ONE HUNDRED YEARS OF RADIO

In the beginning there were radiowaves. And I mean the very beginning. Science and religion disagree about many things, but on this point, they explicitly concur. For example, The Book of Genesis, in recounting the creation of the world, says that on the first day, "God said, 'Let there be light'." That's probably a paraphrase. What the Creator might really have said was, "Let there be electromagnetic waves at micron wavelengths propagating at three hundred million meters per second". In other words, radiowaves from Day One.

Now, the Genesis version of creation is not that widely accepted here at the end of the Second Millenium, so what does science tell us? It tells us that the world began with a Big Bang, accompanied by a blinding flash of light. Either way you look at it, radiowaves from the very beginning.

If anyone here is nervous because my historical overview is starting so far back in time, you can relax. We humans came along much later than radiowaves and, even then, remained unaware of their existence until very recently. So I can skip ahead a few billion years without leaving anything out.

In the mid-1860's, the Scottish mathematician James Clerk Maxwell postulated that a changing electric field induces a magnetic field, just as Faraday had found that a changing magnetic field induces an electric field. Putting these two ideas together, Maxwell produced a pair of equations whose solution predicted electromagnetic waves propagating at the speed of light! This theory was profound in its implications but at first unproven.

A little over 20 years later, the German physicist Heinrich Hertz proved in the laboratory that Maxwell was right. Brilliant as he was, however, Hertz seems to have missed a key point. Observing that radiowaves could not propagate efficiently at low frequencies, he concluded that radio could not be a reliable medium for transmitting telegraph signals. What he missed, of course, was the idea of the high-frequency radiowave as a *carrier* of low-frequency information signals.

Enter Marconi. Merging scientific knowledge with engineering inventiveness and entrepreneurial vision, he set out to prove and exploit the commercial possibilities of radio (called *wireless* back then). His specific target was wireless telegraphy, whose creation he pioneered and for which he received the 1909 Nobel Prize in physics. One hundred years ago today, at nearby Twin Lights, he publicly demonstrated the practical use of wireless telegraphy, and the radio communications revolution was on.

In a prophetic twist, the transmissions received at Twin Lights that day were not the ones Marconi had planned. According to his daughter's account, the planned-for transmissions from two ships at sea were to report on the progress of the America's Cup yacht race off Sandy Hook. However, Commodore Dewey and his fleet made an appearance on their triumphant return from Manila following the Spanish-American War. The America's Cup Races were temporarily postponed and the shipboard transmitters reported, instead, on the progress of Dewey and his fleet sailing up the Hudson River.

This turn of events can stand as a metaphor for the twists and turns of *any* revolution once started. Marconi's demonstration was followed by developments in electronic amplification, wave filtering, and methods of modulation and detection; these enabled further great advances in, and uses of, wireless transmission: commercial broadcast radio, long-distance telephony, radar, television, satellite communications and, of course, wireless communications in its present-day meaning. Despite the evolution these past 100 years from copper wires to coaxial cables to optical fibers, radio is still the best solution for many communications needs and the *only* solution for some. As Marconi famously said, "It is dangerous to put limits on wireless", and so his revolution lives on.

Needless to say, not all revolutions please everybody. Marconi is the godfather to the BBC and the Fox Network, rock stations and classical FM, National Public Radio and talk radio. Whatever you like or don't like on this list, I guess you can thank or blame Guglielmo Marconi. But there is no doubt that what he started changed the world forever. I'll give you two examples that have impressed me.

In 1865, as Maxwell was developing his theory of radio waves, President Lincoln was shot and killed in Washington, DC. It took days, maybe weeks, for the news to reach the four corners of the earth. Ninety-eight years later, President Kennedy was shot and killed in Dallas, and the whole world knew about it in minutes. The difference was radio.

The second example is the fall of Communism in the late 1980's. History will cite many causes for it, but I believe a major one is that radio signals, beamed across national boundaries or down from satellites, brought sounds and images to the people of eastern Europe and the USSR about the world outside. In this way, they learned of the freedom and prosperity being enjoyed by others, defeating the best efforts of their leaders to control the information they received. This created social and political pressures that hastened the collapse of the Soviet empire. Here again, radio made the difference.

