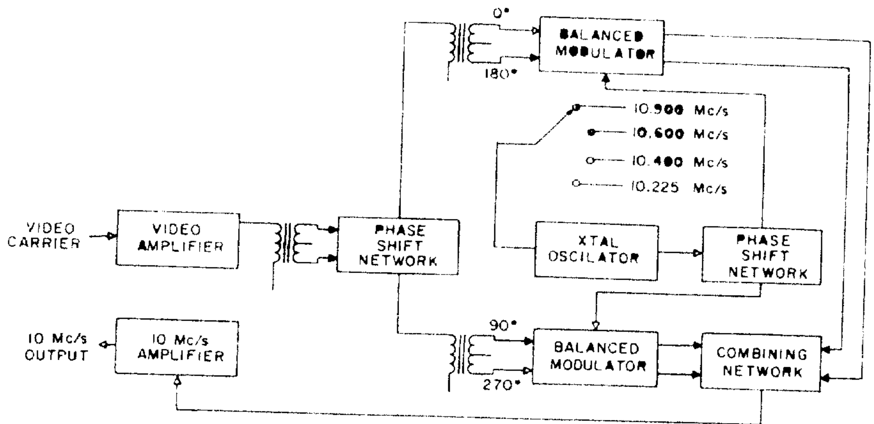

Fig 2—Up-converter module.

phase-shift techniques and balanced modulators for the up-conversion process in the reproduce mode have led to a unique translating device which was developed specifically for a predetection recording system designed to facilitate acquisition and storage of FM/FM, PCM/FM, SS/FM, PAM/FM, etc. telemetry data. The device uses more than 80% of available recorder bandwidth in contrast to approximately 50% for non-translation predetection systems, and permits the system to record high bit-rate PCM signals or standard IRIG signals at reduced recorder speeds.

Making use of conventional techniques, the down-converter accepts the 10 Mc/s IF from the receiver and converts to any one of four selectable center frequencies (video carrier) for recording at various tape speeds. A "tight" AGC loop insures a constant record level of ± 1 db. Spurious conversion products prevent using conventional techniques in the up-conversion process. Fig. 1 points out that wideband playback requires effective suppression of the image band and oscillator "feed-through" as well as various secondary effects which fall within the IF passband. Sharp filters are not desirable in this application because of phase distortion effects.

The "up-converter" incorporates circuitry similar to that used in some types of single-sideband exciters. A wideband phase-shift network in conjunction with dual balanced modulators and a combining network cancel the undesired sum, product and local oscillator signals to effectively suppress these components in the 10 Mc/s output. Referring to Fig. 2, the video phasing network provides two outputs with a differential phase of 90° over the 100-1500 kc/s frequency range. Each of these signals feed into individual balanced modulators through wideband transformers which apply push-pull signals to the deflection plates of RCA type 7360 beam deflection tubes. Phase relationships—shown on Fig. 2—are such that the undesired "sum components" subtract while the desired "difference components" add in the combined output.

Performance depends to a great extent on the equality of amplitude and exactness of the 90° phase difference between the signals applied to the 7360 deflection electrodes. Differential phase accuracy is determined largely by the passive phasing network which encompasses more than 4 octaves in the video band.

$R = [(1 - \cos q)/(1 + \cos q)]^{1/2} \cong q/2$ gives the effect of phase balance on image rejection. Here R is the ratio of sidebands and q the deviation of difference phase from $\pi/2$ expressed in radians. Thus, for an image rejection of 30 db. $q = 0.0634$ radians or 3.67° over the entire video band. Since amplitude errors also contribute to the problem, phasing errors are held to less than 2°.

Conversion oscillator feed-through is a function of balanced modulator performance. Use of beam deflection tubes with their inherently balanced construction permits oscillator frequency rejections of 40 db minimum.

STATUS OF FREQUENCY AND TIME CONTROL

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In recent years, precise and accurate measurement of physical quantities has been given accelerated emphasis. Although frequency and time are relatively advanced when compared to measurements of pulsed-power, radio noise, field strength, and others, there are still many unresolved problems and a need for continued improvements.

Oscillators

Fig 1 gives some idea of the instability currently noted in high quality quartz oscillators. Here the reference U. S. Frequency Standard was received from WWVL (20 kc/s) and we have, essentially, a plot of data published each month in the *Proc. IRE* and a summary of the performance of WWV since 1960. Throughout this period the control oscillators contained a 2.5 Mc/s fifth overtone quartz crystal unit; however, since March 1960 the control oscillator has been a compact solid state unit with associated standby batteries, and operated in the open without special precautions.

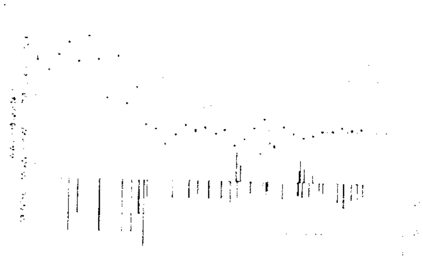

Fig 1—Performance of WWV control oscillators.

