MEMORANDUM REPORT

NATIONAL BUREAU OF STANDARDS

SM-1014

SUMMARY REPORT

STANDARD VLF BROADCAST STATION

NBS PROJECT 84123

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24 July 1959

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

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1. REQUIREMENT

a. To broadcast U.S.A. standard frequency, time intervals and timing code, world wide, to a much higher precision than is possible with existing transmissions.

b. The precision required for frequency comparison measurements is to be better than 1 part in 10^{10}.

c. The precision required for time interval measurements is to be better than 10 microseconds.

d. Measurements to these precisions to be made in relatively short intervals of time.

2. URGENCY

a. The needs have steadily increased for higher stability of radio transmissions and propagations, to enable making standard frequency and time interval measurements to higher precisions. This was brought about by the atomic age, with expanding technological measures for defense and offense.

b. With the advent of supersonic missiles and aircraft, on large and important scales, the critical needs for higher precisions became of extreme importance, and urgent. Higher speeds and higher precisions of measurements are directly related.

c. Various government and contracting agencies, working on such problems as the transit time of missiles, rate of travel of jet propelled aircraft, world wide synchronization of time intervals, space probe investigations, have urgent needs for making measurements of higher precisions.

It is evident that progress on major defense and technological projects will be enhanced with the availability of radio transmissions to be provided under this project.

d. Numerous other groups, such as scientific laboratories, air transport and communication companies, navigators, manufacturing companies, and others, have urgent need for making measurements by radio standards of higher precision than now available. This was brought about by the rapid technological developments recently.

3. JUSTIFICATION

a. The services to be provided will contribute materially to defense efforts of the Free World, by enabling making more precise measurements of standard frequency and time intervals wherever such data are urgently needed.

b. The broadcasting of radio signals of standard frequency is one of the prime functions of the National Bureau of Standards. (15 USC 272). Inherent in this authority is the obligation to provide improved services as the "state of the art" and the needs of the Nation require.

When the NBS initiated radio transmissions of standard frequencies in 1923, using HF with station WWV, this was a pioneer effort. Since then, its capabilities and limitations have been well established.

The technique for providing greatly improved services by VLF are also well established, and need to be made available on a world-wide basis.

c. It is vitally important that the U. S. A. maintain pre-eminence in this field.

4. SYSTEM TECHNICAL INFORMATION

Technical data from many sources, in many parts of the world, have proven conclusively that the possible precision of frequency comparison measurements, over great distances, is in the

order of 1000 times better with Very Low Frequency than with High Frequency. Following relate to some of the sources of technical information and to some of the data submitted.

a. THE U. S. STATE DEPARTMENT CCIR STUDY GROUP VII COMMITTEE

Allen, E. W.	Federal Communications Com. Washington, D. C.
Costello, A. W.	Columbia Radiation Lab. New York, New York
Dowling, Florence T.	Department of State Washington, D. C.
George, W. D.	National Bureau of Standards Boulder, Colorado
Hastings, H. F.	Naval Research Laboratory Washington, D. C.
Hicks, C. M.	Hughes Aircraft Culver City, California
Krcek, J. A.	Bureau of Ships Washington, D. C.
Markowitz, William	U. S. Naval Observatory Washington, D. C.
McDowell, R. B.	Bureau of Ships Washington, D. C.
Morgan, A. H.	National Bureau of Standards Boulder, Colorado
Pierce, J. A.	Cruft Laboratory Cambridge, Massachusetts

Selby, M. C.	National Bureau of Standards Boulder, Colorado
Stewart, James P.	U. S. Coast Guard Seattle, Washington
Thompson, M. C.	National Bureau of Standards Boulder, Colorado
White, C. E.	Research & Adv. Div. 20 South Union Street Lawrence, Massachusetts
White, Nathaniel	U. S. Army RFE Office The Pentagon Building Washington, D. C.
Woodward, Richard H.	Pickard & Burns, Inc. Needham, Massachusetts
Young, D. J.	RCA, David Sarnoff Res. Cen. New York, New York

Following is from their Draft Interim Recommendation dated 28 August 1958:

"c) that in communications, research and industry there is an increasing need for high accuracy of frequency measurements in a short period of time;

"d) that measurements on controlled stations in band 4 have demonstrated that a precision of frequency comparison of 1.10^{-10} can be achieved in a period of a few hours during daylight at a range of 5000 km; at great ranges the precision decreases, but is still much greater than presently obtainable in bands 6 and 7;

"e) that therefore the possibility exists of achieving a world-wide frequency reference of high precision in band 4 between 15 and 25 kc/s by means of a single station or at most two or three phase-synchronized transmitters operating on different frequencies;

