AMBE Exposed!

- Bruce Perens K6BP
- bruce@perens.com

Congress Avenue Bridge Bats

- Last night 4 of us went to see the bats emerge from under the Congress Avenue Bridge at sundown, around 8 P.M.
- It appeared there were several Million of them.
- This is the peak season for them, in the Winter they migrate to Mexico.
- It's very much worth seeing if you can get the time.

The Pieces are Coming Together!

- We're getting the pieces together for the future SDR-based, Open Platform, App-using Amateur Radio Transceivers.
- This talk is about including the legacy AMBE-based digital voice systems in future equipment.
- Later today, in my talk about the Algoram Digital Voice Server, I'll talk about the way we will make the “App Store” for digital voice work.

Pieces Coming Together (continued)

- Graham will be speaking tomorrow about how FlexRadio will provide an open platform for codecs and softmodems within their equipment.
- On Sunday, Chris will teach about the rapid gate-array programming environment he's used on *Whitebox,* the radio modem hardware for *HT of the Future.*

Motivation

- Today we have three commercial digital voice systems in Amateur Radio: D-STAR, Yaesu System Fusion, and DMR/MotoTRBO. All use an AMBE or IMBE codec.
- I'm working on the next generation of digital voice for Amateur Radio.
- In that next generation, it would be nice to support legacy systems, and interoperate with them.

Exposing AMBE

- To support legacy systems, we to answer some questions about them:
- Do we have sufficient technical knowledge to make Open Source software for those systems?
- Can we do so without running into legal issues?
- Are we limited to supporting them with proprietary software?
- Are we limited to supporting them with accessory hardware?
- If patents are the problem, when do they expire?

Review

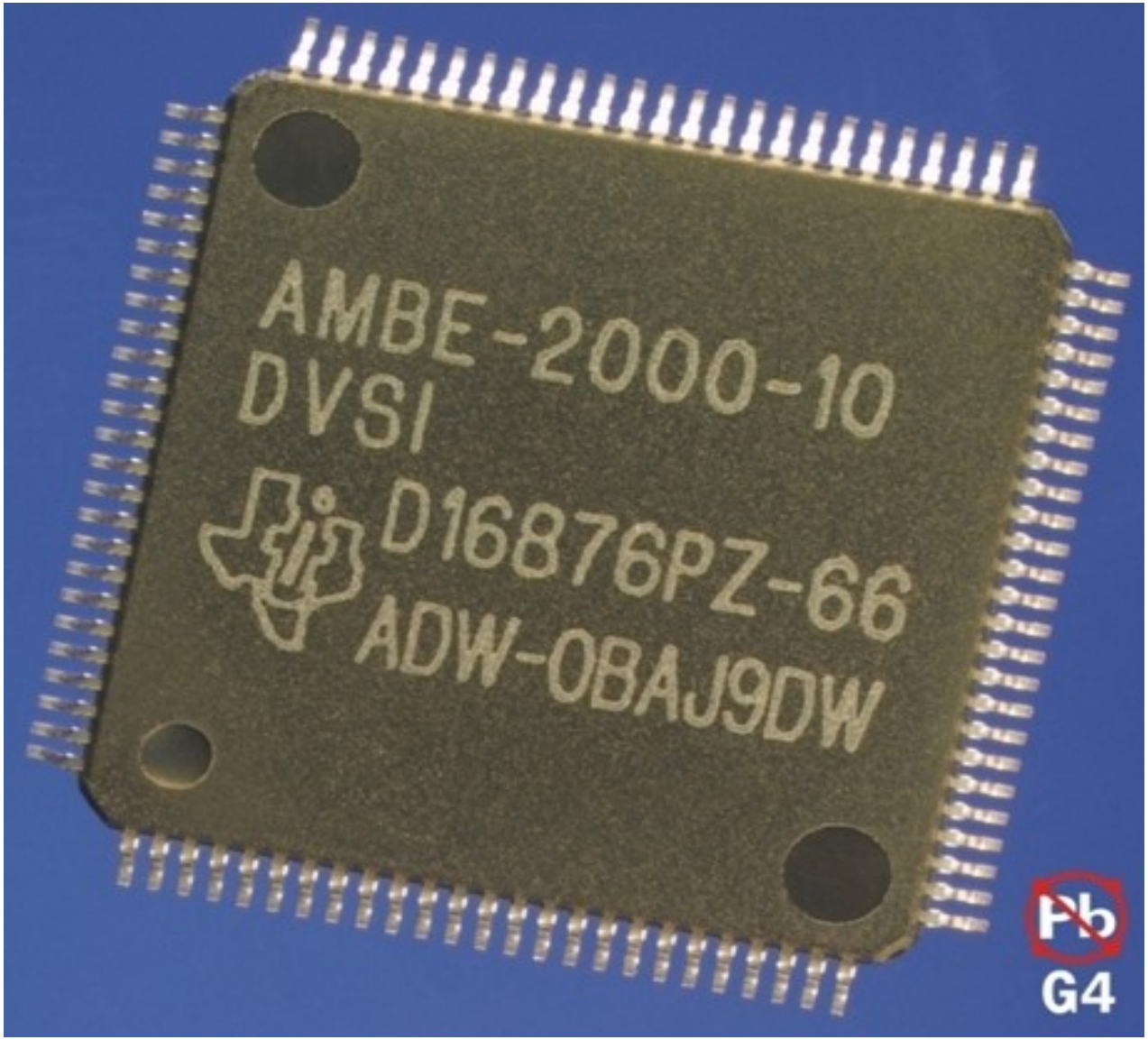
- We'll start with a very fast primer for those new to the issue and our television audience.
- Those of you who have heard it before, please bear with me for a few minutes.

