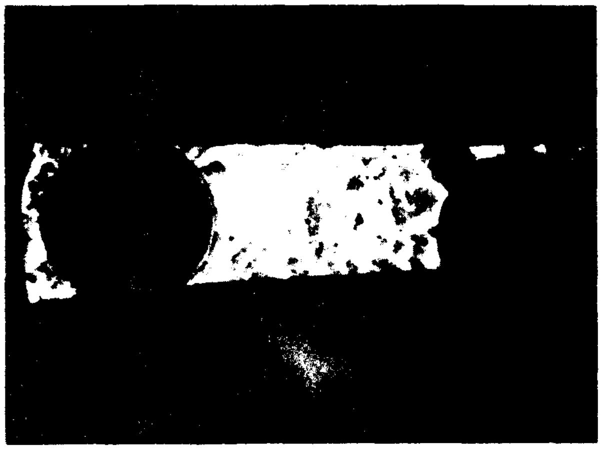
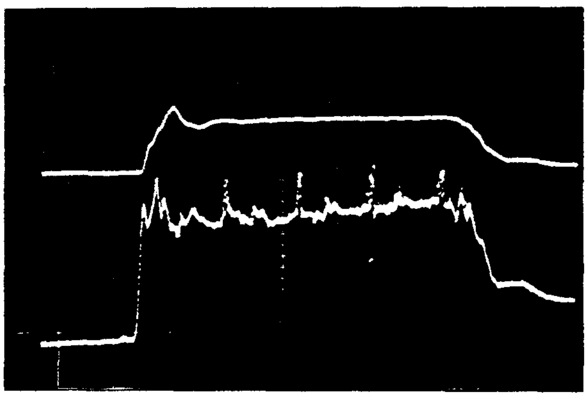


Fig. 1. GaAs on sapphire Gunn device, Sample 1. Distance between contacts 0.58 mm.

TABLE I

GUNN OSCILLATOR PARAMETERS

	Sample 1	Sample 2
Length (cm)	0.073	0.058
Thickness (microns)	34	25
n (300°K)(/cm³)	3×10^{15}	9.4×10^{14}
μ (300°K)(cm²/V·s)	5300	3780
n (77°K)(/cm³)	2.3×10^{15}	—
μ (77°K)(cm²/V·s)	22 000	—
Oscillation frequency (MHz)	140	208
Threshold field (V/cm)	1900	4100



(a)

(b)

Fig. 2. (a) Sample 1: top trace, voltage 200 V/cm; bottom trace, current 200 mA/cm. (b) Sample 2: top trace, voltage 200 V/cm; bottom trace, current 100 mA/cm. Horizontal: 5 ns/cm.

oscillations in the high-mobility samples are comparable with those seen in bulk material with similar characteristics.

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The Use of Television Signals for Time and Frequency Dissemination

Abstract—Measurements indicate that a television microwave path is stable to a few microseconds over a period of months. The paths measured are those used by the three major U. S. television networks between Washington, D. C., and Denver, Colo. Path stabilities of ±5 ns (for half-hour periods) were measured by observing the phase of the television color subcarrier. A time dissemination system using the television signal format is described. Using locally broadcast VHF television signals, time information was recoverable with a resolution of several nanoseconds. This corresponds to a frequency stability of a few parts in 10^{12} for one hour averaging.

Tolman *et al.*[1] and Souček[2] demonstrated that television synchronization pulses transmitted over microwave networks may be used to set clocks to microsecond accuracy for distances of 870 km. They also found that VHF television signals from a common transmitter could be used to synchronize clocks (separated by distances up to 300 km) to the same order of accuracy. This latter method is now being used routinely to synchronize the time broadcasts from Fort Collins, Colo., with the NBS time standard at Boulder, Colo.[3]

We have extended the television microwave signal measurements to greater distances and have obtained similar results for the three major U. S. television networks. Measurements were made at the U. S. Naval Observatory in Washington, D. C., which is about 3.2 km from the furthest transmitter site, and in the NBS Laboratory at Boulder, Colo., which is about 29.0 km from the Denver transmitter sites. The microwave path between Washington, D. C., and Denver is about 6400 km so that the VHF portion of the path represents about 0.5 percent of the total path. Fig. 1 shows that the time delay variation due to all causes (including VHF and microwave propagation anomalies, microwave repeater delay variations, etc.) is of the order of a few microseconds for the networks, with an occasional large change due to rerouting.

