Standard Frequencies and Time Signals WWV and WWVH*

The National Bureau of Standards' Radio Stations WWV (in operation since 1923) and WWVH (since 1949) broadcast six widely used technical services: 1) Standard Radio Frequencies, 2) Standard Audio Frequencies, 3) Standard Time Intervals, 4) Standard Musical Pitch, 5) Time Signals, 6) Radio Propagation Forecasts. All inquiries concerning the technical radio broadcast services should be addressed to: National Bureau of Standards Boulder Laboratories, Boulder, Colorado.

The radio bands in which the foregoing services are broadcast are: 2500±5 kc (2500±2 kc in Region 1); 5000±5 kc; 10,000±5 kc; 15,000±10 kc; 20,000±10 kc; 25,000±10 kc. These bands were allotted by international agreement, in 1947, for exclusive standard-frequency-broadcast use.

The National Bureau of Standards' radio stations are located as follows: WWV, Beltsville, Maryland (Box 182, Route 2, Lanham, Maryland); WWVH, Maui, Territory of Hawaii (Box 901, Puunene, Maui, T. H.). Coordinates of the stations are: WWV (lat. 38°59′33″ N., long. 76°50′52″ W.); WWVH (lat. 20°46′02″ N., long. 156°27′42″ W.).

The WWV-WWVH broadcasts are a convenient means of transferring the national standard of frequency and time interval and making it readily available throughout the United States and over much of the world. The broadcast program is shown schematically in Fig. 1.

Standard Radio Frequencies

Station WWV broadcasts on standard radio frequencies of 2.5, 5, 10, 15, 20, and 25 mc. The broadcasts are continuous, night and day, except WWV is off the air for approximately 4 minutes each hour. The silent period commences at 45 minutes, plus 0 to 15 seconds, after each hour.

Station WWVH broadcasts on standard radio frequencies of 5, 10, and 15 mc. The WWVH broadcast is interrupted for 4 minutes following each hour and half hour and for periods of 34 minutes each day beginning at 1900 UT (Universal Time, UT is the same as GMT and GCT.)

The standard radio frequencies are widely used, *e.g.*, by the communications and electronics industry, research laboratories, and government. A local oscillator may be set vs the received frequency, and any desired radio frequency, including microwave frequencies, may be accurately measured in terms of the standard. The beat frequency method, or variations of it, is generally used. With a very narrow band receiver the standard radio frequency can be used when the received field strength is too low for audibility on ordinary radio receivers.

The accuracy of each of the radio frequencies as transmitted is better than 1 part in 100,000,000. The stability (quality of remaining fixed or unvarying) at the transmitter is normally within 1 part in 10^9 at WWV and 5 parts in 10^9 at WWVH. Deviations at WWV are about 2 in 10^{10} each day; frequency adjustments are made each day if necessary at 1900 UT. Deviations at WWVH are about 4 in 10^{10} each day; frequency adjustments are made each day if necessary during the interval 1900 to 1935 UT. If received accuracies better than 3 parts in 10^7 are desired it is necessary to make measurements over a long interval, *e.g.*, 24 hours, to obtain an accuracy of 1 part in 10^8. Such long-interval measurements should preferably be of the type that result in a strip chart record of frequency or phase changes (local oscillator vs WWV or WWVH) during the measurement interval. During intervals of about 10 hours or less, one may obtain highest accuracy when ionospheric conditions are normal and when measurements are made at the optimum time of day which is when sunrise or sunset does not occur over the radio propagation path.

Final corrections to the broadcast frequencies are available on a quarterly basis from the National Bureau of Standards Boulder Laboratories, Boulder, Colorado.

