DVX
VHF Digital Voice Transceiver

Ver. 1.03

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1. Introduction

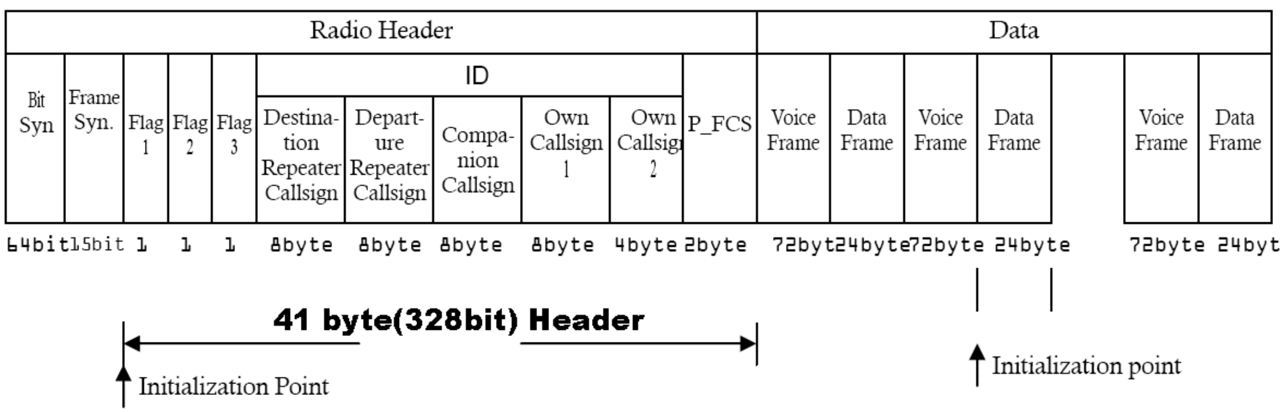
Interest continues to grow in amateur radio digital voice/data communications on both HF, VHF, and above. The most common means for implementing digital modes in recent years has been with a soundcard and a PC. This paper explores the use of some new IC's that have become available to implement an experimental stand-alone digital transceiver.

2. D-Star System

An existing digital voice/data system has been developed by JARL and ICOM called D-Star. This system has various layers including not only the point to point digital voice links but more elaborate repeater and Internet connectivity for worldwide coverage using VHF/UHF radios.

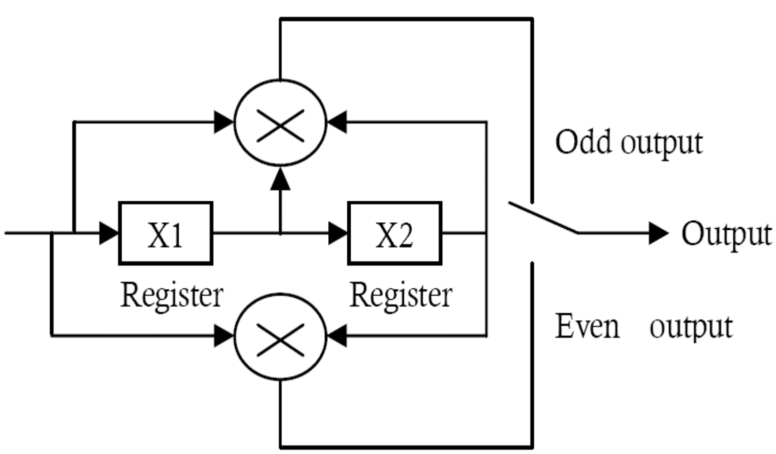
There are other articles detailing this system so this paper will concentrate on a few relevant topics.

2.1. Packet Data Format



The following description is of the header data encoding process. Decoding is the reverse order of operations.
The Voice Data packets begin with a 64bit bit sync word and 15 bit Frame sync word. The following 328 bits of header data is transformed into 660bits for transmission in the following manner:

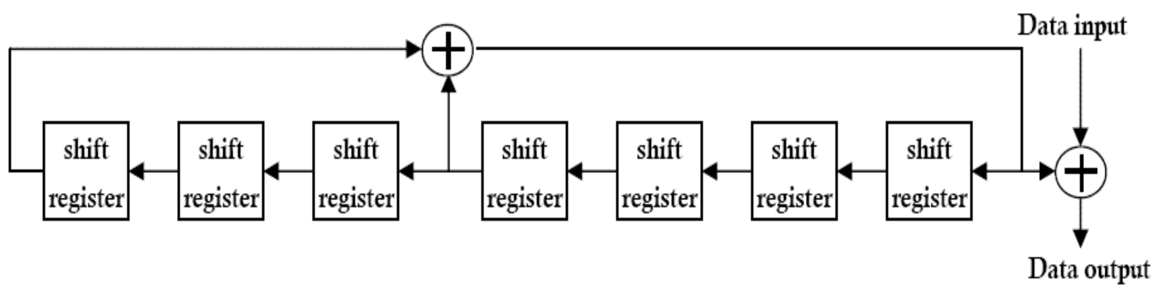
1. The 328 bits are expanded into 660 bits by running through a ½ rate, constraint length 3 convolution encoder. 2 extra zeros are shifted in at the end to create the final 660 bit packet.



2. The 660 bits of convolution data are then interleaved using a 28 by 24 matrix. This adds time diversity to the bits making it easier for the convolutional decoder to correct bursts of errors.

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
0	0	24	48	72	96	120	144	168	192	216	240	264	288	312	336	360	384	408	432	456	480	504	528	552	576	600	624	648
1	1	25	49	73	97	121	145	169	193	217	241	265	289	313	337	361	385	409	433	457	481	505	529	553	577	601	625	649
2	2	26	50	74	98	122	146	170	194	218	242	266	290	314	338	362	386	410	434	458	482	506	530	554	578	602	626	650
3	3	27	51	75	99	123	147	171	195	219	243	267	291	315	339	363	387	411	435	459	483	507	531	555	579	603	627	651
4	4	28	52	76	100	124	148	172	196	220	244	268	292	316	340	364	388	412	436	460	484	508	532	556	580	604	628	652
5	5	29	53	77	101	125	149	173	197	221	245	269	293	317	341	365	389	413	437	461	485	509	533	557	581	605	629	653
6	6	30	54	78	102	126	150	174	198	222	246	270	294	318	342	366	390	414	438	462	486	510	534	558	582	606	630	654
7	7	31	55	79	103	127	151	175	199	223	247	271	295	319	343	367	391	415	439	463	487	511	535	559	583	607	631	655
8	8	32	56	80	104	128	152	176	200	224	248	272	296	320	344	368	392	416	440	464	488	512	536	560	584	608	632	656
9	9	33	57	81	105	129	153	177	201	225	249	273	297	321	345	369	393	417	441	465	489	513	537	561	585	609	633	657
10	10	34	58	82	106	130	154	178	202	226	250	274	298	322	346	370	394	418	442	466	490	514	538	562	586	610	634	658
11	11	35	59	83	107	131	155	179	203	227	251	275	299	323	347	371	395	419	443	467	491	515	539	563	587	611	635	659
12	12	36	60	84	108	132	156	180	204	228	252	276	300	324	348	372	396	420	444	468	492	516	540	564	588	612	636	
13	13	37	61	85	109	133	157	181	205	229	253	277	301	325	349	373	397	421	445	469	493	517	541	565	589	613	637	
14	14	38	62	86	110	134	158	182	206	230	254	278	302	326	350	374	398	422	446	470	494	518	542	566	590	614	638	
15	15	39	63	87	111	135	159	183	207	231	255	279	303	327	351	375	399	423	447	471	495	519	543	567	591	615	639	
16	16	40	64	88	112	136	160	184	208	232	256	280	304	328	352	376	400	424	448	472	496	520	544	568	592	616	640	
17	17	41	65	89	113	137	161	185	209	233	257	281	305	329	353	377	401	425	449	473	497	521	545	569	593	617	641	
18	18	42	66	90	114	138	162	186	210	234	258	282	306	330	354	378	402	426	450	474	498	522	546	570	594	618	642	
19	19	43	67	91	115	139	163	187	211	235	259	283	307	331	355	379	403	427	451	475	499	523	547	571	595	619	643	
20	20	44	68	92	116	140	164	188	212	236	260	284	308	332	356	380	404	428	452	476	500	524	548	572	596	620	644	
21	21	45	69	93	117	141	165	189	213	237	261	285	309	333	357	381	405	429	453	477	501	525	549	573	597	621	645	
22	22	46	70	94	118	142	166	190	214	238	262	286	310	334	358	382	406	430	454	478	502	526	550	574	598	622	646	
23	23	47	71	95	119	143	167	191	215	239	263	287	311	335	359	383	407	431	455	479	503	527	551	575	599	623	647	

3. Finally, the interleaved bits are scrambled to help break up any long runs of 1's or 0's. The scrambler is implemented with a polynomial $S(x) = x^7 + x^4 + 1$.



