Test and Evaluation of VOR/DVOR System Voice Channel

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The United States Government does not endorse products or manufacturers. Trade or manufacturer's names appear herein solely because they are considered essential to the object of this report.
Investigated was the tonal distortion of the voice channel of the standard second generation very high frequency omnidirectional range (VOR) and the Doppler VOR (DVOR) using a solid state distributor. The distortion tests were made relative to the following: distance to the avionic VOR receiver from the VOR transmitter, signal level, noise level, and audio tone. Since the Federal Aviation Administration (FAA) may use the voice channel of the VOR to broadcast Automated Weather Observation System (AWOS) voice messages, a commercial AWOS tape supplied by a manufacturer was evaluated for percent distortion. Flight testing was completed at an operational VOR when the voice channel was modulated at 30 percent with pure tones while the aircraft flew a series of radials and orbits. Laboratory measurements were accomplished to measure distortion of tones from a DVOR when the signal level and noise were controlled. Additionally, AWOS voice messages from Muncie Airport, Muncie, Indiana; and Hobbie Airport, Houston, Texas, were recorded by phone and used to modulate the DVOR and a standard FAA very high frequency (VHF) communications transmitter. Signal levels into the VOR and communications avionic receivers were controlled. The receivers audio outputs were recorded on cassette tape recorders to permit subjective evaluation by listeners.

Results indicated that the VOR receiver tested did not exceed the 25 percent distortion tolerance as detailed in the Minimum Operational Performance Standard of the Radio Technical Commission for Aeronautics (RTCA). The distortion does increase with increasing range; i.e., decreasing signal level. However, a tonal distortion of 25 percent does not appreciably degrade the intelligibility of the VOR voice channel.
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EXECUTIVE SUMMARY

The Automated Weather Observation System (AWOS) may use the voice channel of the very high frequency omnidirectional radio range (VOR) to broadcast speech messages to avionic receivers. The VOR voice channel quality is investigated in this report. Both laboratory and flight tests were conducted.

The tonal distortion of the standard second generation VOR and the Doppler VOR (DVOR) using a solid state distributor was investigated. The distortion tests were made relative to the following: distance of the receiver from the VOR transmitter, signal level, noise level, and audio tone. In addition, the initial distortion of AWOS audio tones was measured using a manufacturer supplied tape recorded directly from an AWOS audio output.

Summary of the Test Results are:

1. Combined signal distortion and noise at the VOR avionic receiver output did not exceed the 25 percent distortion tolerance as detailed in Radio Technical Commission for Aeronautics (RTCA) Paper No. 423-84/SC 153-32 for either the DVOR or the standard second generation VOR.

2. Tonal distortion increases at the VOR receiver output as a function of distance from the VOR transmitter, i.e., as signal level decreases.

3. At -20 dB below noise level to raise the VOR receiver flag, distortion remained at the same percentage as that of low noise ambient level.

4. Intelligibility was high for an AWOS message transmitted by the DVOR and received at -95 dBm with low ambient noise. At -95 dBm, the VOR receiver flag was raised.

Summary of the Conclusions are:

1. Tonal distortion of 25 percent does not appreciably reduce message intelligibility of the VOR system.

2. Noise if -20 dB below the level which causes the VOR receiver flag to rise, will not seriously degrade message intelligibility.
INTRODUCTION

BACKGROUND.

The Federal Aviation Administration (FAA) is planning to use the voice channel of the very high frequency omnidirectional radio range (VOR) navigation system to provide speech messages for the Automated Weather Observation System (AWOS). Weather information provided by various weather sensors will be transmitted to central locations where the data will be automatically compiled by computers that will generate a speech message describing the local weather. The message will then be transmitted over phone lines or by radio links to a VOR facility where it will be broadcast over the voice channel of the VOR.

OBJECTIVE/PURPOSE.

A request was made by AES-500, via Program Directive F18-042, for the FAA Technical Center to determine the distortion to voice signals (350-2500 Hz) when transmitted by a (1) standard second generation VOR navigation system and (2) Doppler VOR (DVOR) voice channels. The questions answered by this activity are:

1. How does the voice distortion of a Doppler VOR system compare to the voice distortion generated by the standard VOR system?

2. What is the relationship between percent distortion and signal strength in space?

3. How do the combined effects of noise and bandwidth affect speech quality and how is this related to the articulation index (AI)?

4. What is the quality of digital signals provided by AWOS commercial equipment?

The voice channel of the VOR and DVOR is planned to be utilized for transmitting the AWOS weather message for terminal aviation.

Several studies have been conducted in the past to determine the quality of the VOR voice channel (references 1, 2, and 3). Generally, these studies included (1) a technical description of the VOR system, (2) information showing a relationship between frequency/intelligibility and energy of voice signals, and (3) informal surveys of local pilots to indicate their opinion of the voice channel quality. Actual flight test data were not included in these reports.

