

AM V. FM: The Battle of the Bands

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1. Introduction

Between 1946 and 1948, the number of Frequency Modulation (FM) radio broadcast stations authorized by the Federal Communications Commission (FCC) increased from 456 to 1,020 and the number of licensed stations increased from 48 to 142.¹ In its Annual Report for 1947, the Commission observed that: "The fiscal year witnessed a tremendous spurt of activity in FM broadcasting, further demonstrating the important role this new and superior broadcast service is assuming in the postwar era."²

The Commission was not alone in its view that FM would soon make a significant contribution to radio broadcasting. Indeed, some industry participants apparently believed that FM might replace Amplitude Modulation (AM) as the dominant form of delivery of radio programs. For example, in 1945, Paul W. Kesten, then Executive Vice President, Columbia Broadcasting Systems wrote:

...I believe that FM is not merely one aspect of the future of audio broadcasting-but that it contains in itself almost the whole future of audio broadcasting. Most of us at CBS have believed, from the very early days of FM that, except in certain rural areas, FM was technically destined to replace AM transmission, as surely and inevitably as the tungsten lamp was destined to replace the old carbon filament.³

¹Broadcasting/Cable Yearbook '89, H-58,59.

²Federal Communications Commission, Thirteenth Annual Report, Fiscal Year Ended June 30, 1947, Washington, D.C.: U.S. Government Printing Office., p. 20.

³Kesten, Paul W. and Stanton, Frank, The Transition From AM to FM Broadcasting, Statements before the Federal Communications Commission, Docket No. 6768, Washington, D.C., July 30, 1945, p. 1. Note that Armstrong makes the identical point: "I have long been convinced that given a free hand FM would rapidly supersede AM, except in certain remote areas where an AM station could perhaps

Similarly, J.E. Brown, Assistant Vice President, Zenith Radio Corporation, testifying before a Congressional committee in 1948, noted that:

An accurate analysis of the status of FM broadcasting toward the end of the war would be that it had been tried and proven, was found satisfactory and was destined to become the great new postwar development in radio.⁴

Even after the FCC shifted FM from the 42-50 kHz band to the 88-108 kHz band in 1945, leaving owners of FM receivers "stranded" with receivers that would soon be unable to receive any FM broadcasts and requiring existing FM station owners to modify their transmitters, enthusiasm for the new technology continued. In February 1946, in the inaugural issue of a trade magazine devoted to FM, the publisher wrote:

The new vistas opened up by this great new development stagger the imagination. Thousands of additional stations will be built, all capable of superior signals, many emphasizing community interests and specialized interests, the whole of them destined to give the radio listener greater diversity and a wider choice of programs.⁵

Moreover, a number of industry participants saw FM as a way to overcome the competitive handicap they faced in AM. For example, this was the view of ABC, which had obtained NBC's least attractive

serve the territory more economically." Radio Frequency Modulation, Hearings before the Committee on Interstate and Foreign Commerce House of Representatives on H.J. Res. 78 (A joint Resolution Relating to Assignment of a Section of the 50-Megacycle Band of Radio Frequencies for Frequency Modulation (FM), Eightieth Congress, Second Session, February 3 and 4, 1948 [hereafter cited as Radio Frequency Modulation], p. 38.

⁴Radio Frequency Modulation, p. 48.

⁵M. Codel, "A New Industry...A New Journal," The Journal of Frequency Modulation, 1, February 1946, p. 4.

affiliates when NBC had been forced to divest one of its two radio networks in 1941. A trade press report in 1946 noted that "ABC President Mark Woods, during an FCC hearing on the network's expansion plans testified that he sees in FM the only way ABC can match NBC and CBS power-wise and frequency-wise."⁶

Similarly, there was considerable optimism about the number of FM receivers that would be sold at the end of the War. Armstrong, testified in 1948 that: "The General Electric Co's. executive in charge of radio predicted that 5,000,000 [FM] sets would be sold during the first year of postwar production."⁷ In a letter "TO MEMBERS OF THE NBC NETWORK" dated January 21, 1944, Miles Trammel, President, NBC noted that "It is almost a foregone conclusion that most, if not all, American manufacturers will include an FM band in their receivers...."⁸ and in a public statement of its position, NBC concluded that:

Because of the widespread publicity given to Frequency Modulation, it is a foregone conclusion that most receiver manufacturers will include on their post-war models a frequency modulation band which they will promote extensively as a high fidelity static-less type of radio reception....It is generally believed by the

⁶"ABC's Projected FM Network", Frequency Modulation Business, Volume 1, Number 7, August 1946. In the same story, however, Keith Kiggins, an ABC vice president is quoted as saying that "It is regrettable that many stations look upon an FM application as an 'insurance policy' and unless there is real competition for available FM channels, they are for the time being, satisfied with maintaining the status quo."

⁷Armstrong testimony, p. 12. This estimate was apparently made before the frequency shift.

⁸National Broadcasting Company, Some Observations on Frequency Modulation, January 21, 1944.

manufacturers that any manufacturer who disregards FM and offers only a standard band receiver will not be able to compete with those who have this added facility.⁹

There were many reasons to be optimistic about FM's future. First, it was universally viewed as a technology that was superior to AM. For example, NBC, in a statement released to the public, listed the following technical advantages of FM over AM: (1) FM virtually eliminates static; (2) FM has higher fidelity due to the use of wider channels; (3) the effective service area of an FM station is constant between day and night, whereas the service areas of AM stations can vary widely; and (4) FM stations can operate in closer geographical proximity on the same frequency without interference than can AM stations.¹⁰

Second, since FM stations would operate in a different portion of the radio frequency spectrum from that occupied by AM stations, FM promised a substantial increase in the number of radio stations that could be licensed. Kesten of CBS noted that "the spectrum space which the Commission has wisely allocated for FM should permit the licensing of at least two or three times as many stations as the AM band permits."¹¹

Third, not only would the new stations offer additional service to listeners, their presence could be expected to increase competition in the radio broadcasting industry, which could be

⁹National Broadcasting Company, Some Observations on Frequency Modulation, Radio City, New York, 1944, p. 17.

¹⁰Some Observations on Frequency Modulation, National Broadcasting Company, Radio City, New York, 1944, p. 6,8.

¹¹Op. cit., p. 7.

expected to benefit advertisers and program suppliers, in addition to viewers. Although this additional competition could hardly be welcomed by AM broadcasters, the FCC might have been expected to be more sanguine. The Commission, in its rules limiting concentration in media ownership¹² and in its Chain Broadcasting Rules¹³, had indicated a concern about concentration in radio broadcasting, and the prospect of more stations and more networks should have been welcome.