Following the header are alternating 72 bit voice packets and 24 bit aux data packets. The voice data packets are fed directly into the AMBE2020 vocoder chip at a rate of 3600bps. (72/(72+24) * 4800). The AMBE2020 data packets contain their own FEC encoding for an actual data rate of 2400bps compressed voice data. The AMBE2020 then decompresses this into 16bit, 8000sps audio data ready to go to the audio codec.

AMBE2020 W0 msb	AMBE2020 W0 lsb	AMBE2020 W1 msb	AMBE2020 W1 lsb
AMBE2020 W2 msb	AMBE2020 W2 lsb	AMBE2020 W3 msb	AMBE2020 W3 lsb
AMBE2020 W4 lsb	User Data Byte 0	User Data Byte 1	User Data Byte 2

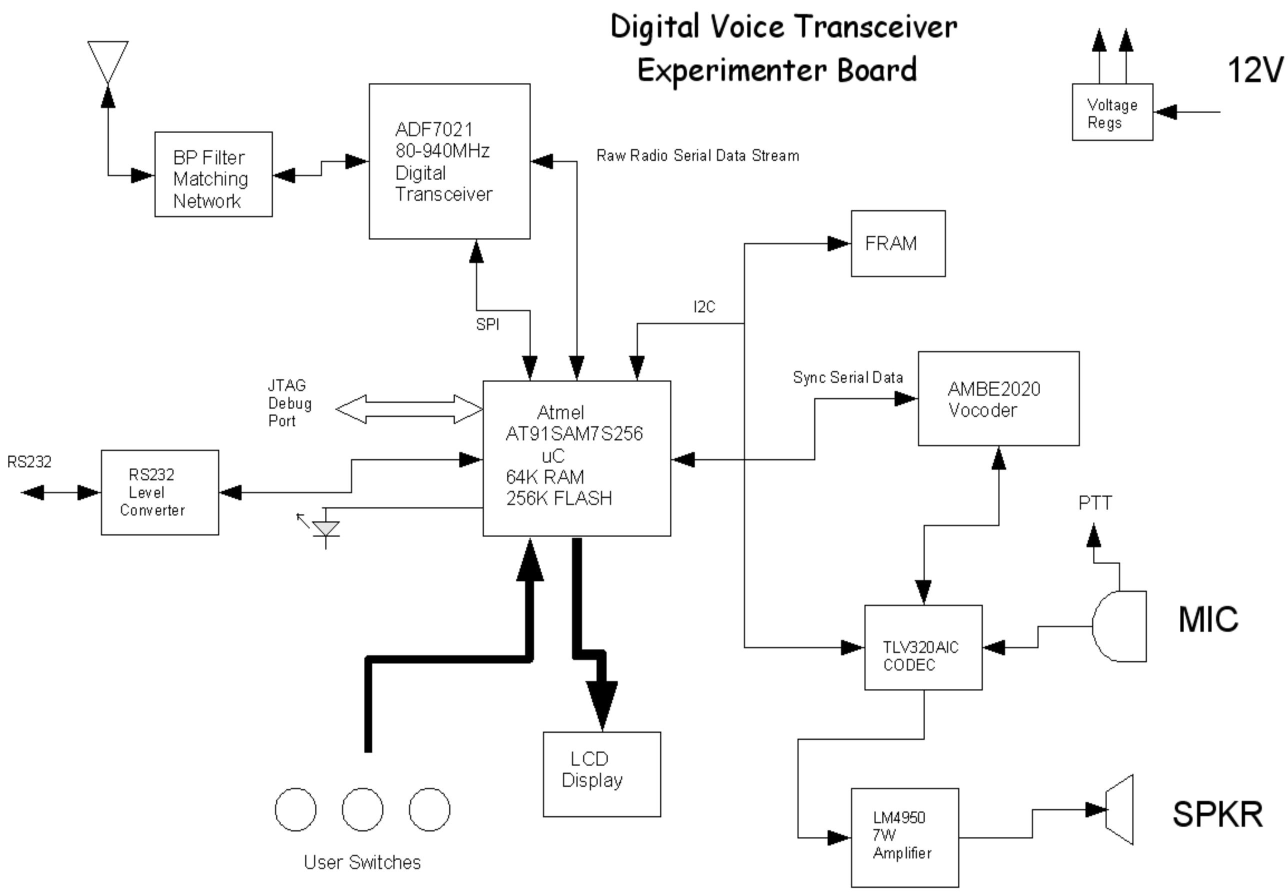
The 24 byte auxiliary data packets are scrambled but contain no FEC. The first data frame and every 21 data frames thereafter contain only synchronization patterns. The final data packet of a transmission contains a unique sync word to indicate end of transmission.

Currently data packets contain text data as well as periodic repeats of callsigns allowing sync and identification even if the receiving station misses the main header packet. Only the 3 User Data bytes are scrambled with the scrambler reset each frame.

