Will DAB finally TAKE OFF?

A DECADE IN DESIGN, DIGITAL AUDIO BROADCASTING IS READYING TO TAKE TO THE AIRWAVES. AS A RESULT, BROADCASTERS, EQUIPMENT MAKERS, AND IC VENDORS ARE ANXIOUSLY EVALUATING REAL-WORLD CONSUMER ACCEPTANCE.

DAVID MARSH, CONTRIBUTING TECHNICAL EDITOR

As the United States struggles to develop its own digital-audio-broadcast (DAB) technology, Europe and the rest of the world are forging ahead with proven satellite and terrestrial delivery systems. Ironically, perhaps, the satellite system that soon will bring content-rich mixed audio and data services to the Third World comes courtesy of US-based WorldSpace Corp. Meanwhile, affluent European countries, together with countries as diverse as Canada and China, have selected Eureka-147 technology DAB services for satellite and terrestrial delivery.

The philosophies motivating the Eureka-147 and WorldSpace enterprises remain—in more than one sense—worlds apart. Eureka-147, a consortium mostly comprising European semiconductor makers, technical specialists, and broadcasters, seeks to serve new markets, such as providing information to car drivers on the move. Such applications combine traditional entertainment with real-time data delivery, a mix that might help you avoid the next motorway snarl-up. In stark contrast, WorldSpace's remit is to provide up-to-date information, entertainment, and data-delivery services directly to customers residing in the world's poorer regions.

Although Eureka-147 and WorldSpace DAB services are physically incompatible, they share considerable common technical ground, arguably because the delivery systems originate in European think tanks. Despite successful Eureka-147 trials, the United States has rejected the system and currently has two DAB systems in development: a satellite system in the 2.3-GHz S-band and a terrestrial service called IBOC (in-band, on-channel), which is effectively an extension of conventional AM/FM radio.

The United States is some time away from a viable service implementation, but elsewhere what's holding things up is uncertainty surrounding consumer acceptance. However, this year has seen a host of product launches as well as strong promotion from broadcasters such as the BBC in the United King-

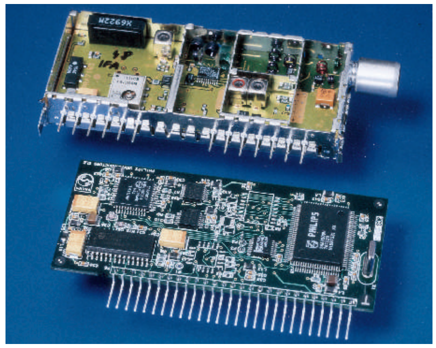
Photo courtesy Philips

dom. Ever-cautious silicon vendors are slowly taking up the challenge. But you can now specify sufficient building blocks to implement commercially viable DAB multimedia receivers, and many more highly integrated solutions are already in the pipeline.

DAB introduces new techniques

To understand what's involved in a practical DAB-receiver design, consider the system's objectives. It is basically a wireless data pipe that can provide high-quality audio and data to mobile, portable, and fixed receivers using a simple, nondirectional antenna. The key to flexible audio and data delivery lies with digital-compression and coding techniques, together with variable coding rates and multiple data-protection levels. The Eureka-147 transmission signal is designed for reliable mobile reception because it is highly resistant to fade and multipath propagation effects.

DAB uses multiple techniques to conserve RF spectrum, maximise transmitter efficiency, and guarantee reception clarity. One unusual concept is the single-frequency network (SFN), in which all transmitters operate on the same frequency, carrying programme services in a multiplex of approximately 3-Mbps capacity. A single broadcast frequency can deliver at least seven programme services, depending on how the broadcaster balances system resources. The transmission signal comprises programme and data services that are randomised for equal energy spread, encoded for ruggedness, and multiplexed into an "ensemble" (see **sidebar** "Building the Eureka-147 DAB signal"). Approved European transmission frequencies lie within VHF Band 3 (174 to 240 MHz) or the satellite L-band (1452 to 1492 MHz) that WorldSpace also adopts.



You can take a black-box approach to DAB receiver design with ready-made tuner and decoder modules from Philips.

A conceptual receiver's signal path comprises an analogue front-end tuner, A/D converter, and symbol demodulator, followed by a channel selector that feeds data to audio or data decoder functions (**Figure 1**). The tuner receives and amplifies the incoming analogue signal before passing it to the ADC. The symbol demodulator transforms the signal back into its individual components for the channel decoder to select—in response to the user's programme choice. Audio samples and data packets pass to output stages to emerge as sound or display information or to interface with other devices, such as a PC, fax machine, or global-positioning-system receiver.