In short, FM promised not only a technically superior service but a less concentrated industry structure. Although not everyone would gain from these changes, the net benefits were expected to be large.¹⁴

In just a few years, however, the picture had changed dramatically. Instead of the optimism it had previously expressed, the Commission noted in its Annual Report for 1949 that:

¹²See W.K. Jones, Cases and Materials on Electronic Mass Media, Mineola, NY: Foundation Press, 1976, pp. 74-75, for a summary of these rules.

¹³See *id.*, pp. 118-134, for a discussion of these Rules.

¹⁴Michael L. Katz in his review of an earlier version of this paper notes that "Without...an analysis [of the costs of switching from AM to FM], one has no way of knowing whether the costs of switching were indeed less than the benefits." As a theoretical matter, Katz is clearly correct since a movement to a technically superior technology may not be economically efficient. Farrell and Saloner (1985) label this phenomenon "excess momentum" while Katz and Shapiro (1991) call it "insufficient friction." Nonetheless, at the time that FM was introduced, it was generally agreed that the benefits of switching exceeded the costs and policy-makers appeared to have accepted this view. Much of this paper accepts the premise that FM should have succeeded and analyzes why it did not. The possibility that the premise is incorrect is explored briefly in Section 6.

While the construction planned by many FM broadcast stations was completed during the year, many of them decided not to install high powered equipment because of economic problems....Although FM service was expanded by previously authorized stations commencing operation and by existing stations improving their facilities, the rate of filing of new FM applications fell off sharply during the year....Also, the total number of FM stations authorized decreased from 1,020 to 865.¹⁵

As we now know, FM did not supplant AM during this period as the dominant source of radio programming -- indeed, it did not even supplement it to any significant degree.¹⁶ Why did the apparent prospects for FM change so markedly in only three years? Was it foreseeable in 1946 that the rosy outlook that some held for FM was illusory? Were there events that could not have been anticipated that dimmed the outlook for this new technology? What could, and should, the FCC have done differently?

Explaining the outcome of the "battle of the bands" between AM and FM is the objective of this paper.¹⁷ The paper analyzes the development of FM radio during the critical period between 1946 and 1950 when the belief of some that FM might be "the great new postwar development in radio" was replaced by a concern over

¹⁵Federal Communications Commission, Fifteenth Annual Report, Fiscal Year Ended June 30, 1949, Washington, D.C.: U.S. Government Printing Office, pp. 39-40.

¹⁶The possibility that FM might have completely displaced AM in the short-run does not appear reasonable in light of the large investments in both AM stations and receivers. The relevant alternatives appear to have been that FM could have: (a) displaced AM as the dominant force in radio, with AM retaining a substantial role; (b) become a major addition to AM; or (c) had only a modest impact.

¹⁷David and Bunn (1987, 1988) describe the "battle of the systems" between alternating and direct current electricity.

whether FM could survive even as a modest supplement to the existing broadcast system. I interpret this history in part through the use of the modern economic theory of standards which has as one of its central questions whether, and under what conditions, a new superior technology like FM will be able to compete effectively with an inferior technology like AM.¹⁸ A major conclusion of this theory is that an economically superior technology may be unable to enter the market, or may be confined to a very limited role, because individuals do not take account of "network externalities" when they make choices among competing technologies.¹⁹ Clarifying the conditions under which "excess inertia" will prevent the adoption of the superior technology, and what might be done to overcome it, has been a central focus of much theoretical analysis.

One explanation for the failure of a new technology to develop that has been explored in the standards literature is the inability of suppliers of complementary inputs to coordinate their behavior.²⁰ In the present context, for example, even if it were socially efficient for FM to enter the market, consumers might not purchase AM-FM receivers²¹ if there were too few FM stations and

¹⁸For a survey of this theory see Besen and Saloner (1989).

¹⁹See, e.g., Farrell and Saloner (1985).

²⁰Church and Gandal (1989) present a model in which hardware and software are produced by different firms and software that is developed for one type of hardware cannot be used with another.

²¹S. Kempner, "Broadcaster * Manufacturer * Dealer", 'Greater cooperation among various elements in the industry is urgently needed before any effective sales pattern can be established', The

broadcaster might not operate FM stations if too few consumers could receive FM broadcasts. However, since a large number of FM stations did go on the air during this period, purchasers of AM-FM receivers could receive FM broadcasts. Thus, a failure by radio broadcasters and receiver manufacturers to coordinate their behavior does not appear to explain adequately why FM failed to develop in the period immediately after World War II.²²

The explanation that I offer, although based in part on the existence of network externalities among listeners, also takes into account: (1) the effect of the previous shift in the frequencies on which FM operated on the willingness of consumers to purchase FM receivers; (2) the policy of the FCC that, by permitting FM stations to "simulcast" the programming of AM stations, may have limited the programming benefits of FM reception; (3) the incremental cost of AM-FM receivers; (4) a variety of technical factors that limited the benefits that purchasers of AM-FM receivers could expect to obtain; and (5) the effect of the frequency shift on the production of FM receivers. When the combination of these forces resulted in very limited sales of FM receivers, many FM stations left the air. This made the purchases of FM receivers even less attractive, further reducing the benefits

Journal of Frequency Modulation, Volume 1, Number 3, New York, April, 1946, p. 37, reports that "There will be no straight FM sets for the time being; all sets containing frequency modulation will have both AM and FM circuits."

²²As I discuss below, however, the limited availability of unique FM programming may partly explain why more FM receivers were not purchased.

of operating an FM station.

Like all new technologies in "network" industries, FM faced an difficult battle in its contest with AM, and it is by no means clear that it would have been an early success even in the best of circumstances. In this particular case, however, some actions by the FCC likely made the task of FM more difficult, although some may have seemed supportive at the time. I conclude by suggesting some policies the Commission could have pursued that might have accelerated the diffusion, and ultimate success, of FM.

2. A Brief History of FM Authorizations

E.H. Armstrong received four patents for frequency modulation in 1934 and the technology was demonstrated publicly for the first time in 1935.²³ Subsequently, the Federal Communications Commission issued a number of experimental FM licenses and in 1940 it authorized commercial FM operation.²⁴ FM was assigned forty channels between 42,000 and 50,000 kilocycles, with each station operating with a bandwidth of 200 kc. In mid-1941, there were 69 FM stations under construction.

The entry of the United States into the Second World War led to a cessation of licensing of broadcast stations by the FCC, but some of those stations that had already been authorized went on the

²³For some of this history see Lessing (1969) and Krasnow and Longley (1978).

