

VDL MODE E RECEIVER PERFORMANCE MEASUREMENTS

Fred Studenberg, P.E., Rockwell Collins, Inc., Melbourne, FL

Abstract

VDL Mode E is a digital communications system proposed as a worldwide standard for replacement of the existing analog AM voice system used for VHF aeronautical communications. It provides a needed increase in voice channel capacity as well as offering a digital data link for CPDLC with the high integrity and low latency needed for time-critical ATC messages.

This report summarizes results of measurements of proposed minimum requirements for an aeronautical receiver for VDL Mode E. A software defined radio (SDR) currently used in Commercial Air Transport communications was used for the tests.

Introduction

To solve radio frequency congestion issues and provide high integrity, and guaranteed QOS (quality of service), a replacement is needed for the analog AM system now used worldwide for VHF aeronautical communications.

VDL Mode E [1] is one of several next-generation digital systems being considered by the Future Communications System (FCS) study group as a global standard for a new system operating in the 118-137 MHz aeronautical communications band [2].

VDL Mode E has been included in the list of candidates since it can provide capacity increase, the required voice and data link performance, and is spectrum compatible with the European analog AM system using 8.33 KHz channel spacing. The system can also be efficiently implemented within the 25 kHz channel spacing system used elsewhere in the world, including the United States.

In previously reports, it was shown that a VDL Mode E voice and data link network is scaleable to provide capacity as needed for growth in aeronautical communications beyond the year 2050 [3].

The 8.33 KHz spectrum compatibility of VDL Mode E permits a seamless “drop-in” transition to a modern digital system by the replacement of any 8.33 KHz analog channel with a VDL Mode E

digital circuit. In the 25 KHz channel spacing environment, up to 3 individual VDL Mode E channels (6 independent voice or data circuits) can be accommodated in place of one analog AM channel.

Overview of Digital VHF Communications Systems

VDL Mode E is a digital TDMA system based on the key parameters and protocols from VDL Mode 3. VDL Mode 3 was developed by the United States FAA, MITRE Corporation, and industry partners. VDL Mode 3 uses a D8PSK waveform with operation on 25 KHz channel spacing. It provides 4 digital circuits per channel with configurations for various combinations of voice and data link circuits.

Multi-mode, FAA TSO approved VHF Communications transceivers that provide VDL Mode 3 capability are now commercially available. One example is the Rockwell Collins VHF-2100, shown in Figure 1. This software defined radio (SDR) also provides all legacy operating modes such as analog AM voice, VDL Mode A, and VDL Mode 2.



Figure 1. Rockwell Collins VHF-2100

Certification flight tests of the VHF-2100 demonstrated that the VDL Mode 3 system meets and exceeds all performance requirements for range

and signal quality [4]. Versions of the VHF-2100 VHF Communications Transceiver are now entering service with major commercial air carriers.

Notwithstanding the unqualified success of the VDL Mode 3 development program, the schedule for implementation of VDL Mode 3 in the U.S. has been delayed to allow the FCS study group to make its recommendations in 2007.

A concern by some stakeholders for the global implementation of VDL Mode 3 is the incompatibility of the required 25 KHz channel waveform with the 8.33 KHz channel spacing now being used in Europe. To accommodate a new VDL Mode 3 channel in that environment, it is necessary to find new frequencies for 3 contiguous 8.33 KHz channels. There is also concern over improvement in capacity with only 33% increase in voice channel capacity in a 25 kHz band compared to 8.33 KHz analog operation (4 vs 3).

VDL Mode E was developed to overcome these concerns by providing operation within an 8.33 KHz channel. By reducing the symbol rate of the VDL Mode 3 D8PSK waveform so it is contained in an 8.33 KHz channel, all the features of VDL Mode 3 are preserved. The reduction in data rate reduces the number of independent voice or data circuits from 4 to 2. However, in a 25 kHz channel, three VDL Mode E channels can provide 6 independent circuits instead of 4 circuits with VDL Mode 3.

Minimum Operational Performance Specifications (MOPS)

The VHF aeronautical communications system was first introduced in 1946 with AM voice operation using 100 KHz channel spacing. Since that time, industry technical standards have been developed and continually revised as technology advances. These standards are necessary to insure compatibility between equipment produced by different manufacturers.

