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# The Allocation of the Radio Spectrum

*The electromagnetic spectrum from 10 kilohertz to 300 gigahertz is a natural resource of communication that must be fairly allocated. Reforms in the system of allocation are currently being considered*

by Charles Lee Jackson

It is clear that both national and international wireless communication would dissolve in chaos without some system for allocating the finite number of places on the radio spectrum among the many claimants. It is not so clear that the systems now in force are the best ones possible or that they work as efficiently as they could. My purpose in this article is to describe how the spectrum is currently managed (with the system in the U.S. serving as the principal example) and to outline the major reforms that are under consideration.

The part of the electromagnetic spectrum that is regarded as the radio spectrum (the term radio encompassing all forms of wireless communication, including television, all radio broadcasting, telephone calls sent by microwave radio and so on) can be described in terms of both frequency and wavelength. It ranges from very low frequencies of a few kilohertz (thousands of cycles per second) and wavelengths of several kilometers up to 300 gigahertz (billions of cycles per second), where radio microwaves shade into the far infrared. The officially allocated part of the spectrum extends from 10 kilohertz (wavelength 30 kilometers) to 300 gigahertz (wavelength one millimeter) and is densely populated by communication services of all kinds.

Frequency is not the only component of the spectrum resource. Geographical location also makes a difference. A given frequency can be assigned to several locations if they are far enough apart. For example, in the U.S. Channel 4 serves television stations in Boston, New York, Washington and about 50 other communities. The necessary separation is determined by the propagation characteristics of radio waves at the particular frequency and by the design of the communication system.

The primary international institution established to allocate places on the spectrum and to promulgate technical rules is the International Telecommunications Union, usually referred to as the ITU; it is a specialized agency of the United Nations. In the U.S. the responsibility for managing the spectrum is divided between the President, in whose name the part of the spectrum assigned to agencies of the Federal Government is controlled by the National Telecommunications and Information Agency in the Department of Commerce, and the Federal Communications Commission (FCC), which oversees all other users. The FCC's jurisdiction extends not only to commercial television and radio stations but also to state and municipal mobile-radio activities, the wireless part of the telephone system, citizens-band radio and even the small radio units that open and close garage doors.

Although the focus of this article is on the allocation of the spectrum, the reader should bear in mind that national and international policy on the management of the spectrum deals with other issues. It has a bearing on the structure of a nation's system of mass communications. In many countries it involves the question of how to manage the design of large communication systems with multiple owners. It also addresses the questions of how to distribute the benefits of a public resource and how to compromise such conflicting alternatives as expanded broadcasting service and improved communications for power-company repair crews. I shall treat such issues as special subproblems of allocation, but actually the subject of spectrum policy could be discussed with any of them as the focus.

To understand spectrum-allocation policies one must understand how the spectrum is utilized. Its use is governed by the physics of radio-wave propagation and by the practical limitations of communications engineering. The operation of a typical amplitude-modulation (AM) radio station, WNBC in New York, illustrates a simple radio-communication link.

