NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT
8420-12-84124

May 1, 1961

NBS REPORT
6765

METHODS AND TECHNIQUES OF LOW AND VERY LOW FREQUENCY MONITORING AT BOULDER LABORATORIES

A. H. Morgan and D. H. Andrews
National Bureau of Standards
Boulder, Colorado

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
BOULDER LABORATORIES
Boulder, Colorado

TABLE OF CONTENTS

METHODS AND TECHNIQUES OF LOW AND VERY LOW FREQUENCY MONITORING AT BOULDER LABORATORIES

by

A. H. Morgan and D. H. Andrews
National Bureau of Standards
Boulder, Colorado

METHODS AND TECHNIQUES OF LOW AND VERY LOW FREQUENCY MONITORING AT BOULDER LABORATORIES

A. H. Morgan and D. H. Andrews

1. ABSTRACT

A brief description of three methods of monitoring standard LF and VLF broadcasts at Boulder Laboratories is given. The phase-lock system is discussed in more detail than the others including its advantages, stability and accuracy.

Results obtained in monitoring GBR (16 kc) and NBA (18 kc) vs the US Frequency Standard are given in table form. It is planned to continue these type measurements indefinitely.

NATIONAL BUREAU OF STANDARDS
Radio Broadcast Service Section
Boulder Laboratories
Boulder, Colorado

METHODS AND TECHNIQUES OF LOW AND VERY LOW FREQUENCY MONITORING AT BOULDER LABORATORIES

by A. H. Morgan and D. H. Andrews

2. INTRODUCTION

Three different methods of observing the variations in the phase, or time of arrival of a signal, have been used at the Boulder Laboratories (BL). One is a photographic method and the other two are analogue methods, i.e., the difference between the local and received phase is converted to a current or voltage which is continuously recorded vs time.

A formal report[1] is being prepared on the above mentioned methods as well as several others which have been considered at BL.

3. BRIEF DESCRIPTION OF METHODS USED

A simple photographic method[2] has been successfully used at BL. The incoming signal of frequency, f_r, is used to modulate the Z-axis of the oscilloscope. A locally derived frequency, nominally equal to f_r, is used as the oscilloscope sweep trigger. Time-of-day marks on the film, e.g., brief interruptions each hour of the sweep, and calibration of the oscilloscope sweep provides the information required to convert the recording on the film to the average difference in the received and local frequencies over the interval of the measurement chosen. Usually a 24-hour measurement period is used to achieve high precision and to minimize the diurnal effects. Another simple method[2] used is the beat-frequency technique. With it a narrow-band system (about 0.01 c/s) is easily achieved by post-detection integration. To adjust the period of the beat frequency so the phase can be obtained at appropriate intervals, the reference oscillator can be offset from the received signal. The recorded phase can be accurately obtained only at the zero crossing of the beat frequency because the variation received signal amplitude appears in the amplitude of the beat signal.

A system which has many advantages over the two described above is shown in simplified form in Fig. 1. The local reference frequency is adjusted to a value which is nominally the same as that received. It is very important that the local frequency be free of phase variations such as may occur in locked-oscillator dividers or multivibrators. A recently developed synthesizing system[3], at BL, was proved to be superior to any of the others used or tested.

The local frequency, after passing through the phase-shifter, is kept in phase-lock with the received frequency by the action of the phase-detector and servosystem as shown in the block diagram.

To convert the angular position of the phase-shifter to a voltage, a tapped, 360°, potentiometer is connected to this shaft. With a constant direct voltage applied across the linear potentiometer, the position of the shaft then is proportional to the voltage appearing between the movable tap and one side of the potentiometer. The latter voltage (or current) is recorded vs. time of day on a strip chart. Although in the block diagram in Fig. 1 the phase-shifter is used at the nominal received frequency, it may actually be used at a higher frequency in the synthesizer. At BL it is operated at 100 kc so that one revolution of the shaft shifts the phase of the local signal by 10 microseconds. The direct voltage applied to the potentiometer is then adjusted so that one turn of the tap causes the recording pen to traverse the recorder chart once. Thus, full scale on the chart represents ten microseconds of phase-shift.

Other desirable features of the servosystem[4, 5, 6] include:

(1) The availability of two frequencies from the local oscillator, one of which is phase-locked to the signal as received, and the other undisturbed and thus available for other uses,

(2) no disturbance in performance of the local oscillator is caused by action of the servosystem; this would occur in systems which adjust the frequency of the local oscillator,

(3) the phase-locked frequency is, on the average, precisely the same as that received. The controlled variable of the servosystem in this case is the phase which, in this positional type servo, will have a constant steady-state error except for system perturbations by "noise" with periods longer than the integration time of the servo.