EuroDAB silicon remains sparse

The original Eureka-147 system semiconductor-vendor partners include Philips (the main contractor in the European Union-sponsored programme), STMicroelectronics, and Temic. Other semiconductor makers such as Oki Semiconductor (www.okisemi.com) and Texas Instruments (www.ti.com) have since joined, but they seem set to hold a watching brief until DAB gains consumer acceptance. Meanwhile, DAB-specific silicon remains sparse (**Table 1**). But you should expect the situation to change; for example, STMicroelectronics is developing a five-chip set that's scheduled to arrive as a three-chip production derivative by mid-1999.

Front-end silicon is your most limited choice. To serve emerging terrestrial

(continued on pg 48)

WORLDSPACE GETS READY FOR LIFTOFF

By the end of 1999, WorldSpace expects to have three geostationary satellites in orbit, all launched by Ariane-4 boosters. The satellites will irradiate Africa, Asia, the Caribbean, Latin America, the Mediterranean Basin, and the Middle East—potentially reaching almost 4.6 billion people. The satellites will combine uplink data from broadcasters in the 7.025- to 7.075-GHz range before returning services to earth at 1452- to 1492-MHz L-band frequencies. The uplink frequency lets broadcasters use very-small-aperture terminals (VSATs) having antenna diameters ranging from 2 to 3m.

Each satellite transmits three downlink beams—covering distinct "footprints"—providing two primary-rate channels (PRCs) of approximately 3.6-Mbps capacity each. The satellite simultaneously transmits the six time-division-multiplexed carriers. Carrier-channel separation is 3.22 MHz, with adjacent channels having orthogonal polarisation to avoid interchannel interference. A primary-rate channel accommodates 96 16-kbps channels that combine to deliver up to 128 kbps. The key DAB design work, including the core MPEG-2 Layer 3 audio coding, comes from applied research agency Fraunhofer Gesellschaft, which also developed the prototype WorldSpace receiver.

The heart of a WorldSpace receiver is the "Starman" chip set from Micronas Intermetall and SGS-Thomson. Potential WorldSpace receiver makers need a WorldSpace licence before purchasing either chip set; in addition, companies need to buy for production in quantities of 1 million. Manufacturers such as Hitachi, JVC, Matsushita, and Sanyo plan to build WorldSpace receivers that will also tune into AM and FM broadcasts using conventional radio technology.

Earlier this year WorldSpace acquired a 10% stake in BayGen Power, the company that builds the "Freeplay" clockwork wind-up receiver. Expect to see a practical wind-up WorldSpace receiver within the next two years, initially priced at approximately $200—with a $50 price target as production matures.

BUILDING THE EUREKA-147 DAB SIGNAL

Eureka-147 digital-audio-broadcast's (DAB's) signal-generation path comprises multiple signal-processing blocks that tackle audio/data coding, transmission coding and multiplexing, frequency interleaving, and modulation (Figure A). The system achieves formal standards-body recognition in ETS 300 401.

The audio-compression system uses MPEG-1/2 Layer II psycho-acoustical coding, also known as MUSICAM (Reference A). The technique removes redundant information from the audio signal without perceptibly reducing audio quality. Relying on the human ear's masking characteristics, the system reduces a 16-bit, 48-kHz sampled audio stream of approximately 1.5 Mbps to bit rates of 64 to 384 kbps. The system also allows the 24-kHz "half-sampling" frequency, so a mono channel's bit rates may range from 32 to 192 kbps.