To check the accuracy and resolution of network television signals as a means of disseminating frequency, we measured the phase stability of the 3.58 MHz color subcarrier at Boulder when the signal originated from the New York studios of the three major networks. The local reference used for these phase comparisons was synthesized from a cesium frequency standard. For over 100 half-hour phase measurements, the random phase variations that limit the resolution of frequency determination were typically 5 to 10 ns. This approximates the phase stability of the rubidium standards used by the networks as well as the cesium frequency standard used for a phase reference.

Since the measurements discussed show that television has the resolution and stability required for a precise time-frequency broadcast system, we developed a prototype system that would utilize this potential. Channel

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[1] J. Tolman, V. Ptáček, A. Souček, and R. Stecher, "Microsecond clock comparison by means of TV synchronizing pulses," *IEEE Trans. Instrumentation and Measurement*, vol. IM-16, pp. 247–254, September 1967.

[2] A. Souček, "Travel time stability on TV relay links," *Radio and Television*, no. 5, pp. 29–31, 1969.

[3] J. B. Milton, "Standard time and frequency: Its generation, control, and dissemination from the National Bureau of Standards Time and Frequency Division," NBS Tech. Note 379, pp. 1–27, August 1969.

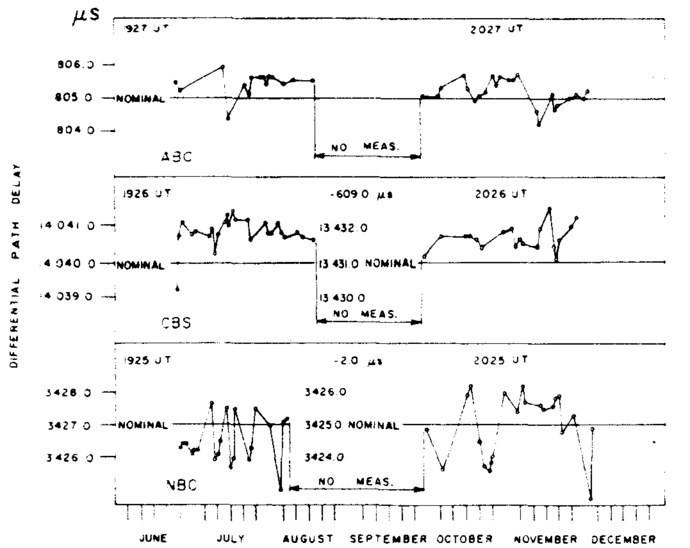


Fig. 1. Variation in the microwave path delay between Washington and Boulder for the three major networks (1969).

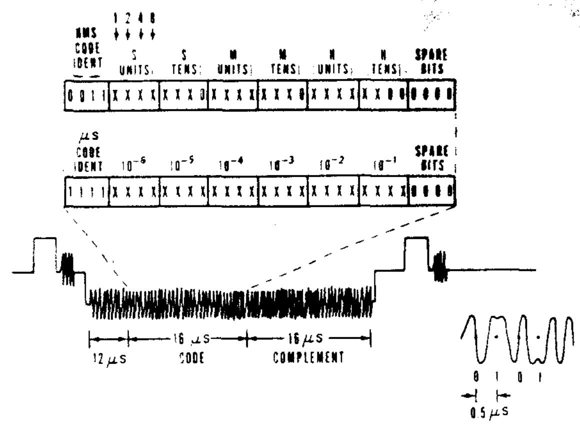
7 in Denver agreed to cooperate in field tests and received FCC authorization to broadcast a time code on Line-17 in the vertical blanking interval. Transmission of the time code [Fig. 2(a)] started on September 8, 1969.

Two separate code groups are transmitted as biphase modulation of a 2 MHz cesium stabilized subcarrier. A 32 bit (+ complement) 8421 BCD code of hours, minutes, and seconds in universal time appears on the first and third Line-17's after the start of each second. The first four bits of the code identify the group. The last four bits are unused. A six digit code representing the number of microseconds from the beginning of the previous second to the start of the code appears on the second Line-17. All remaining Line-17's contain a 2 MHz sine wave which is used to phase lock a crystal oscillator in the receiver.