One such set of standards are those prepared by members of RTCA, a United States based technical coordinating body for avionics systems.

RTCA DO-271C contains the Minimum Operational Performance Specifications (MOPS) for VDL Mode 3. The primary specifications for VDL Mode 3 receiver and transmitter physical

layer performance are contained in DO-271C, along with suggested test procedures.

When VDL Mode E was developed, it was a requirement for the design that VDL Mode E operation could be provided with only a software update of VDL Mode 3 equipment. This approach would result in the ability to operate with new software defined radios, such as the VHF-2100, and would provide the lowest overall cost of development and validation for VDL Mode E.

Because VDL Mode E was designed as a reduced bit-rate version of VDL Mode 3, the MOPS for VDL Mode 3 transmitter and receiver were scaled as required for operation 8.33 kHz channels.

Tables 1 and 2 show the key characteristics of transmitter and receiver performance for 25 kHz channels (VDL Mode 3) and those proposed for 8.33 KHz channels. (VDL Mode E).

Table 1. Transmitter Key Characteristics

TRANSMITTER	VDL MODE 3	VDL MODE E	Units
Frequency Band	118-137	118-137	MHz
Channel Spacing	25	8.33	KHz
RF Output Power	NLT 15	NLT 15	W
Frequency Tolerance	±5	±5	PPM
Waveform Type	D8PSK	D8PSK	
Nyquist Filtering	Raised cosine	Raised cosine	
Excess Bandwidth	$\alpha = 0.6$	$\alpha = 0.3$	
Bit Rate	31500	15750	Bits/sec
Energy in 1 st Adjacent Channel	NMT -18	NMT -18	dBm
1 st Adjacent Channel Bandwidth	16	6.6	KHz
Symbol Constellation Error (EVM)	NMT 6	NMT 6	%

Table 2. Receiver Key Characteristics

RECEIVER	VDL MODE 3	VDL MODE E	Units
Frequency Band	118-137	118-137	MHz
Channel Spacing	25	8.33	KHz
Sensitivity for .001 Bit Error Rate	NMT -98	NMT -98	dBm
Frequency Capture Range (Doppler + Tx Freq Error)	±967	±967	Hz
1 st Adjacent Channel Rejection	NLT 40	NLT 40	dB
Co-Channel Interference	NMT 20	NMT 20	dB

Previous reports have demonstrated that with software-only updates to the multi-mode VHF-2100, the transmitted VDL Mode E waveform can be generated that meets all proposed MOPS for transmitter operation, as shown in Table 1 [1].

The following sections of this report discuss results of recent measurements of key VDL Mode E receiver requirements using prototype receiver software installed in the VHF-2100.

Prototype VDL Mode E Receiver Design

Software for demodulation of the 15750 bit/sec D8PSK waveform for VDL Mode E was developed for use in the VHF-2100. The demodulator design was based on the VDL Mode 3 demodulator with sampling period adjusted for the 50% reduction in symbol rate. No change due to the reduction in the raised cosine alpha factor was needed since this waveform does not require a matched filter at the receiver.

Because the VHF-2100 provides analog AM operation on 8.33 kHz channels, no change in frequency tuning was necessary to select 8.33 kHz channels.

The receiver bandwidth needed for demodulation was modified from that used for 8.33 KHz AM operation so as to provide more adjacent channel rejection capability. Figure 2 shows an expanded amplitude vs frequency of the VDL Mode E waveform.

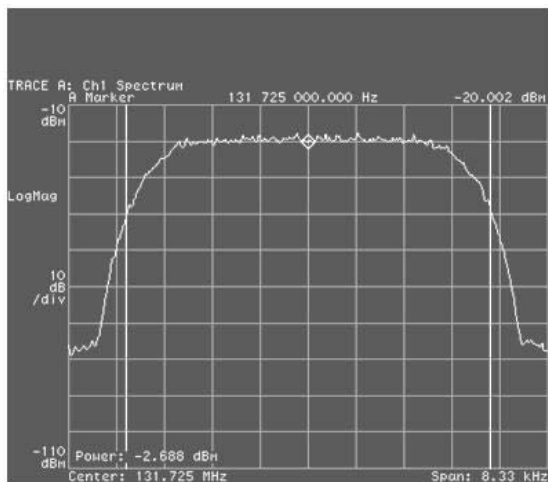


Figure 2. Spectrum of VDL Mode E

This figure shows that the VDL Mode E waveform has a -6 dB response at ± 2625 Hz. A ± 3.0 kHz receiver passband response was selected. This will allow margin for receiver and transmitter frequency errors and maximum Doppler shift on received signals of ± 282 Hz.