CODECs

- Digital voice over two way radio uses a component called a CODEC, which stands for “COder” / “DECoder”.
- A codec changes a voice signal from analog audio to digital bits, and back.
- Two codecs in use on Amateur Radio are AMBE and Codec2.

AMBE Chip

(photo: DVSI Inc.)



Why a Chip?

- The sole purpose of the chip is to protect the AMBE intellectual property.
- The chip is actually a general-purpose DSP, with the AMBE program loaded and the “read” and “reprogram” fuses blown so that it can't be read or altered.
- The chip does not add speed to the system to which it's attached.

As Software

- Newer ICOM radios are said to incorporate AMBE as licensed software.

Where is AMBE?

- D-STAR and Yaesu System Fusion both use AMBE, manufactured by Digital Voice Systems Inc. (DVSI).
- APCO Project 25 (P25) uses AMBE or IMBE, an older version from DVSI.
- None of these three systems inter-operate with each other, even though they use essentially the same CODEC technology.

Channel Spacing

Mode	Channel Spacing Possible (kHz)	Occupied Bandwidth (kHz)	Effective Occupied Bandwidth	Can use Non-Linear Amplification
FM	20	15	15	Yes
Yaesu System Fusion AMBE (2-slots, not multiplexible).	15	12.5	12.5	Yes
P25 Phase 1 IMBE	15	12.5	12.5	Yes
DMR AMBE (2-slot, multiplexible).	15	12.5	6.25	Yes
P25 Phase 2 AMBE	15	12.5	6.25	
D-STAR AMBE	10	6.5	6.5	Yes
Codec2 + FSK modem (theoretical)	5	3	3	Yes
FreeDV (Codec2 + multi-carrier modem).	2	1.3	1.3	No

Range and Battery, Simplified

- In general, as occupied (not effective) bandwidth decreases, range per Watt increases.
- Battery efficiency increases as effective bandwidth decreases.
- Non-Linear amplification is more battery efficient.
- All of this is simplification of the math.

History

- The Japanese Amateur Radio League (JARL) designed D-STAR, working with ICOM, which created commercial D-STAR products.
- JARL chose AMBE for D-STAR.