²⁴In the Matter of Aural Broadcasting on Frequencies Above 25,000 Kilocycles Particularly Relating to Frequency Modulation, Report on Frequency Modulation, Docket No. 5805 (May 20, 1940), 39 FCC 29.

air during the War. By the beginning of 1946, there were 55 operating FM stations.²⁵ Some were members of loose radio networks in which one station retransmitted the signal of another on a different frequency and there was some interconnection using American Telephone and Telegraph lines. During this period, approximately 500,000 FM radio receivers were sold.²⁶

Beginning in 1944, the FCC conducted a proceeding that led in 1945 to the shift of FM broadcasting from the frequency range in which it had been operating to a position higher in the radio frequency spectrum, 88-108 megacycles.²⁷ Although existing FM stations were, for a time, permitted to continue to operate at their old frequencies, all subsequent FM authorizations were made at the higher frequencies. This, together with the fact that the existing stations would shortly be forced to move to the higher band, made it clear as early as 1946 that if FM radio were to survive and prosper it would have to do so at the frequencies to which it had newly been assigned.²⁸

²⁵Broadcasting/Cable Yearbook '89, H-58, 59.

²⁶Radio Frequency Modulation, p. 11.

²⁷In the Matter of Allocation of Frequencies to the Various Classes of Non-Governmental Services in the Radio Spectrum from 10 Kilocycles to 30,000,000 Kilocycles (Docket No. 6651), (June 27, 1945), 39 FCC 222. Note that 88 megacycles is the same as 88,000 kilocycles.

²⁸A rear guard action of sorts was conducted until 1948 seeking to preserve at least a few of the experimental stations at their initial frequencies, but it was clear that these stations were too few in number to provide a basis for a new industry.

3. The Licensing of FM Stations

FM did not survive and prosper in the years immediately following World War II, but its demise was not obvious in 1946, nor did it occur at once. Table 1 shows the number of authorized and operating FM stations between 1946 and 1957.

Table 1²⁹

Frequency Modulation Stations

	<u>Authorized</u>	<u>On Air</u>
1946	456	55
1947 (6/30)	918	238
1948	926	458
1949	966	700
1950	788	733
1951	703	676
1952	650	637
1953 (6/30)	601	580
1954	580	560
1955	559	552
1956	557	540
1957	554	530

There were only 56 authorized FM stations on June 30, 1945. By mid-1946, 456 new FM radio stations had been authorized and approximately 250 FM applications were pending.³⁰ By the middle of 1947, the number of authorizations had increased 16-fold from mid-1945. Similarly, there was a 12-fold increase in the number of operating stations between 1946 and 1949.

But 1949 or 1950 was the high water market for FM during this period. By January 1, 1957, there were only 530 operating FM

²⁹Broadcasting/Cable Yearbook '89, p. H-59. Data are for January 1 unless otherwise indicated.

³⁰Federal Communications Commission, Twelfth Annual Report, Fiscal Year Ended June 30, 1946, p. 15.

stations, a decline of about 28 percent from 1950. At the same time, the number of authorized FM stations fell by almost 30 percent, from 788 to 554.

During the same period, AM radio stations continued to increase greatly in number. In 1949, there were 1912 operating AM stations, so that about one-fourth of all operating stations were in the FM band. By 1957, with 3,008 operating AM stations, FM stations represented only about 16 percent of the total. It was not until 1985, when there were 4,888 FM stations and 4,754 AM stations, that the number of FM stations finally exceed the number of AM stations.³¹

4. FM Receiver Purchases

The proximate cause of the declines in the number of authorized and operating FM stations after the initial postwar increases is not difficult to identify. The proportion of households with receivers capable of receiving FM broadcasts was simply too small to support the large number of FM stations that had gone on the air. Table 2 reports data on receiver purchases for four different years during this period:

³¹All data are from Broadcasting/Cable Yearbook '89, H-58,59. The eventual success of FM is usually attributed to its superior technical characteristics and the development of high fidelity recording, a combination that ultimately overcame the headstart of AM.

Table 2

Radio Receiver Purchases (000)³²

	<u>1947</u>	<u>1952</u>	<u>1953</u>	<u>1954</u>
A	14067	6556	7260	6448
B	10591	3428	3576	2966
C	10297	3164	3303	2842
D	294	264	273	124
D/B	.027	.077	.076	.042
E	3415	566	524	377
F	1965	152	132	81
G	1083	24	63	28
H	882	128	69	53
H/F	.449	.842	.522	.654

- A. Home-type radio receivers (except radio-phonograph combinations)
 B. Socket-powered table models
 C. Socket-powered table models (AM)
 D. Socket-powered table models AM-FM (includes FM only and FM converters)
 E. Home-type radio-phonograph combinations, complete sets
 F. Console models
 G. Console models (AM)
 H. Console models (AM-FM)

In each of these years, the proportion of socket-powered table model radios, the type most commonly sold, that were capable of FM reception [D/B] never reached 8 percent. Although AM-FM combinations were much more common among more expensive radio-

³²Data for 1947, 1952, and 1953 from U.S. Department of Commerce, Bureau of the Census, Facts for Industry, Home-Type Radio Receivers and Television Sets, Automobile Radios, Phonographs, and Record Players, 1953, May 14, 1954, Quantity of shipments. Data for 1954 from the same publication, 1955, January 15, 1957.

phonograph combinations, ranging from 45 to 84 percent of purchases [H/F] in the years for which data are provided, these purchases were too small to overturn the conclusion that the vast majority of all new radio receivers sold could not receive FM broadcasts. In the four years for which data are shown, over 34 million radio receivers were sold, but only about 6 percent could receive FM. With so few FM receivers being purchased, FM station owners eventually realized that their market was limited. Not surprisingly, they began to return their authorizations to the Commission and to take stations off the air.³³

5. Why Were So Few FM Receivers Sold?

This section addresses the question of why there were so few sales of AM-FM receivers. I begin with an analysis of receiver demand in order to understand why someone might choose to buy an AM-only receiver despite the fact that FM appeared to offer better quality reception. After exploring several demand side factors, this section concludes with a discussion of whether limitations on supply might also help to explain why receiver sales were so small.

³³The sorry performance of the sales of FM in the immediate postwar period apparently contrasts sharply with the sales of FM receivers prior to the War. S. Kempner, op. cit., p. 37, notes that "The first new AM-FM lines thereafter were shown in June 1941, and were those of Philco and Stromberg-Carlson. In practically every community where these receivers were displayed to dealers, the orders for these sets ran far ahead of those on straight AM. In many instances, the sales of AM-FM were as much as eight to one over those of straight AM."

a. Network Externalities and the Fear of "Stranding"

A network industry is one in which the value of a product to a user depends not only on its intrinsic qualities but on the number of others who have compatible products.³⁴ In such an industry, a prospective purchaser, who is either deciding whether to join a new network, choosing among networks de novo, or contemplating a shift from one network to another, must anticipate the choice that others will make.