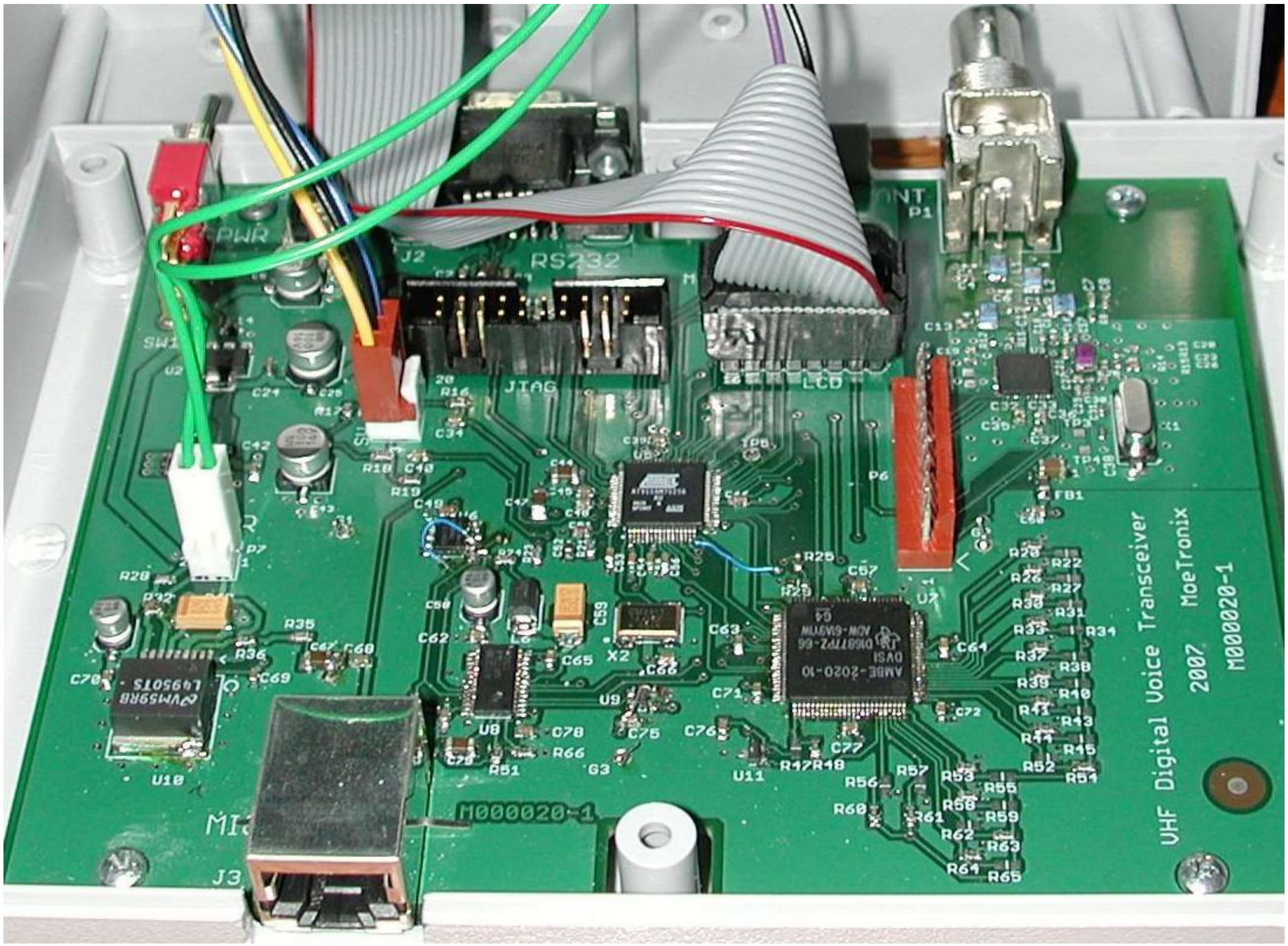
3. DVX Experimenter Board

The experimenter board was designed to be able to test out various ideas and components that are used in digital voice radios. It can be used to just do voice data compression/decompression or can be used to play with the ADF7021 transceiver chip on various bands.