The Problem

- AMBE is a closed system. It's patented, copyrighted with all rights reserved, their binary code is protected under trade-secret law, you'll never see the source.
- The whole premise of Amateur Radio is to be an experimental and educational service, where everything can be hands-on, and tweaking and homebrewing are encouraged.
- Closed systems aren't really compatible with that.

First Closed System for Amateur Modulation

- The selection of AMBE for D-STAR was really the first closed technology admitted to Amateur Radio as an essential component for interoperation.

Why Did JARL Choose a Closed System?

- At the time, there was no alternative available to JARL. No CODEC that was good for use with two-way radio at that data rate existed.
- It would have been difficult to convince anyone at the time that an open codec could be created easily.

Why Did APCO Choose IMBE and AMBE?

- APCO Project 25 had a different motivation from Radio Amateurs, but they have their own definition of openness.
- They required publication of the IMBE and AMBE codec algorithms.
- They required that the patents necessary to practice the technology be made available to manufacturers of P25 radios on a “Reasonable and Non-Discriminatory Basis” (RAND).

Reasonable and Non-Discriminatory?

- Standards committees often use the term “Reasonable and Non-Discriminatory” to refer to the cost of licensing patents and the terms that can be allowed in those licenses, but they don't usually define what that means.
- In any case, those terms are only available for the purpose of producing a P25 implementation, not D-STAR, etc.

Open Source AMBE Decoder

- An Open Source decoder for AMBE, called “mbelib”, was developed by an un-named group using information from the APCO 25 specifications and DVSI's patents, and was released under the BSD license.
- Because those folks do not wish to tangle with DVSI and its attorneys, they remain anonymous, and identify themselves using a cryptographic public key.

Codec2

- I have evangelized the fight for open technology in Amateur Radio at these TAPR / ARRL Digital Communications Conferences, and elsewhere, since D-STAR came about.
- David Rowe VK5DGR was convinced to create a new CODEC called Codec2, based on code he wrote for his 1997 Ph.D. thesis and earlier work. Codec2 is an open system without patent or even significant copyright restrictions.

So, Who Would Be Interested in AMBE?

- Codec2 is technically superior. It uses much less bandwidth than AMBE for the same speech quality, allowing your signal to go farther and making it possible to split channels.
- However, we have these three historical systems, P25, D-STAR, and System Fusion, which use AMBE.
- It would be nice to be able to inter-operate with them on future systems. Not essential, but nice.

Where is AMBE Going in the Future?

- To understand what we'll be doing with AMBE, I'll talk about the future of Amateur Radio.

The New Wave in Amateur Manufacturers

- Who is doing the innovative work in Amateur Radio these days?
- Elecraft: K3, KX3
- FlexRadio: SDR transceivers for end-users.
- SteppIR: CrankIR
- Insert your favorite example here.
- It *isn't* ICOM, Yaesu, or Kenwood.

It Happens Every Generation

- When I was a kid, Collins, Drake, and Heathkit were innovative Amateur Radio manufacturers.
- We can not look to the current “Big 3” Amateur Radio manufacturers to lead with innovative products. New companies will establish themselves by doing that.
- No surprise that Yaesu made very conservative decisions in making their digital voice system.

Three Opportunities for The New Wave of Amateur Manufacturers: *1: Software-Defined Radio*

- Radio technology is in transition to software-defined. Software-defined radio has the capability of being changed and improved after it leaves the manufacturer.
- The conservative manufacturers only use this opportunity to distribute updates of their own software.
- The forward-looking ones make open platforms.

2: Apps and Open

- The consumer is used to the app store. They buy an open platform, and then they get the software to run on that platform from third parties.
- Open Source and “Makers” have shown that loosely-organized groups can exceed the capability of companies, and can manufacture real products that would not be profitable for conventional business.