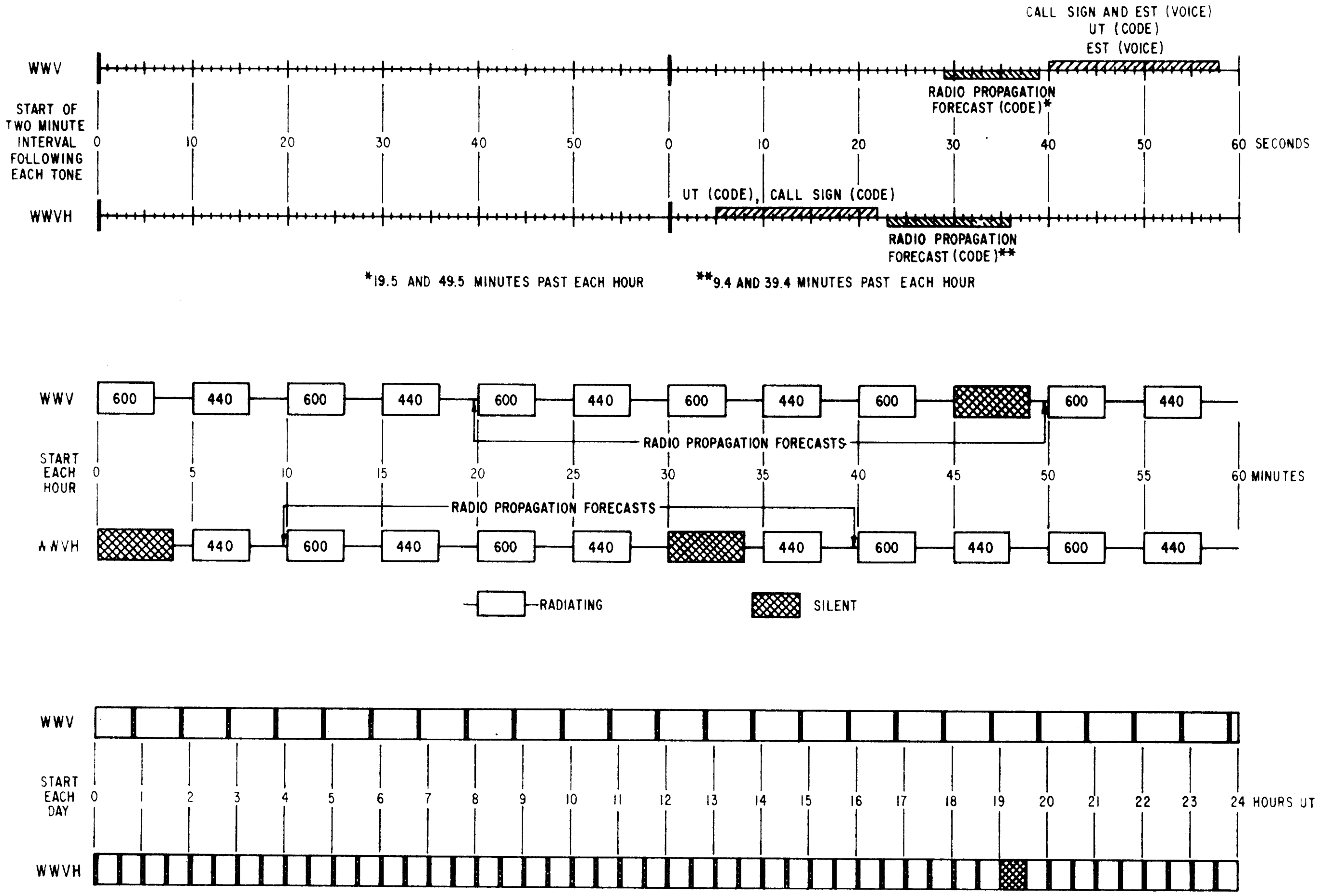


Fig. 1

* Received by the IRE, July 23, 1956.