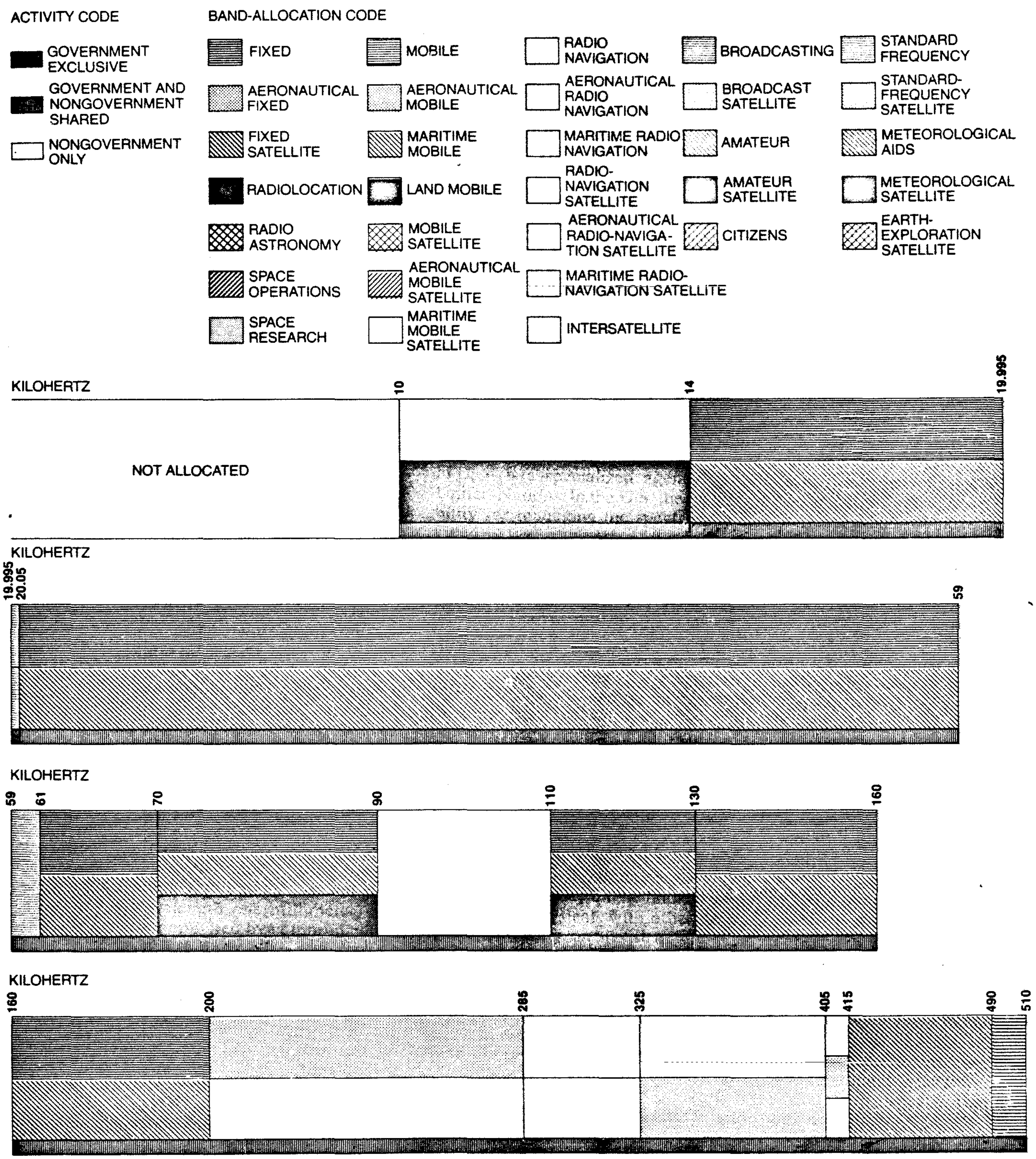
When an announcer speaks in the studio, the microphone transforms the sounds into electrical signals. They are carried by cable from the studio to the transmitter, which is on High Island, 20 kilometers east of New York. There the signals modulate an electromagnetic wave oscillating at a carrier frequency of 660 kilohertz. The modulated wave is fed to an antenna, from which it spreads out in all directions as electromagnetic radiation.

Now picture a listener with a portable transistor radio on Jones Beach, about 30 kilometers from the transmitter. A small fraction of the radiated signal is captured by the antenna of the radio. The radio selects the WNBC signal from among all the radio signals reaching the antenna because the radio is tuned to 660 kilohertz. The radio amplifies the signal and demodulates it, thereby recovering the electrical signal that represents the announcer's voice. The signal then goes to a speaker that transforms it into sound.

The radio captures only a tiny fraction of the 50 kilowatts transmitted by WNBC. If the transmitted power were spread out evenly in all directions from the transmitter, the density of the energy at a distance of 30 kilometers would be down to .000004 watt per square meter. Actually the power does not spread out evenly, since the transmitter directs most of it toward the horizon. Nevertheless, the signal the transistor radio must work with is about a millionth of a watt.