"f) that it appears possible by specialized techniques to derive a highly precise time reference free from carrier phase ambiguity from these emissions in band 4 by radiating simultaneously on two frequencies spaced, for example, by 10 c/s;"

b. THE NBS STANDARD FREQUENCY BROADCAST BAND 4 ADVISORY COMMITTEE

Bailey, Stuart L.	President, Jansky & Bailey, Inc. 1339 Wisconsin Ave., NW Washington 7, D. C.
Baldwin, R. S.	Electronic Engineer Bureau of Ships, Navy Dept. Washington 25, D. C.
Brunner, Loren E.	U. S. Coast Guard - Code 1405 1300 E. Street, NW Washington 25, D. C.
Buscemi, J. V.	REA Telephone Engineering Washington 25, D. C.
Crain, C. M.	Rand Corporation 1700 Main Street Santa Monica, California
Dean, Walter N.	Air Armament Division Sperry Gyroscope Co. Great Neck, New York
George, W. D.	National Bureau of Standards Boulder, Colorado

Gustafson, W.	U. S. Navy Electronics Lab. San Diego, California
Helliwell, R. A.	Assoc. Prof. Engineering Stanford University Stanford, California
Holloway, W. W.	American Telephone & Tel. Co. New York, New York
Merrill, F. G.	Bell Telephone Laboratories Murray Hill, New Jersey
McCutchin, James M.	REA Electrical Engineering Div. Washington 25, D. C.
Morgan, A. H.	National Bureau of Standards Boulder, Colorado
Pierce, J. A.	Cruft Laboratory Harvard University Cambridge 38, Mass.
Smith, Carl E.	Consulting Radio Engineers 4900 Euclid Avenue Cleveland 3, Ohio
Wait, J. R.	National Bureau of Standards Boulder, Colorado
Watt, A. D.	National Bureau of Standards Boulder, Colorado
Woodward, Richard H.	Pickard & Burns, Inc. 240 Highland Avenue Needham 94, Massachusetts

c. Article "PHASE VARIATIONS OF 16 KC/S TRANSMISSIONS FROM RUGBY AS RECEIVED IN NEW ZEALAND"
By R. D. Crombie, et al.
Institution of Electrical Engineers
May 1958

d. Article "INTERCONTINENTAL FREQUENCY COMPARISON BY VLF RADIO TRANSMISSION"
By J. A. Pierce
Proc. IRE, Vol. 45, pp. 794-803

e. Article "FREQUENCY VARIATIONS IN NEW ZEALAND OF 16 KC/S TRANSMISSIONS FROM GBR RUGBY"
By A. H. Allen, et al.
Nature, Vol. 177, pp. 178-179

f. Article "RECENT LONG DISTANCE FREQUENCY COMPARISONS"
By J. A. Pierce
Proc. IRE, Vol. 1-7, pp. 207-210

g. NBS Report 5080 "LOW FREQUENCY STANDARDS TRANSMISSIONS"
By W. D. George
May 1957

h. "POWER REQUIREMENTS AND CHOICE OF OPTIMUM FREQUENCY FOR A WORLD-WIDE STANDARD FREQUENCY BROADCAST STATION"
By A. D. Watt and R. W. Plush
NBS Journal of Research, Vol. 63D, No. 1
July 1959

i. NBS Tech. Note "PROPOSAL FOR A NEW METHOD OF TIME SIGNAL MODULATION ON VLF CARRIERS"
By A. H. Morgan
February 1959

j. NBS Report PM-85-14 "ANTICIPATED COVERAGE OF A VLF STANDARD FREQUENCY BROADCASTING STATION LOCATED NEAR FORT COLLINS, COLORADO"
By A. D. Watt and W. W. Brown
August 3, 1959
Refer to accompanying copy of this report

5. TRANSMITTING STATION GENERAL

a. The station is to provide world-wide coverage of U.S.A. standards of frequency, time intervals and timing code.

b. The station is to transmit on 20,000 cycles per second for standard frequency; and on a combination of 20,000 and 20,010 cycles per second for standard time intervals and timing code.

c. The following precision of measurements will be possible:

Frequency - better than 1 part in 10^{10}

Time intervals - better than 10 microseconds

d. The new transmitting station is to be located near Fort Collins, Colorado.

e. World wide usefulness of the transmitting station is indicated in accompanying NBS Report PM-85-14.

f. Although the main object of this station is to transmit U.S.A. standards world wide, it might eventually be under control of the Bureau of International Weights and Measures.

g. This inland station could provide VLF communications in emergencies to back up VLF communication stations near the coasts.

h. Formal request has been submitted to the Inter-Departmental Radio Advisory Committee, for authorization to radiate 100 kw within the frequency range between 19,950 and 20,050 cycles per second.