3.1. Block Diagram



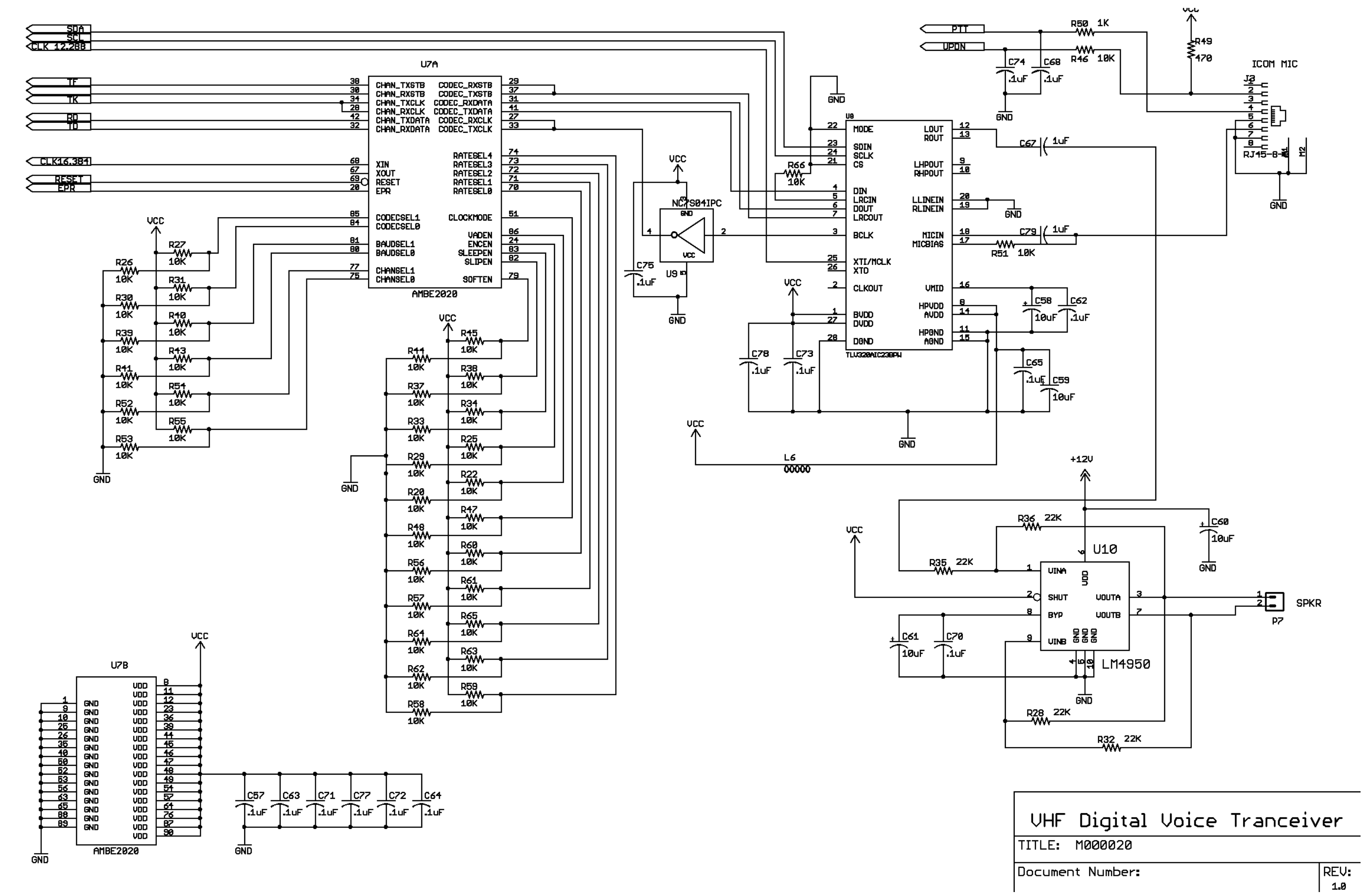
3.2. Prototype PCB




Rx -113dBm
ELECTRET CONDENSER MIC

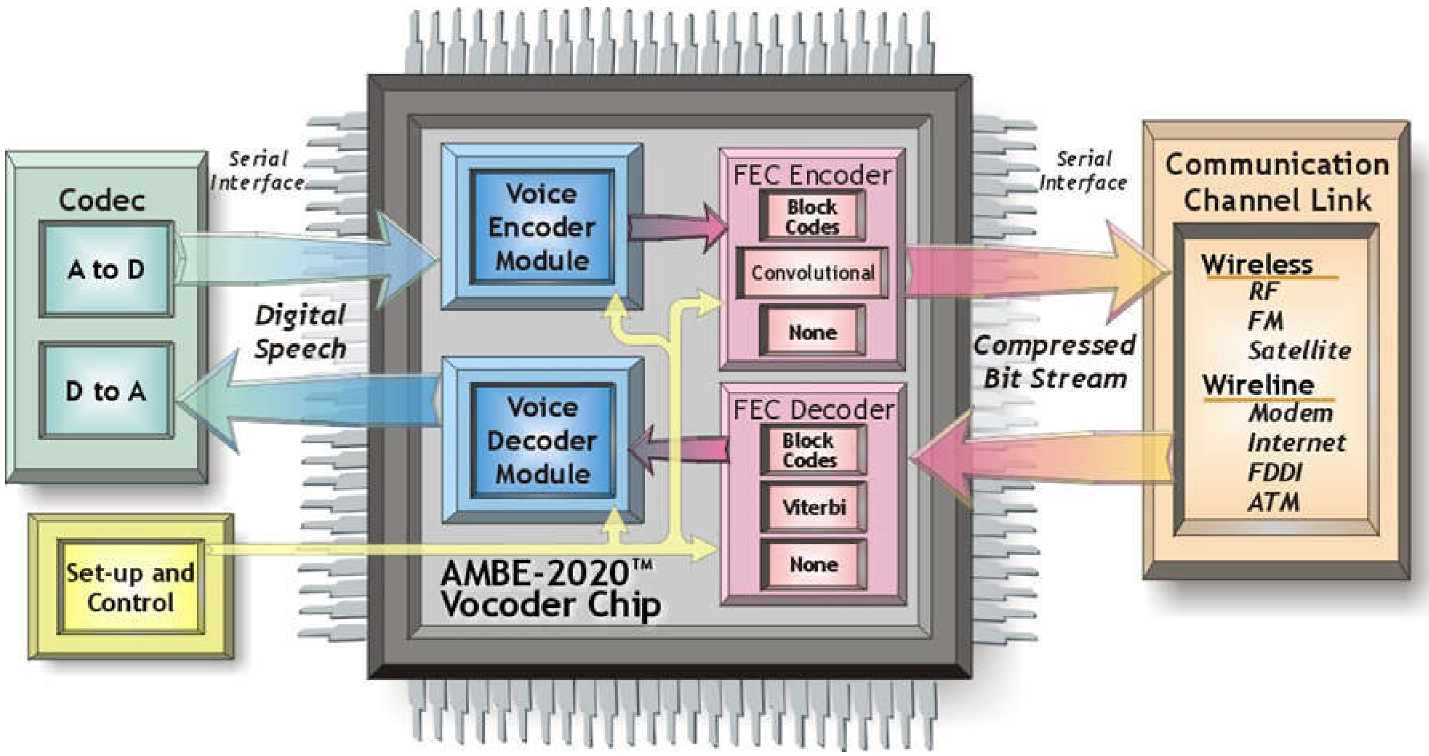
3.3. TLV320AIC23B Audio Codec

This TI 16 bit codec was chosen because it contains a built in microphone preamp as well as other parameters that can be changed using its I2C control port. It is a little strange in that it is a stereo codec so only one channel is being used.



3.4. AMBE-2020 Vocoder

The same AMBE-2020 Vocoder Chip that D-Star uses was chosen so that a compatible system could be implemented. The chip has many other bit rates and FEC rates so various other formats can be tried. Things such as touch tone encoding/decoding, VOX, and background noise addition are some of the many features of this chip.



Below is a table showing many of the various data rates and modes of this chip.

Table 5-C Rate Selection Using Rate Info 0-4, compatible w/ AMBE-1000™ (AMBE)

Rate Info 0	Rate Info 1	Rate Info 2	Rate Info 3	Rate Info 4	Speech Rate (bps)	FEC Rate (bps)	Total Rate (bps)
0x9030	0x0000	0x0000	0x0000	0x4330	2400	0	2400
0x902f	0x0000	0x0000	0x0000	0x6930	2350	50	
0x9348	0x0000	0x0000	0x0000	0x6f48	3600	0	3600
0x9243	0x0080	0x0000	0x0000	0x5348	3350	250	
0xab50	0x0000	0x0000	0x0000	0x3950	4000	0	4000
0x934b	0x0080	0x0000	0x0000	0x3950	3750	250	
0xab60	0x0000	0x0000	0x0000	0x7960	4800	0	4800
0xab5b	0x0080	0x0000	0x0000	0x6860	4550	250	
0x9348	0x2030	0x0000	0x0000	0x7060	3600	1200	
0x923e	0x2800	0x0000	0x0000	0x7460	3100	1700	
0xab53	0x2c00	0x0000	0x0000	0x5680	4150	2250	6400
0xab58	0x3000	0x0000	0x0000	0x4490	4400	2800	7200
0xbf9b	0x0080	0x0000	0x0000	0x49a0	7750	250	8000
0xab5d	0x3400	0x0000	0x0000	0x31a0	4650	3350	
0xbfc0	0x0000	0x0000	0x0000	0x72c0	9600	0	9600
0xab16	0xe400	0x0000	0x0000	0x67c0	4850	4750	

Table 5-D Rate Selection Using Rate Info 0-4, AMBE-2020™ only (AMBE+)

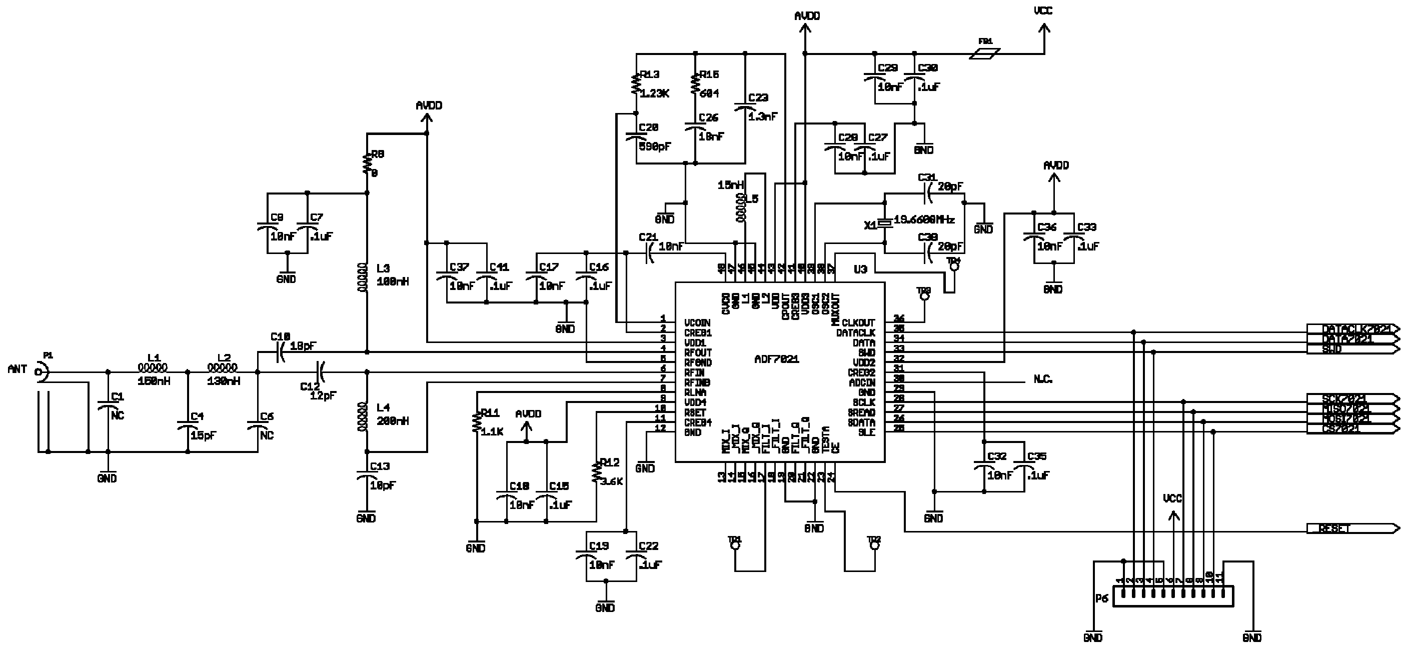
Rate Info 0	Rate Info 1	Rate Info 2	Rate Info 3	Rate Info 4	Speech Rate (bps)	FEC Rate (bps)	Total Rate (bps)
0x0028	0x0000	0x0000	0x0000	0x6428	2000	0	2000
0x5048	0x0000	0x0000	0x0000	0x3948	3600	0	3600
0x1030	0x0001	0x0000	0x4230	0x0048	2400	1200*	
0x1030	0x4000	0x0000	0x0000	0x0048	2400	1200**	
0x5250	0x0000	0x0000	0x0000	0x4150	4000	0	4000
0x1030	0x0001	0x0000	0x341a	0x6750	2400	1600	
0x5360	0x0000	0x0000	0x0000	0x6c60	4800	0	4800
0x5250	0x2010	0x0000	0x0000	0x7460	4000	800	
0x5048	0x0001	0x0000	0x2412	0x6860	3600	1200	
0x1030	0x0005	0x180c	0x3018	0x7360	2400	2400	
0x6b80	0x0000	0x0000	0x0000	0x6c80	6400	0	6400
0x5250	0x0001	0x0000	0x542a	0x5280	4000	2400	
0x5258	0x0009	0x1e0c	0x4127	0x7390	4400	2800	7200
0x7fa0	0x0000	0x0000	0x0000	0x52a0	8000	0	8000
0x5250	0x0005	0x2010	0x6834	0x72a0	4000	4000	
0x7fc0	0x0000	0x0000	0x0000	0x69c0	9600	0	9600
0x5048	0x000e	0x4010	0x6a2e	0x65c0	3600	6000	
0x1030	0x000e	0x681a	0x511b	0x76c0	2400	7200	