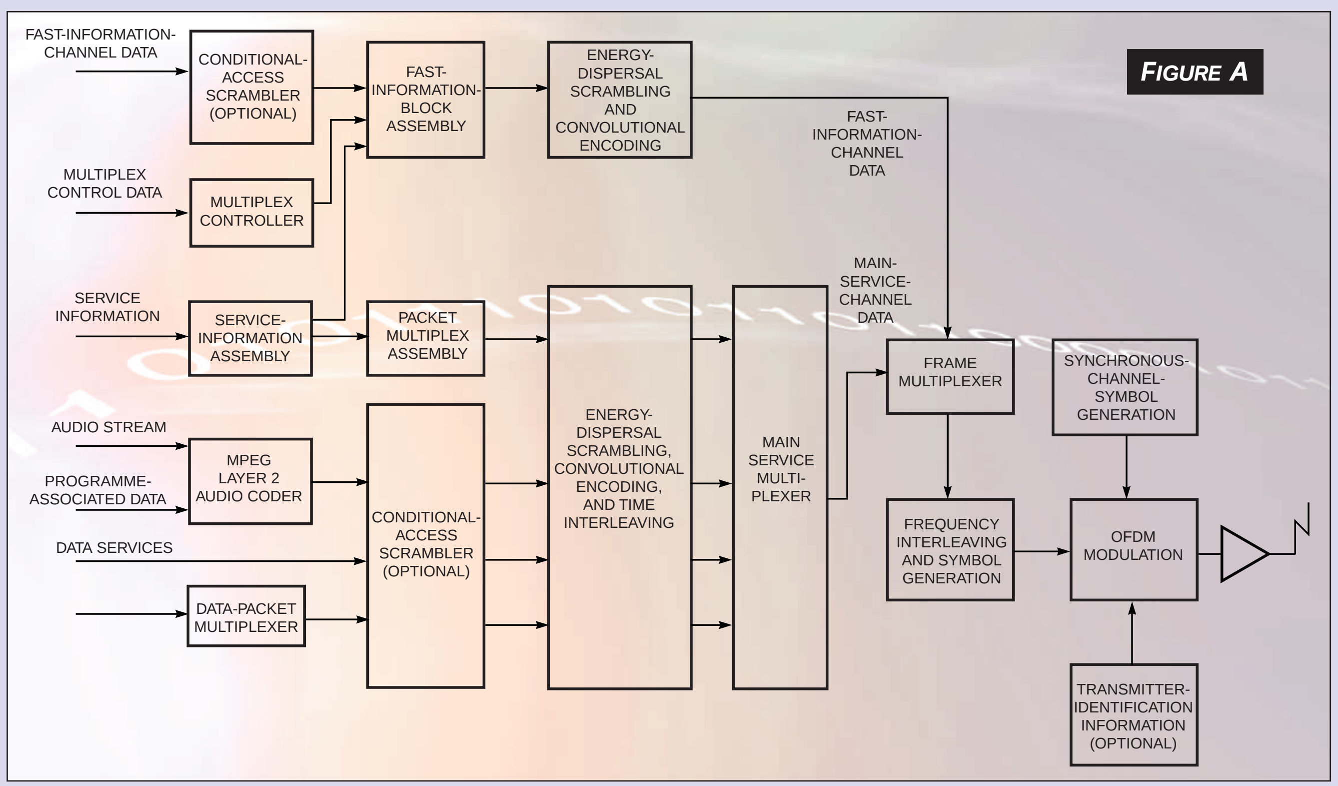
The audio programme includes a programme-associated-data (PAD) block at the end of the frame. PAD capacity varies from 667 bps to 65 kbps and contains audio-programme-specific data, such as dynamic range-control information or programme titles. The DAB system can also carry separate data services in a continuous stream or as data packets in a packet submultiplex. Optional conditional-access (CA) mechanisms can protect services with scrambling/descrambling as well as entitlement checking and management functions.

TABLE A—DAB'S CAPACITY VARIES WITH DATA REDUNDANCY

	Protection level				
	5 (minimum)	4	3	2	1 (maximum)
Audio bit rate (kbps)	Maximum no. of audio channels				
32	54	41	36	29	24
64	27	20	18	14	12
128	13	10	9	7	6
192	9	7	6	5	4
224	7	6	5	4	3
256	6	5	4	3	3

Each data stream passes through a randomiser that disperses data energy and increases transmission efficiency. The data is forward-error-protected with convolutional coding. To guarantee robust reception, the system adds more redundancy to critical data, such as headers, than it does to less important data, such as audio subsamples (called "unequal error protection," or UEP). A recent specification revision adds equal error protection (EEP) as an alternative. The overall coding rate is variable to allow trade-offs between data capacity and reliability (Table A).

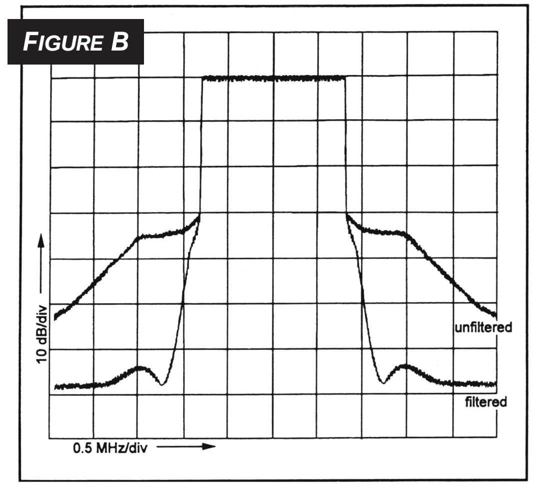
FIGURE A



The Eureka-147 DAB signal-generation process requires multiple signal-processing stages.