Noise, meaning various kinds of interfering radio waves, ultimately limits a receiver in picking up a signal at a certain level of weakness. Noise can be generated both within a receiver and by external processes. External noise comes from many sources but can be classified in three broad categories: natural radiation, incidental man-made radiation and radiation from other communication systems. Natural phenomena, notably lightning, generate radio signals that can interfere with communication. Elec-

**THE ALLOCATED RADIO SPECTRUM in the U.S. is presented on a logarithmic scale starting below and continuing over the next three pages. The color key on this page indicates the kinds of communication services that have been allocated part of the spectrum. The chart is based on the most recent one that has been prepared by the Department of Commerce and the Executive Office of the President.**



trical equipment such as sewing machines and power tools can generate radio waves capable of interfering with communication, as when horizontal streaks appear on a television screen during the operation of a power tool nearby. Finally, each radio transmitter generates signals that constitute noise to anyone who is not trying to receive that particular signal. An example is the common experience of not being able to tune in a particular AM radio station at night without picking up another station in the background or hearing an objectionable whistle caused by interference.

The control of interference lies at the heart of spectrum allocation, which entails the development of systematic plans for the use of frequencies in radio communication. The process usually involves three steps: allocation, assignment and licensing. In the allocation step regions of the spectrum are set aside for specific purposes. For example, the band from 535 to 1,605 kilohertz is reserved internationally for AM radio broadcasting.

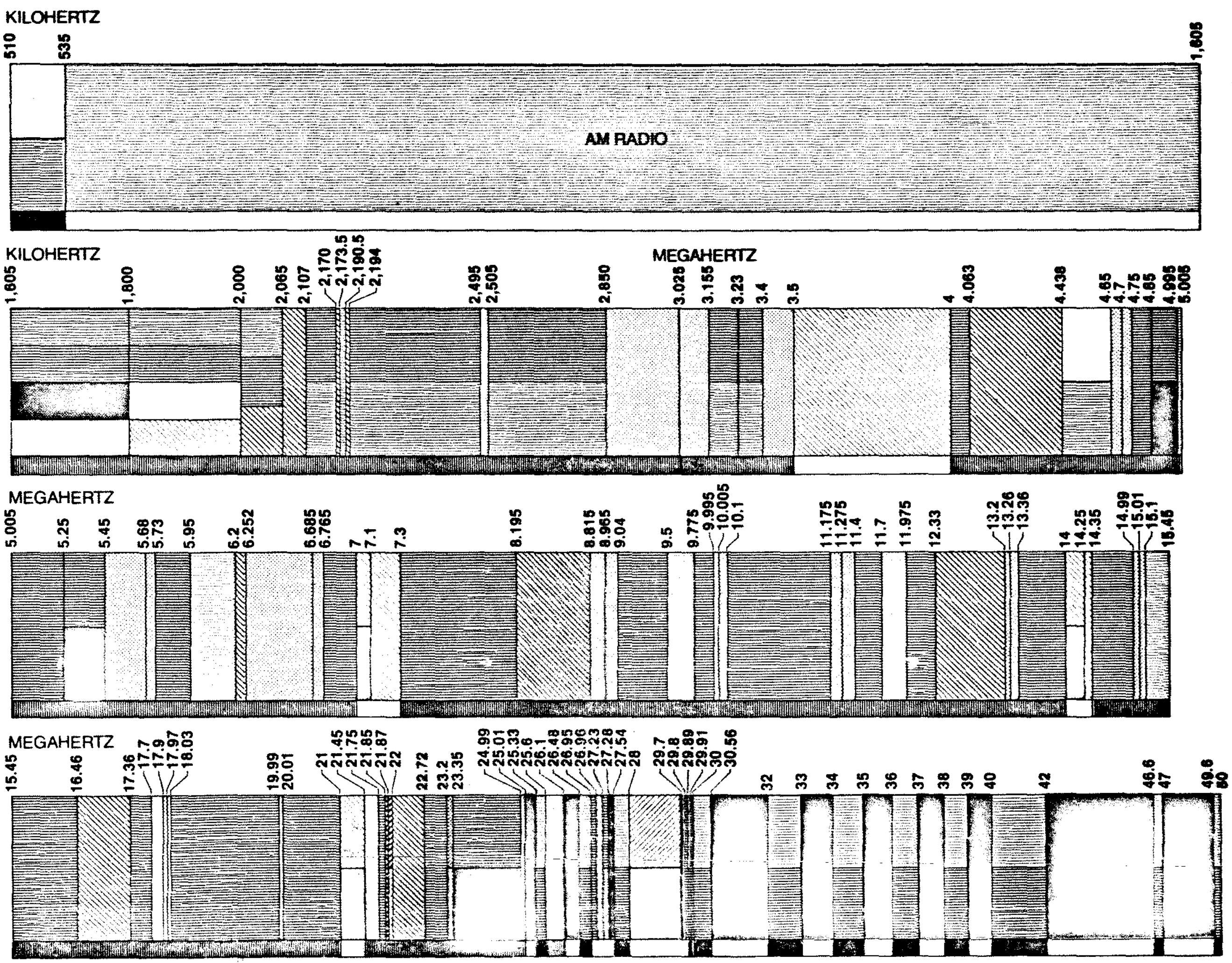
Setting aside regions of the spectrum for clearly defined, compatible uses simplifies the control of interference. Television broadcasting stations interfere with one another symmetrically: if station *A* interferes with station *B*, *B* interferes equally with *A*. A mobile radio and a broadcasting station, however, may interfere quite asymmetrically. For example, a mobile radio may interfere with television reception whereas the signals from the television station do not affect the mobile station. Hence the incentives for cooperation and coordination are much greater if a single class of radio users is assigned to each region of the spectrum.