* FEC is a convolutional code

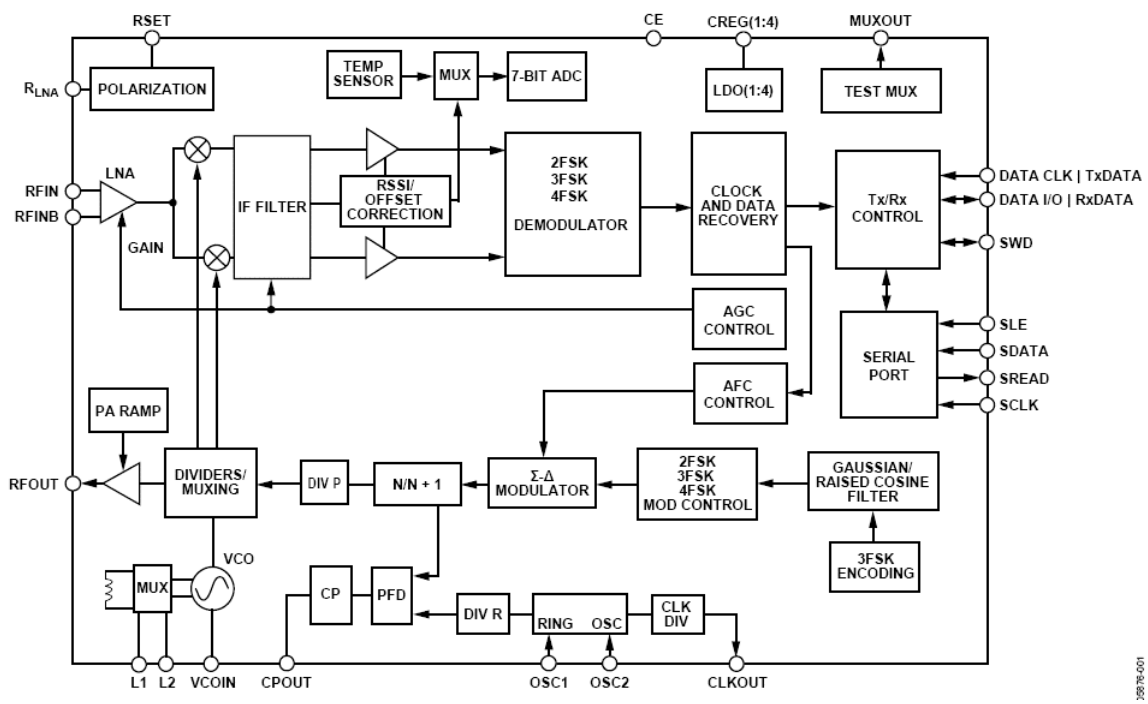
** FEC is a block code

3.5. ADF7021 80 to 940 MHz RF/Mod/Demod Chip

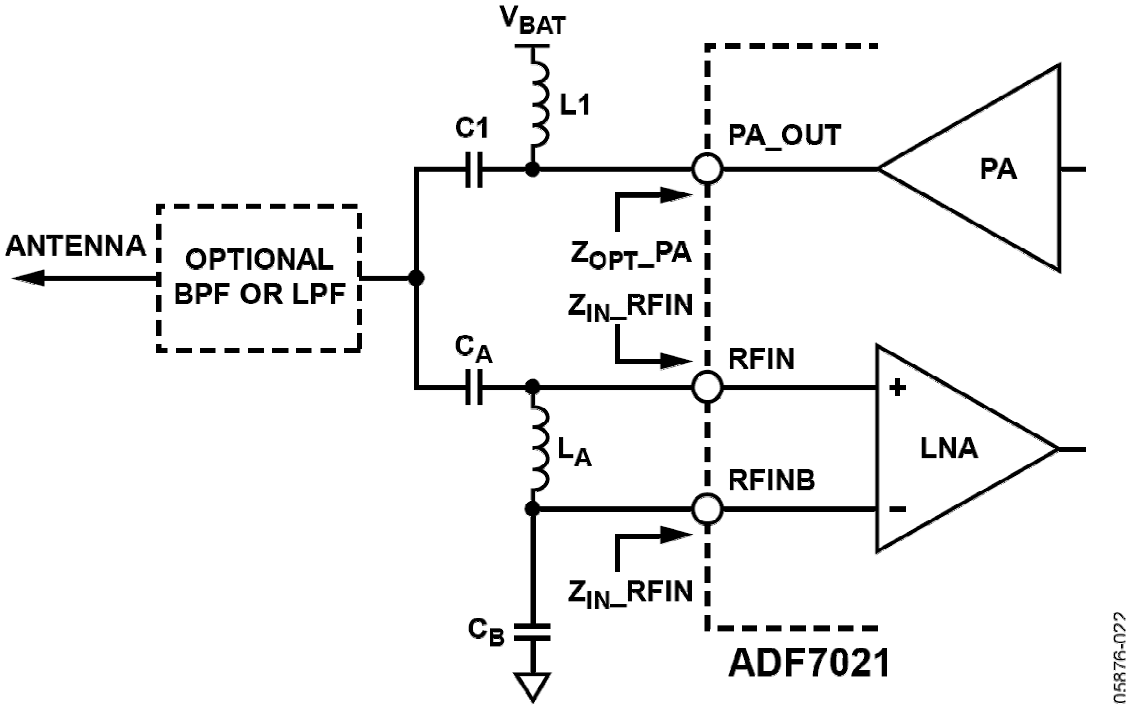
The RF section is comprised of a single chip from Analog Devices that is meant for use in narrow band short range digital data applications. It is fairly new and contains a complete modulator and demodulator that supports many modes including GMSK. It is a low power device and its filters are probably not sufficient for use in a real radio system, but it was chosen as a simple way to play with various modulation schemes and bit rates without having to tear apart an existing radio.