Individual data streams are time-interleaved before being combined in the main service multiplexer. This process assembles component data into the main-service-channel (MSC) frame. The MSC carries useful audio or data content that makes up the services within the multiplex; it has 2.3-Mbps gross capacity. Depending on how much redundancy the signal carries, useful bit rates vary from approximately 0.6 to 1.7 Mbps. Further multiplexing adds synchronisation-channel (SC) and fast-information-channel (FIC) data. The SC carries reference frequency and timing signals that synchronise the receiver. The FIC carries multiplex configuration information (MCI) and service information (SI), telling a receiver how to extract the service that the listener selects. Total gross output stream capacity is approximately 3 Mbps.

FIGURE B



The VHF Band III DAB transmission spectrum shows signal purity within its 1.536-MHz bandwidth.

The transmission frame follows a fixed format that allows receivers to synchronise and extract data. The frame starts with SC data—a null followed by a phase reference symbol that provides receiver lock. Transmitter-identification-information (TII) data may be added at this stage. The FIC data follows—with the rest of the frame carrying MSC data. Guardbands separate individual services in the MSC payload, and each service has its own fixed time slot. The total frame duration depends on the transmission mode and is an integer multiple of 24 msec (Table B). Before transmission, the frame is frequency-interleaved, that is, broken down into numerous lower rate bit streams. The coding scheme is coded-orthogonal frequency-division-multiplexing (COFDM); this feature suits DAB for multipath, single-frequency network environments.

Each lower rate bit stream modulates individual orthogonal carriers using differential quadrature-phase-shift keying (DQPSK), so that symbol duration is longer than the transmission channels' delay spread. Each symbol comprises 2 bits. A guard interval between successive symbols avoids inter-symbol interference due to multipath propagation and channel-selectivity effects.

Transmissions in the United Kingdom use operational Mode 1 in the 217.5- to 230-MHz frequency band. That 12.5-MHz bandwidth accommodates seven DAB multiplexes, or "ensembles," that broadcast companies can licence for their own use. The BBC has one frequency assignment, known as channel 12B. In Mode 1 operation, each DAB ensemble is 1.536 MHz wide and comprises 1536 carriers at 1-kHz intervals—sufficient to carry at least seven high-quality audio programmes. The transmission signal is spectrally pure (Figure B). DAB can accommodate frequency usage from approximately 30 MHz to 3 GHz (or higher for fixed reception) and suits terrestrial, satellite, cable, and hybrid delivery systems. So far, all European transmission proposals span 174 to 240 MHz (VHF Band 3) and 1452 to 1492 MHz (L-band).

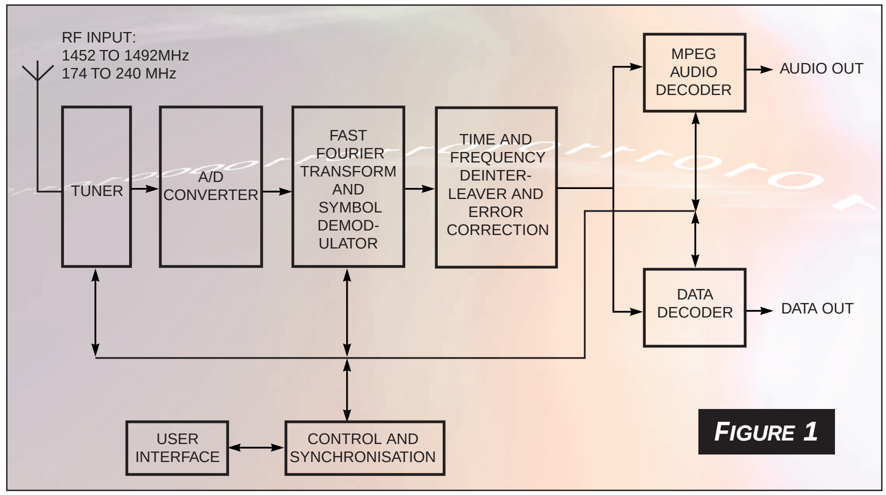
DAB's operational modes target specific applications with various carrier spacings and other parameter tweaks. For example, Mode 3 is intended principally for satellite use. But experience shows that the new Mode 4 can provide a more economical alternative for hybrid delivery systems in sparsely populated areas such as Australia, reducing the number of "filler" transmitters needed to support a single frequency network. Because these are still the early days for real-world DAB, you can expect further refinements as the technology matures.