The purchaser may, perhaps naively, base his assessment on the current number of those on each network, the "installed base", so that he is more likely to join a network if it is large than if it is small.³⁵ Alternatively, the purchaser may attempt to forecast the future size of the network in a more sophisticated manner. For example, the consumer may expect a product to have a large network because the brand-name of its producer will cause others to believe that the network will be large and make their purchase decisions accordingly. If many consumers share such expectations, the product will succeed and the expectation will be fulfilled. Such self-fulfilling expectations may explain why many choose to purchase a product although it has a small installed base.³⁶

³⁴Note that these networks can be real, e.g., the telephone network, or metaphorical, e.g., the network of VHS videocassette recorder owners or the network of IBM-compatible computer owners. The common element is the dependence of the utility from ownership on the number of other users of "compatible" products.

³⁵Arthur (1989) contains a model of this type.

³⁶Katz and Shapiro (1985) analyze "fulfilled expectations" equilibria of this type.

However, a shift to a new technology that would make all users better off may not occur if consumers adopt a more conservative strategy and cannot coordinate their behavior. If each consumer is concerned that there may be few other adopters, so that he may be "stranded" with the wrong technology if he makes an early purchase, each may choose to defer his purchase until the installed base is large enough to make the purchase worthwhile. But if each consumer adopts a "wait and see" approach, the process of adoption may never begin even if all consumers would be better off if it did.³⁷ This result has been labeled "excess inertia."³⁸

There are various ways in which inertia might be overcome. First, users may coordinate their behavior.³⁹ Second, there may be pressure from the government to achieve coordination.⁴⁰ Third, subsidies may be paid to early adopters to reduce their risks.⁴¹

³⁷Of course, the significance of stranding depends on the additional costs that must be incurred to purchase FM receivers and on the benefits from having an FM receiver even if the installed base is small.

³⁸Farrell and Saloner, op. cit.

³⁹However, users tend not to be well represented in organizations where standards are chosen. Horwitt (1987) p. 43 notes, for example, that "User organizations still are not taking an active role in communications standards development efforts...." User participation is likely to be especially limited where users are households rather than firms.

⁴⁰Besen (1990) pp. 529-530, describes efforts by the Council of the European Communities to promote standardization of telecommunications technologies.

⁴¹Subsidies may also be required where some users shift to the new technology and others do not but total welfare would be larger if all shifted. See Dybvig and Spatt (1983) for an analysis of the need for such subsidies.

Fourth, there may be an externally-imposed requirement that all users switch.⁴² Finally, some users with foresight may start the "bandwagon" to the new technology.⁴³ Nonetheless, since the process of coordination may be formidable, the movement to the better technology is not guaranteed to occur.⁴⁴

A consumer might also purchase a new product in a network industry if he is given an inducement to do so by its sponsors. Since purchases by early adopters are pivotal, because they may influence the choices made by others, firms that are attempting to get a new technology introduced may employ "promotional pricing." By offering low, perhaps below cost, prices to early purchasers, these firms may be able to increase the future demand for their products.⁴⁵ However, where many firms offer a new product, the incentive for any one to engage in promotional pricing will be reduced because most of the benefits from doing so will be captured

⁴²Since everyone is compelled to move, no one need fear being stranded with the new technology.

⁴³Bresnahan and Chopra (1990) attribute the choice of a factory Local Area Network standard to efforts by large users.

⁴⁴Farrell and Saloner, *op. cit.*, also show that "excess momentum," where there is a movement to the new technology but the net effect on users is negative, may occur. In such cases, some consumers are made better off by the shift but others, who adopt the new technology to minimize their losses, are made worse off by a larger amount. Moreover, Arthur (1989) shows that the "right" technology will not always be selected when a choice is made between competing standards.

⁴⁵Katz and Shapiro (1986) analyze the use of promotional pricing by two firms that offer incompatible products.

by other firms.⁴⁶

Potential buyers of FM receivers could not be certain during the postwar period that others would purchase such receivers. Because the benefits from owning an FM receiver depend, in part, on the number of others who do so, this may have caused consumers to defer their purchases. Thus, "inertia" of the type described in the theory may partly explain the small number of FM sets that were purchased.

A second factor that may have contributed to this inertia is the rapid growth in the number of AM stations that occurred during this period. The argument here is based on the earlier point that, in choosing which of two competing technologies to adopt, a consumer will make a forecast about the size of the respective networks that each technology will obtain. Although the number of authorized FM stations grew rapidly during this period, the rate of growth in the number of authorized AM stations was even faster.⁴⁷ If potential purchasers inferred from the rapid growth in the number of AM stations that FM's programming inferiority would be more or less permanent, they would be less likely to purchase FM receivers. This inference might have been prevented if the FCC had

⁴⁶The incentives of the Radio Corporation of America, a major receiver manufacturer, to engage in promotional pricing were somewhat attenuated by its large interests in AM radio and television broadcasting, both of which could be expected to compete with FM.

⁴⁷For example, between January 1, 1946 and January 1, 1950, the number of authorized FM stations increased from 456 to 788, or 73 percent, while the number of authorized AM stations grew from 1,004 to 2,234, or 125 percent.

limited the growth of AM and channeled the demand for radio to FM. But, of course, it did not do so.

In addition to the standard "network externality" explanation, the shift of FM from the frequencies that had been assigned to it before World War II is also likely to have played a role in limiting the demand for FM receivers. By "stranding" listeners with receivers that were obsolete, the FCC's action added to the inevitable uncertainty that is faced by adopters of a new technology. Having been "burnt once," or having seen others been burnt, listeners were reluctant to purchase FM receivers during the period immediately after the frequency shift. In this view, a concern about stranding by potential purchasers of FM receivers which would exist under any circumstances, was exacerbated by the FCC's decision to shift the FM frequencies, in fact stranding those who had owned FM receivers in 1945.⁴⁸

The following colloquy between J.E. Brown of the Zenith Radio Corporation, and Congressman O'Hara nicely captures this concern:

Mr. O'Hara: And do you find, or did you find during the terms of these shifts, people who were certainly in the purchasing end of it who were skeptical about buying something when they did not know whether their set would be any good a year from then?

Mr. Brown: That is true, and it was a bad thing commercially.