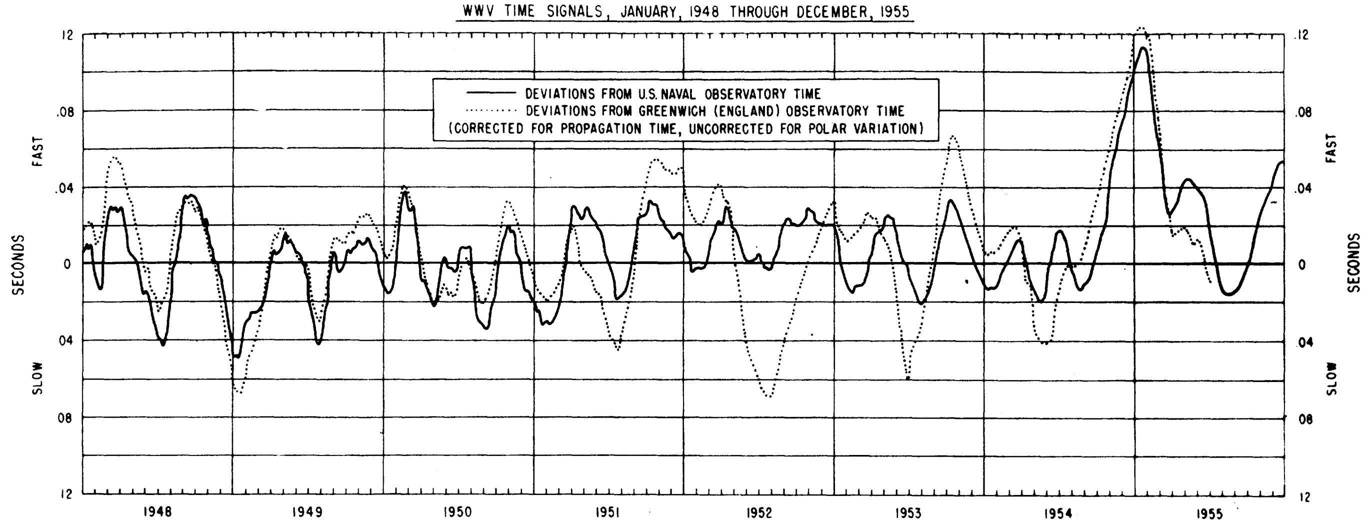
Standard Audio Frequencies

Two standard audio frequencies, 440 cps and 600 cps, are broadcast on each radio carrier frequency. The audio frequencies are given alternately starting with 600c on the hour for three minutes, interrupted two minutes, followed by 440c for three minutes and interrupted two minutes. Each 10-minute period is the same except for transmitter interruptions [see 1, p. 1470]. The accuracy of the audio frequencies as transmitted is better than one part in 100,000,000. Changes in the transmitting medium (Doppler effect, etc.) result at times in fluctuations in the audio frequencies as received.

Standard Time Intervals

Seconds pulses at intervals of precisely one second are given as double sideband amplitude modulation on each radio carrier frequency. The pulse duration is 0.005 second. The pulse wave form is shown in Fig. 2. At WWV each pulse consists of five cycles of a 1000c frequency. At WWVH each pulse consists of six cycles of a 1200c frequency. The pulse spectrum is composed of discrete frequency components at intervals of 1.0c. The components have maximum amplitudes at approximately 995c and 1194c for the WWV and WWVH pulses respectively. At WWV the tone is interrupted 0.040 second for the seconds pulse. The pulse commences 0.010 second after commencement of the interruption.

The seconds pulses provide a useful standard time interval for quick and accurate measurement or calibration of time and frequency standards and timing devices. For example, a watch rate recorder may be checked by recording the seconds pulses. Intervals of one minute are marked by omitting the pulse at the beginning of the last second of every minute and by commencing each minute with two pulses spaced by 0.1 second. The two-minute, three-minute, and five-minute intervals are synchronized with the seconds pulses and are marked by the beginning or ending of the periods when the audio frequencies are off.