Reference

A. MPEG-1 Audio Layer II specification, ISO/IEC 11172-3. See also MPEG-2 Audio Layer II, ISO/IEC 13818-3.

TABLE B—FOUR OPERATIONAL MODES FOR SATELLITE AND TERRESTRIAL TRANSMISSION

DAB operational modes	Mode 1	Mode 2	Mode 3	Mode 4
Typical application	Terrestrial	Terrestrial	Satellite	Terrestrial
Frame duration (msec)	96	24	24	48
Symbol duration	1 msec	250 msec	125 msec	500 msec
Guard interval (msec)	246	62	31	123
Number of symbols/frame	76	76	153	76
Number of radiated carriers	1536	384	192	768
Carrier spacing (kHz)	1	4	8	2
Carrier bandwidth (MHz)	1.536	1.536	1.536	1.536
Maximum transmission frequency	500 MHz	2 GHz	4 GHz	1.5 GHz
Maximum single-frequency network-transmitter spacing (km)	96	24	12	40



A DAB receiver's major system blocks rely heavily on DSP techniques.

and satellite services, you'll want a dual-band receiver. The basic technique is to downconvert incoming RF by successively mixing the signal with lower frequency local oscillators and filtering out the result, as in the classic superheterodyne radio-signal path. DSP then recovers the useful information from the complex signal before delivering it for audio or data output (**Figure 2**).

DAB has some characteristic challenges, such as those resulting from close carrier-signal spacing. Because Eureka-147 transmission Mode 1 carriers are spaced 1 kHz apart, the first local oscillator must be spectrally pure and virtually noise-free. Other problems include typical mixed-signal concerns. Locating high-speed digital circuitry close to sensitive RF stages demands careful pc-board layout, screening, and decoupling. Most digital-control signals use the two-wire I^2C serial interface, avoiding wide parallel data buses that radiate proportionally more noise.

Downconvert incoming RF

Philips' front-end ICs accommodate dual-band operation and follow discrete-component antenna amplifier stages. The TEA3570 IC is an L-band low-noise amplifier (LNA) and downconverter that features a double-balanced mixer architecture providing at least 20-dB image rejection. The design requires an external local oscillator that can run at 1557 to 1612 MHz as well as bandpass filters for RF input, local-oscillator input, and output signals. The output signal is differential and downconverted to the first IF at 112.6 MHz. The TEA3571 mixer-oscillator IC further downconverts to a second IF at 38.9 MHz. TEA3571 also provides the VHF input downconversion stage. A complementary IC, the UMA1022, provides the system PLL function with dual-band frequency-synthesis capability.

FOR MORE INFORMATION...

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USEFUL DAB CONTACTS:

BBC Digital Radio
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+44 171 765 4457
www.bbc.co.uk/dab

Eureka-147 Project Information
www.kp.dlr.de

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Sophia Antipolis, France
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www.etsi.fr

Fraunhofer Gesellschaft
Erlangen, Germany
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www.iis.fhg.de

International Telecommunication Union (ITU)
Geneva, Switzerland
www.itu.ch

JESSI Project Information
muresh.et.tudelft.nl

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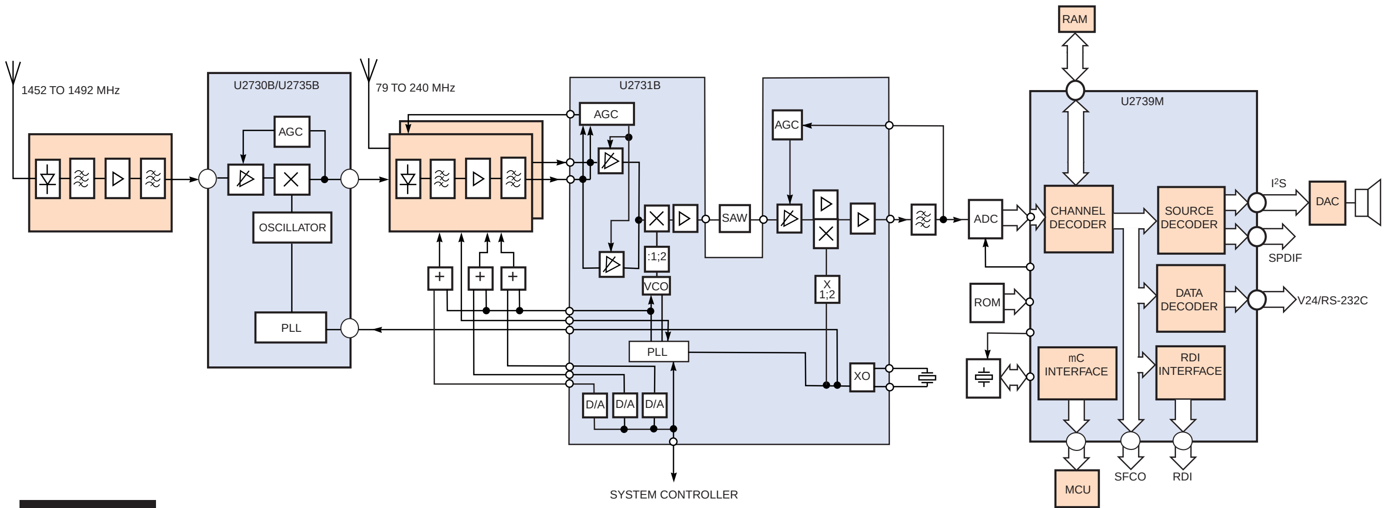


FIGURE 2

Temic's Eureka-147 DAB chip set demonstrates today's integration level for a practical dual-band receiver.