Mr. O'Hara: And has that affected the various segments of

⁴⁸In the testimony of Lee McCanne of Stromberg-Carlson, Radio Frequency Modulation, p. 71, he argues for "an announcement that the high-band FM service is all set for a couple of years. We discussed the market instability and the fact that people are holding back from buying sets...we think that now some symbol and some indication of stability would be a very helpful thing."

the FM industry?

Mr. Brown: I think it has.

Mr. O'Hara: As well as the purchasing public?

Mr. Brown: I know it has

Mr. O'Hara: I know it has me, for one, as one prospective purchaser. I did not want to buy any FM sets until I knew what was going to happen. I did not want to buy a set and suddenly find out that it was not any good, and I would have to get that fixed up or changed to another band for which the set was not originally built.⁴⁹

Nonetheless, even after the shift in frequencies, there were still those who believed that increased sales of receivers would follow once a sufficiently large number of FM stations were on the air. A trade press report in 1946 indicated that:

Dark as the view for FM set production seemed after the FCC's survey of radio receiver production was made public, observers familiar with FM are not too downcast about this year's potentials. When FM stations get on the air, listeners will demand FM sets, they say. And where there is a demand, manufacturers will not long let it go unsupplied. It isn't so much a question of how many sets; the problem is to get them to the right places (where the stations are) at the right times.⁵⁰

With hindsight, it is clear that this optimism was misplaced. We turn now to some other explanations for why FM receiver sales were so small.

b. Simulcasting, Receiver Costs and the Demand for FM Receivers

The incremental benefit that a listener obtains from owning an

⁴⁹Radio Frequency Modulation, p. 62.

⁵⁰E. Abrams, "Washington", 'Sets Will be There', Frequency Modulation Business, Volume 1, Number 4, New York, May 1946, at 42.

AM-FM receiver instead of one capable of receiving only AM broadcasts⁵¹ depends on three things: First, there is the value of the additional programs that are available on FM stations but not on AM stations. Second, there is the value of improved reception of those programs that are "simulcast" on AM and FM stations, i.e., that are broadcast simultaneously on an AM and an FM station. Finally, there is the additional cost of purchasing an AM-FM receiver over that of buying an AM-only receiver. The smaller are the amount of additional programming and the improvement in the quality of reception, and the larger is the incremental cost of an AM-FM receiver, the smaller will be the number of AM-FM receivers that are sold.

There are doubts about the incremental value of receiving FM broadcasts on several scores. First, early in the history of FM, declined to adopt rules that would have limited simulcasting by the AM-FM broadcast combinations.⁵² This was a mixed blessing for FM. On the one hand, it meant that listeners could receive popular programs on FM, so that, if FM reception was of superior quality, they would have an incentive to purchase AM-FM receivers and to

⁵¹Realistically, few persons were likely to purchase FM-only receivers given the large number of AM stations that were in operation and, in any event, there were few, if any, FM-only receivers available to be purchased.

⁵²For a brief history of early regulation in this area see In the Matter of Amendment of Part 3 of the Commission's Rules, regarding AM station assignment standards and the relationship between the AM and FM broadcast services, 25 RR 1615, 1963, para. 11-22. Limits on program duplication were imposed In the Matter of Amendment of Part 73 of the Commission's Rules, regarding AM station assignment standards and the relationship between the AM and FM broadcast services, 2 RR 2d 1658, 1964.

listen to the broadcast of these programs on FM. On the other hand, since the incentive to develop programming exclusively for FM was reduced, and so much FM programming duplicated that of AM stations, the incentive to purchase FM receivers to obtain programming not available on AM was reduced. Although widespread simulcasting initially gave listeners some reason to purchase AM-FM receivers, it may eventually have limited its prospects.

A number of industry participants argued that permitting simulcasting would speed the movement from AM to FM. Typical was the statement of Paul W. Kesten of CBS. In the section of his 1945 statement to the Commission entitled Identical Programming will Shorten the Transition Period, Kesten provides five reasons why simulcasting would have this effect.⁵³ First, it will accelerate the purchases of FM sets because the demand for such sets will be adversely affected if FM offers "only second string programs."⁵⁴ Second, it will encourage the entry of new FM broadcasters because "access to network programs [presumably available through simulcasting] will increase FM audiences and create a larger FM listening base for new broadcasters to consider when deciding whether to enter FM market."⁵⁵ Third, simulcasting will save the listener's money because "with separate programming, he must sooner

⁵³As we note below, one can construct an argument that permitting simulcasting delays the transition. Moreover, this argument for permitting simulcasting implies that provision should be made for "sunsetting" simulcasting and, perhaps, for sunsetting AM itself.

⁵⁴Id., p. 15.

⁵⁵Id., p. 16.

or later buy a combination FM-AM set or two separate sets."⁵⁶ Fourth, simulcasting will avoid listener confusion.⁵⁷ And, fifth, simulcasting will permit the maintenance of program standards.⁵⁸

Although there is every reason to believe that these arguments are self-serving, at least two can easily be restated in a form that is consistent with the modern economic theory of standards. The contention that allowing simulcasting will encourage others to construct FM stations can be viewed as a straightforward "network externality" argument. The logic is that FM set purchases will be stimulated through permitting simulcasting of network programs. This, in turn, will increase the potential audiences of new FM broadcasters, who otherwise would have access only to a much smaller installed base of listeners with FM receivers. As a result, some FM stations will go on the air that otherwise might not.⁵⁹

Similarly, the argument that listeners will experience cost saving as a result of simulcasting can be cast in terms of the modern theory. Here, the argument appears to be that simulcasting

⁵⁶Id.

⁵⁷Id.

⁵⁸Id., p. 17.

⁵⁹Later, we consider the countervailing argument that new FM station owners might be discouraged from building new stations because, although there might be more FM receivers because of simulcasting, the new stations face more formidable competition from popular AM programs. In any event, as we now know, new FM stations faced the worst of both worlds. Few FM sets were sold and they had to compete with popular AM programs even among listeners who received FM broadcasts.

encourages the immediate purchase of AM-FM receivers, where otherwise listeners might delay their purchase only to discover later the need for a separate FM receiver or a replacement for their AM-only set. In a sense, allowing simulcasting signals to listeners that FM will be the future standard, i.e., it makes it a "focal" point, so that they should purchase receivers now that meet that standard. By giving credibility to FM, the fears of listeners that they may be "stranded" with the wrong technology may be overcome.⁶⁰

Nonetheless, it is certainly possible to construct an argument under which permitting simulcasting would actually retard a transition to FM. Erickson states such an argument succinctly:

...allowing the AM stations to duplicate their AM programming over FM gave the listener no incentive to own an FM set, gave the manufacturer no incentive to make FM radios, and did not foster programming uniquely suited to show off the benefits of FM listening.⁶¹

In this view, listeners are more likely to purchase FM receivers when they can obtain differentiated programs, although these might be programs produced at lower costs, than if they merely obtained the popular AM programs on FM, albeit with improved reception quality.⁶²

⁶⁰As we note later, an even stronger signal would have been to announce the sunseting of AM.