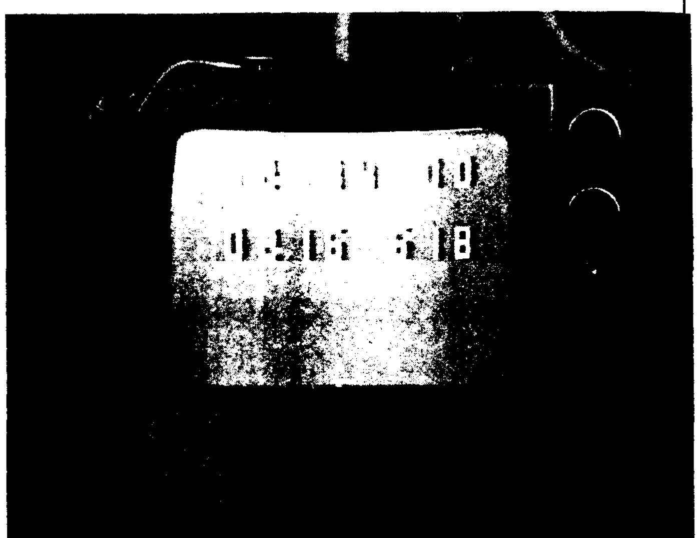
The time decoder includes a modified commercial television receiver. The hours, minutes, and seconds time code is decoded and displayed on the television screen [Fig. 2(b)]. The microseconds code is used to generate a 1 pps output which is compared with a local clock. Timing information to 1 μs is contained in the code. Additional resolution is provided by the 2 MHz phase-locked oscillator driving the 1 pps divider. The time difference, with a resolution of 100 or 1 ns (switch selectable), is displayed as a second line on the television screen. Although the time difference display typically varies ±2 ns in a minute or less, the long-term (5 minutes or more) stability is limited by the controlling cesium standards. Both displays are self-updating so that momentary loss of signal does not affect accuracy or stability.

A primary limitation of any time dissemination system is the ability to predict path delay. The results of the measured and predicted VHF propagation delays for a number of geodetic survey points in eastern Colorado are summarized in Fig. 3. Time code measurements were made at five geodetic markers located between 69 and 135 km from the transmitter. The marker at 69 km was used as an arbitrary reference point for the other four more distant measurements. The first line of the table (Fig. 3) gives the radial difference rounded to the nearest 0.1 km between the reference point and each of the other four locations. From these incremental distances, the propagation delay from the reference point to each of the other four points was calculated. We assumed a refractive index of 1.0 for the signal velocity. The second line of the table gives the difference in microseconds between the predicted and the measured delay. These data indicate that delays can be predicted to better than 1 μs if the user knows his location.

An interesting application for the television timing system is position determination. If the user can observe signals from three or more stations having synchronized time codes, then he can calculate his location. The system is analogous to a high-resolution (but limited-range) Loran-C. With only one synchronized station, we still found the system was very helpful in locating geodetic markers in the open areas of eastern Colorado. By comparing the predicted and the measured time difference signals, we



(a)



(b)

Fig. 2. TV time code format. (a) The coherent biphase modulated code appears on two horizontal Line-17's each second. The remaining 58 Line-17's contain a 2 MHz sine wave used to phase lock a crystal oscillator in the receiver. Inset in lower right corner is an expanded view of the biphase modulation. (b) Photograph of display generated from the TV time code. The top line gives HH MM SS and the bottom line is the time difference between the local clock and the time recovered from the TV signal to 1 ns.

	LOCATION A	LOCATION B	LOCATION C	LOCATION D
RADIAL DIFFERENCE (km)	17.3	29.8	33.5	65.9
DIFFERENCE BETWEEN PREDICTED AND MEASURED DELAY (μs)	0.37	0.67	0.03	0.60 0.71 *

* MEASUREMENTS ON TWO DIFFERENT DAYS

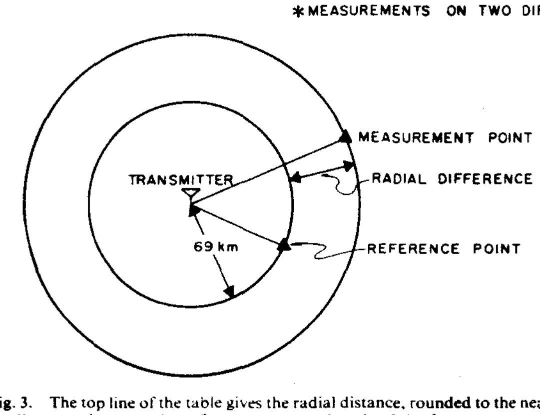


Fig. 3. The top line of the table gives the radial distance, rounded to the nearest 0.1 km (see diagram), between the reference point and each of the four measurement points. The second line of the table gives the difference between predicted and measured delay for each of the four locations.

were able to locate the radius arc on which the marker was located.