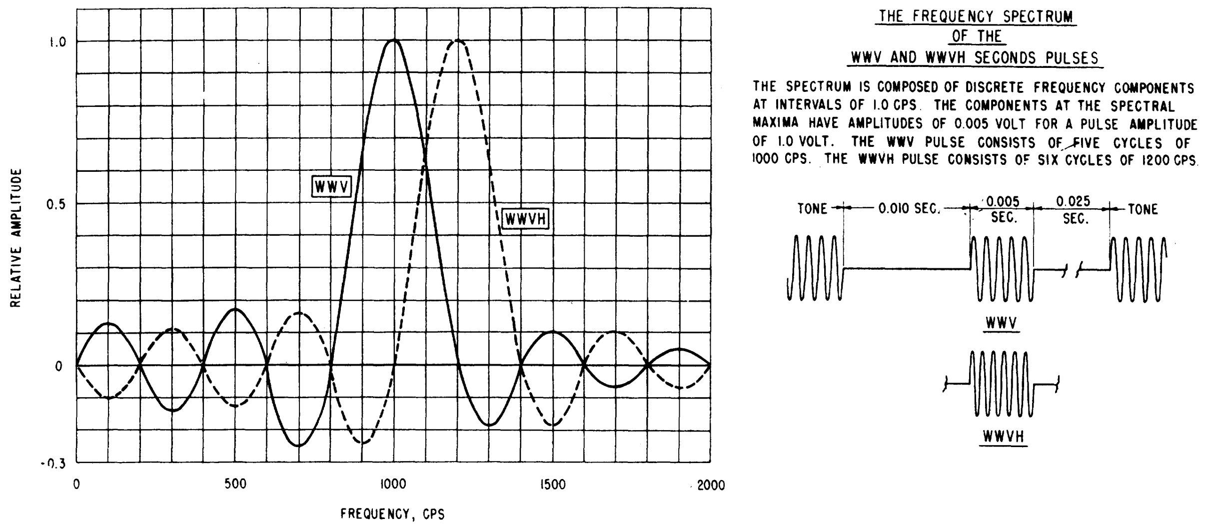


Fig. 2

The two standard audio frequencies are useful for accurate measurement or calibration of instruments operating in the audio or ultrasonic regions of the frequency spectrum. The frequencies broadcast were chosen because 440c is the standard musical pitch and 600c has the maximum number of integral multiples and submultiples; also, 600c is conveniently used with the standard power-frequency 60c.

Electronic circuits may be associated with radio receivers which automatically convert 600c to 1000c, 100c, etc.

The accuracy of the audio frequencies, ...

A time interval as broadcast from WWV is accurate to 1 part in 10^8 plus or minus 1 microsecond. Received pulses have random phase shifts or jitter because of changes in the propagating medium. The magnitudes of these changes range from practically zero for the direct or ground wave to about 1000 microseconds when received via a changing ionosphere. Multiple pulses and echoes are sometimes received because of propagation around the world and reflection from objects on the earth's surface. The beginning of the first pulse received, *i.e.*, the part having least delay, is most accurate and should be used. When ionospheric conditions are normal and the correct time of day is chosen, a frequency standard can be checked in a few hours vs WWV with a precision of about 1 part in 10^9; however, it is best to use intervals of 24 hours when comparing with this precision.

In using the time interval markers for high precision work it is necessary to remember that step adjustments of precisely ± 20 milliseconds may be made at the transmitter on Wednesdays at 1900 UT; this is explained under the section on Time Signals.

The seconds pulses from WWVH are adjusted if necessary each day during the interval 1900 to 1935 UT so as to commence simultaneously with those from WWV, within plus or minus 500 microseconds.

Standard Musical Pitch

The frequency 440 cps for note A above middle C has been the standard in the music industry in the United States since 1925. The radio broadcast of this standard was commenced by the National Bureau of Standards in 1937. It is now given six times per hour, 18 minutes per hour, from WWV and WWVH as shown in Fig. 1. With this broadcast the standard pitch is maintained and musical instruments are manufactured and adjusted vs an unvarying standard. Listeners of music are benefited because there are fewer instruments not in tune and practically no instruments are manufactured which cannot be tuned to 440c.

A high frequency or short-wave radio receiver is the only equipment needed to effectively use the musical pitch standard.

Time Signals

The audio frequencies are interrupted at precisely two minutes before each hour. They are resumed precisely on the hour and each five minutes thereafter; they mark accurately the hour and the successive 5-minute periods (see Fig. 1).

Time signals from WWV are maintained in close agreement with uniform time, called UT 2, determined by the U. S. Naval Observatory. This is done by occasional step adjustments in time, when necessary, of precisely plus or minus twenty milliseconds. These adjustments may be necessary several times per year. When required, they are made on Wednesdays at 1900 UT simultaneously at WWV and WWVH.