FUNCTIONAL BLOCK DIAGRAM

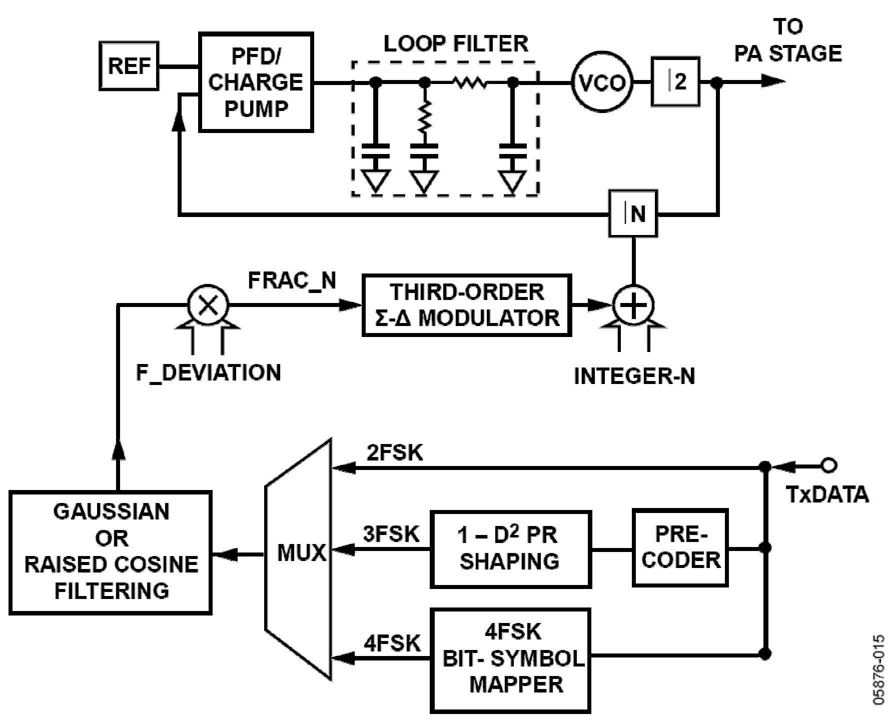


RF Matching Network topology:



ADF7021 with Internal Rx/Tx Switch

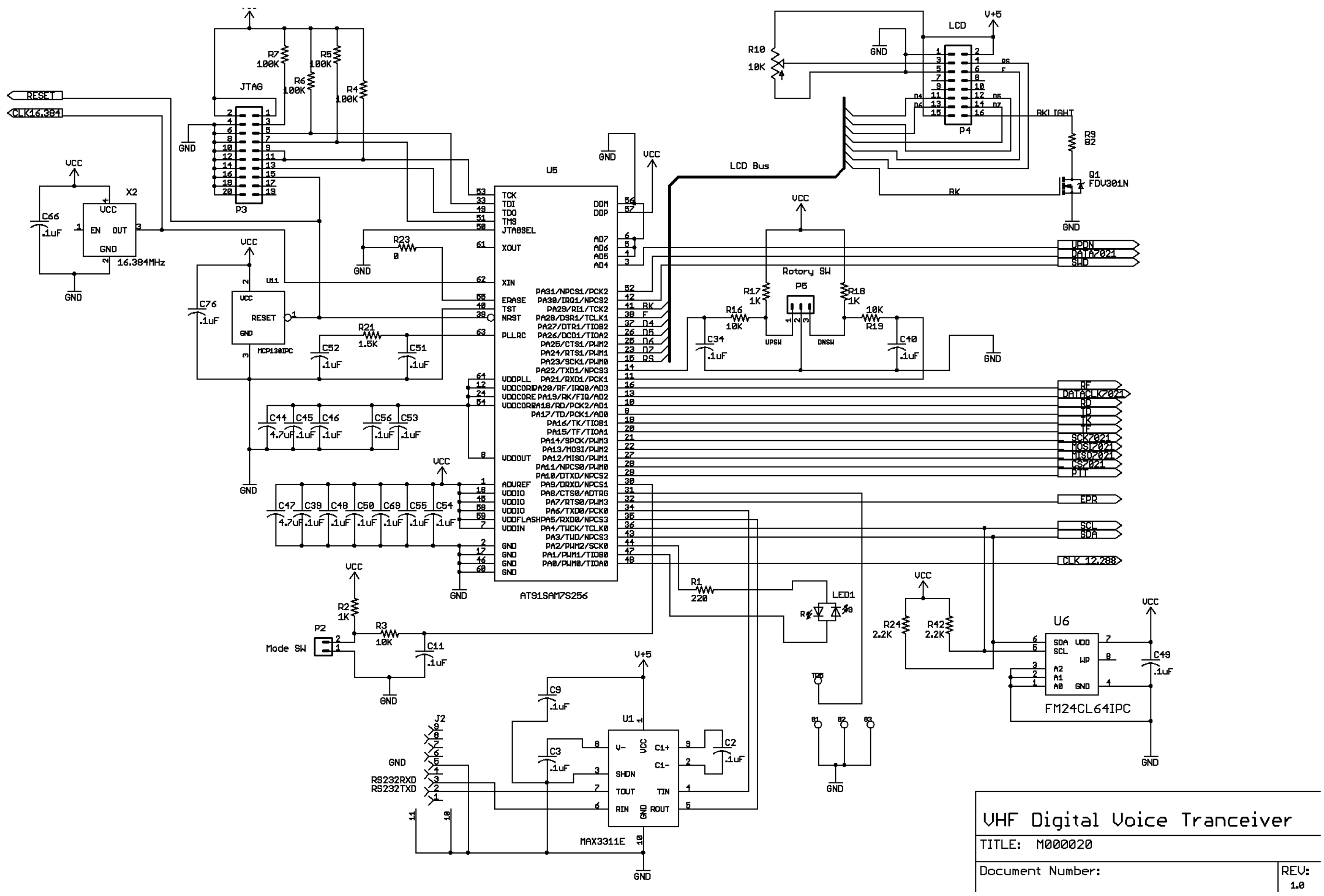
RF Modulator block diagram:



Transmit Modulation Implementation

3.6. Controller

The main controller is an Atmel SAM7S256 ARM7 microcontroller. This single chip solution has plenty of memory and MIPS to allow lots of experimentation with packet formats and various FEC schemes. The software can be written using completely free GNU development tools. All of these tools and a real time debugger and IDE are available using Eclipse.



4. Test Results

The basic DSTAR voice data format was implemented to be able to evaluate the performance of the DVX board. A fixed header was used and the user data was not implemented in the transmit direction.

4.1. Transmit Power

First the Transmit RF signal was measured and analyzed. Power output was about 10dBm. The chip spec is +13dBm so about 3 dB was lost in the matching network.

4.2. Spectral Purity

Spectral purity was analyzed using an AR5000 receiver and SDR-14 spectrum analyzer and compared against a Yaesu FT530 transceiver output.