3: The End of Modes

- Amateur Radio is facing the *end of modes.*
- While voice, text, and video were formerly their own modulations, these all become just different kinds of data carried over some form of digital radio.
- What formerly were modes will now just be different bandwidths of digital radio channels. What “mode” those channels carry will change from moment to moment.
- *FreeDV* has shown that we can preserve the “Sport” of Amateur Radio while doing that.

Put Them Together

- The next wave of innovative Amateur transceiver manufacturers will take advantage of:

1)Software-defined radio.

2)Open Platforms.

3)The end of modes.

- Each will bring their own ideas to that mix.

So, Where Does AMBE Fit In This?

- AMBE and the digital voice systems that use it become apps. Indeed, *all* modes become apps.
- We're starting to see this with things like DV-Dongle and AmbeServer DV3000. These are hardware products with AMBE chips in them.
- But they are *only* hardware products due to intellectual property considerations. They don't bring any additional speed to your main CPU.

AMBE Becomes a Competitor

- As an app, AMBE becomes a competitor among multiple codecs on the platform, some of which are zero-cost or technically superior, or both.
- On an open digital voice platform, AMBE is desirable for interoperability, but no longer essential for operation.

Digital Fragmentation

- Digital Fragmentation has already become a problem for Radio Amateurs.
- Each old-line transceiver manufacturer creates its own digital fiefdom, in which only their own products can operate.
- Although they each say they will allow other manufacturers to build systems compatible with theirs, they don't take advantage of that offer themselves. Otherwise, Yaesu would run D-STAR.

Neutralizing Digital Fragmentation

- The only way to deal with this is for the Digital Voice standard to come from the Amateur community.
- By creating a 100% Open Source system, and assuming that users will run it as an app on any platform, we hope to seed that community effort.
- So, can we fit AMBE into this?

Can Hams Use Software AMBE?

- So, we get to a point where it's possible for hams to use *software* AMBE as an app, rather than a hardware AMBE dongle or daughter board, *except* for intellectual property considerations.
- We have a public specification of AMBE and IMBE, perhaps incomplete, but enough for developers to figure out the rest.
- There is now an Open Source AMBE decoder.
- The *only* problem is patents.

Public Specification of IMBE

ANSI/TIA-102.BABA 2003
Approved: December 23, 2003

TIA
STANDARD

Project 25

Vocoder Description

TIA-102.BABA

Part of the IMBE Description

$$\mathcal{E}_w(m,\omega_0) = \begin{cases} \mathcal{F}_0(\omega_0)\mathcal{V}_R(64n) & \text{for } \lceil a_0 \rceil \le m < \lceil o_0 \rceil \\ \mathcal{F}_1(\omega_0)\mathcal{V}_R(\lfloor 64n - \frac{16384}{2\pi}\omega_0 + .5 \rfloor) & \text{for } \lceil a_1 \rceil \le m < \lceil o_1 \rceil \\ \quad . & \\ \quad . & \\ \mathcal{F}_l(\omega_0)\mathcal{V}_R(\lfloor 64n - \frac{16384}{2\pi}l\omega_0 + .5 \rfloor) & \text{for } \lceil a_l \rceil \le m < \lceil o_l \rceil \\ \quad . & \end{cases} \tag{25}$$

where a_l, o_l and $\mathcal{F}_l$ are defined in equations (26) thru (28), respectively. The notation $\lceil x \rceil$ denotes the smallest integer greater than or equal to x.

$$a_l = \frac{256}{2\pi}(l - .5)\omega_0 \tag{26}$$

$$o_l = \frac{256}{2\pi}(l + .5)\omega_0 \tag{27}$$

$$\mathcal{F}_l(\omega_0) = \frac{\sum_{m=\lceil a_l \rceil}^{\lceil b_l \rceil - 1} \mathcal{E}_w(n)\mathcal{V}_R^*(\lfloor 64n - \frac{16384}{2\pi}l\omega_0 + .5 \rfloor)}{\sum_{m=\lceil a_l \rceil}^{\lceil b_l \rceil - 1} |\mathcal{V}_R(\lfloor 64n - \frac{16384}{2\pi}l\omega_0 + .5 \rfloor)|^2} \tag{28}$$