The methods of assignment vary. For citizens-band radio there is no method; anarchy prevails. For the AM broadcasting band and the land mobile-radio bands the method is first come, first served. A prospective user searches for a place in the band where a new assignment is possible. If he finds one, he registers his intent to use it, and assignments must not conflict with his choice.

Sometimes the regulators put more structure into the assignment process. The FCC worked out a table of assignments for television broadcasting before it opened the band for licensing. The commission's objectives were to simplify the process of licensing and to ensure balance in assigning frequencies to communities. Licensing is a specific authorization to a broadcaster to use a frequency. The steps of assignment and licensing are often combined.

The allocation of the spectrum can be viewed as the allocation of a resource. The problems of spectrum allocation and management can also be viewed in other ways. In the most fundamental one the spectrum-management process is seen as providing the crucial coordination needed to avoid interference. Even if twice as many channels were available as could ever be used, it would still be necessary to register and coordinate the uses in order to avoid interference.

Another view sees spectrum management primarily as the structuring of communications, in particular mass communications. Broadcasting policy



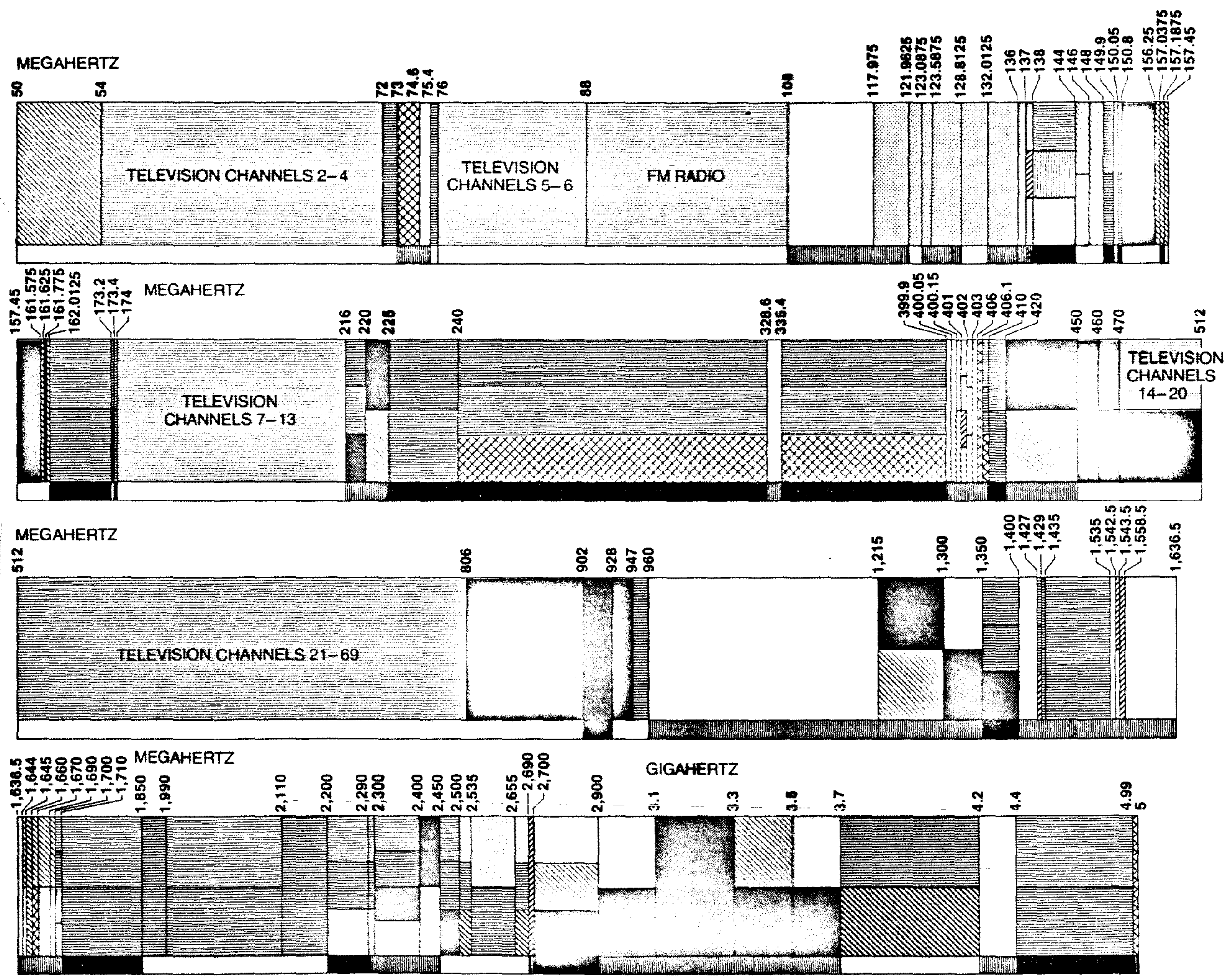
consists of many elements: technical standards, the choice of the number of outlets in each community, rules on ownership and the definition of the kinds of service to be provided by broadcasters. In many countries only the government owns broadcasting stations. In the U.S. the FCC puts on broadcasters certain requirements that are not applied to the owners of other media. For