When greatly improved oscillators with instabilities of only a few parts in 10^{12} or 10^{13} come into use, relativistic effects must be taken into account. Frequency shift with gravitational potential is about 1.76 parts in 10^{13} per mile of altitude at the earth's surface and the quadratic Doppler shift amounts to about 1 part in 10^{12} at 700 miles per hour.

Standards

In frequency and time, as in most physical quantities, we have the advantages which result from universal agreement on the units of measurement. When we say, for example, that a spectral line is 1420 Mc/s, or a standard frequency broadcast is 20 kc/s, or an interval is 10 microseconds, there is general understanding of just what is meant. For a more exact understanding one can refer to the definition of the scale involved. A major problem exists in developing a sound proposal—and in obtaining official worldwide agreement—on a new second and its associated new time scale (in this case atomic time). There is need for a fundamentally constant second which can be immediately generated with an atomic clock. When the new unit of time is finally adopted, we can expect close agreement with the ephemeris second and little if any change in the ordinary operations which involve accurate time.

In contrast to this, a considerable lack of agreement and a number of unsolved problems occur in our day to day operations. Examples of long standing relate to an improved calendar and a decimal system in subdividing days, hours, and minutes. These are mentioned to emphasize difficulties in bringing about improvements, which in some cases are comparable with introducing the metric system or with making a major change in language.

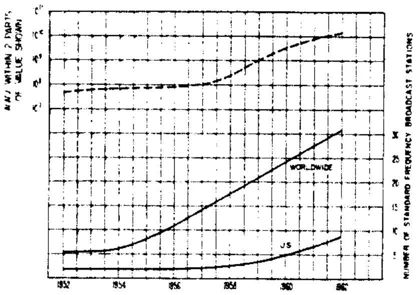

Fig 2—Trends in standard frequency broadcasts.

A better example concerns the broadcasts of time signals on many different radio carrier frequencies. In an excellent publication of the Hydrographic Office (H. O. Publication 117, "Radio Navigational Aids."), we find a list of radio time signals which are regularly given by 30 or so countries on about 380 radio frequencies ranging from about 16 kc/s to 25.840 Mc/s. All these stations are not continuously giving time signals—other valuable information is often broadcast.

Here, however, there is duplication in the services given and a need for unification of the many different time signal systems used. This lack of standards leads to inefficiency and greater expense in operations and unnecessary use of an already-crowded radio spectrum.

Similar remarks apply to time codes where an efficient, rapid, precise, and unambiguous code—including year, month, day and time—must be developed and incorporated into the several systems now used. NBS is continuing the broadcast of a time code commenced in 1960. Also, in 1960, the