4. RESULTS OBTAINED

Two opposing factors require that the integration time of the servosystem described above be a compromise. On many long radio paths the diurnal phase shifts may occur relatively fast, i.e., in an hour or so, especially on N-S or S-N paths. It is important that the servosystem be designed so it can follow these changes very closely, and this of course requires a relatively fast response time. On the other hand, a long integration time reduces the effective bandwidth of the system and thereby minimizes the effects of external noise. It should be noted that the response time to a step function of phase shift, may give an overall equipment response time longer than the integration time.

At BL the integration time of the system is around 4 seconds but it is planned to increase this by a factor of from four to ten, the value depending on the length of the particular radio path and frequency being recorded.

Stability tests of the overall system, including the radio receiver, show that one part in 10^{12} over a 24 hour period, is not too difficult to achieve. By comparison, diurnal phase shifts may produce Doppler frequency changes amounting to ±3 parts in 10^9 at 5200 Km.[1] This of course requires a local oscillator of comparable or better stability.

At BL measurement of the received frequency of GBR, (16 kc) has been made since mid-November 1960 and of the U.S. Navy Station NBA (18 kc) since mid-February 1961. It is planned to continue these type of measurements indefinitely. Results of these measurements are attached.

5. REFERENCES

1. A.H.MORGAN and D.H.ANDREWS, "Frequency calibration receiving systems using standard LF and VLF signals", (in preparation).

2. J.A.PIERCE, "Intercontinental frequency comparison by VLF", Proc. IRE, 45, 6, 794 (1957).

3. P.A.SIMPSON, "Fractional frequency dividers using magnetic beam switching tubes", (in preparation).

4. L.MOOSER, "Frequency and phase control of local oscillators by transmitters of standard frequency", Proceedings 14th Annual Symposium on Frequency Control, 421-28 (1960).

5. R.R.STONE, W.MARKOWITZ, and R.G.HALL, "Time and frequency synchronization of Navy VLF transmissions", IRE Trans. Instrumentation, 1-9, No.2, 155-161 (1960).