For the DVOR, the quality of the voice as received by avionics might be marginally adequate particularly under high noise conditions (1, 5), since the DVOR system has greater noise associated with its voice transmission due to the 1500 and 9960 Hertz (Hz) sideband signals.
DESCRIPTION OF TEST FACILITY.

The DVOR voice tests were accomplished at the FAA Technical Center utilizing the experimental Doppler VOR site. The DVOR site is a nonstandard facility with a 150-foot counterpoise. The second generation equipment used at the DVOR facility consists of a power supply cabinet FA-9996/1A, VOR cabinet FA-9996/2, input/output terminal, and a teleprinter. This equipment is the same type used in a standard conventional VOR system. The Doppler distributor used at this facility is a new solid-state unit type under test.

The conventional VOR tone tests were accomplished at the Waterloo VORTAC facility located in Delaware. This facility is a standard VOR operating on 112.6 MHz.

The DVOR and a very high frequency (VHF) communications transmitter were modulated in separate tests by the same tape recorded AWOS messages. The transmitters were at the FAA Technical Center DVOR building 188 and Consolidated Communication Facility building 176. The communications transmitter was a Model T1108(V) 4/GRT-21(V) while the VOR transmitter was a Collins second generation unit operating with a Henderson Industries solid state distributor, Model DVDA-FA-9997.

DISCUSSION

TEST PROCEDURES.

FLIGHT TESTS. The voice channel in the DVOR and VOR ground equipment was 30 percent modulated with a sine wave audio signal. Instrumentation employed in the testing/recording included a Hewlett-Packard model 339A distortion analyzer, a Hewlett-Packard model 200CD audio oscillator, and a Sony model TC270 tape recorder. Airborne instrumentation included a Scott model 659DA tape recorder, a Centry oscillograph model FA-7916 recorder, a Bendix FA-4165.3A VOR receiver, and a Collins VIR 351 VOR receiver.

A Boeing 727 aircraft, N-40, was employed to obtain flight test recordings of voice distortion using two VOR receivers. The audio channel outputs of both receivers were recorded on a dual channel tape recorder. The VOR receiver automatic gain control (AGC) output level was recorded on a Centry recorder. The airborne data collection instrumentation is shown in figure 1.

Twelve nautical-mile (nmi) orbits at 3,500 feet above mean sea level (m.s.l.) and 5,500 feet above m.s.l. were flown to obtain a sampling of the DVOR and VOR systems voice modulation, respectively. The Tactical Air Navigation (TACAN) systems were used by the aircraft for distance guidance.

Radial flight tests were conducted at each facility to measure DVOR and VOR audio distortion at various distances from the navigation facility. Inbound and outbound flight test recordings of the Waterloo, Delaware VOR were accomplished.
FIGURE 1. TEST SETUP USED TO COLLECT AIRBORNE DATA
on the 210° radial at an altitude of 5,500 feet above m.s.l. Similar measurements were made using the DVOR facility on the 213° radial at an altitude of 3,500 feet m.s.l. The criteria used for distance coverage, as per reference 4, is a minimum signal level of 5 microvolts at Automatic Gain Control (AGC), measured on the VOR receiver.

LABORATORY TESTS. An AI can be a valuable numeric comparative for many audio system performances without resorting to extensive subjective evaluation based on a group of listeners. However, it was not possible during the laboratory testing to establish an AI from the audio tones received primarily because the AI is predicated on measuring the volume or intensity of tone in terms of air pressure, and the tones are assumed to be essentially undistorted. Since the VOR tones are clearly shown to be distorted, an AI could not be computed. Finally, the AI does not predict well where response of the communication channel is irregular (reference 4).

From the measurements made of the audio distortion as a function of four levels of noise relative to the VOR rf signal level, it is clear that the VOR voice channel message distortion is a direct function of signal to noise power difference. When the noise and signal are equal, 0 dB of table 1, distortion is approaching 100 percent as it will when receiver sensitivity slightly above -103 dBm is reached. At -95 dBm the distortion level is well above the acceptable specified level of 25 percent for Radio Technical Commission for Aeronautics (RTCA) Minimum Performance Standard (MPS) receivers.

Laboratory tests were conducted to determine the combined effects of noise and bandwidth on speech quality from a DVOR facility and airborne VOR receiver. The DVOR facility was used for radiating the VOR signal to a Remote Communications Air/Ground (RCAG) facility located at a distance of 2,500 feet. Figure 2 shows the test configuration with attenuators and noise generator for specified test signal level conditions. The percent distortion was determined from tape recordings of the audio signal from the VOR receiver.

AWOS messages tape recorded from the telephone as transmitted from Hobbie Airport, Houston, Texas, and Muncie Airport, Muncie, Indiana, were used to appraise speech quality from the Technical Center DVOR through an avionic VOR receiver. Figure 2 shows the test configuration for the DVOR and VOR receiver tests.

