Thank you, Anantha-san.

Good evening, ladies and gentlemen. And a happy 60th anniversary to ISSCC2013. And a happy 60th anniversary to ISSCC2013.

I thought I was invited as an old boy for this special occasion since I had been involved and served for many years in this ISSCC community. But I received a homework and was asked to prepare for a short talk on this panel. It was a very difficult subject. So, the first thing I did was, look around for my old subject. So, the first thing I did was, look around for my old books and notebooks in my house and office.
(2) I found some, I sorted them out, and put them together on my bookshelf. Here they are.

This evening, if I am allowed to introduce you only one unique circuit application, it would be a circuit application of a p–n–p–n diode structure. In a normal operation mode, this device works as a Thyristor, which can drive a large current and can make even a big linear motor car float and move very swiftly. On the other hand, when this is in off-state, it has very, very small leakage current, which is very important for our modern society seeking for low-power. Energy-saving systems. And in a dynamic operation mode, this device may work as a simple p–n–p–n capacitance, that can detect and store one single electron. I think this is a key device of an image sensor.

(3) There are many physics involved to understand this p–n–p–n diode structure and its related circuit behaviors.

So I tried to recall my freshman year in college, when I was taking a physics course. Prof. Leighton, and sometimes Prof. Feynman himself, gave us lectures. Their lectures were always fascinating to us. They always tried to appeal intuitively to our young minds.

Feynman once said that an electron is always free, moving around rapidly in free space, even in a solid, and it never stops. It is very hard to catch. We don’t know exactly where it is. Our civilization is based on the catch. We don’t know exactly where it is. Our civilization is based on the technology of controlling a single electron.
(4) So I was always being guided to try to understand physics by paying special attention to the behavior of one single electron interacting with a photon in a solid, in a metal, in an insulator, in a capacitor, in a p-n junction and in a transistor. A p-n junction is also called a diode, a rectifier, a LED, a solar cell or simply a p-n junction capacitor depending on how we want to use it. If we don’t want to use, but if it is still there, I learned later that it is also called a parasitic p-n junction capacitance, which is a very important circuit element for predicting a very complicated VLSI circuit performance in some cases.

(5) I thought I had a very good background in Feynman physics. Feynman physics always talked about the behavior of one single electron in free space and in a solid. The situation gets more complex when an electron interacts with a photon. Well, a picture is worth one thousand words.

This is a picture of boys trying to catch a girl on the hill top but most of the boys are guided to the collector junction cliff and fall down to be collected at the collector terminal. And only a few boys out of say 100 energetic boys can catch a girl on the hill top and they can recombine can catch a girl on the hill top and they can recombine and become happy. And the pair can produce a baby-photon. This is in a sense a light-emitting photo-transistor with a very poor efficiency of a few percents.
(6) And this is a picture of an incoming photon incident to the bipolar transistor base region. The photon energy creates an electron-hole pair and the photo-electron can be stored in the base as the majority carrier. So I see that a bipolar transistor can also function as a photon detector and/or a storage container. As you know, a room in a hotel must be empty and clean before the first hotel guest arrives. So must be this transistor base region empty and clean with no guest electrons this transistor base region empty and clean with no guest electrons at the beginning. In this way, I thought a transistor is useful since it can capture, confine and control one single electron. But I did not know yet how to move that single photo-electron in the base container to the outside terminal so that we can use it as a signal. That is, I had no way yet to know whether the guest has checked in the hotel and resting in the hotel room. I had no way yet to ask the hotel guest to come up to the hotel room. I had no way yet to ask the hotel guest to come up to the hotel lobby to meet me. I had to wait a few more years to find the answer. We all know now it is CCD, a charge coupled device that is a series of capacitance that can store and transfer one single electron. With a output circuit of a pre-charge reset set gate and a source-follower circuit we can finally meet our hotel guest at the hotel lobby!

(16) But soon I found out this is not good for imaging. It has a metal layer on the top! The metal layer does not allow light to pass through. So we still needed the original photo-diode, the photo-transistor, and the p-n-p-n photo-diode that I had studied when I was an the p-n-p-n photo-diode that I had studied when I was an undergraduate student. At least they can pass the light through the device and catch a single electron in the dynamic capacitance mode of their operations.
(11) Then the third book I studied, with the guidance of Prof. John McCaladin, was "Physics and Technology of Semiconductor Devices" by Andy S. Grove.
When I was about to start my graduate work, I learned about a new device called CCD. I thought we now have a device to detect the arrival of the first guest electron in our empty hotel room! With this device I thought I could ask the guest electron to come up to the hotel lobby to meet us! I was excited. I thought this is the device we were looking for, that can transfer one single electron in solid from one place to another and to the final output circuit stage. I was excited, and many people were also excited! Many researchers worked on this device with great expectations. I was excited and worked on this device with the guidance of Prof. T.C. McGill.
I became specifically interested in a buried channel CCD structure since this device protects a single electron, our important hotel guest, from being trapped by the Si-SiO2 interface states. I analyzed how the electron charge move in the buried layer of BCCD structure by computer simulation, done at JPL Caltech Pasadena, with the guidance of Prof. T. C. McGill and Prof. C. A. Mead in Caltech. And, I published my PhD thesis work on buried channel CCD at ISSCC1974, in Philadelphia, USA.
Yoshiaki Higihara: The p-n-p-n Diode in Future Linear Motor Cars and in Modern Imagers