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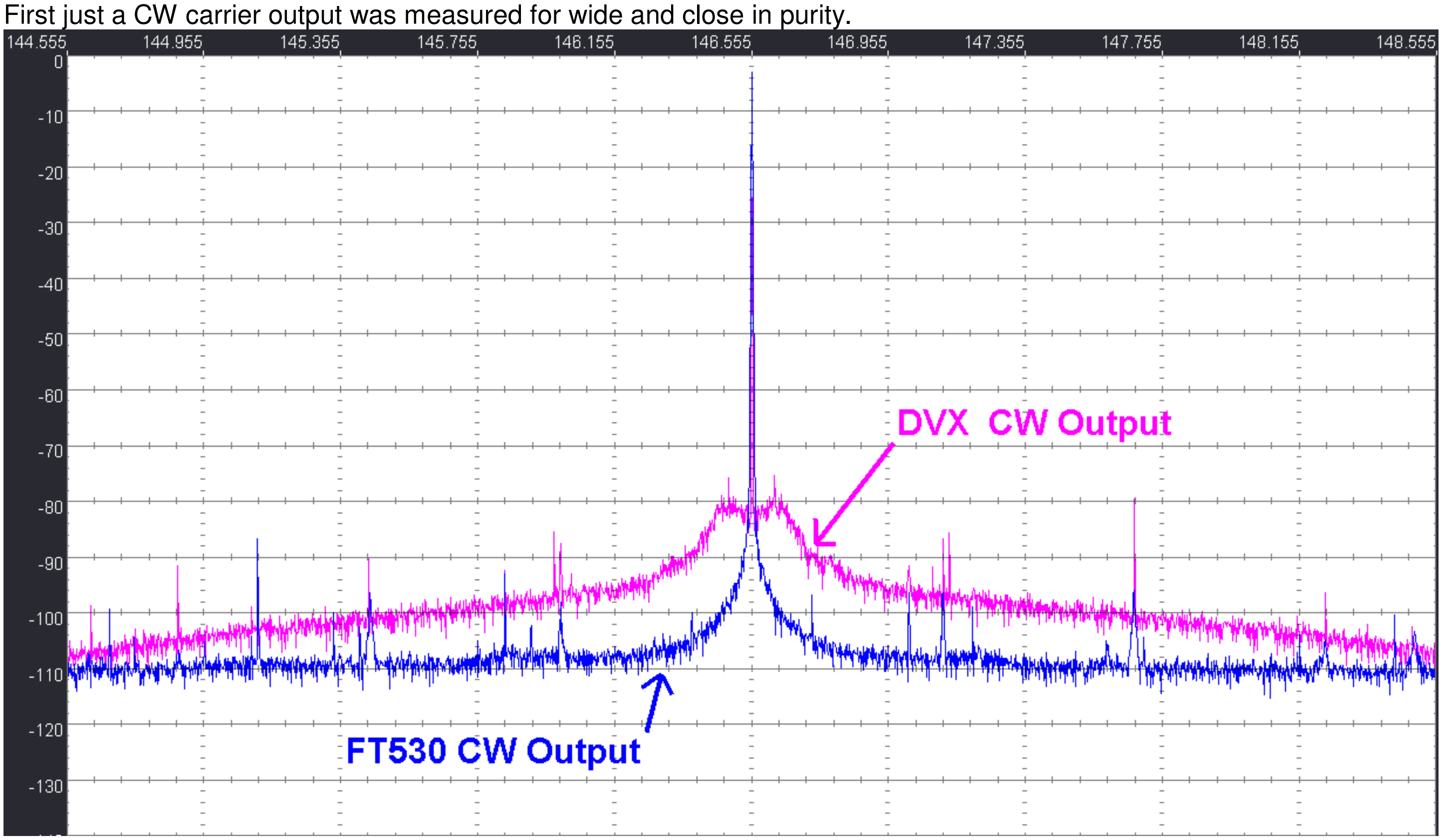
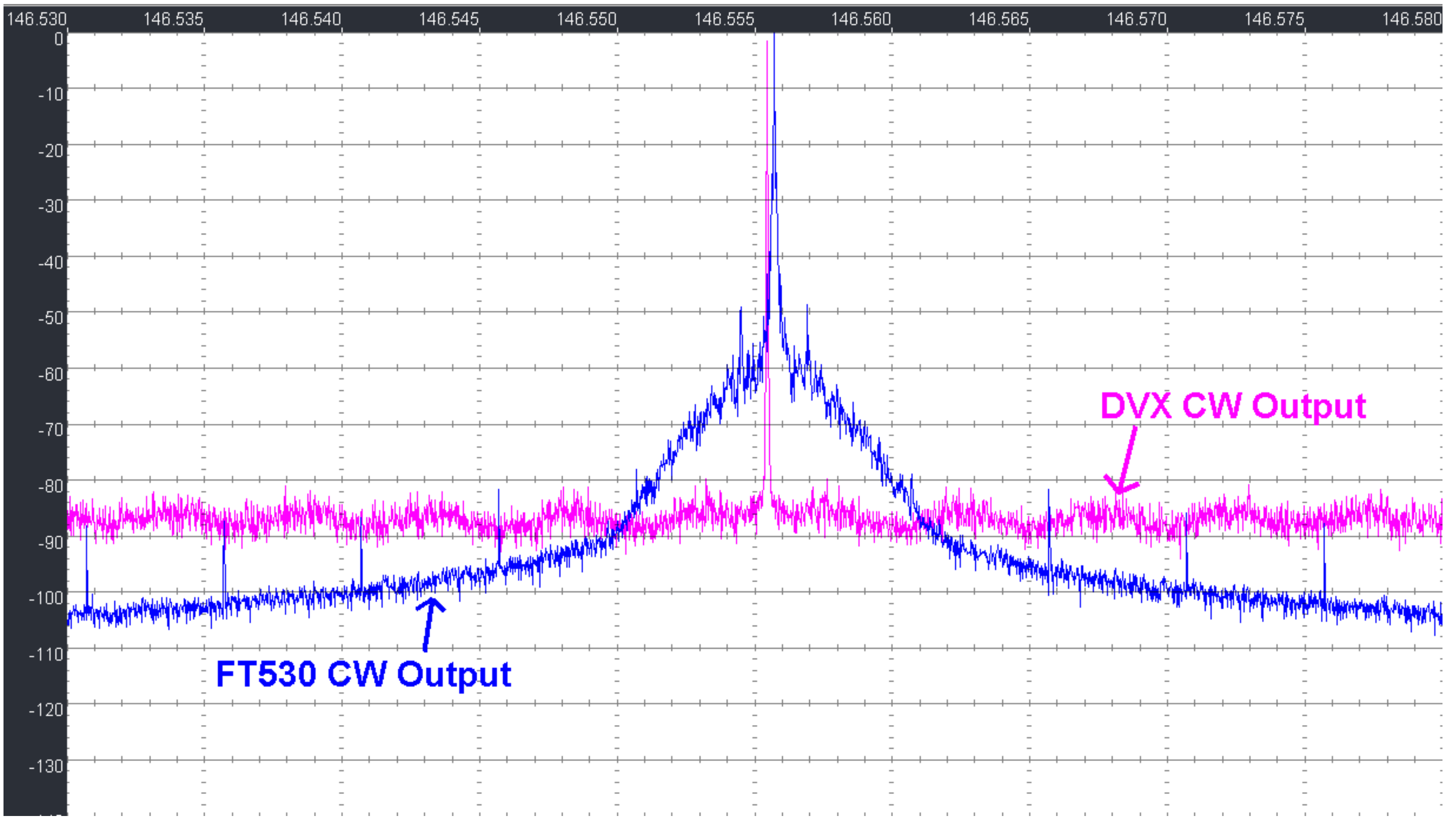
First just a CW carrier output was measured for wide and close in purity.