⁶¹Erickson (1973), p. 82.

⁶²Erickson's argument concerning the effect of allowing simulcasting on the demand for FM receivers appears to have two parts. First, listeners have a small demand for FM receivers because it offers only the same programs. Second, the programs that are offered on AM do not exploit fully the advantages of FM transmission.

There are thus two alternative hypotheses about the effect of permitting simulcasting on the demand for FM receivers. One is that simulcasting increased demand by giving the FM access to the higher quality programming available on AM. The other is that the duplication of programming reduced demand by giving listeners little incentive to incur the additional cost of purchasing AM-FM receivers. Whether listeners would have been more or less likely to purchase these receivers if the programming had been different (but possibly inferior) on FM cannot be answered on a priori grounds and it was likely to have been difficult at the time to decide which hypothesis was correct.⁶³

There is also some uncertainty about exactly how much simulcasting actually occurred during this period. Because of opposition from the musician's union, at various time during this period FM stations were unable to simulcast the programs of an AM station, although this was permitted by FCC rules.⁶⁴ On one

⁶³The Federal Communications Commission In the Matter of Advanced Television Systems and Their Impact on the Existing Television Broadcast Service, 5 Federal Communications Commission Record, August 24, 1990, p. 5627, recently announced that it will award High Definition Television (HDTV) licenses to existing television broadcasters who are expected to offer the same programs on both the stations they currently own and their new HDTV outlets, i.e., to simulcast. It justified this decision in part on the grounds that "...our selection of a simulcast system will eliminate confusion for consumers about which type of receiver to purchase." (p. 5628)

⁶⁴For brief references to the "Petrillo duplication ban," named after the President of the musician's union, see "Modulations," FM Journal, February 1946, p. 31 and Statement of Lee McCanne, General Manager, Vice President and Director of the Stromberg-Carlson Co., Radio Frequency Modulation, p. 70. It is has been difficult to determine the precise extent of the ban.

theory, the absence of simulcasting may have reduced the incentive to purchase FM receivers, both because it lowered the quality of programming available on FM and increased uncertainty about whether popular programs would be available on FM.

Finally, it is important to consider the additional costs that a listener would incur to purchase an AM-FM radio instead of one that was capable of receiving only AM broadcasts.⁶⁵ The manufacturing cost of an FM converter for an existing AM receiver, which presumably exceeded the cost of adding FM capability to a new receiver, was put at \$10, with a retail price of \$29.50.⁶⁶ One estimate put the incremental price of FM capability in a new receiver at \$10⁶⁷, approximately \$40 in 1991 prices.⁶⁸ Since the

⁶⁵The trade press reported that only AM and AM/FM combinations were being sold. See

⁶⁶Progress of FM Radio, Hearings before the Committee on Interstate and Foreign Commerce, United States Senate, Eightieth Congress, Second Session, on Certain Charges Involving Development of FM Radio and RCA Patent Policies, March 30, April 23, May 12, 13, 21, 1948. Charles B. Joliffe, Executive Vice President, RCA Laboratories Division, Radio Corp. of America, is the source of the manufacturing cost (p. 67) and Senator Homer Capehart is the source of the retail price (p. 114).

⁶⁷G. Howe, Office of Information, U.S. Department of Agriculture, FM for You, Washington, D.C., October 19, 1945, p. 5. Although the statement refers to a "cost" of \$10, it is clear both from the context and from the following sentence that it is the incremental price that is being discussed. J.E. Brown of Zenith Radio Corporation noted that "...Our newest FM set has seven tubes in it, and all seven are used for FM and six of them are used for AM reception. It has both FM and AM. It costs us one extra tube in there for the FM." Radio Frequency Modulation, p. 66.

⁶⁸Calculated using the Durable goods price indexes for 1946 and 1991, respectively, from Economic Report of the President, 1989, Table B-60, p. 376, Consumer price indexes, commodities, services, and special groups, 1946-88, [1982-84=100], and Economic Report of the President, 1992, Table B-58, p. 364, Consumer price indexes,

lowest priced AM-FM receiver was then selling for about \$50⁶⁹, adding FM capability apparently raised the price of that receiver by about 25%.⁷⁰ Thus, whether viewed in absolute terms or as a percentage of the purchase price, the incremental cost of FM capability was not trivial.

c. The Quality of FM Transmissions

In addition to the effect of simulcasting, two additional factors might make one skeptical about the extent of the improvement in service offered by FM over AM during the late 1940s. The first concerns the capabilities of the FM receivers that were actually sold during this period. The second involves the quality of the network interconnections that linked FM stations.

Although FM receivers were, in theory, capable of receiving transmissions at 15,000 cycles, some receivers that were sold during this period may have had a smaller bandwidth.⁷¹ Moreover, a trade press account suggests that there were formidable difficulties in selling FM receivers, quite apart from any effect of the frequency shift.⁷² Among the difficulties identified were:

commodities, services, and special groups, 1950-91, [1982-84=100].

⁶⁹Brown, Radio Frequency Modulation, p. 65.

⁷⁰Of course, for more expensive receivers, the increase was proportionally smaller.

⁷¹S. Kempner, op. cit., notes that "Some models of different manufacturers will provide for audio reproduction up to 15,000 cycles." (emphasis added) This suggests, of course, that some models did not attain these frequencies.

⁷²S. Kempner, op. cit., p. 12.

...all sets with so-called FM circuits will not give identical performance....retailers must be wary of their selection and sale of FM models. They should favor receivers having maximum sensitivity, minimum noise level and widest audio range.

Furthermore, it will be essential that [dealers] sell and completely install antenna systems required for the new FM sets. These systems will be somewhat more complex than those required for standard broadcasting (AM) since transmission and reception on the upper portion of the spectrum will present problems quite different from those encountered up to now.