example, broadcasting stations are required to cover controversial issues of public importance "fairly." No such rule applies to newspapers, magazines or book publishers. The Supreme Court has upheld the policy, stating: "In view of the scarcity of broadcast frequencies, the Government's role in allocating those frequencies, and the legitimate claims of those unable without governmental assistance to gain access to those frequencies for expression of their views, we hold the regulations and ruling at issue here are both authorized by statute and constitutional."

The point to be emphasized is that (at least in the U.S.) broadcasting policy flows from spectrum-management policy. The practical result is that since the Government allows some people to broadcast and excludes others, it must have a mechanism for choosing among applicants. Nothing in the laws of physics or politics requires this mechanism of choice to focus exclusively on technical standards. Indeed, social and political forces push toward the consideration of nontechnical criteria in deciding who should operate broadcasting stations. Spectrum-allocation policy becomes linked with fundamental social and political activities.

The allocation of the spectrum can also be viewed in terms of economics. Economists writing about spectrum-allocation policy usually treat the spectrum as an example of a resource (like land and water) that requires economic management. It is an unusual kind of resource, however, in that the people who are authorized to use it do not pay for their part of it and cannot sell or share the allocation without the approval of the granting agency. Moreover, large bands of the spectrum are allocated to various users—commercial televi- ... ernments and so on—that may underuse their part of it, but it cannot be transferred from one type of user to another.

