard CRT) is only semi-continuous, or porous.
3. A conductive transparent faceplate under the phosphor to collect secondary electrons.

The tube works this way:

It has two electron guns instead of the usual single gun. One gun writes like any CRT does: It bombards the phosphor screen with a focused electron beam, at very great speed. The phosphor lights up; this dot of light, moving across at high speeds, appears as a solid line. This is the waveform you see.

The beam, as it writes, also does another thing: Hitting with tremendous force, it knocks loose great numbers of secondaries. Thus, the written surface (where the waveform is), losing electrons, charges positive.

Now the graph can be stored, using the second electron gun:

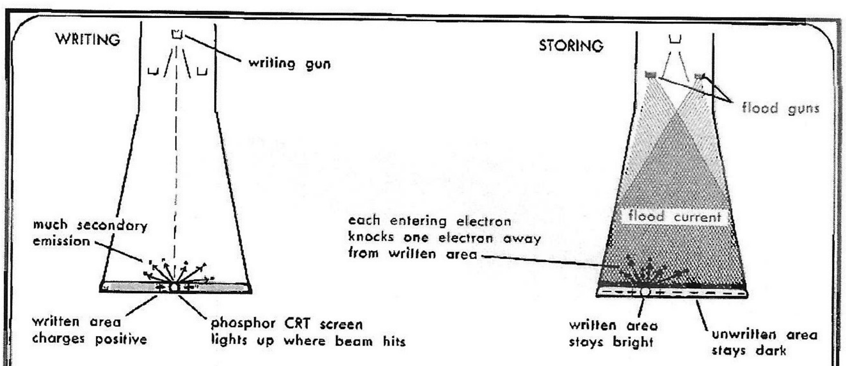
This flood gun emits a low-energy stream of electrons over the whole screen. They hit the unwritten areas too slowly to jar loose many secondaries. These areas merely collect the electrons until they're driven negative, and can attract no more current.

But the invisible charged image, where the beam has written, attracts the flood electrons at considerable velocity—hard enough not only to keep the phosphor bright but hard enough also that each entering primary knocks loose one secondary. Thus the written area neither gains nor loses electrons, and remains positive—able to keep attracting the flood current; thus it can store the bright trace as long as you need to.

(You may compare the action of the primaries on the charged areas to the action of a strong stream of water falling from a height into a cup. It will never fill the cup, because its own force keeps splashing some water out.

Another cup, held close to the faucet, would be filled by the same stream.)

This, then is the phenomenon of storage: The same flood current that holds the background dark also holds the written trace bright—and it will do so as long as you want it to.



WRITING GUN bombards screen. High-energy electrons light phosphor, and also knock loose many secondaries. Written area, losing electrons, charges positive.

FLOOD-GUN electrons hit unwritten areas too slowly to light phosphor. They merely accumulate, driving areas negative. But written area (positively charged) attracts electrons at high speed, keeping phosphor lit, as well as knocking enough secondaries away to ***hold*** *area positive.*

III. THE STORAGE CAPABILITY: WHAT IT OFFERS US

Storage may not revolutionize either oscillography or communications. But it will surely provide them both with an exciting new dimension.

Storage opens many doors. Some may lead nowhere. But even a partial list is impressive. And if some are only possibilities, others equally exciting are already in the works.

The biggest economic benefit, prosaic though it sounds, is simply that we'll add storage to more oscilloscopes. And continued basic improvements to all storage tubes—in brightness, contrast, stable range and writing rate—also will mean market gains.

In addition to oscilloscopes, the simplicity and low cost of the Anderson tube make it a ready component for a wide variety of other instruments and devices that otherwise couldn't add storage without becoming prohibitively complex.

Our tube, unlike competing ones, may be built very large, since it has no storage mesh, as they do. Large tubes, for strength, must have curved faceplates. Many competing mesh tubes require flat faceplates, and thus are limited as to size.

The size limit on our storage tube is mostly economic. Above a certain size, tube cost goes up steeply, and potential customers decline. But we know that a large tube will have many uses. An obvious one is Tek's display instrument, which when marketed will transmit, store and display images of typewritten material and can also provide the viewer a permanent page of copy.

Our storage monitor for computers also will use the large tube. So may radar installations—or any application that requires the stored display of a highly readable image.

But the most intriguing storage-related area is electrical **readout**—transmission of a stored scope signal to be displayed on some other viewing device. To give an idea of its importance, readout has been said to be as great an enhancement to storage instruments as storage was to non-storage instruments.

Readout will allow enlarged display of a stored signal, on an inexpensive monitor, or many monitors, at remote locations (like seeing a scope signal from Beaverton on a dozen 21-inch TV monitors in New York.)

More than that, readout will allow "windowing"—selective magnification on the monitor of a part of the stored signal. You may also add or subtract signals on the monitor (one bright and one dim, or maybe in different colors). In a highly computerized operation you may be able to set "go/no go" limits on the monitor, to automatically reject or accept, say, an electronic component being tested.

Storage also may be coupled to another kind of device, the image-intensifier. The Army's "sniperscope", an infra-red night-vision telescope, is one example. Night-viewing field glasses are another. Still another image-intensifier may "see" jet planes at night by the heat of their exhaust. The intensified images might be retained by adding a storage tube.