6. C.H.LOONEY, Jr., "A very low frequency (VLF) synchronizing system", Proc. IRE, 49, 2, 448 (1961).

6. FIGURE

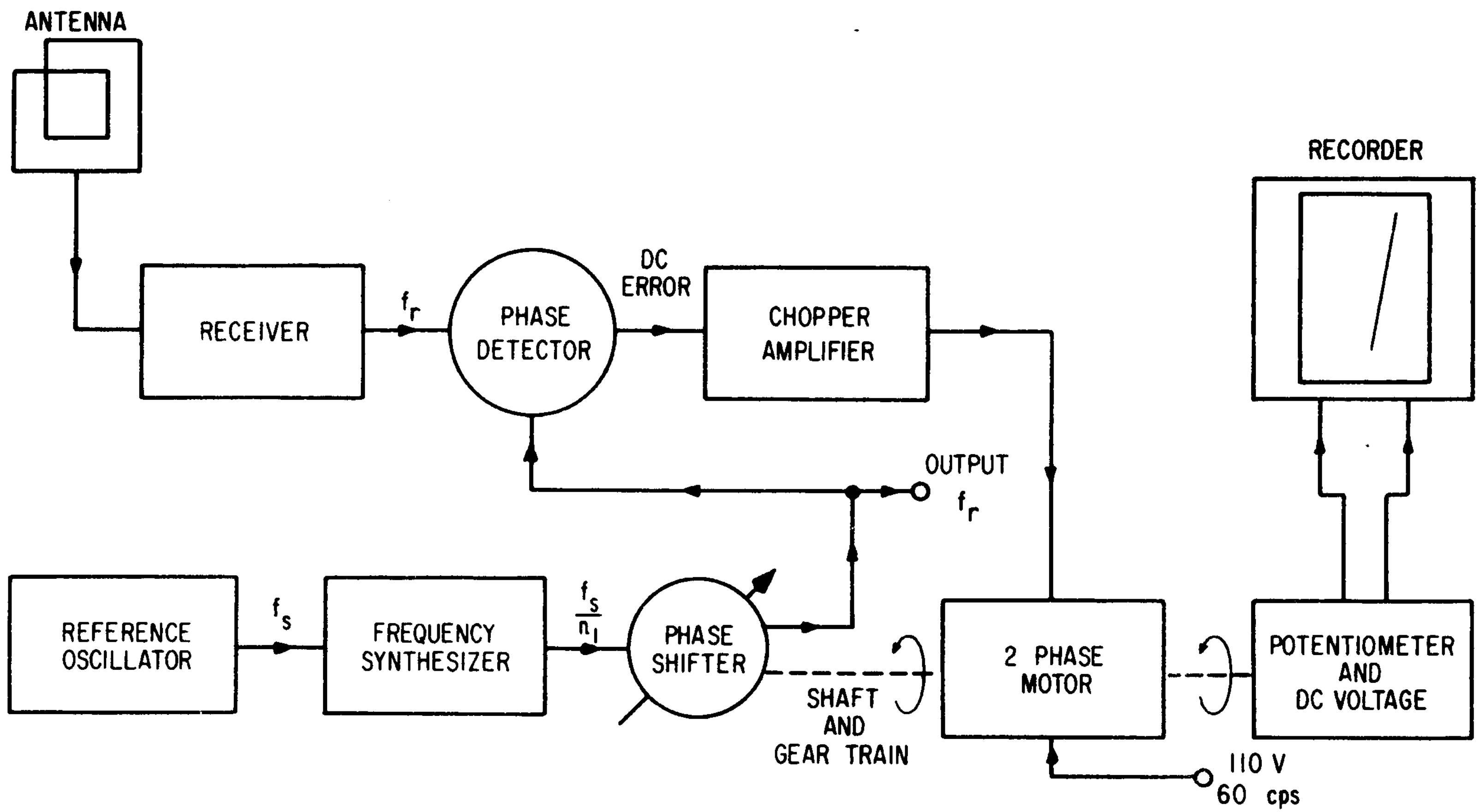

FIG. 1 PHASE-LOCK SYSTEM AND RECORDER

7. TABLES

February 20, 1961
84.20 FM (1)

NATIONAL BUREAU OF STANDARDS
Boulder Laboratories
Boulder, Colorado
Radio Broadcast Service Section

Deviations of Frequencies
Received at NBS, Boulder Laboratories
Versus the U.S. Frequency Standard

1960 November	GBR-16KC 0500UT-0500UT	1960 December	GBR-16KC 0500UT-0500UT
17	-170.1	1	N.M.
18	-164.0	2	-153.1
19	-164.2	3	N.M.
20	-160.7	4	N.M.
21	-163.8	5	N.M.
22	-161.6	6	-150.8
23	-159.7	7	N.M.
24	-159.2	8	-146.4
25	-158.7	9	-145.0
26	-158.9	10	-144.1
27	-157.3	11	-143.1
28	-157.5	12	N.M.
29	-155.6	13	-140.8
30	N.M.	14	-139.6
		15	-140.5
		16	N.M.
		17	-148.0
		18	-151.4
		19	-150.4
		20	N.M.
		21	-148.1
		22	N.M.
		23	N.M.
		24	N.M.
		25	N.M.
		26	N.M.
		27	N.M.
		28	N.M.
		29	-139.6
		30	-142.9
		31	-141.2

NOTES:
1. The values are the mean over the intervals shown.
2. Parts in 10^{10}. A minus sign indicates that the received frequency was low.
3. The date shown is that of the initial reading.
4. The uncertainty of measurement is 0.5×10^{-10}.

February 27, 1961
84.20 FM (2)

NATIONAL BUREAU OF STANDARDS
Boulder Laboratories
Boulder, Colorado
Radio Broadcast Service Section

Deviations of Frequencies
Received at NBS, Boulder Laboratories
Versus the U.S. Frequency Standard

1961 January	GBR-16KC 0500UT - 0500UT
1	-142.1
2	-139.0
3	-141.4
4	-140.1
5	-141.4
6	-143.3
7	-143.2
8	-142.6
9	-144.7
10	-141.8
11	-143.4
12	-144.0
13	-145.4
14	-147.5
15	-146.7
16	-147.9
17	-147.5
18	-150.9
19	-151.7
20	-151.2
21	-151.1
22	-147.4
23	-150.5
24	-148.7
25	-150.3
26	-148.4
27	-154.1
28	-151.7
29	-154.1
30	-152.3
31	-151.4

NOTES:
1. The values are the mean over the intervals shown.
2. Parts in 10^{10}. A minus sign indicates that the received frequency was low.
3. The date shown is that of the initial reading.
4. The uncertainty of measurement is 0.5×10^{-10}.

March 22, 1961
84.20 FM (3)

NATIONAL BUREAU OF STANDARDS
Boulder Laboratories
Boulder, Colorado
Radio Broadcast Service Section

Deviations of Frequencies
Received at NBS, Boulder Laboratories
Versus the U.S. Frequency Standard

1961 February	GBR-16KC 0500UT-0500UT	NBA-18KC 1800UT-1800UT
1	-146.9	-153.4
2	-151.0	-153.9
3	-150.6	-154.8
4	-148.2	-152.2
5	-149.4	-153.9
6	-148.3	-151.9
7	-145.8	--
8	-148.9	--
9	-148.0	--
10	-145.7	--
11	-145.9	--
12	-145.2	--
13	-144.2	--
14	-141.4	-150.3
15	-140.2	-152.3
16	-141.2	-152.4
17	-142.8	-152.1
18	-144.3	-151.6
19	-143.4	-150.7
20	-145.2	-150.5
21	-145.6	--
22	-146.8	--
23	-148.6	--
24	-151.6	-153.2
25	-151.7	--
26	-149.5	--
27	-147.1	--
28	-143.6	--

NOTES:
1. The values are the mean over the intervals shown.
2. Parts in 10^{10}. A minus sign indicates that the received frequency was low.
3. The date shown is that of the initial reading.
4. The uncertainty of measurement is 0.5×10^{-10}.