The developments discussed here suggest that television has considerable potential for time and frequency dissemination. Coverage of 70 percent of the U. S. population could be achieved by installing synchronized coders at the three major network centers in New York and distributing the code via the microwave network. Implementation of such a system would be inexpensive because the primary means of distribution already exists. Receivers can be constructed at modest cost. Parts cost for the complete time display receiver used in the experimental system was approximately $400. A frequency comparison receiver capable of 1×10^{-11} resolution in a half hour could be built for less than $50 plus the cost of a television set.

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Active RC All-Pass Networks with a Grounded Operational Amplifier

A number of letters have appeared in the literature for realizing second-order all-pass transfer functions [1]–[9]. Recently, Dutta Roy proposed two structures, which use differential-input operational amplifiers, for realizing an all-pass transfer function of any order, with simple poles on the negative real axis [10], [11]. The purpose of this letter is to show that such an all-pass transfer function may also be realized by a structure containing only one grounded operational amplifier and an RC two-port.

Consider the network of Fig. 1, for which the transfer function may be written as

$$T(s) = \frac{E_2(s)}{E_1(s)} = -\frac{\lambda y_{22} + (1+\lambda)y_{21}}{y_{22}} \tag{1}$$

where y_{21} and y_{22} are the y parameters of the RC two-port. Expression (1) is identical to expression (5) of Dutta Roy [10]. Thus the class of transfer functions realizable by the present structure is the same as the one realizable by his structure, and the method adopted by him in extracting y_{21} and y_{22} from a given all-pass transfer function is equally applicable to the present structure.

We shall now show that some of the earlier networks proposed for second-order all-pass functions are special cases of this structure.

a) Letting

$$\lambda = 4m + 1$$

$$-y_{21} = \left(\frac{1}{R} + sC\right)$$

$$y_{22} = \left(\frac{1}{R} + sC\right) + \left(mR + \frac{m}{sC}\right)^{-1}$$

in expression (1), the present structure reduces to that of Ganguly [9].

b) If in expression (1) we now choose

$$-\frac{y_{21}}{y_{22}} = \frac{\frac{1}{x} - x + jm}{\frac{1}{x} - x + jm} \tag{2}$$

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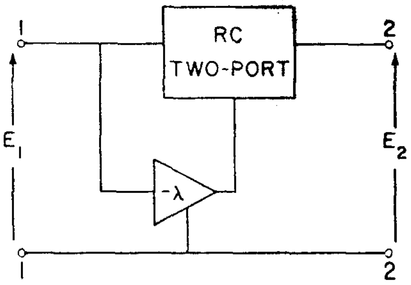

Fig. 1. Structure realizing an all-pass function of any order, with simple poles on the negative real axis.

where

α, m = real constants independent of frequency
$x = \omega/\omega_0$
ω_0 = frequency at which (2) is real
$\lambda = (m+\alpha)/(m-\alpha)$

then the structure of Fig. 1 will realize the same class of biquadratic all-pass functions as that of Sen Roy [4].

c) Finally selecting

$$\lambda = \frac{1}{5}$$

$$-y_{21} = \left(R + \frac{1}{sC}\right)^{-1}$$

$$y_{22} = \left(\frac{1}{R} + sC\right) + \left(R + \frac{1}{sC}\right)^{-1}$$

the present structure reduces to that of Bhattacharyya [1].

Thus a structure using a single grounded operational amplifier and an RC two-port has been given for realizing an all-pass function of any order. This structure is seen as an alternative to that of Dutta Roy. It should also be noted that by applying RC:CR transformation [12], the structure of Fig. 1 realizing an all-pass transfer function of the form

$$T(s) = K\frac{(s-a_1)(s-a_2)\cdots(s-a_n)}{(s+a_1)(s+a_2)\cdots(s+a_n)}$$

will also realize the all-pass transfer function

$$T(s) = K\frac{(1-a_1s)(1-a_2s)\cdots(1-a_ns)}{(1+a_1s)(1+a_2s)\cdots(1+a_ns)}$$

if the different resistors R_i's and capacitors C_i's are replaced by capacitors and resistors of values $(1/R_i)$'s and $(1/C_i)$'s, respectively.

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Author's Reply[1]

Bhattacharyya and Swamy's remarks on the two all-pass realization schemes of the author [10], [11] are timely and most welcome. The alternative circuit proposed by them (Fig. 1) uses the idea of the dual-input network suggested by Sen Roy [4]. In this scheme (Fig. 2),

$$\beta_0(s) = N_0(s)/D_0(s) = (e_0 - me_i)/(e_i - me_i)$$

[1] Manuscript received March 3, 1970.