Universal Time is announced in telegraphic code each five minutes from WWV and WWVH. This provides a quick reference to correct time where a timepiece may be in error by a few minutes. The zero- to twenty-four-hour system is used starting with 0000 at midnight. The first two figures give the hour and the last two figures give the number of minutes past the hour when the tone returns. For example, at 1655 UT, or 11:55 A.M., Eastern Standard Time, four figures (*1*, *6*, *5*, and *5*) are broadcast in code. The time announcement refers to the end of an announcement interval, *i.e.*, when the audio frequencies are resumed.

At Station WWV a voice announcement of *Eastern* Standard Time is given before and after each telegraphic code announcement. For example, at 9:10 A.M., EST, the voice announcement in English is: "National Bureau of Standards, WWV; when the tone returns, Eastern Standard Time is 9:10 A.M."

Final corrections to the time signals, as broadcast, are determined and published, on a weekly basis, by the U. S. Naval Observatory, Washington 25, D. C.

Radio Propagation Forecasts

A forecast of radio propagation conditions is broadcast in telegraphic code on each of the standard radio carrier frequencies: from WWV at approximately 19.5 and 49.5 minutes past each hour, and from WWVH at approximately 9.4 and 39.4 minutes past each hour, as shown in Fig. 1. Propagation notices were first broadcast from WWV in 1946; the present type of announcement has been broadcast from WWV since July, 1952, and from WWVH since January, 1954.

The forecast announcement tells users the condition of the ionosphere at the regular time the forecast is made and how good or bad communication conditions are expected to be in the succeeding 6 or more hours. The NBS forecasts are based on information obtained from a world-wide network of geophysical and solar observatories, including radio soundings of the upper atmosphere, short-wave reception data, and similar information. Trained forecasters digest the information and formulate the predictions.

From WWV the forecasts refer only to North Atlantic radio paths, such as Washington to London or New York to Berlin. The times of issue are 0500, 1200 (1100 in summer), 1700, 2300 UT. These are the short-term forecasts prepared by NBS-CRPL North Atlantic Radio Warning Service, Box 178, Fort Belvoir, Va.

From WWVH the forecasts are for North Pacific radio paths, such as Seattle to Tokyo or Anchorage to San Francisco. The times of issue are 0200 and 1800 UT, with these forecasts first broadcast at 0239 and 1839 UT respectively. These are short-term forecasts prepared by NBS-CRPL North Pacific Radio Warning Service, Box 1119, Anchorage, Alaska. (Another short-term forecast at 0900 UT may be broadcast at a later date.)

The forecasters assume that the most suitable radio freqencies for communications are available and in use for the typical paths. Because of this assumption, their notices must be interpreted on a relative scale in terms of experience on each radio circuit in use. It is impossible to rate conditions on an absolute scale since the varied effects of transmitter power, type of communications traffic and procedure, antennas and receivers, prevent an evaluation which will be valid for all circuits. One purpose of broadcasting both a description and a forecast is to show more clearly whether propagation conditions are expected to deteriorate or improve in the coming period.

The forecasts broadcast by WWV and WWVH apply only to short-wave radio transmissions over paths which are near the auroral zone for a considerable part of their length. In this zone the ionospheric layers are very likely to be disturbed, and because short-wave, long-range radio transmissions are dependent on the condition of the ionosphere, communications may be disrupted. Often the ionospheric disturbance accompanies intense magnetic field variations and a brilliant aurora. The resulting propagation effects range from severe fading to a complete break in the communications link.

The forecast is broadcast as a letter and a digit. The letter portion of the announcement identifies the radio quality at the time the forecast is made. The letters denoting quality are "N," "U," and "W," signifying that radio propagation conditions are normal, unsettled, and disturbed. The digit portion is the forecast of the radio propagation quality on a typical North Atlantic (from WWV) or a typical North Pacific (from WWVH) transmission path during the 6 or more hours after the forecast is made. Quality is graded in steps ranging from 1 (useless) to 9 (excellent) as follows in Table I. If, for example, propagation conditions at the time the forecast is made are normal but are expected to be only "poor-to-fair" within the next 6 or more hours, the announcement would be broadcast as N4 in international Morse code.