Another aspect of spectrum allocation is the creation and distribution of wealth. The close link between the two is illustrated by an idealized television market based on three assumptions: (1) total advertising revenue is fixed at $20 million per year regardless of the number of stations in the market; (2) the operating cost for each station is $3 million per year, and (3) the revenue is shared equally by all the stations. If the regulating agency assigned three stations to the market, each station would make $3.6 million in profit per year. The assignment of a fourth station would lower the profit of each station to $2 million; with a fifth station the profit would be $1 million. One can see how sensitive the economics of broadcasting is to slight changes of policy on allocating television stations and what incentives broadcasters have to oppose the addition of new stations to a market.

Historically the allocation of the spec-



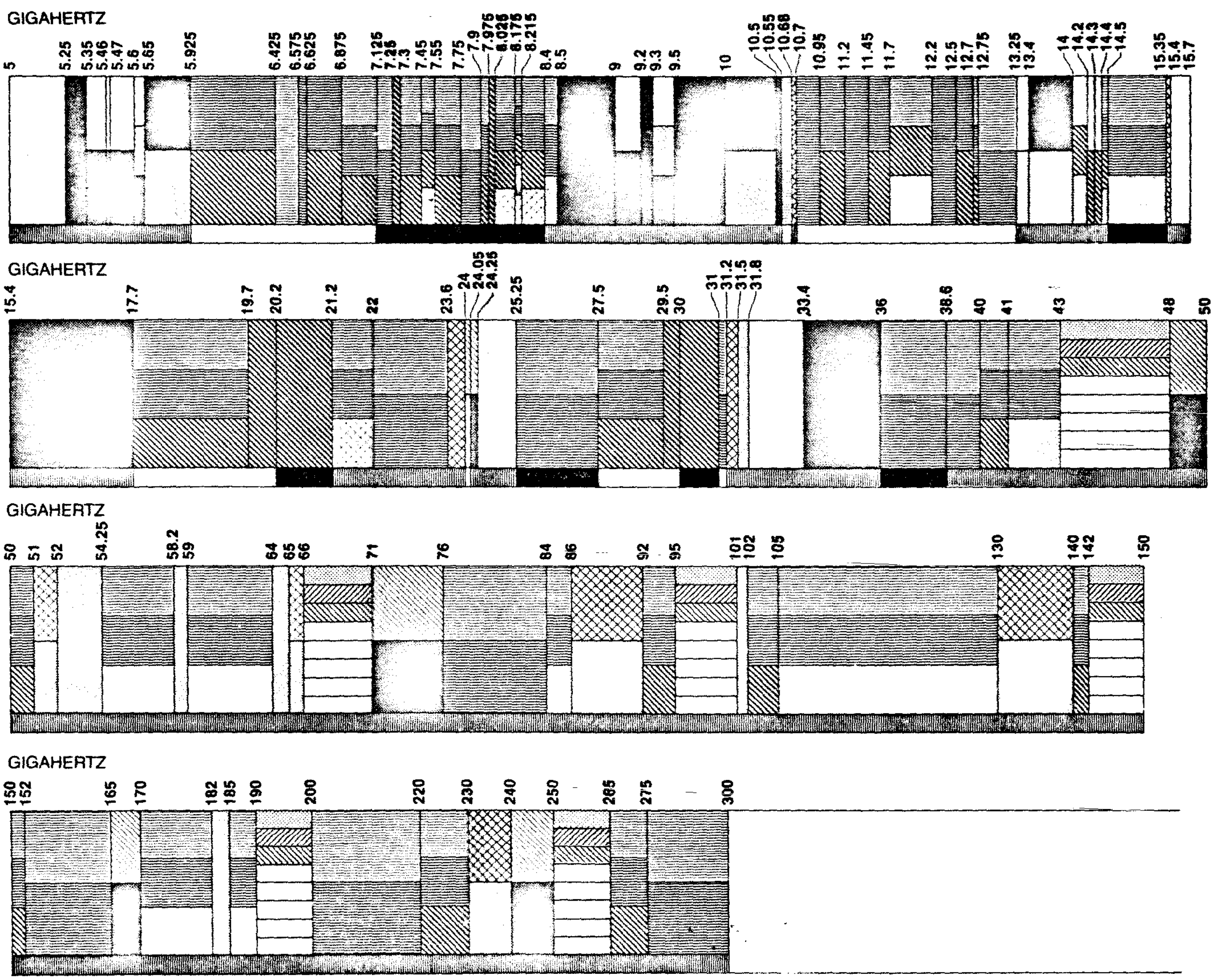
trum has followed a simple pattern. The regulatory authority would set aside a region of the spectrum for a service and would establish technical rules. Prospective users would then apply for licenses on a first-come, first-served basis. Latecomers had to engineer their systems around the earlier ones. This pattern has been followed consistently both internationally and within nations, with few exceptions. The system had (and to a large degree still has) several major advantages, among them its simplicity, low cost and the fact that only a minimal transfer of information is needed to make it work.