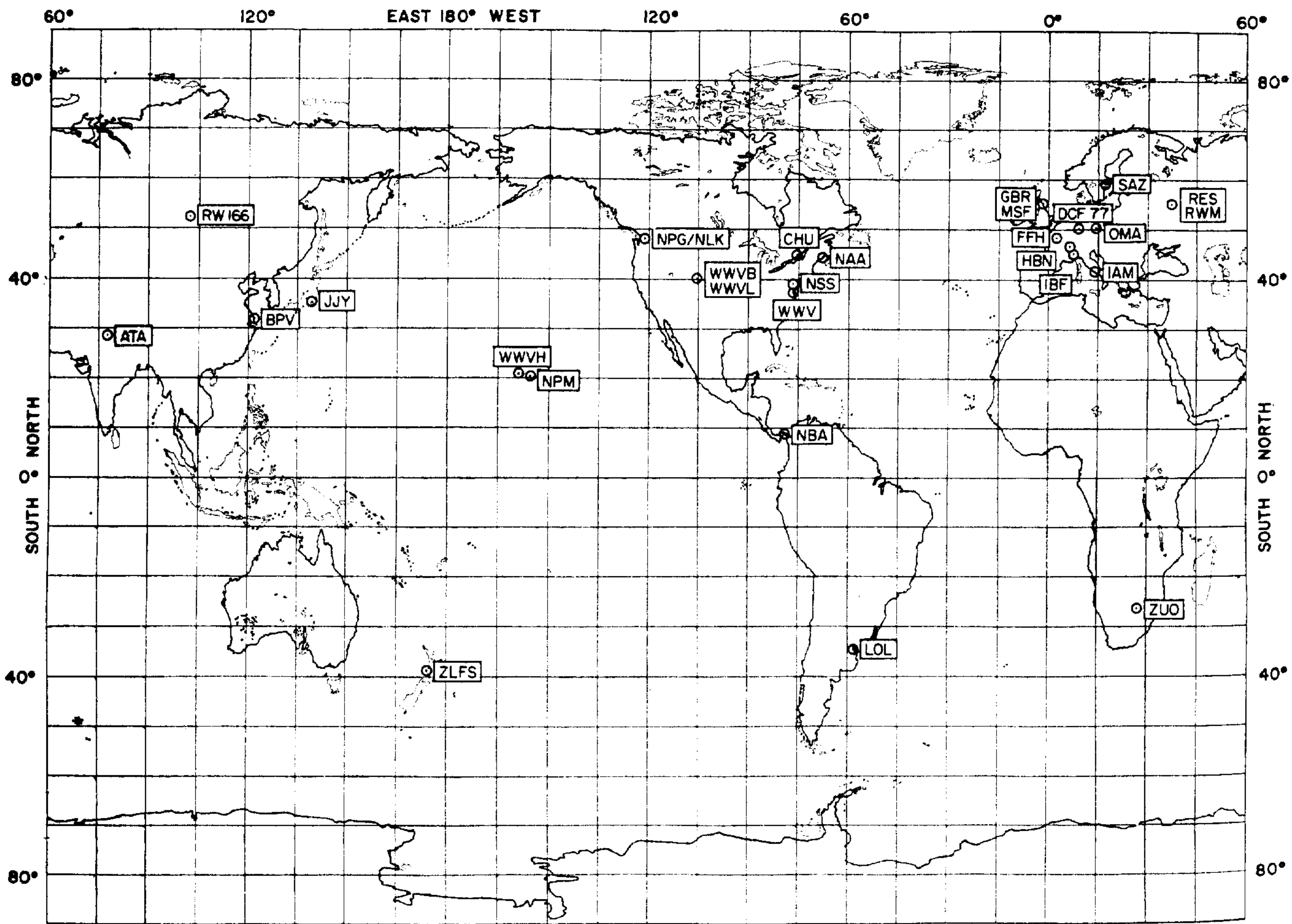

Fig 3—Worldwide distribution of standard frequency and time signal stations (From CCIR, 1962). Breakdown indicates that additional stations may be justified in Africa, Australia and South America.

Inter-Range Instrumentation Group (IRIG) recommended a standard for range timing signals which is now in use. The latter is, in effect, a combination of two codes in one format so as to meet already existing equipment requirements.

Another old but unsolved problem in the distribution of standard frequencies and time signals is sometimes referred to as frequency offset and step-adjustments. In recent years there has been international coordination of time and frequency with a resulting procedure, described in a revision of the CCIR Recommendation No. 319 as follows: "that the time signals should consist of impulses repeated at intervals of one second and maintained within approximately 100 milliseconds of universal time (UT2). Changes in the phase of the pulses should be exactly 50 milliseconds and should be made simultaneously by the stations concerned." Also, we find in a revision of CCIR Report No. 166, "the frequency is maintained as constant as possible by reference to atomic or molecular standards and at the offset from nominal announced for each year by the Bureau International de l'Heure. Some users, including at least two industrial standards laboratories and one manufacturer of quartz crystal units, would prefer an "on-frequency" operation without offset. They reason that application of a large correction is inconvenient and may result in an additional source of error. Also, a broadcast very closely maintained on frequency can be used, generally, without regard to small errors at the transmitter.

It may not be easy to improve the present system which now gives accurate frequency and time with built-in simplicity for the large number of ordinary users. The problem is to broadcast, with maximum convenience, the UT2 and Atomic time scales. Several possibilities exist:

► Operate the carrier precisely on frequency using an atomic standard and operate the seconds pulses from a UT2 clock.

► Make carrier and seconds pulses coherent, with corrections for UT2 users.

► Use two time scales, putting the atomic and UT2 seconds on a carrier controlled by an atomic standard.

In the area of terminology, there is a lack in the definition of oscillator instability and the meaning of the terms *short-time* instability and *long-time* instability. Unfortunately a proposal of official status is not yet available; however, some clarification results when you designate the instability from thermal or shot noise, inherent in the resonator and associated circuitry, as short-time instability. Changes in frequency for other reasons, e.g., instability of components, are referred to as long time changes.

Future Trends

Improvement in standard frequency broadcasts for the past 10 years is indicated in Fig 2. Over a period of several decades, we find that the precision of the broadcast frequency increases about one order of magnitude per decade. Note, however, that a two orders increase in precision came about with development of operational atomic frequency standards and that further improvement can be expected.

Points on the lower curve of Fig 2 come from URSI and CCIR records. Advances in science and technology will continue to require improved services from standard frequency stations which presently operate on carrier frequencies ranging from 16 kc/s to 150 Mc/s in bands 4, 6, 7, and 8.

Loran-C has been useful in synchronizing and setting clocks to a relative accuracy of better than 1 microsecond. This system which can give both position and time simultaneously is expected to meet many of the needs for increased precision in the distribution of time signals. It's probably safe to predict that many of the present standard frequency and time signal stations will become less useful when we have precisely controlled broadcasts from satellites orbiting the earth at an altitude of about 23,400 miles where they may be controlled to remain nearly stationary or to pass very slowly overhead. Incorporation of high precision frequency control and a time code in television broadcasts from such satellites may be found to be an effective means of distributing frequency and time standards by radio.

Editor's Note: Early this year, Mr. George met with tragic and sudden death while attending a CCIR conference in Geneva. Our staff regarded him not only as an able and devoted worker in his field, but as a sincere friend and advisor to our magazine. We will miss him.