At the same time, it should be noted that some industry observers apparently believed that the quality of FM receivers did not constitute a problem. For example, in answer to a question from the Chairman of the House Committee on Interstate and Foreign Commerce concerning the quality of low-price sets, Brown of Zenith Radio Corporation testified that "they do give excellent service."⁷³

The second factor involves the bandwidth of the interconnections being used to link FM stations to carry network broadcasts. Although some of the early FM network connections involved one station retransmitting the signal of another station taken directly off the air, some used telephone lines leased from the telephone company. However, these lines, initially at least, were incapable of carrying the entire frequency range of FM broadcasting. Writing in 1944, W.B. Lewis noted that the connection between Cleveland and New York was

over a telephone wire capable of carrying not more than 5,000 cycles; ideally, Frequency Modulation requires 15,000 cycles. The FM transmitter could send to your

⁷³Radio Frequency Modulation, p. 65.

set, and your FM set could receive, no more quality than the telephone line delivered.⁷⁴

Some improvements in telephone circuits did take place after the war, and the telephone company promised even further ones. For example, AT&T is quoted as indicating that:

With facilities now available and in prospect, the Telephone Companies have a wide degree of flexibility in meeting future requirements for FM broadcasting stations....we believe we are already in a position, when war restrictions are relaxed, to give the FM broadcasters nation-wide networks meeting any transmission requirements which they select as desirable.⁷⁵

Nonetheless, for a time, the higher bandwidth capabilities of FM were underexploited, further reducing any advantage it might have over AM.

Testifying in 1948, Lee McCanne of Stromberg-Carlson noted that:

At the present time [FM networks] cannot get enough telephone circuits and those telephone circuits are expensive...There is a big difference between 5,000 and 8,000 cycles over a telephone line, and there is another big difference that is strived for from 8,000 to 15,000 cycles....A 15,000 cycle line takes as much room on their coaxial cable or on their wire circuit as 5 telephone conversations, and they have to charge as if it were 5 telephone conversations.⁷⁶

If FM networks found it too expensive to use the 15,000 cycles, they would have been providing lower quality transmissions than

⁷⁴W.B. Lewis, "The Possibility of a Fifth Network," Fm and Television, November 1944, p. 18. Lewis also noted that phonograph records "were delivering to the transmitter 4,000 cycle quality or less, and the transmitter could broadcast no more than it received."

⁷⁵"15,000 Cycles for All Networks," FM and Television, February 1945, p. 24.

⁷⁶Radio Frequency Modulation, p. 73.

what was theoretically possible using FM.⁷⁷

d. Supply Limitations

I have been interpreting the small volume of FM receiver sales as a "demand side" phenomenon, i.e., that few sets were sold because few people wanted them because of network externalities and programming and technical limitations. However, some contemporaneous observers offered "supply side" explanations. For example, Armstrong, stated in response to a question about whether manufacturers were making a large quantity of FM sets that:

Some of them are, Congressman, and some of them have dragged their feet. That has been done for a variety of reasons. I can tell you from the standpoint of an inventor, there has never been anything more heartbreaking than to see the full capacity of a good deal of our radio industry grinding out AM sets when if our wave lengths had not been changed, they would have been building FM sets.⁷⁸

In testimony at the same hearing, J.E. Brown of Zenith Radio

⁷⁷If FM stations had been permitted to serve large areas, the dependence of FM networking on telephone lines would have been reduced somewhat because some stations could have retransmitted the signals of others that were taken directly off the air. However, the FCC's Single Market Plan for FM effectively limited the range of FM stations, making this alternative infeasible. As McCanne notes in his testimony, "...we would like to see the single market plan waived [for the low FM band], so that...relay stations, taking the place of telephone lines, can cover just as much area as possible." Radio Frequency Modulation, p. 71.

⁷⁸Statement of Edwin H. Armstrong, Radio Frequency Modulation, p. 32. Note that attributing the small production rate to the frequency switch can have either a demand or a supply interpretation. The demand explanation is that the switch discouraged the purchase of FM receivers. The supply explanation is that manufacturers had difficulty in retooling to manufacture receivers at the higher frequencies. Armstrong appears to be emphasizing the supply side at this point.

Corporation emphasized the supply explanation:

In 1947, fewer than 7 percent of the radio receivers manufactured in the United States contained FM. While many factors may have contributed to this poor showing, there is reason to believe that the most predominant factor was the problem of the design and manufacture of receivers for public use for the 100-megacycle band, a problem which had never before been met by the radio-receiver industry.⁷⁹

Brown and the Chairman of the Subcommittee also engaged in the following exchange:

The Chairman: How much, in your opinion, did the change in the frequencies delay the production of FM receivers in volume?

Mr. Brown: In volume, certainly 2 years. We have not had up to now a good FM receiver production, I would say from now back until the time when that decision was made, 2 years.⁸⁰

It should be noted, however, that a contemporary trade press report made a somewhat less pessimistic assessment of the effect of the frequency shift on FM receiver production: "According to the best-informed estimates, a radical shift in FM frequencies will delay the major part of postwar radio production by six to eighteen months."⁸¹ However, the same publication observed that if FM stayed at the lower frequencies, "Both transmitters and receivers, representing substantial improvements over prewar models, have been designed, field-tested, and can be put into production as soon as

⁷⁹Radio Frequency Modulation, p. 47.

⁸⁰Id. at 64.

⁸¹"What's New this Month", 'FM Broadcast Frequencies', FM and Television, Volume 5, Number 4, New York, April 1945, p. 4, 83.

authority is granted by the WPB [War Production Board]."⁸²

6. What Could Have Been Done Differently?

FM was generally recognized as a superior method of radio broadcasting during the 1940s. Nonetheless, for a variety of reasons, few people purchased FM receivers and, subsequently, many FM stations went off the air. As I have previously shown, the various policies that the FCC adopted during this period either failed to contribute to the growth of FM or may actually have discouraged it.

One possible explanation for the behavior of the FCC is that it did not believe that the rapid adoption of FM was socially efficient. Not all users may benefit from the introduction of a new superior technology.⁸³ Moreover, a new technology may be adopted even when the losses exceed the gains because early adopters do not take into account the resulting losses to others.⁸⁴ Clearly, in such cases, the government should either discourage the inefficient adoption of the superior technology or, at least, not encourage it. Viewed in this light, policies that had the effect

⁸²"Final Decision on FM Frequencies", 'We don't want a Successful Operation and a Dead Patient on our Hands', FM and Television, Volume 5, Number 2, New York, February 1945, p. 19.

⁸³Losers include both those who remain with the old technology but who are on a smaller "network" because of the existence of the new technology and those some who switch to the new technology to be on a larger network but were better off before the new technology was introduced.

⁸⁴See Farrell and Saloner (1984) and Katz and Shapiro (1991). Of course, without the assistance of government, a new technology may not be adopted even if it is socially efficient.

of slowing the growth of FM may actually have been socially beneficial.