The function $\mathcal{E}_w(n)$ refers to the 256 point Discrete Fourier Transform of $s(n) \cdot u_R(n)$, and $\mathcal{V}_R(n)$ refers to the 16384 point Discrete Fourier Transform of $u_R(n)$. These relationships are expressed below. Reference [11] should be consulted for more information on the DFT.

$$\mathcal{E}_w(n) = \sum_{n=-110}^{110} s(n)u_R(n)e^{-j\frac{2\pi mn}{256}} \qquad \text{for } -127 \le n \le 128 \tag{29}$$

IMBE Description

- The authors of the IMBE description seem to have taken some time to describe it in the most mathematically intractable way possible,
- Implementors are left to figure out how to do it quickly. Fortunately, that knowledge is more in the public domain today due to work on open codecs, DSP, and SDR.
- Nobody would really use a 16K point DFT.

Public Specification of How AMBE Differs from IMBE

PN-3-3633-AD1

APCO Project 25 Half-Rate Vocoder Addendum

APIC Vocoder Task Group

TIA TR-8.4 Vocoder subcommittee

TIA-102.BABA-1

Version 1.0.5

27 April 2009

TELECOMMUNICATIONS INDUSTRY ASSOCIATION

One of Many Pages of AMBE VQ Table

Annex E (Normative) PRBA24 Vector Quantizer Levels

Quantization Vectors for b_3

b_3	G_2	G_3	G_4	b_3	G_2	G_3	G_4
0	0.526055	−0.328567	−0.304727	50	0.286428	−0.210542	−0.029587
1	0.441044	−0.303127	−0.201114	51	0.257656	−0.261837	−0.056566
2	1.030896	−0.324730	−0.397204	52	−0.235852	−0.310760	−0.165147
3	0.839696	−0.351933	−0.224909	53	−0.334949	−0.385870	−0.197362
4	0.272958	−0.176118	−0.098893	54	0.094870	−0.241144	0.059122
5	0.221466	−0.160045	−0.061026	55	0.060177	−0.225884	0.031140
6	0.496555	−0.211499	0.047305	56	−0.301184	−0.306545	−0.446189
7	0.424376	−0.223752	0.069911	57	−0.293528	−0.504146	−0.429844
8	0.264531	−0.353355	−0.330505	58	−0.055084	−0.379015	−0.125887
9	0.273650	−0.253004	−0.250241	59	−0.115434	−0.375008	−0.059939
10	0.484531	−0.297627	−0.071051	60	−0.777425	−0.592163	−0.107585
11	0.410814	−0.224961	−0.084998	61	−0.950500	−0.893847	−0.181762
12	0.039519	−0.252904	−0.115128	62	−0.259402	−0.396726	0.010357
13	0.017423	−0.296519	−0.045921	63	−0.368905	−0.449026	0.038299
14	0.225113	−0.224371	0.037882	64	0.279719	−0.063196	−0.184628
15	0.183424	−0.260492	0.050491	65	0.255265	−0.067248	−0.121124
16	0.308704	−0.073205	−0.405880	66	0.458433	−0.103777	0.010074
17	0.213125	−0.101632	−0.333208	67	0.437231	−0.092496	−0.031028
18	0.617735	−0.137299	−0.213670	68	0.082265	−0.028050	−0.041262
19	0.514382	−0.126485	−0.170204	69	0.045920	−0.051719	−0.030155
20	0.130009	−0.076955	−0.229303	70	0.271149	−0.043613	0.112085
21	0.061740	−0.108259	−0.203887	71	0.246881	−0.065274	0.105436
22	0.244473	−0.110094	−0.051689	72	0.056590	−0.117773	−0.142283
23	0.230452	−0.076147	−0.028190	73	0.058824	−0.104418	−0.099608
24	0.059837	−0.254595	−0.562704	74	0.213781	−0.111974	0.031269
25	0.011630	−0.135223	−0.432791	75	0.187554	−0.070340	0.011834
26	0.207077	−0.152248	−0.148391	76	−0.185701	−0.081106	−0.073803
27	0.158078	−0.128800	−0.122150	77	−0.266112	−0.074133	−0.085370
28	−0.265982	−0.144742	−0.199894	78	−0.029368	−0.046490	0.124679
