Frequency standard hides in every color TV set

As part of color video transmission, the three major networks generate a highly stable subcarrier; this signal can easily be used as a reference for calibrating other signal sources

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☐ Along with every color broadcast, the major TV networks provide a quick, inexpensive means for measuring frequency with a resolution of a few parts in 10^{11}. ABC, NBC, and CBS each generate a highly stable 3.58-megahertz signal for color video transmission. This signal can be taken from a color TV set and used as a reference for calibrating other signal sources.

In theory, resolution in the range of 1×10^{11} is presently attainable by phase-tracking low-frequency and very-low-frequency broadcasts from the National Bureau of Standards. But in practice it would take too long. To obtain resolution of this order from such broadcasts, it would be necessary to phase-track for as long as a week or more in order to average out the effects of such propagation anomalies as sun spots and changes in the height of the ionosphere. As a result, it would also be necessary to take into account the long-term drift of the oscillator being calibrated. In contrast, the excellent short-term stability of the color TV signal makes the calibration task quick and simple to perform.

The National Television System Committee (NTSC) system of compatible color television broadcasting obtains color information from the sum of two quadrature double-sideband suppressed carrier signals at 3.58 MHz. Phase comparison information for the locked subcarrier is supplied by an eight-cycle burst of a 3.58-MHz signal on the trailing edge of each horizontal sync pulse transmitted along with the picture information. The 3.58-MHz reference signal necessary for demodulating the chroma sidebands is supplied in the home television receiver by a phase-locked crystal-controlled oscillator.

If the viewer is not to see objectionable changes in color on his screen, this subcarrier oscillator must be capable of locking to within ±5° of the burst reference frequency. Most receiver designs have this capability and so provide a system that permits the measurement of the phase difference between the transmitted color subcarrier and a local reference standard with resolution of one part in 10^{11}.

Each of the major television networks derives its 3.58-MHz burst reference frequency from a rubidium-controlled oscillator/synthesizer whose output is stable to within one part in 10^{12} per day. By being phase-locked to this burst reference frequency, therefore, a color TV set's 3.58-MHz oscillator is essentially as stable a source as the rubidium standard itself.

Figure 1 shows the measurement scheme. The local standard to be calibrated—in this case a 5-MHz signal —is converted into a 3.58-MHz signal which is fed to one input of a linear phase comparator. The comparator's other input comes from the color TV's crystal-controlled oscillator. Though it would be possible to build a receiver and crystal-controlled oscillator from scratch, it's usually more convenient just to buy a color TV set since they cost as little as $200.

Included in Fig. 1 is a representative 1-hour strip chart record comparing a network subcarrier with the NBS frequency standard, which has been synthesized to 3.58 MHz. The local station breaks every half-hour appear as several cycles of phase change over a period of 1 or 2 minutes. The changes occur because the 3.58-MHz oscillators at local stations aren't as stable as the ones at network studios; the changes have no effect on the overall resolution of the measuring scheme.

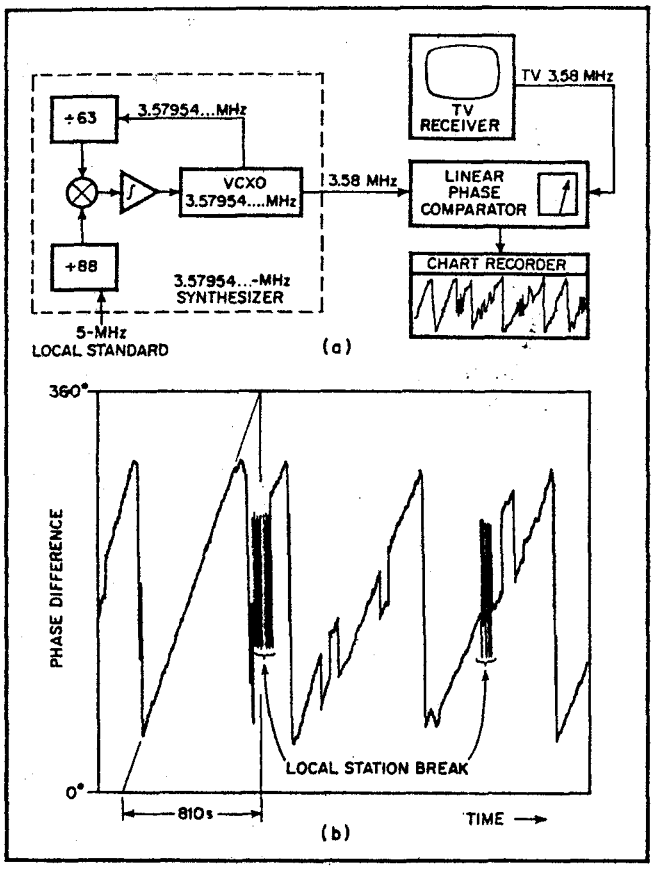
The frequency offset is obtainable from the slope of the linear trace and is measured by extending the trace to a base line corresponding to a 0° shift and a top line corresponding to a 360° shift. The time difference between the two intercept points corresponds to the time required for a phase change of 360°, which for a 3.58-MHz signal is equivalent to 280 nanoseconds (one period at 3.58 MHz). In the case of Fig. 1, frequency offset, $\Delta f/f$, is given by