Nonetheless, the FCC claimed that its policies were intended to help FM, so that it is reasonable to ask whether there were other policies that could have been pursued that would have changed this outcome and led to the more rapid diffusion of FM. Two such policies are suggested: requiring that all radio receivers sold be capable of FM reception and "sunsetting" AM.

Suppose that all listeners have FM receivers. An independently owned FM station could duplicate AM programming and attract more listeners than an AM station with the same programming because it has a superior signal.⁸⁵ If an AM-FM combination could not either let the FM station go dark or simulcast, it would have the same incentives as an independently-owned station because if it chose to abandon its license an independently-owned station could displace it. Thus, once all listeners have receivers that are capable of receiving FM signals, there should be a rapid shift of programming to the superior FM transmission method. The length of this transition would depend on how quickly listeners purchased FM-capable receivers. One obvious way to accelerate the transition would be to require that all radio receivers be capable of receiving FM broadcasts.

As part of its effort to overcome the handicap faced by UHF television stations in competing with VHF stations, the Congress

⁸⁵A sufficient condition for this to occur is that the costs of station operation are the same.

adopted the All Channel Receiver Law in 1964. The Law, which required that all television receivers sold in the United States be cable of UHF reception, was largely unsuccessful in reaching its objective because the signals of UHF stations were inferior to those of their VHF counterparts. Moreover, an analysis of the effect of the adoption of the law concluded that its costs exceeded its benefits.⁸⁶

The All-Channel Television Receiver Law generated few benefits because the lack of all-channel receivers in the hands of the public was only part of the problem faced by UHF television stations. Because the signals of UHF stations were inferior to those of their VHF competitors, UHF stations continued to face significant competitive handicaps even after most receivers in the hands of the public could receive UHF broadcasts. For the case of FM, however, the new technology was widely regarded as superior to the old one. Here, the objective of the policy would not be to overcome an inherent competitive handicap faced by FM but rather to overcome the inertia faced by any new technology in a network industry. As a result, there is more to recommend such a policy here than in the case of the All-Channel Television Receiver Law. In any event, such a policy was not adopted and FM continued to languish.

The objective of accelerating the purchase of FM receivers could also have been accomplished if it were known that, at some

⁸⁶Webbink (1969), p. 561, concludes that "The All-Channel Television Receiver Law was a mistake."

date in the future, all stations would be shifted to FM, i.e., that AM would be "sunsetting."⁸⁷ Under this scenario, listeners would purchase FM-capable receivers not because they were required to do so but because they know that AM-only receivers would soon be obsolete. This, in turn, would accelerate the shift of programming to FM, as in the case where FM receivers were mandated.

However, not only did the FCC not pursue a policy of sunsetting FM, but it actually permitted the number of AM stations to accelerate rapidly during the period we are considering. A likely result of such a policy was to discourage further the purchase of FM receivers. This, in turn, would have made it less likely that existing FM stations could stay on the air and that new FM stations would come into being.

7. Conclusion

FM faced considerable handicaps in displacing an entrenched AM radio industry in the 1940s. To the inherent handicaps faced by a new technology in a network industry were added economic developments that were peculiar to FM. Nonetheless, there were regulatory changes that might have accelerated the transition to

⁸⁷The Federal Communications Commission, Radio Broadcast Services; Advanced Television Systems, 56 Federal Register, November 18, 1991, p. 58211, has tentatively concluded in its High Definition Television (HDTV) proceeding that "the public interest requires setting a firm date or other triggering event for broadcasters to surrender their NTSC frequencies and convert entirely to ATV." The National Television Systems Committee (NTSC) standard is the one currently used for broadcast television and Advanced Television (ATV) is the Commission's designation for systems that provide improved audio or video transmissions.

FM, but these were not taken. Nor is this surprising. As we know from other contexts, the initial reaction of the FCC to a new technology that threatens the existing economic order is to adopt policies that either slow or arrest the change. Although the policies adopted by the FCC in the case of FM were not as overtly protectionist as in the case of cable television, for example, the effect was no less harmful to the new technology.

REFERENCES

Arthur, B., "Competing Technologies, Increasing Returns, and Lock-in by Historical Events," Economic Journal, 99, 116-131, 1989.

Besen, S.M., "The European Telecommunications Standards Institute: A preliminary analysis," Telecommunications Policy, 14, 521-530 1990.

Besen, S.M., and G. Saloner, "The Economics of Telecommunications Standards," in R.W. Crandall and K. Flamm (eds.), Changing the Rules: Technological Change, International Competition, and Regulation in Communications, Brookings Institution, 1989.

Bresnahan, T.F., and A. Chopra, "The Development of the Local Area Network Market As Determined by User Needs," Economics of Innovation and New Technology, 1, 97-110, 1990.

Church, J., and N. Gandal, "Complementary Network Externalities and Technological Adoption," Boston University School of Management Working Paper 89-20, December 1989.

David, P.A., and J.A. Bunn, "'The Battle of the Systems' and the Evolutionary Dynamics of Network Technology Rivalries," High Technology Impact Program Working Paper No. 15, Center for Economic Policy Research, Stanford University, 1987.

David, P.A., and J.A. Bunn, "The Economics of Gateway Technologies and Network Evolution: Lessons from Electricity Supply History," Information Economics and Policy, 3, 1988, 165-202.

Dybvig, P.H., and C.S. Spatt, "Adoption Externalities as Public Goods," Journal of Public Economics, 20, 231-247, 1983.

Erickson, D., Armstrong's Fight for FM, University of Alabama Press, 1973.

Farrell, J., and G. Saloner, "Standardization, Compatibility, and Innovation," Rand Journal of Economics, 16, 70-83, 1985.

Farrell, J., and G. Saloner, "Installed Base and Compatibility: Innovation, Product Preannouncements, and Predation," American Economic Review, 76, 940-955, 1986.

Horwitt, E., "Vendors Still Dominate Standards Effort," Computerworld, 20, 43, April 1987.

Katz, M.L., and C. Shapiro, "Network Externalities, Competition, and Compatibility," American Economic Review, 75, 424-440, 1985.

Katz, M.L., and C. Shapiro, "Technology Adoption in the Presence of Network Externalities," Journal of Political Economy, 94, 822-841, 1986.

Katz, M.L., and C. Shapiro, "Product Introduction with Network Externalities," unpublished manuscript, 1991.

Krasnow, E.G., and L.D. Longley, The Politics of Broadcast Regulation, Second Edition, New York: St. Martin's Press, 1978.

Lessing, L., Man of High Fidelity: Edwin Howard Armstrong, New York: Bantam Books, 1969.

Webbink, D.W., "The Impact of UHF Promotion: The All-Channel Television Receiver Law," Law and Contemporary Problems, 34, 535-561, 1969.