6. THE TRANSMITTING ANTENNA

a. The triatic type, as adopted for this station, is essentially as developed for the U. S. Navy Department. This type has proven to be entirely satisfactory at three of their High Power, VLF communication stations through several years.

b. The design for this application has been very thoroughly evaluated electrically, reflecting results of extensive measurements on the Navy antennas. The insulated section will be supported by eight 600-foot towers.

c. This design employs multiple tuning, a proven effective means to provide relatively high efficiency.

d. The following physical and electrical properties have been established:

Number of tuning points	2.	
Operating frequency - kc	20.	
Total capacitance - Mfd	0.0418	(TAB-4A)
Natural frequency - kc	71.2	(TAB-4A)
Rated terminal voltage - kv	200.	(TAB-4A)
Gross resistance - ohm	0.240	(12 of 26)
Gross power at 200 kv - kw	303.	(15 of 26)
Radiation resistance - ohm	0.079	(12 of 26)
Radiated power - kw	100.	
Efficiency - %	33.	(16 of 26)

7. TRANSMITTERS

a. The type adopted will incorporate essentially the proven basic features in existing High Power, VLF equipments. Nominal improvements with certainty of satisfactory performance will be incorporated.

b. The carrier frequency will be related to atomic standard for extreme precision.

c. Two transmitter units, each having a nominal power output rating of 150 kw, will normally supply 300 kw to the antenna. The station may be operated with half normal power, while either transmitter unit is out for maintenance or emergencies.

d. Antenna tuning apparatus will be essentially as in successful use at Navy High Power, VLF stations. An additional feature will be to provide automatic antenna regulation with saturable reactor.

e. The following electrical properties have been established:

With 303 kw gross power delivered to the antenna, the transmitter input will be 510 kw. (23 of 26)

Corresponding efficiency - 59.4%. (23 of 26)

8. BUILDINGS

a. For the transmitter and power buildings, concrete block construction will be used.

b. A special type of construction is necessary for each of the two buildings to enclose the antenna tuning and regulating apparatus. This will consist of concrete walls lined with copper, or of an aluminum frame construction with aluminum facing on the inside.

9. POWER

a. Plans are to purchase outside power for normal operation; and to provide a local Diesel plant capable of maintaining station operation in emergencies.

b. The following power relations have been established, in terms of kw:

Radiated power		100
Antenna input	303	
Antenna radiated	100	
Antenna losses		203
Transmitter input	510	
Transmitter output	303	
Transmitter losses		207
Station miscellaneous		100
High frequency transmitters		100
Total station normal load		710 kw (22 of 26)

Power factor - 91.4%

10. SITE

a. The airline distance between the NBS Laboratories in Boulder and the station site North of Fort Collins is approximately 50.5 statute miles.

b. "Informal Clearance" for the site has been received from the Los Angeles Regional Airspace Subcommittee.

11. INCLUSION OF HF

a. The VLF High Power broadcast will supplement but not supplant the HF broadcasts by WWV and WWVH.

b. Although the HF broadcasts have inherent limitations to highest precisions urgently needed, they do provide services sufficiently accurate for numerous users.

c. Furthermore, receptions of HF broadcasts may be accomplished with relatively simple apparatus.

d. Most of the HF transmitting facilities at WWV have been in continuous use for nearly 15 years, and have become worn to such an extent that performance is unreliable, even with high maintenance.

e. Procurement of obsolete parts is not always possible, often necessitating making substitutions with attendant complications.

f. Two alternatives were presented:

(1) Replace the existing with new equipments, and install them in the existing WWV station near Washington.

(2) Procure new equipments, but install them in the new VLF station near Boulder.

g. Advantages of the latter alternative:

(1) Consolidate the NBS standard broadcasts on the continental U.S.A. at the central location.

(2) Developments could be performed much more effectively near the Boulder Laboratories.

(3) Maintenance and operations of the HF facilities would be much more economical.

h. These and other advantages lead to the conclusion that HF facilities should be included with the VLF in initial planning for the new station to be near Boulder.

12. ESTIMATED COSTS

a. Capital investment in the station, including VLF and HF equipments $8,000,000.00

b. Operating costs for the first year $194,552.00

c. Operating costs for each succeeding year.. $173,779.00

13. TIME SCHEDULE

a. Site surveys, physical and electrical, 1959.

b. Station availability, mid-1963.

END