There is another enterprise that began 100 years ago, one closely related to the practical uses of radio and also close to my professional heart. It is the science and study of radio propagation. Marconi and his colleagues knew well the importance of understanding how radio signals propagate between two points. Only with that understanding can one design a system to have the desired range and performance at the least possible cost. From the beginning of radio, every time a new system has been built in a new band, or in a new environment, or for a new service, major new questions have had to be answered about the nature of the radio propagation. It was true for Marconi's wireless telegraph; it is true for today's cellular systems; and it will be true for as long as people dream up new ways to use radiowaves. Propagation is different at 6 GHz than at 850 MHz; indoor propagation differs from outdoor propagation; fixed wireless paths differ from mobile ones; and so on.

I have engaged on and off in the study of radio propagation throughout my career. Although interesting just from a scientific standpoint, its main attraction to me has always been utilitarian: How much do we need to know to design or analyze a particular radio system? This mindset can make one impatient to learn the propagation quickly and then move on. Yet, Nature often reveals her secrets on a timetable different from ours.

In the 1980's, I had the pleasure of working with Donald Cox at Bell Labs, before he went off to Bellcore and then Stanford. Don was and is, in my view, one of the very best propagation researchers in the world, and he has produced invaluable results for cellular radio, satellite communications and PCS. He may remember that I used to question him about the value of all the time and effort that went into studying propagation. Never at a loss for a firmly held opinion, he would answer, "Before we can build a new radio system, we have to understand the propagation". And, of course, he was right.

Andy Viterbi told me not long ago that he often impresses on his Qualcomm colleagues the importance of first knowing the radio channel. And, of course, *he*'s right.

I assume, with some confidence, that Fumiyuki Adachi and his colleagues at NTT DoCoMo, Dick Frenkiel and his WINLAB colleagues, and David Goodman and his radio colleagues at Polytechnic University, all share this general sentiment. If so, then of course, *they're* right.

I myself have recently completed, with my colleagues at AT&T, an ambitious study of propagation on fixed wireless paths, for applications such as wireless local loops. This effort has yielded a large body of results not previously available and very relevant to the design of fixed wireless systems. Having learned from experience and the wisdom of others, I believe this was

a very worthwhile investment in understanding this very different kind of radio channel. And, of course, *I'm* right.

I'll return briefly to this point, but first let me return to Marconi. One hundred years ago, he and his contemporaries stood at the end of the century of Napoleon, Bismarck, and Lincoln, of the Victorian Era, the Meiji Restoration and the Industrial Revolution. Peering ahead, they could not possibly have predicted all the marvels *and* horrors of the coming century. Now, here we all stand at the end of that wonderful and terrible century, and the folly of predicting the next century is even greater, because technology and society are changing so rapidly. Bob Lucky has often warned of the perils of prophecy, but that hasn't stopped him from doing it anyway. I can heed his warning or follow his example; either way I'm in good company, so I think I'll try some easy predictions.

I predict that the world of the future will be more democratic. I don't mean the "end of history", with all the major ideological issues settled and the world blended into one peaceful, Internet-surfing, global consumer society. The world has never been that boring and probably never will be. But I do believe that a major feature of the next century will be the distributed nature of information and ideas. Such a process is inherently subversive, and the coming 'information democracy' will be messy and chaotic, as democracies always are. But the ability of tyrants to limit and control access to information will be curtailed. That genie is probably out of the bottle for good, at least for any country that means to compete in the global economy. Believing, as Churchill said, that "democracy is the worst possible system, except for all the others", I expect the ultimate effect to be a better world. And I predict that when future historians ponder the causes of this more democratic world, one of the paths they trace will lead them back to Marconi's radio demonstration near here 100 years ago today, and to the communications revolution that followed it.

Finally, what about that other, more modest, enterprise that Marconi started 100 years ago—the science and study of radio propagation? I predict that, at some future time, in some country, some researcher at some laboratory will be equipping a measurement van and preparing to study propagation in yet another band, for use in yet another environment, for yet another kind of service. And that researcher will be told to finish quickly and get on with the business of designing, analyzing and building some new radio system. And the researcher will say, "Yes, but before we can build a new radio system, we have to understand the propagation."

And, of course, she'll be right.

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