Temic similarly tackles the front-end design with a two-chip set that splits L-band and VHF receiver functions. The U2730B-B IC comprises an LNA, a mixer, a VCO, and a PLL, which perform the L-band-to-first-IF downconversion. The companion U2731B-A tackles VHF-band downconversion to IFs up to 45 MHz, as well as providing the second downconversion stage for L-band signals. Each chip replaces as many as three ICs in Temic's previous product generation, showing how far the technology has advanced in a few years. But you still need an array of discrete components for the antenna amplifier, bandpass filters, and other support circuitry. System integrators can get a head start with packaged DAB modules from Bosch, Philips, and Roke Manor Research.

In a WorldSpace receiver, a discrete-component amplifier/filter stage bandlimits the incoming L-band signal for image rejection. STMicroelectronics' STA001 RF front-end IC then provides approximately 20-dB gain in its LNA before downconverting the incoming RF in two stages, again using a superheterodyne architecture. The first-stage VCO operates at approximately 2.7 GHz, tuned by the host processor to lock in over L-band's frequency range in 460-kHz steps. A flag signals PLL lock, and the 115.244-MHz first IF signal passes through an external SAW-shaping filter to the second-stage VCO. This second stage converts the second IF to a 1.84-MHz baseband output signal ready

DIGITAL-AUDIO-BROADCAST ACRONYM BUSTER

ADC—analogue-to-digital converter
AFC—automatic frequency control
AGC—automatic gain control
BC—broadcast channel
CIP—controller-interface protocol
COFDM—coded orthogonal frequency-division multiplex
(D)QPSK—(differential) quadrature-phase-shift key
(E)/(U)EP—(equal/unequal) error protection
FIC—fast information channel
FFT—fast Fourier transform
IF—intermediate frequency
I/Q—in-phase/quadrature
MCI—multiplex configuration information
MFP—master frame preamble
MPEG—Moving Picture Experts Group
MUSICAM—masking-pattern, universal sub-band integrated coding and multiplexing
MSC—main service channel
PAD—programme-associated data
PLL—phase-locked loop
PRC—prime-rate channel
RDI—receiver-data interface
SAW—surface acoustic wave
SC—synchronisation channel
SI—service information
SFN—single-frequency network
TDM—time-division multiplex
TII—transmitter-identification information
TSCC—time-slot-control channel
VCO—voltage-controlled oscillator
VHF—very high frequency
VSAT—very-small-aperture terminal

for A/D conversion. The second VCO also generates the 39-MHz clock for the A/D-conversion stage, and the system requires one 14.72-MHz crystal reference.

DAB's RF spectrum efficiency costs computing horsepower. Eureka-147 transmission Mode 1 delivers a complex signal from the tuner/ADC block that requires a 2048-point complex FFT to execute in 1.24 msec. Together with demodulating this signal, the process demands 60-Mflops computation—equivalent to 133-MHz Pentium performance. Then, you need 1 to 2