TABLE I

Disturbed Grades (W)	Unsettled Grade (U)	Normal Grades (N)
1—useless	5—fair	6—fair-to-good
2—very poor		7—good
3—poor		8—very good
4—poor-to-fair		9—excellent

Radiated Power, Transmitting Antennas, Modulation

Radiated power is shown in Table II below.

TABLE II

Frequency, mc	Power, kw WWV	Power, kw WWVH
2.5	1	
5	8	2
10	9	2
15	9	2
20	1	
25	0.1	

The broadcast on 2.5 mc is from a vertical quarter-wave antenna. The broadcasts on all other frequencies are from vertical half-wave dipoles. The radiation is omnidirectional.

The per cent amplitude modulation, double sideband, is:

audio frequencies 440 or 600 cps	75 per cent
voice and seconds pulses, peak,	100 per cent.

At WWV, the tone frequency 440 or 600 cps, except on 25 mc, is experimentally operated as a single upper sideband with full carrier. Power output from the sideband transmitter is about one-third the carrier power. Single sideband tone on 25 mc may be added at a later date. Other signals (announcements and seconds pulses) are double sideband, 100 per cent amplitude modulation.

ACCURACY

Frequencies from WWV and WWVH are accurate to within 1 part in 10^8 as broadcast; this is with reference to the U. S. Naval Observatory time and is limited by uncertainties in the immediate determination of astronomical time.

The radio frequencies may be consistently received with accuracies equal to those transmitted for several hours per day during total light or total darkness over the transmission path at locations in the service range. This was described in the first section.

Large errors are caused by motion of the radio receiver relative to the transmitting stations or by motions of the reflecting ionospheric layers on which long-distance radio propagation depends. For example, on a vehicle moving 60 miles per hour relative to a fixed station, the received frequency would be in error by about 1 part in 10^7. Measurements made at NBS Boulder Laboratories and at WWVH have shown that during the

TABLE III

Call Sign	Location	Carrier Frequency Mc	Modulation cps	Carrier Power kw
LOL	Buenos Aires, Argentina	2.5, 5, 10, 15, 20, and 25	1, 440, 1000	2
ZUO	Johannesburg, South Africa	5	1	0.1
ZLFS	Lower Hutt, New Zealand	2.5	—	0.035
—	Moscow, USSR	10 and 15	1	—
MSF	Rugby, England	2.5, 5, and 10	1, 1000	0.5
JJY	Tokyo, Japan	2.5, 5, 10, and 15	1, 1000	1
IBF	Torino, Italy	5	1, 440, 1000	0.3
—	Uccle, Belgium	2.5	—	0.02

course of the day errors in the received frequencies vary approximately -3 to $+3$ parts in 10^7.

Daily deviations in frequency and time of stations WWV and WWVH are tabulated on a quarterly basis. These data are available on request. In Fig. 2 are plotted time signal deviations extending back 7 years. The deviations may be considerably less commencing in 1956.

DISTANCE RANGE OF RECEPTION

Of the standard radio frequencies (2.5, 5, 10, 15, 20, and 25 mc), the lowest provide service to short distances, and the highest to great distances. Reliable reception is in general possible throughout the United States and the North Atlantic and Pacific Oceans, and reception at times throughout the world. One should select the frequency that gives best reception at any particular place and time. This can be done by two methods:

1) By tuning to the different frequencies and selecting the one most suitable at that time.

2) By making use of techniques of prediction of usable frequencies. NBS publications useful for this purpose are the reports of the CRPL-D series, "Basic Radio Propagation Predictions," which are issued monthly, three months in advance of the month of prediction, and Circular 465 of the National Bureau of Standards, "Instructions for the Use of Basic Radio Propagation Predictions." These two publications may be obtained from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., price in U. S. $1.00 per year (12 issues) and 30 cents per copy, respectively (foreign, $1.25, and 40 cents).

OTHER STANDARD FREQUENCY AND RADIO TIME SIGNAL SERVICES

The U. S. Naval Observatory, Department of the Navy, broadcasts time signals at regular intervals from NSS (Annapolis, Md.), NPG (Mare Island, Calif.), NPM (Pearl Harbor, Hawaii), NBA (Balboa, Canal Zone). Detailed information may be obtained from the U. S. Naval Observatory, Washington 25, D. C.