$$\frac{\Delta f}{f} = \frac{\Delta t}{t} = \frac{280 \times 10^{-9}s}{810s} = 3.3 \times 10^{-10}$$

where Δt is the period for the reference signal, and t is elapsed time between intercepts.

Several versions of the 5-MHz-to-3.58-MHz synthesizer were constructed for comparison and evaluation (the 5-MHz level was chosen because many installations use it as the frequency for their local reference). The synthesizer makes a negligible contribution to measurement error. All versions had less than 2-ns long-term (one day) phase instability and less than 1-ns short-term jitter. Parts cost for the unit shown in Fig. 2 is under $50.

Commercial linear phase comparators that are able to perform satisfactorily at 3.58 MHz are relatively expensive. Less costly comparators are suitable for operation at low frequencies (around 100 kilohertz),



1. Calibrating. Synthesizer converts output of source being calibrated (5 MHz in this case) into 3.58-MHz signal which is then compared with color subcarrier from TV set. Chart recorder plots phase difference as function of time. In typical plot phase difference increases linearly (except when station breaks or other sources of distortion occur) until it approaches some value close to 360°, when it drops to some low value, and then begins increasing linearly again. Frequency offset (Δf/f, where f is frequency of reference) is found by extending linear portion of trace to 0° and 360° base lines and dividing time between intercepts (810s) into period of reference signal (280 ns).

but have excessive dead band at 3.58 MHz, i.e., when inputs to the comparator differ in phase by less than 0.1 microsecond, the comparator is unable to resolve the difference and its output is ambiguous.

Instead, the linear phase comparator shown in Fig. 3 was designed for this application. Its dead band is about 0.3 ns with better than 1% linearity. The unit, which uses four ICs and several discrete semiconductor components, costs about $20.

The locations of the 0° base line and 360° top line are found by turning the circuit's switch to CALIBRATE and adjusting the CAL resistor until the recorder trace goes to a maximum value, which is the level of the 360° line. Next, the resistor is turned to just above the 360° position, causing the trace to fall to a minimum level—the 0° base line. Finally, the resistor is turned back to the 360° position, and the switch is turned to OPERATE.

Frequency stability measurements of the color subcarriers of all three major U.S. networks (all of which broadcast from New York) have been made at the NBS Laboratories in Boulder[1,2]. These measurements indicated that it's possible to resolve the phase difference between the subcarrier and another 3.58-MHz signal to less than 10 nanoseconds. This, as the following equation shows, corresponds to a determination of frequency difference of about one part in 10^{11} in 1,000 seconds (approximately 17 minutes).

$$\frac{\Delta f}{f} = \frac{\Delta t}{t} = \frac{10\text{ns}}{1{,}000\text{s}} = \frac{10^{-8}}{10^{3}} = 10^{-11}$$

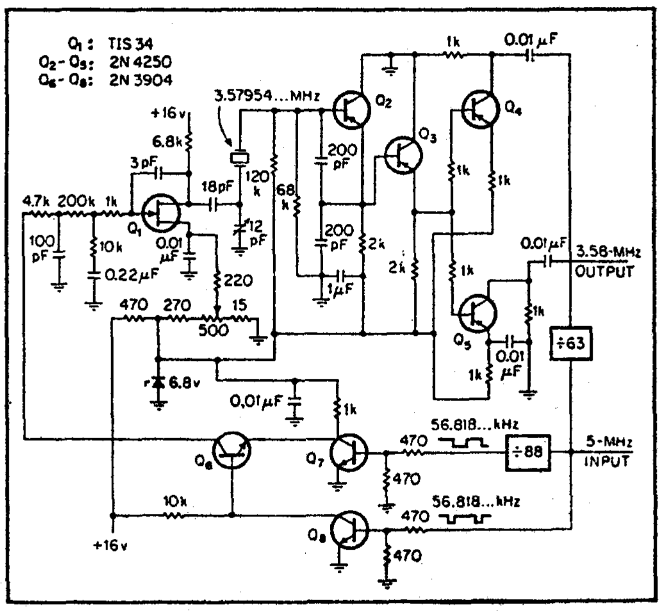
Resolution of frequency differences to one part in 10^{11} does not mean accuracy is that good. A local frequency source can be calibrated by this method with a network's rubidium source to within one part in 10^{11} but it won't necessarily agree with a national standard unless the rubidium standard itself has been adjusted to agree. In November 1970 the rubidium oscillators used by the major television networks in New York differed from the NBS frequency standard as follows:

ABC: -1×10^{-11}
CBS: $+20.7 \times 10^{-11}$
NBC: -33.6×10^{-11}

But these figures change from month to month, and at present there's no convenient way of getting information on the precise amount of offset. However, if the adoption of this measurement scheme creates a demand for this information, ways of making the offset size known can be made available (see panel).

Absolute accuracy, however, isn't necessary in many applications. For example, a comparative scheme would prove valuable for synchronizing two frequencies, and would provide users of single sideband with a rapid means of presetting their operation frequencies. Similarly, long baseline interferometry requires

2. Synthesizer. Circuit for converting frequency to be calibrated into a 3.58-MHz signal can be relatively simple. One above is for 5-MHz local sources.



two widely spaced stations with precisely synchronized frequencies.

Obviously, before using the 3.58-MHz subcarrier as a frequency reference, it must be determined whether a particular program originates from a network's New York studio or from the local station, since the local station will use a relatively unstable crystal oscillator. There are a couple of ways to do this.

First, if the user has a copy of the television schedules for his own and an adjacent time zone, comparing the two will show which programs are being broadcast simultaneously and are probably "live" from the network. The most likely candidates are daytime serials and quiz shows. Second, it's possible to take advantage of the fact that the local stations have relatively poor 3.58-MHz references—stable to at best 1 hertz in 5 minutes. A "suspected" network program can be tuned in and the user's oscillator adjusted to agree. The other two major network stations can then be tuned in successively to see if their 3.58-MHz subcarriers are drifting relative to the first. For two "live" network programs, the relative frequency offset will be less than 1 cycle per 10 minutes, while for local programs the offset will generally drift about 1 cycle every few seconds. This approach requires an oscillator with a drift rate of no more than a few parts in 10^8 per day, and short-term stability of plus or minus one part in 10^9 per hour.

There's another consideration involved in using the color subcarrier as a standard frequency source. The local network affiliate receives programing from New York over the American Telephone and Telegraph microwave relay system. Depending on the station's location, from one to 100 repeaters are included in the microwave system. Although the microwave relay system is phase-stable, problems arise when one of the microwave links fails and is replaced by a protection or "back-up" channel. The resulting change in path delay, or change in the distance traveled by the signal, will cause an abrupt shift in the phase of the color subcarrier as received. The color seen on the receiver screen is not affected because the composite video is delayed by the same amount as the burst. But since the phase measurement requires comparison with an independent standard, an instantaneous change of phase to another stable value occurs. □

Absolute measurements

The accuracy of measurements made using the 3.58-MHz received TV color subcarrier as a stable frequency reference depends on how closely the frequency standards used by the networks agree with the national frequency standard at the National Bureau of Standards.

Two methods could be used to calibrate the subcarrier frequency in terms of a national standard. One would be to publish, but not change, the amount of frequency offset of the three networks on a regular monthly basis. This would be adequate since the rubidium oscillators used as standards by the major network change frequency very slowly—by parts in 10^{12} per day.

The other method would be to adjust the frequency of the rubidium oscillators whenever the offset exceeds some prescribed, arbitrary value. If, for instance, the limit were established at plus or minus two parts in 10^{11}, adjustments would be required only once a month. Even without any calibration, the accuracy of the network frequency standards is never worse than one part in 10^9. This exceeds the accuracy of high-frequency broadcasts (WWV and WWVH) by approximately two orders of magnitude.

References

1. D.D. Davis, J.L. Jespersen and G. Kamas, "The Use of Television Signals for Time and Frequency Dissemination," Proc. IEEE (Letter), Vol. 58, No. 6, pp. 931-933, June 1970.

2. D.D. Davis, "Transmission of Time/Frequency Signals in the Vertical Interval," Synopses of Papers (108th Tech. Conf. & Equip. Exhibit, Soc. Mot. Pict. & Tele. Eng., New York, N.Y., Oct. 4-9, 1970), Paper No. 43, Oct. 1970.

3. Phase comparator. In addition to comparing local signal with 3.58-MHz subcarrier, circuit provides built-in calibration When switch is turned to CALIBRATE, resistor can be adjusted to determine position of 0° base line and 360° top line.