TABLE 1—REPRESENTATIVE DAB SILICON

Vendor	Product	Function	System/standard	Price
Hitachi Circle No. 404	HD 6437490F baseband receiver/ decoder	One chip; single/dual-channel decoding; supports modes 1 to 4; Viterbi decoding; optional 24/ 48-kHz MPEG-2 audio decoding; volume control; CIP command set FIC and PAD extraction, TII decoding; 8-bit parallel port	ETS 300 401	$17 (10,000) (due Q4 '98)
Micronas Intermetall Circle No. 405	DRD 3515A digital radio demodulator	Channel-demodulator IC; includes AGC, ADC, QPSK demodulator, Viterbi and Reed-Solomon decoders, decryption, audio DAC with volume control	WorldSpace	Two-chip et, $25 (1 million)
	MAS 3506D broadcast channel decoder	Channel-demultiplexer IC; includes MPEG 2.5 Layer 3 decoder; embedded dc/dc converter for two-cell operation	WorldSpace	See above
Philips Circle No. 406	TEA3570 front end	1452- to 1492-MHz image-rejection front-end IC; includes LNA, mixers, local oscillator, phase shifter/ combiner; provides 112.6-MHz differential IF output	ETS 300 401	TEA3570, 3571, UMA1022M kit, $6 (100,000)
	TEA3571 mixer-oscillator	174- to 240-MHz VHF downconverter IC; also downconverts 112.6-MHz L-band IF to 38.9-MHz IF; includes mixers, oscillators, output-buffer amplifier	ETS 300 401	See above
	UMA1022M synthesiser	Dual-band PLL frequency synthesiser	Not applicable	See above
	SAA3500 DAB decoder	Demodulator and decoder IC supports DAB modes 1 to 4 and dynamic multiplex reconfiguration; includes mixer, AFC and AGC detectors, symbol detectors, UEP for 64 subchannels, FIC buffering, receiver-data interface	ETS 300 401	$20 (more than 100,000)
	SAA2502 audio source decoder	General-purpose MPEG decoder IC; output formats include analogue, I^2S, SPDIF, and 256 3 oversampled bit stream; includes clock generator, demultiplexer, error concealment, scaling, output DAC, I^2C mP interface	ETS 300 401 MPEG-1 and -2, layers 1 and 2	$8 more than (100,000)
STMicro-electronics Circle No. 409	STA001 RF front end	20-dB receiver LNA and 1.84-MHz baseband down-converter IC; includes I^2C mP interface, two VCOs, receiver chain, on-chip power regulation	WorldSpace	Three-chip set, $30 (1 million)
	STA002 channel decoder	Demodulator IC; includes ADC, QPSK demodulator, signal-power estimator, AGC, time-division demultiplexer, Viterbi and Reed-Solomon decoders, deinterleaver and decryption, channel selection, audio and data separation	WorldSpace	See above
	STA003 source decoder	Audio-decompression IC for MPEG-2.5 Layer 3 with tone and volume control	WorldSpace	See above
Temic Circle No. 410	U2730B-B front end	1452- to 1492-MHz downconverter IC (190- to 230-MHz IF); includes LNA, AGC, mixer, gain control block, VCO/frequency synthesiser, output buffer	ETS 300 401	$6 to $60 (10,000)
	U2731B-A front end	VHF downconverter IC, also downconverts U2730B-B IF output; includes balanced input amplifier, AGC, VCO, lock detector, tuner DACs	ETS 300 401	$10 to $53 (10,000)
	U2739M-A channel source decoder	Channel-demodulator/audio-decoder IC; supports DAB modes 1 to 4; includes AFC, AGC, full-rate interleaver, I^2S, SPDIF, and RS-232C outputs	ETS 300 401 MPEG-1 and -2 Layer 2	$32 to $67 (10,000)

DIGITAL AUDIO BROADCAST

Mbytes of RAM to deinterleave the signal back into its correct sequence. Prototype DAB receivers used arrays of as many as five general-purpose DSPs to accomplish signal decoding—a task that now fits in one IC. But half the cost of a DAB receiver remains in the DSP subsystem.

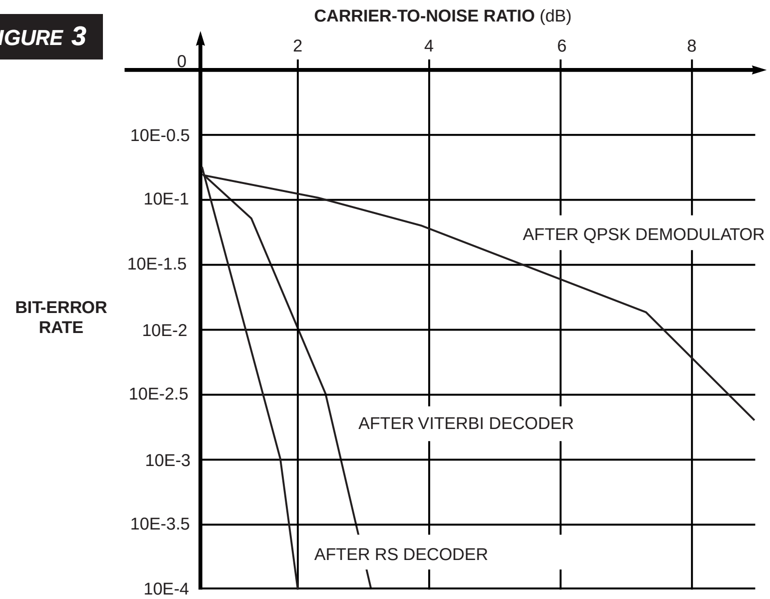
The Philips and Temic parts naturally complement each company's RF front-end components. Features include:

- full-rate DAB decoding, which handles all incoming data rather than a subset;
- support for all four DAB transmission modes;
- dynamic multiplex reconfiguration support, which permits transparent on-the-fly receiver set-up changes;
- full MPEG-1 and -2 support with dynamic range control;
- transmitter-identification-information (TII) extraction; and
- conveniences, such as the controller-interface protocol (CIP) command-set, and receiver-data-interface (RDI) output port.