The same recordings were used to modulate a VHF transmitter, GRT-21 at 30 to 40 percent. The avionic receiver was a Collins Model 253 to which a Scott cassette recorder was connected to record the audio output. This recording and all others were made at approximately equal input voltage levels.

Additionally, an audio tone tape with the 15 frequencies of table 1 was requested from an AWOS manufacturer. The tones on the supplied tape were tested to determine distortion. The measured distortion of tones was 1 percent or less.
FIGURE 2. VOR INTELLIGIBILITY TEST CONFIGURATION
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**TABLE 1. PERCENT DISTORTION FOR AUDIO FREQUENCY, Hz**
TEST RESULTS.

FLIGHT TEST RESULTS. Figures 3 through 4 are plots of the data obtained during orbital flight tests of the DVOR and VOR facilities. The plots show the change in percent distortion as a function of audio frequency for various test conditions. Test results show that the combined distortion and noise in the VOR receivers audio output did not exceed the 25-percent distortion tolerance listed in RTCA Paper No. 423-84/SC153-32, paragraph 2.2.11, for either the DVOR or standard VOR facilities.

Figures 5 and 6 are plots of the data obtained during radial flight tests of each facility. Figures 7 and 8 are plots of data obtained during radial flight tests of the Waterloo VORTAC facility. The plots show the change in percent distortion as a function of distance to/from the facility.

LABORATORY TEST RESULTS. Figures 9, 10, 11, and 12 are plots of percent modulation obtained during laboratory tests using the DVOR facility VOR receiver, and noise generator. Table 1 shows the corresponding tabular data.

The digital recording supplied by one commercial AWOS manufacturer had a tonal distortion of 1 percent or less. By listening with earphones and 4" cone speakers to the tape recordings of the DVOR and VHF communications AWOS messages, the audio intelligibility of each did not diminish significantly even at the signal level input to receivers of -95 dBm. The flag was out at -95 dBm.

Copies of these tape recordings are on file at the FAA Technical Center and may be borrowed for short periods by contacting E. Sawtelle, ACT-520, x5311.

CONCLUSIONS

1. The Doppler VOR (DVOR) produced slightly greater audio tone distortion than the standard second generation very high frequency omnidirectional radio range (VOR).

2. Percent distortion rises with a declining signal level.

3. Because of VOR tonal distortion and irregular frequency response, Articulation Index is not an appropriate measure, however, tape recordings of -95 dBm Automated Weather Observation System (AWOS) messages, without high noise levels, are of high intelligibility.

4. At a noise level of -20 dB below that level required to raise the VOR receiver flag, noise does not adversely increase distortion even to a signal level of -95 dBm.

5. Commercial AWOS digitally generated tones have distortion of 1 percent or less indicating a high quality audio source.
FIGURE 3. PERCENT DISTORTION WITH TYPE VIR 351 COLLINS VOR RECEIVER COMPARING DOPPLER VOR AND CONVENTIONAL VOR FACILITIES, 12 NMI ORBIT

FIGURE 4. PERCENT DISTORTION WITH TYPE FA 4165.3A BENDIX VOR RECEIVER COMPARING DOPPLER VOR AND CONVENTIONAL VOR FACILITIES, 12 NMI ORBIT
FIGURE 5. INDICATED DISTORTION PERCENT WITH TYPE VIR 351 COLLINS VOR RECEIVER, OUTBOUND FLIGHT

FIGURE 6. INDICATED DISTORTION PERCENT WITH TYPE FA-4165.3A BENDIX VOR RECEIVER, OUTBOUND FLIGHT
FIGURE 7. INDICATED DISTORTION PERCENT WITH TYPE VIR 351 COLLINS VOR RECEIVER, INBOUND FLIGHT

FIGURE 8. INDICATED DISTORTION PERCENT WITH TYPE FA 4165.3A BENDIX VOR RECEIVER, INBOUND FLIGHT
FIGURE 9. INDICATED DISTORTION PERCENT WITH VARIABLE SIGNAL LEVELS NORMAL VOR RECEIVER OPERATION

FIGURE 10. INDICATED DISTORTION PERCENT WITH VARIABLE SIGNAL LEVELS MAXIMUM DISTORTION (NOISE LEVEL) VOR RECEIVER (FLAG INDICATOR)
FIGURE 11. INDICATED DISTORTION PERCENT WITH VARIABLE SIGNAL LEVELS NOISE LEVEL REDUCED 20 db (REFERENCE FIGURE 10)

FIGURE 12. INDICATED DISTORTION PERCENT WITH VARIABLE SIGNAL LEVELS NOISE LEVEL REDUCED 10 db (REFERENCE FIGURE 10)


5. FAA Order 6790.4A, Change 5, Appendix 2, August 29, 1980.