The system has been able to meet the expanding demand for space on the radio spectrum by the fortunate circumstance that as demand grew, technology advanced, so that more of the spectrum could be exploited and all of it could be utilized more efficiently. The system does give rise to certain problems, however, a major one of which can be illustrated with a comparison of the broadcasting and telephone systems in the U.S. In 1960 the U.S. had 474 television stations on the very-high-frequency (VHF) band, encompassing channels 2 through 13. Today there are 617. In 1945 the country had 900 full-time AM radio stations; now the band set aside for them supports 2,000 full-time stations. As for telephones, in the early 1950's the Bell System began sending some of its telephone calls by microwave radio. At that time the common-carrier equipment could fit only 2,100 telephone circuits into the microwave band. Today's equipment can fit 36,000 telephone circuits into the same band.

To put it another way, the technical efficiency of the broadcasting system has not really improved at all during a time when the efficiency of the common-carrier microwave system improved by 2,000 percent. This disparity grows out of the incentives offered by the system of spectrum management. The telephone industry and its customers share in the benefits of improved efficiency, so that a telephone company has an incentive to develop and install equipment that makes more efficient use of the spectrum. A broadcasting station cannot share in such benefits, all of which flow to others (such as the buyers of radios and television sets). Indeed, more efficient technology would make it possible for more stations to operate in each market. The advertising revenues and profits of the existing stations would go down.

It should also be recognized that the adoption of new technology is harder in broadcasting than in the telephone system. The ownership of a broadcasting system is divided between the broadcaster, who owns the transmitter, and the listeners, who own the receivers. The larger part of the investment is in the receivers. Most technical changes require changes in both the transmitter and the receiver, and coordinating any change in the millions of receivers would be difficult.

Another kind of difficulty with the present system appeared at the general meeting of the World Administrative Radio Conference in Geneva last fall. (The general meetings, which are held about every 20 years, provide the means whereby the member nations of the International Telecommunications Union allocate regions of the spectrum. The



group also holds more frequent meetings on specific subjects, such as satellite communications. All the meetings entail complicated multilateral negotiations, whose substantive results are embodied in treaties.) Many of the newer nations, which were colonies at the time of the last general conference, are now moving to establish their own satellite-communications and short-wave radio systems. They are therefore competing fiercely to obtain places on the spectrum, many of which are already occupied or assigned to developed nations. The issues were largely unresolved by the conference and therefore remain pending.

Many people have put forward detailed suggestions for making the process of spectrum allocation work better. The suggestions fall into three groups: (1) Improve the current system. (2) Find ways to design radio systems that require less human management. (3) Change the economic incentives so that all users are encouraged to adopt the most appropriate technology.

The current system can be improved in at least two ways. One is to apply more resources (people, money and computers) to the problem. Another is to computerize the traditional process to a greater degree. Both approaches are being taken to some extent already. Data on the uses of the spectrum were once kept in manual files; now they are increasingly being put into a form that can be read out by machine. Searches of the files are being done by computer rather than by hand. Expenditures on the management of the spectrum are increasing.

Another possible improvement in the U.S. is to do away with the present two-headed system of managing the spectrum. Although the division of authority between the FCC and the President has worked reasonably well in the past, a single authority for the allocation of the spectrum would probably do better at shifting allocations between Federal and civil users when such shifts are possible and appropriate.

Improvements that come under the heading of designing radio systems that require less human management introduce a concept that could be called the "anarchy band." (Other names that have been suggested are freedom band, bedlam band and frontier band. They all reflect the relative lack of formal management embodied in the concept.) To make an anarchy band work the regulators would have to arrive at two initial decisions. The subsequent tasks of enforcement and collecting data would then be minimal.