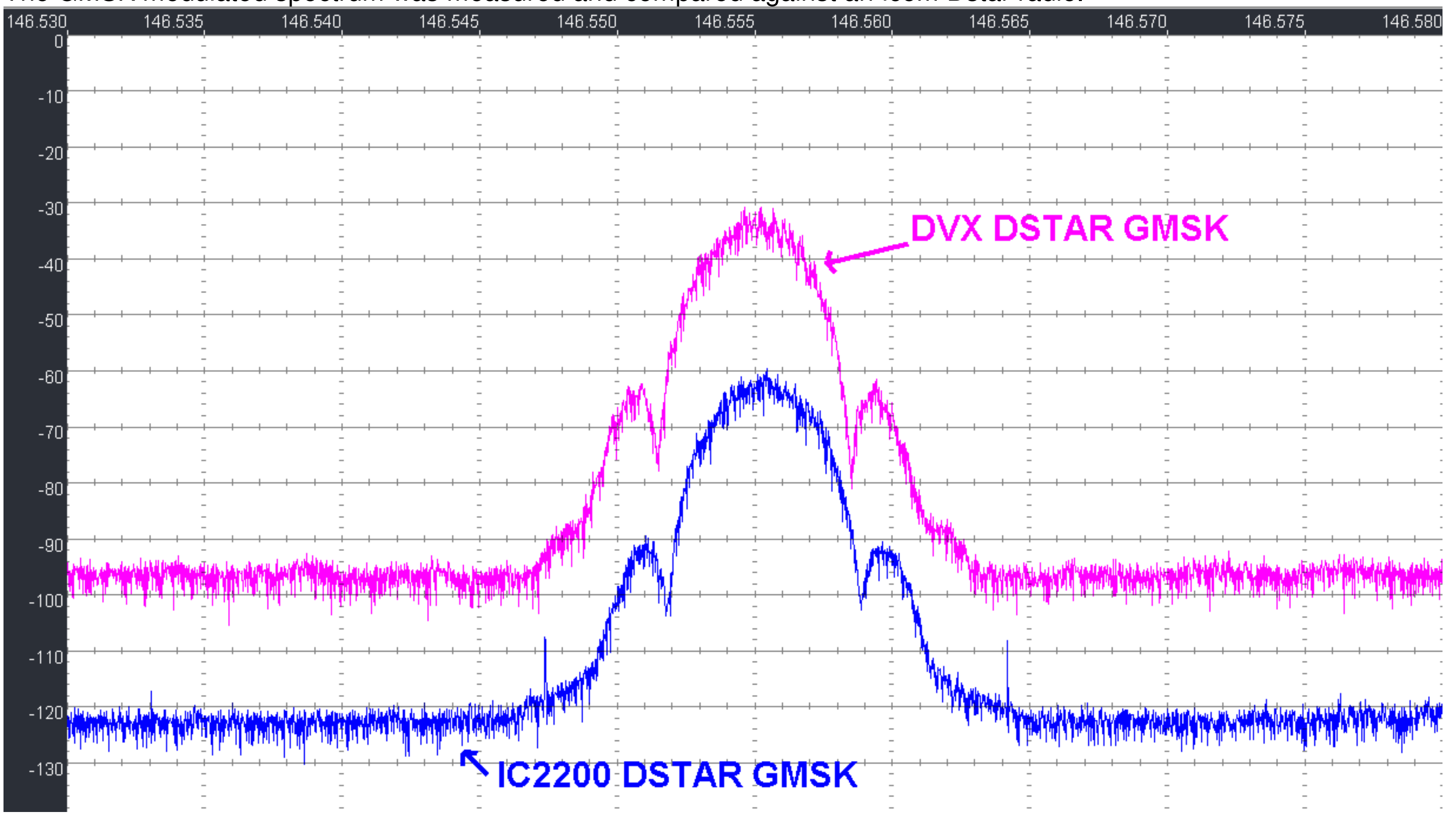




146.530
146.535
146.540
146.545
146.550
146.555
146.560
146.565
146.570
146.575
146.580
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
DVX CW Output
FT530 CW Output

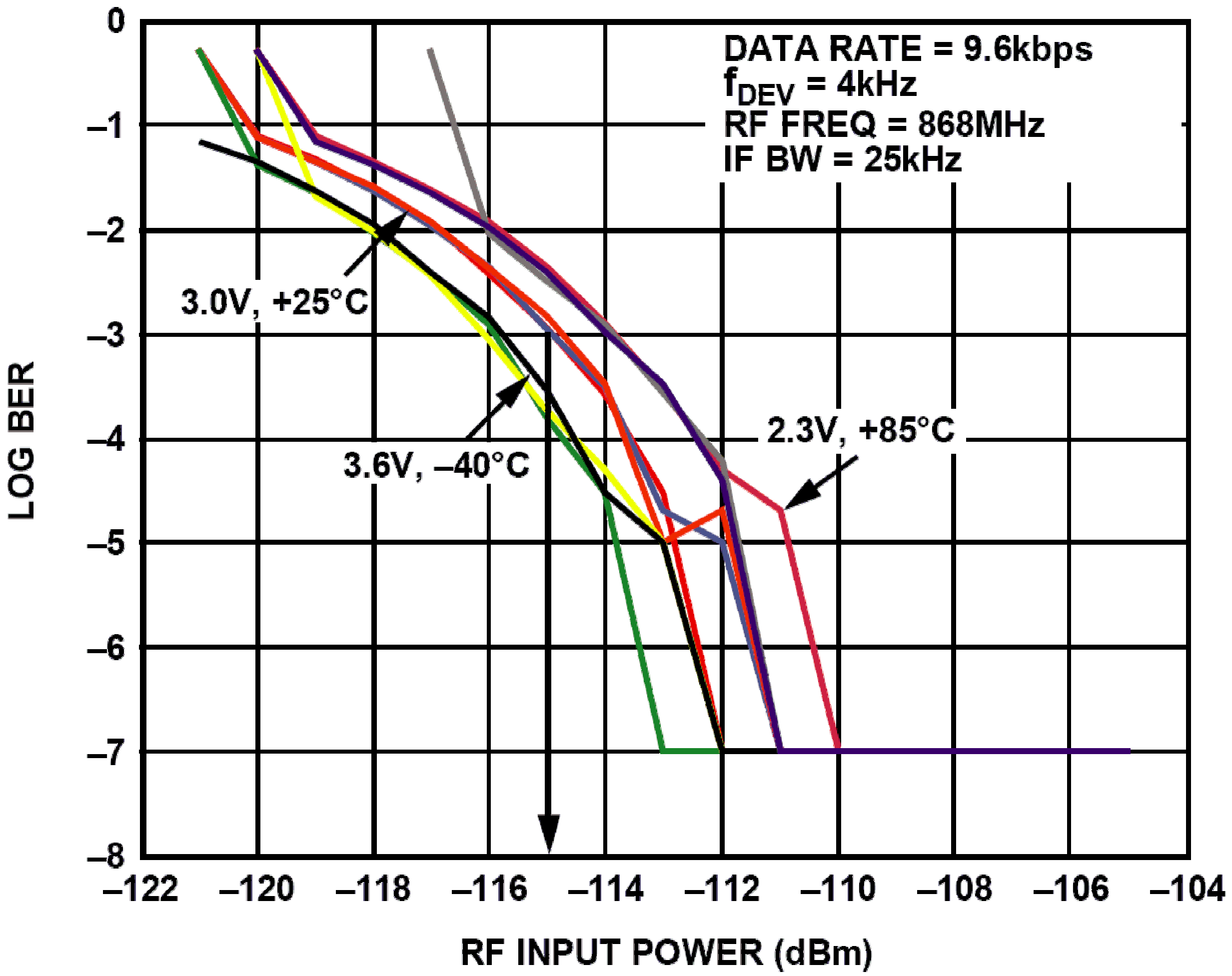
4.3. Modulation Spectrum

The GMSK modulated spectrum was measured and compared against an Icom Dstar radio.



4.4. Receiver Sensitivity

The DVX receiver sensitivity has not yet been measured but a graph from the ADF7021 data sheet is shown. As a point of reference, most of the Icom Dstar radios specify a sensitivity of around –116 dBm for a Log bit error rate of -2.



4.5. On the Air Experience

The first contact between the DVX transceiver and an Icom D-STAR radio was with N4IP on 2007-4-8 spanning a whopping 100 yards or so. A few other contacts were made all within about a ½ mile radius. The DVX is very under powered but proved the possibility of a non-Icom D-STAR radio.

5. Alternative Data Formats

One of the main purposes of this project was to have a means to try various alternative formats to the D-Star standard. There may be some tradeoffs that can be made to allow better speech quality or better weak signal performance with improved FEC. Perhaps a new mode that is voice only or even a wider bandwidth mode for good voice quality could be explored.

Another idea is to double the data rate and bandwidth an implement a full duplex voice radio. No more waiting for the long winded guy to finish, just butt in and tell them to shut up!

6. Future

At the time of this writing, no product plans have been made as this is just an exploratory project to learn about digital voice over RF. If anything useful comes of this, then a real product could possibly be spun off.

Possible Product spinoffs:

1. AMBE 2020 USB Dongle for PC/Soundcard based applications. No radio interface, just the voice compression/decompression
2. D-Star(or custom) Interface to non-Icom, non-DSTAR radio interfaces. Use CMX589 chip.
3. Stand alone Radio for homebrew use. Add power amplifier and maybe a preamp.