John Louis Moll (1921–2011) was studying a p-n-p-n diode switch in his Ph.D. dissertation work when the first ISSCC was held in 1954. In a normal operation mode, this device works as a thyristor, which can drive a large current and is the key device structure of an IGBT applied for a linear motor car of the future (see Figure 9). In a dynamic operation mode, this device may work as a simple p-n-p-n dynamic capacitance that can detect and store one single electron, which is a key device structure of the modern image sensor (see Figure 10).

I recall, when I was taking his physics course at Caltech, that Feynman once said that an electron is always free, moving around rapidly in free space, even in solid, and it never stops. It is very hard to catch an electron because we do not know exactly where it is. Our civilization today is based on a technology that controls electrons, down to a single one.
Imagine a photon incident to a bipolar transistor base region. The photon energy creates an electron-hole pair. And the photo-electron can be stored in the base region as one single majority carrier. That is, a bipolar transistor can also function as a photon detector and/or a storage container. I thought that a room in a hotel must be empty and clean before the first hotel guest arrives. So must be this transistor base region empty and clean with no guest electrons at the beginning. This transistor in a dynamic p-n-p capacitor mode is useful since it can capture, confine, and control one single electron. But as a student, I did not know yet how to student, I did not know yet how to move that single photoelectron sitting in the base region to the outside world so that we can make use of it as a signal. I had no way yet to know whether the hotel guest has arrived and is resting in the hotel room or not. We had no way yet to ask the hotel guest to come up to the hotel lobby to meet me. I had to wait a few more years (until 1970 in my senior year in college) to find the answer. We all know now it is the CCD structure that can store and transfer one single electron. With a precharge reset set gate and With a precharge reset set gate and a source-follower circuit, a scheme invented by Walter Kosonocky. We could finally meet our hotel guest at the hotel lobby.
Antiques from the Innovations Attic

Rousing nostalgia for the IC yesteryear, panel organizers Trudy Stetzler, Bram Nauta, and Anantha Chandrakasan said in their Conference Digest overview “When you clean up your attic you may find things that you have totally forgotten about: old toys you used to play with, old books with lost stories. And then you think back to those past days and view them in the context of today’s busy life, and sometimes find new uses for forgotten items. This panel does a similar thing.”

The six experts they invited from academia and industry “to dig into their memories and find lost treasures in circuit design” were asked specifically “to reveal circuits and concepts that they feel are the most interesting, intriguing, and under-appreciated innovations from the past” and to “explain why the concept is significant today and should be pulled from the innovation attic.”

Their confab, which drew an estimated 2,000 people on Monday evening, offered many notable remembrances:

Eric Vittoz highlighted “current-mode analog circuits in weak conversion” as those seldom used in the past because of their poor precision due to threshold mismatch. But these circuits, he said, may regain interest in deep submicron processes where larger-than-minimum devices could be used to reduce threshold mismatch.

Coincidentally, Rinaldo Castello also highlighted current-based
processing as the antique from the past with renewed appearance as what he termed “pipe” processing and “pipe” filters.

Robert Brodersen offered time-domain processing as his “basic attic idea” and how this could be used to attack the most important problems of radio design. He pointed to impulse radio and active cancellation as “two time-domain projects from the attic.”

Nicky Lu picked core memory as an antique that is now resurfacing as spin-torque transfer magneto-resistive random-access memory (STT-MRAM).

Yoshiaki Hagihara shared his memories of Richard Feynman, his mentor and educator at Caltech, and how he learned from him that control of electrons is at the heart of all electronic devices. As an example from his attic, he pointed to the old p-n-p-n junctions that are now incorporated in modern-day image sensors.

The last speaker of the session, Thomas Lee, focused on the mysteries and misunderstandings surrounding the linear time-varying (LTV) circuits where the Laplace transform in its simple form cannot be used for analysis. Examples from his attic were super-regenerative amplifiers and parametric systems.

A full-length accounting will appear in this magazine in the Summer 2013 issue.

—Ali Sheikholeslami
ISSCC Educational Events Chair