29	−0.356479	−0.204740	−0.156465	79	−0.017378	−0.102882	0.140482
30	0.000324	−0.139549	−0.066471	80	0.114700	0.092738	−0.244271
31	0.001888	−0.170557	−0.025025	81	0.072922	0.007863	−0.231476
32	0.402913	−0.581478	−0.274626	82	0.270022	0.031819	−0.094208
33	0.191289	−0.540335	−0.193040	83	0.254403	0.024805	−0.050389
34	0.632914	−0.401410	−0.006636	84	−0.182905	0.021629	−0.168481
35	0.471086	−0.463144	0.061489	85	−0.225864	−0.010109	−0.130374
36	0.044829	−0.438487	0.033433	86	0.040089	0.013969	0.016028
37	0.015513	−0.539475	−0.006719	87	0.001442	0.010551	0.032942
38	0.336218	−0.351311	0.214087	88	−0.287472	−0.036130	−0.296798
39	0.239967	−0.380836	0.157681	89	−0.332344	−0.108862	−0.342196
40	0.347609	−0.901619	−0.688432	90	0.012700	0.022917	−0.052501
41	0.064067	−0.826753	−0.492089	91	−0.040681	−0.001805	−0.050548
42	0.303089	−0.396757	−0.108446	92	−0.718522	−0.061234	−0.278820
43	0.235590	−0.446122	0.006437	93	−0.879205	−0.213588	−0.303508
44	−0.236964	−0.652532	−0.135520	94	−0.234102	−0.065407	0.013686
45	−0.418285	−0.793014	−0.034730	95	−0.281223	−0.076139	0.046830
46	−0.038262	−0.516984	0.273681	96	0.141967	−0.193679	−0.055697
47	−0.037419	−0.958198	0.214749	97	0.100318	−0.161222	−0.063062
48	0.061624	−0.238233	−0.237184	98	0.265859	−0.132747	0.078209
49	−0.013944	−0.235704	−0.204811	99	0.244805	−0.139776	0.122123

Public IMBE Specification

- As part of specifying P25, APCO required documentation of the IMBE codec, and required the availability of paid licensing of the necessary patents to companies manufacturing P25 systems on a “Reasonable and Non-Discriminatory Basis”.
- It seems that most manufacturers get their technology from DVSI as hardware or under license, rather than license the patents and produce their own version.

Public AMBE Specification

- When AMBE was included in P25 phase 2, it was also specified publicly.
- These public specifications are still copyrighted and patents cover the technology.
- The standard document is copyrighted with all rights reserved and you have to pay for each copy, not like modern open standards.
- But you can get a copy and use the information to implement AMBE, except for the patent problem.

You've Already Paid Once...

- The AMBE technology was developed under a United States Government grant through the Rome Air Development Center at Griffiths Air Force Base of the United States Air Force.
- *You paid for this technology with your taxes.* Now, you have to pay for it a second time if you would actually like to use it *or anything close enough to be covered by the patents*. Or be sued, or go to jail.
- Publicly-funded research should be open!

The Patent Situation

- DVSI has lots and lots of patents, and is busily making more.
- They file *continuation applications,* to encumber existing technology which was created before the date of the new application. The date of the patent that is being continued applies.
- This can potentially be used against some of Rowe's more recent work in Codec2. His thesis work is safe.