The US armed forces have stepped up their image-intensifier program, keeping pace with recent Russian expenditures in the field of night-viewing devices.

Another probability is development of a simple halftone stable storage tube, one that will store in ranges of gray, until erased. The much-discussed telephone-vision device (that lets you see the other person on the line) might use an inexpensive tube of this sort.

In oscilloscopes themselves, storage possibilities are many. (It must always be remembered that any, or all, may fail):

A pocket-sized storage scope;

A tube that will store a dark trace on a light background; one that has a white rather than a green screen; one that can erase any portion of a stored signal, and rewrite it; or one that combines these features;

A "no-penalty" tube that allows storage without diminishing any of the scope's conventional (non-storage) performance. (All storage scopes to date have had to compromise these conventional features);

A tube that combines storage with a character-writing electron gun, which writes the electrical measurement on the screen in numbers and letters. Another that (instead of comparing stored and unstored signals on separate halves of a split CRT screen) superimposes the waveforms. This feature (now available in other more expensive storage tubes) is called "write-through";

A scope with an ultra-rugged storage target. What for? The nickname gives a hint: The "Apolloscope." Any instrument package which would be placed on the moon had better work when it gets there.

Not every bright idea creates wild enthusiasm. One that doesn't is Bob's concept of a "migrating image" tube, in which the stored waveform can be moved after storing. The image would pass across the screen like a ticker tape. The operator could stop it and record any portion that interested him.

"The idea combines two features," Bob grins. "It's almost impossible to build, and no one seems to want it." But he feels it shouldn't be forgotten, since it's a basically different kind of display. ("The guys here think it's a big joke; I think it's only a little joke.")

And so runs the profusion of storage ideas. Some may never materalize; others, undreamed of now, will emerge. But the message is strong and clear:

Storage is here to stay, and is bound to extend and enrich the science of communications. It opens many doors indeed.

And as for the oscilloscope art itself—it will never be the same.

IV. THE STORAGE MAN: WHAT HE THINKS

"If more than half of our projects succeed," says Bob Anderson, "We've chosen the wrong projects."

He makes the storage tube sound so simple you feel you could go home and build one yourself if you didn't have to wash the car instead. And he talks intently about applied research and the inventor's role in a company.

Too often the inventor is pictured as a "nut in an attic", he says, or "Research" may call to mind "a bunch of people sitting around 'analyzing' a grain of sand for a lifetime, then publishing papers."

Such stereotypes aside, he feels the applied researcher must be highly product-oriented, a hard-headed as well as creative individual.

Bob says his Advanced Engineering group's task is to attempt to make the occasional big breakthroughs that can't be scheduled on a regular basis in other groups. Of course, when you try to jump higher, you fall harder—and more often.

There are those who envy what they conceive of as the inventor's carefree life: Freedom to help pick projects and to "play around" with way-out ideas. But they forget that the inventor is not free to stop; unlike most of us, he can't turn to routine, predictable jobs for a change of pace from the frustrations of the way-out projects. He is stuck with trying to invent something all day, every day—and he has agreed with his boss that his pay depends on the results.

If most of the inventor's projects succed, he's not "trying for the hard ones." A natural part of his work is a constant stream of failures.

Tek is full of people who are inventive and who feel they'd thrive on a free-wheeling creative atmosphere. Some of these people may have only half the requirements. What Bob also seeks is the person who can "help decide what's worth doing;" who can tell a legitimate problem from a spurious problem when he sees one (most people can't, he feels; "It's like fools gold") and who can stand to see a year's work end in failure.

He seeks those who "steer" an active imagination with calculating judgment; who know when to drop a project (many people can't), but who will doggedly pursue the "right" ones. After all, the inventor of the submarine had six subs sink before one didn't.

"The inventor's two principal tools are his attitude and his imagination. He need not be super-educated or super-intelligent, but he must be optimistic—and flexible, able to avoid 'freezing' on a single approach to a problem."

An oscilloscope user may come up with suggestions on making a product easier to build. A customer may suggest another knob, or greater bandwidth, on his scope. But these people typically lack the experience, Bob says, to suggest the big breakthroughs.

"We're not uninterested in their problems," he explains, "but we can't make it our personal obligation to let those kinds of ideas dominate our work. They would put us out of business when the competitor makes his breakthroughs."

Where do the inventor's ideas come from? "Sort of from nowhere, or everywhere" he says, in the same whimsical way he describes his inventions as "simple-minded ideas".

"A good idea comes in two parts, like twins: A good problem and a good solution. The first part, good problems, have to be collected and hoarded over the years."

Bob's concept of an ideal organization is one that gives the researcher more access to other exploratory people, even at the high price of less contact with developmental and production people. He feels that many companies, by the place they assign the research function in their organization, show their "uncertainty" about it. "It seems to be human nature to be uncomfortable about this activity—even after its profitability has been established."

Although the inventor may get ideas "just nowhere", he must be hard-headed enough to pick those which will be worth most, and to sift the impossible from the nearly impossible.