Based on an estimate of the energy in the 1st adjacent channel, a rejection of 60 dB was needed at a ± 4.0 KHz. Since the VHF-2100 is a software defined radio, all receiver selectivity for 8.33 kHz operation is provided by software filters. Figure 3 shows the amplitude and phase response of the software bandpass filter used in the prototype testing. The passband is ± 3.0 kHz with attenuation greater than 65 dB at ± 4.0 KHz.

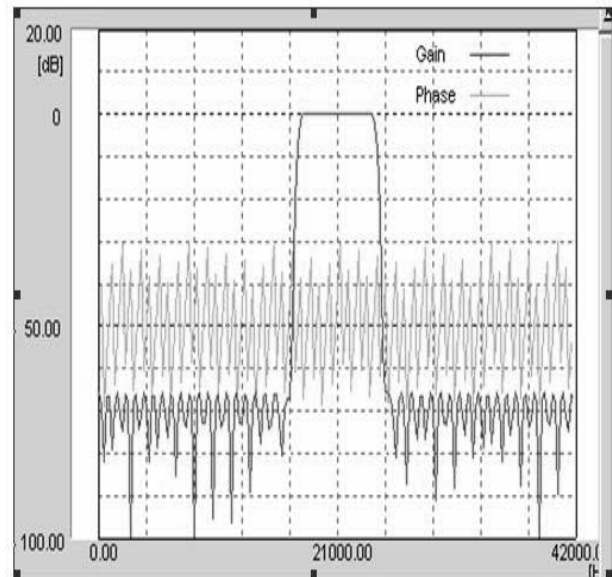


Figure 3. Selectivity Characteristics

Receiver Performance Measurements

For all receiver tests to follow, a test frequency of 127.500 MHz was used with an Agilent E4434B generator used to generate the D8PSK waveform.

Receiver Sensitivity

The RF signal level required for .001 bit error rate was determined with the VHF-2100 operating in VDL Mode 3 and then in VDL Mode E.

Table 3 shows the results. As expected, there was a 3 dB improvement with VDL Mode E due to the 50% reduction in receiver bandwidth.

Table 3. Receiver Sensitivity

Mode	Requirement for .001 BER	RF Level for .001 BER
VDL Mode 3	NMT -98 dBm	-101 dBm
VDL Mode E	NMT -98 dBm	-104 dBm

Receiver Adjacent Channel Rejection

The RF signal level of a 1st adjacent channel signal required to degrade a desired -87 dBm on-channel signal to .001 BER was determined with the VHF-2100 operating in VDL Mode 3 and then in VDL Mode E.

For VDL Mode E, adjacent channel rejection tests, the interfering signal was set at +/- 8.33 kHz and modulation on the interfering signal was set for FM at 400 Hz FM with a peak deviation of 2625 Hz. This is a direct scaling of the VDL Mode 3 test of 400 Hz FM with a deviation of 5250 Hz.

Table 4 shows that VDL Mode E provided similar performance as VDL Mode 3.

Table 4. Receiver Adjacent Channel Rejection

Mode	Requirement for .001 BER	Measured RF Level
VDL Mode 3	NMT 40 dB	45 dB
VDL Mode E	NMT 40 dB	46 dB

Co-channel Rejection

The RF signal level of an on-channel channel signal required to degrade a desired -87 dBm on-channel signal to .001 BER was determined with the VHF-2100 operating in VDL Mode 3 and then in VDL Mode E.

For VDL Mode E, the interfering signal was set at +/- 8.33 kHz and modulation on the interfering signal was set for FM at 400 Hz FM with a peak deviation of 2625 Hz. This is a direct scaling of the VDL Mode 3 test of 400 Hz FM with a deviation of 5250 Hz.

Table 5 shows that VDL Mode E provided similar performance as VDL Mode 3.