Japan's interest in Eureka-147 may follow Hitachi's release of the HD-6437490F baseband receiver/decoder IC, which forms the decoder core of Roke Manor's DAB module. System-level functions combine the in-phase/quadrature (I/Q) generator, AFC, COFDM symbol demodulator, signal deinterleaver, Viterbi forward-error-correction decoder, and MPEG-2 audio decoder. Hitachi's design suits DAB modes 1 to 4 with a decoder that supports single- and dual-channel decoding. Features include full carrier and symbol tracking as well as the CIP command set that makes it easy to retrieve data from DAB's frame structure. Output streams appear in RDI or 8-bit parallel format before MPEG decoding—or are decoded as serial digital audio to drive an external DAC.

WorldSpace signal-coding practice differs from that of Eureka-147 by using quadrature phase-shift-keyed (QPSK) modulation, Viterbi and Reed-Solomon forward error correction, and MPEG-2.5 Layer 3 audio decoding. The WorldSpace technology is simpler and cheaper, and it requires less power to drive a receiver. Power consumption is critical because WorldSpace intends to develop portable receivers based on UK inventor Trevor Baylis' "clockwork-radio" concept, in which a wind-up mechanism

FIGURE 3



Simulation results show that the WorldSpace system bit-error rates for a given carrier-to-noise ratio approach theoretical limits.

drives the power supply, suiting remote Third World environments where batteries are unavailable or unaffordable.

You can choose between Micronas Intermetall and STMicroelectronics to obtain WorldSpace decoder ICs. System partitioning details vary, but either chip set performs A/D conversion, QPSK demodulation, signal demultiplexing, and audio decoding. In STMicroelectronics' STA002, the 1.84-MHz baseband signal oversamples in a flash ADC driven by a 39-MHz clock that also clocks the all-digital QPSK demodulator. The QPSK block includes AGC to level the ADC's output signal, the core I/Q demodulator, AGC to adjust the signal level to carrier- and timing-recovery circuits, a frequency sweep generator, and lock indicator. A carrier-to-noise estimation circuit helps users align the receiver's antenna.

The next stage demultiplexes the data stream within the time-division-multiplexed (TDM) frame. The frame comprises the master-frame preamble (MFP), which contains synchronisation information; the time-slot-control channel (TSCC), which describes the organisation of the following prime-rate-channel (PRC) data; and the 96 16-kbps PRCs. A half-rate Viterbi decoder fixes single-bit errors in the resulting broadcast-channel (BC) data stream. A 255 3 4-byte deinterleaver restores the correct data sequence before the data passes through a 255/233 Reed-Solomon (R-S) decoder. The R-S decoder fixes data-burst errors as long as 16 bytes (128 bits). Simulation results from Micronas Intermetall show that the system bit-error rate for a given carrier-to-noise ratio approaches theoretical limits (**Figure 3**).

Another difference between Eureka-147 and WorldSpace systems involves audio-compression techniques. WorldSpace selected MPEG-2.5 Layer 3, which is an extension of MPEG-2 that supports audio-sampling rates of 8 to 48 kHz. The last stage in MPEG-2.5 Layer 3 compression is Huffman encoding, which preserves quality even at the low sample frequencies that suit mono speech. Layer 3 also supports continuous bit-rate variation within its 8- to 128-kbps range. Both Micronas Intermetall's chip set and STMicroelectronics' "Starman" chip set provide analogue outputs that directly drive headphones or small loudspeakers, and both include volume controls.

When can we hear DAB?

As WorldSpace counts down to liftoff, Eureka-147 DAB services are either operating or undergoing advanced trials throughout Europe and many other parts of the world—including Australia, Canada, China, India, and South Africa (see **sidebar** "WorldSpace gets ready for liftoff"). The BBC is one of digital radio's leading promoters, and the organisation provides DAB coverage to an area reaching approximately 60% of the country's population. The BBC is trying to raise consumer awareness of its digital services and just rolled out a DAB travel-information service and an archive facility, which complement AM/FM mirror services. Other European countries that are rolling out DAB services include Belgium, France, Germany, Hungary, Italy, the Netherlands, Norway, Poland, Portugal, Slovenia, Spain, Sweden, and Switzerland.

You can now buy in-car receivers from manufacturers including Blaupunkt, Clarion, Grundig, Kenwood, and Pioneer. But you'll need to be ready to spend £500 for a basic receiver to approximately £1200 for a fully featured set. You can soon expect to see home DAB receivers from vendors such as Sharp and Technics. Ultimately, the stage is set for DAB to prove its worth in environments spanning the richest and poorest nations on the planet. Both environments provide staggering market potential. You can expect to see much more press coverage on DAB as the technology matures—and consumer acceptance begins to reward today's entrepreneurs. e

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