The Dominion Observatory, Ottawa, Canada, broadcasts time signals continuously over Station CHU on frequencies of 3330, 7335 and 14670 kc. Information may be obtained by writing the Dominion Observatory.

A comprehensive list of United States and foreign radio time signals is given in chapter 3 of "Radio Navigational Aids," Hydrographic Office publication No. 205, for sale by the Hydrographic Office, Washington 25, D. C., price $2.00, U. S. or foreign.

Standard frequencies and time signals are broadcast by other stations as indicated in Table III above.

NATIONAL BUREAU OF STANDARDS,
Boulder Laboratories,
Boulder, Colo.

Analog Computer Amplifier Circuits*

Operational amplifiers most frequently found in electronic analog computers have a general connection shown in the block diagram of Fig. 1(a). Here, A is a dc amplifier whose gain is real and negative over the range of operating frequencies, and N_I and N_F are the input and the feedback networks, respectively. If the gain of A is sufficiently high, the transfer function is determined only by N_I and N_F. In this case the terminals b and c are essentially at the ground potential.[1] Then it can be said that, so long as the reciprocity theorem holds with these networks, the terminal connections of the networks may be re-

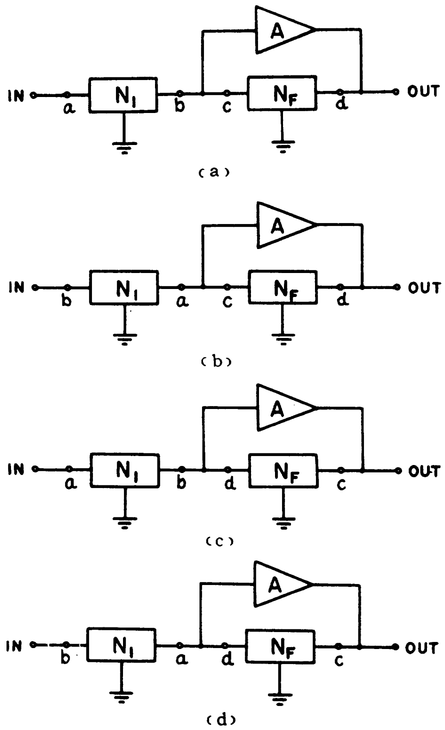


Fig. 1—Operational amplifiers.

versed with no change in the transfer function. In other words, the operational amplifiers of Fig. 1(b), 1(c), and 1(d) give the same transfer function.

An example follows: Fig. 2(a) is a constant coefficient multiplier commonly found in analog computers, whereas Fig. 2(b) is a new constant coefficient multiplier derived from Fig. 2(a) using the principle described above. These multipliers have the identical transfer function when the gain A is very high. When the gain A is limited, the transfer function is affected by A. The amount of error due to this effect depends on the circuit connection. The circuit of Fig. 2(a) is superior, in this respect, to that of Fig. 2(b). However, the

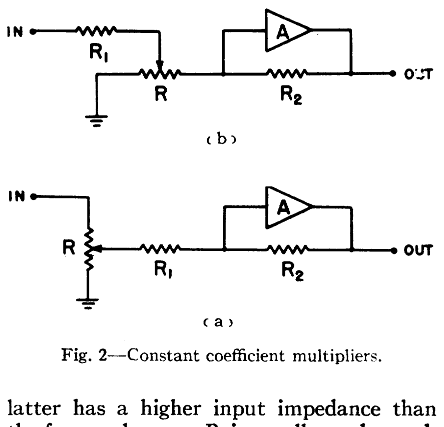


Fig. 2—Constant coefficient multipliers.

latter has a higher input impedance than the former, because R_1 is usually made much higher than R to reduce the error resulting from potentiometer loading.

HIROSHI AMEMIYA,
Showa Denshi, Ltd.,
Totsuka-ku,
Yokohama City, Japan.

* Received by the IRE, June 20, 1956.

[1] G. A. Korn and T. M. Korn, "Electronic Analog Computers," McGraw-Hill Book Co., Inc., New York, N. Y., 1952; Ch. 4.