Key Patent on AMBE

- Patent 8,359,197B2 was filed on April 1, 2003.
- USPTO tardily granted it on January 22, 2013.
- In compliance with legal guarantees, USPTO granted the patent a 5-year and 51-day extension.
- This patent would expire on May 22, 2028, as far as I can tell.
- Can we invalidate it?

Prior Art

- One of the ways to defeat patents is with prior art. If you can prove a particular claim within a patent was *not* an invention, you can defeat that claim.
- David Rowe's thesis, which provides the original code for Codec2, was published in 1997. He has prior publications going back to at least 1992.

Prior Art

- Of course, Rowe's is not the first work on speech coding, and there is a large body of prior art which we can draw upon.
- However, un-encumbering AMBE would be a rather *large* legal project, and it is probably better for us to concentrate on protecting Codec2 and other new work instead.

Doctrine of Laches

- If you have a patent, and you know of an infringement but you *wait for the market to get larger* before you bring suit, that is reason for your lawsuit to be denied.
- This is called the *Doctrine of Laches.*
- The usual duration for a Laches case is 5 years, although Laches cases have been won with as little as a 1-year delay.
- Codec2 “new” work is already several years old. “Open Source AMBE” is already a year old.

No More Releases

- The “mbelib” developers created a D-STAR decoder called “DSD” and published it, with “mbelib”, under the BSD license.
- Another anonymous developer created a proprietary fork called “DSD+” and declined to share his source code with the original developers.
- The original developers know better now, and will put their future work under GPL instead of BSD, but they probably aren't going to do more work that helps DSD+.
- Mbelib has remained at release 1.0 for more than a year.

From One of the Developers

- *Recently, another closed-source DSD fork has appeared called DSD Plus. […] It greatly annoys me that these improvements are locked out and unavailable to people who want to make further improvements. It annoys me even more that people on the forums keep defending the choice of the DSDPlus author to keep the software closed.*
- I think the real pain for this developer of “mbelib” was when he got a public “screw you” from what was really *his* user community.

Still

- The public AMBE specification and the working, although imperfect, Open Source decoder demonstrate that we could provide software AMBE were it not for the patent situation.

So

- IMBE patents are older and there may be hope for P25 users to have an uncontended open IMBE in a reasonable time.
- If we want AMBE to be open, we need to mount a significant legal project.
- Otherwise, we can expect that any compatibility with D-STAR and Yaesu System Fusion will be based on a dongle or licensed code.

Amateur AMBE User Statistics

- 33K D-STAR users have registered with an iGate. Of those, 3K are active in any one month (D-STARUsers.org).
- There could be active users not in reach of an iGate.
- Many more hams have D-STAR *capability* and do not use it.
- P25 and Yaesu System Fusion figures are too small to matter, so far.

Economics

- 33,000 total users, of which 3,000 are active in a month, do not constitute an economically desirable legacy user community for a business.
- Future systems where Codec2 is available and AMBE is potentially an extra-cost option, will have more desirable features (such as running installable apps and having a sophisticated GUI), and can generate a larger sales base than that which exists for AMBE in Amateur Radio today.

Supporting AMBE

- Short runs of AMBE hardware daughter boards, such as the AMBEServer DV3000 card at about $100 per unit, can support the legacy user market without significant investment behind them.
- Conceivably, there could be a community project to invalidate a sufficient number of DVSI's patent claims. But I think I personally will put my energy elsewhere.

Summary

- We always knew that intellectual property was the problem.
- I thought, when I started my research, that it might stop being a problem while AMBE was still useful and that interoperability would be cheap and simple. Given a date in 2028, this does not seem to be the case. It *is* probably the case regarding IMBE and APCO P25 Phase 1.
- I don't think anyone with any sense will include encumbered technology in ham equipment where it is necessary for interoperability again. But then, I thought this before Yaesu did it.

Contact The Speaker

- Bruce Perens K6BP
- bruce@perens.com