Table 5. Receiver Co-channel Rejection

Mode	Requirement for .001 BER	Measured RF Level
VDL Mode 3	NMT 20 dB	18 dB
VDL Mode E	NMT 20 dB	18 dB

Frequency Error from Doppler and Transmitter Frequency Tolerance Receiver Adjacent Channel Rejection

The frequency offset of a desired signal that did not degrade a desired -87 dBm on-channel signal to .001 BER was determined with the VHF-2100 operating in VDL Mode 3 and then in VDL Mode E.

Table 6 shows that VDL Mode E did not provide the expected performance.

Table 6. Receiver Frequency Error

Mode	Requirement for .001 BER	Measured RF Level
VDL Mode 3	NLT ± 967 Hz	± 1267 Hz
VDL Mode E	NLT ± 967 Hz	± 467 Hz

The smaller frequency tolerance than expected was due to the narrow (± 3 KHz) bandpass filter used so as to meet the adjacent channel rejection.

Two options are possible to provide the same performance as VDL Mode 3.

One option is to modify the -6 dB to 60 dB rejection (shape factor) of the VDL Mode E software filter. This approach will trade off adjacent channel rejection for an increase in frequency tolerance. Based on the margin of both measurements with the current configuration, it is possible that a compromise can be reached that still allows meeting both requirements.

A second option is to change the proposed MOPS to use a more rigorous frequency tolerance on airborne transmitters in the system instead of the ± 5 PPM limit used for VDL Mode 3. This will only require a frequency capture necessary for Doppler shift (± 242 Hz) plus whatever frequency error is allocated to the transmitters. Based on the prototype measurements, up to ± 225 Hz frequency tolerance could be tolerated. This is ± 1.6 PPM instead of the existing tolerance of ± 5 PPM.

For option two, rather than require a hardware change for a higher stability reference oscillator, a solution that can be implemented in the VHF-2100 software defined radio is to lock the transmitted frequency to the received frequency of the ground station. If the ground station operates with very small frequency tolerance, for instance less than 10 Hz, then the frequency error of an airborne unit

locked to this will be no more than ± 1 maximum Doppler shift or about ± 141 Hz. When received by another aircraft moving in the opposite direction, the apparent maximum frequency error will be no more than ± 282 Hz. Locking the transmitted frequency to the ground station is possible since the apparent frequency error (due to Doppler and receiver frequency errors) of the “perfect” received ground station can be used to calculate the offset of the transmitted signal.

This technique can also resolve any performance concerns with the adjacent channel rejection when the adjacent channel signal is not exactly at ± 8.33 kHz (as it is measured in the MOPS test). For instance, with ± 5 PPM allowable error, with Doppler, an adjacent channel transmission can be as close as 8333 - 967 Hz or 7.366 kHz.

Conclusions

This paper has identified the key receiver MOPS for VDL Mode 3 and presented results of measurements on a prototype software defined radio.

The tests demonstrated the theoretical sensitivity performance improvements was achievable. Because of the 3 dB improvement, the VDL Mode E transmitter power requirement could be reduced from 15 watts to 7.5 watts and still maintain the same link budget as VDL Mode 3. However, this is not recommended since the lower receiver sensitivity limit of -101 dBm is not likely to be realized in practice due to low level signals entering the antenna from normal aircraft EMI sources. This limits the usable sensitivity since the BER is degraded from the co-channel EMI signals.

The tests also demonstrated that some additional work is needed on defining a software filter with adjacent channel rejection vs frequency error tradeoffs or alternately, decreasing the allowable frequency tolerance for airborne transmitters to about ± 1.5 PPM. With existing software defined radios, this can be accomplished by locking the transmitter to the ground station's frequency and no hardware change is needed. For new designs, either frequency locking or improved reference oscillator stability could be used.

References

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Biographical Sketch

Fred Studenberg is a Senior Engineering Manager for VHF/HF Comm Products with the Air Transport Division of Rockwell Collins in Melbourne, Florida.

As a member of RTCA and EUROCAE Special Committees, he has participated in the development of U.S and European standards and planning for VHF Aeronautical Communications Systems such as 8.33 kHz, VDL Mode 2, and VDL Mode 3. He received a BSEE from The University of South Florida and a MBA from The Florida Institute of Technology. He is a licensed Professional Engineer in the State of Florida.

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