First the regulators must designate a band where anarchy would be the operating principle. Then they must define the technical standards for the equipment that would serve the band. The standards must be chosen to make the overall system work well. The remaining task for the regulators is to ascertain that only the proper equipment is put in service. They can accomplish the task by controlling the sale of equipment.

A good example of an ideal anarchy-band technology would be a radio with a range limited to 10 meters. Such a radio would be particularly suitable for communications within a household or between adjacent households for such purposes as burglar alarms, garage-door openers and the remote control of appliances. The limited range of the transmitters would preclude interference.

To some extent the anarchy-band concept has already been adopted. The Advanced Research Projects Agency (ARPA) of the Department of Defense has developed a system called packet radio that provides voice and data communication over ranges of up to several kilometers. The essence of the system is that each packet, or short sequence, of data is sent over whichever one of a designated group of channels is available. A receiving radio can detect an error in the transmission of a packet due to interference or noise; when such an error is detected, the packet is automatically retransmitted. In terms of the utilization of the spectrum the system can be described as dynamic allocation; it contrasts with the preallocation that characterizes commercial television and radio.

Citizens-band radio is another example of a working anarchy band, although it is far from the ideal because the technical rules applying to the band are so loose. As a result a user of the band often encounters excessive interference. Nevertheless, the band provides a communication service with a minimum of regulatory activity.

The application of economic techniques to the management of the radio spectrum is both promising and possible. The techniques include charging users a fee, auctioning places on the spectrum and even assigning property rights so that a user could buy or trade an allocation. The methods would give the user an incentive to make the most of an allocation and would help to guide the use of the spectrum into more valuable areas. They would also enable the regulators and the users to treat the spectrum as another economic resource like land or electricity. Legislation authorizing the utilization of economic techniques in the management of the radio spectrum has been introduced in each house of Congress by the chairman of the respective subcommittees on communications. Moreover, last September, President Carter sent Congress a message supporting the use of economic techniques in managing the nonbroadcasting portion of the spectrum. Even with such high-level support, however, the concept will be difficult to enact because it is opposed by many of the spectrum's present users.

Both the anarchy-band concept and the application of economic techniques can be characterized as moves away from the present system of centralized regulation toward a decentralized system dominated by the users. Actually all three systems can coexist. They are complementary. Different uses of the spectrum require different techniques of management. No single approach is ideal in all cases.

Looking to the future, one can predict that the already valuable radio spectrum will become more valuable as the cost of complementary resources, particularly electronic equipment, goes down. Hence one can foresee increasing demands for access to the spectrum and an increasing need for its better management. The most easily adopted of the new management techniques, and therefore the most promising one, is the anarchy-band concept. It can be applied within the constraints of the current regulatory framework. The essence of it is the replacement of high-cost human administrators with low-cost electronic equipment.

Controversy over the allocation of the spectrum is likely to be focused on two areas: the ultrahigh-frequency (UHF) television band and the satellite band. UHF will draw attention because of its convenience and availability. Designers of communications systems find the UHF region of the spectrum well suited to their purposes. The equipment is inexpensive and the propagation of the signal is good. Moreover, much of the UHF spectrum is unused even though it has been nominally allocated to broadcasting.

That situation arises from decisions made by the FCC when it originally assigned UHF channels. The commission carefully assigned the channels to cities by taking into account technical constraints that would minimize the cost of UHF sets to the public. Because of improvements in electronics the constraints no longer need to be applied. The existing UHF stations could be accommodated in less than half of the present UHF band, thereby freeing a significant portion of the spectrum for expanded broadcasting or for other services.

The problem with communications satellites arises chiefly from the fact that they must be "stationary," that is, the period of their orbit must coincide with the period of rotation of the earth. They are positioned above the Equator at an altitude of about 22,300 miles. As one might expect, satellite systems at that altitude become an international concern. The U.S. must coordinate its use of the orbital arc with the other nations in the Americas. If markets for satellite communication develop rapidly but the technology advances slowly, contention over the utilization of the satellite portion of the spectrum is certain to arise