Bob calls his 10-man group "program-oriented" (as well as product-oriented) in that it's not restricted to one project, or a few. Its backlog of ideas now exceeds 170. Each project must be chosen from many proposals. Selection is not at all a matter of the inventor's whim. Projects are sometimes chosen, as a matter of fact, according to a formula that yields what he calls an "E rating:"

$E = P \times D$. **Expectation** (from the project) equals **Probability** (of its succeeding) times **Desirability** (to the company).

Some high-rated projects which have become Tektronix technology include the bistable storage tube; the split storage screen; electrical readout of stored oscilloscope signals; the dot storage target, and others somewhat less familiar or not yet at the product stage.

As soon as the inventor can demonstrate that the project will work, he bows out and development people take over. Are there still "bugs" in the invention? Often there are many; sometimes the hard part is just beginning. Why, then, doesn't the inventor follow through?

Partly because the transition from the research to the development stage provides a useful re-evaluation point—a fresh look by new people. Partly because even an invention that works may still fail, for economic reasons. But mostly because the time he'd spend "debugging" would cause Tek to sacrifice four new research projects.

Another way to say it is that research people and development people become different breeds of cat as they gain experience. The best use of the inventor is in doing the particular strange chore cut out for him.

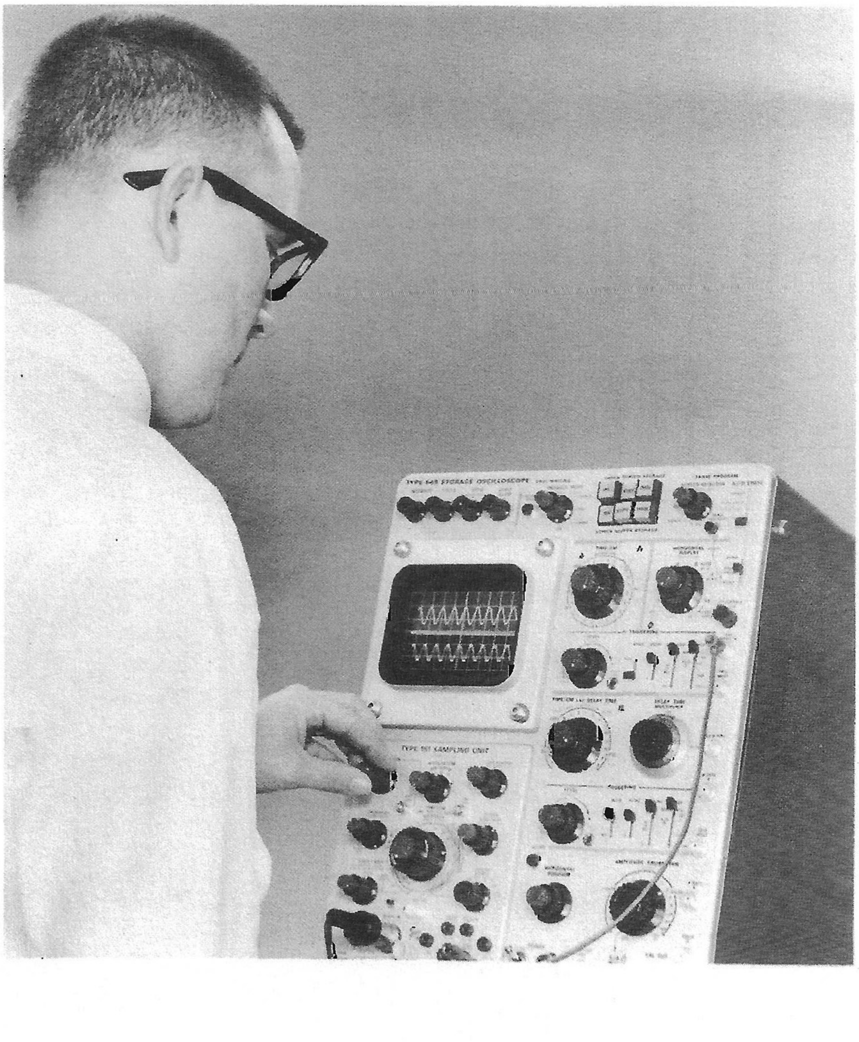
Bob sums up the contribution of his group in this way:

"We are firmly rooted in Tektronix history, building on its foundations. Dick Ropiequet (former Future Products manager) taught us to keep our eyes firmly on new-product objectives. Jean Delord (former Research manager) taught us to be balanced, to be program-oriented; you aren't taking a real company responsibility with just one or two projects.

"I like to think that my contribution is a strong emphasis on planned problem-sensitivity; knowing where your next project is coming from, how it was chosen and who wants it.

"We have a backlog of more thoughtful project proposals than we will live to work on. That's like money in the bank for our group—and for Tek, too, I hope."

"A big portion of what we will attempt to do will be beyond us," Bob Anderson admits. "But we must always work over our heads."



TEKTRONIX' "SECOND GENERATION," storage instrument is the type 549 oscilloscope, introduced last fall. It offers split-screen storage, high writing rate and 30-megaHertz bandwidth, and it can accept a large variety of existing plugin units—a combination available in no other oscilloscope.