DSP Innovations

TWELP 400 bps Vocoder

enables voice communication in extremely challenging conditions where it was previously impossible, delivering speech quality and intelligibility comparable to or better than that of MELPe at 600 bps, even while operating at an exceptionally low bit rate.

For Digital HF Radio and other markets.

TWELP Technology Features. The vocoder is based on newest technology of speech coding called "Tri-Wave Excited Linear Prediction" (TWELP) that was developed by experts of DSPINI.

TWELP technology is a new class of vocoders that differs from any other LPC-based vocoders by:

- advanced reliable method of pitch estimation
- pitch-synchronous analysis
- advance tri-wave model of excitation
- newest quantization schemes
- pitch-synchronous synthesis

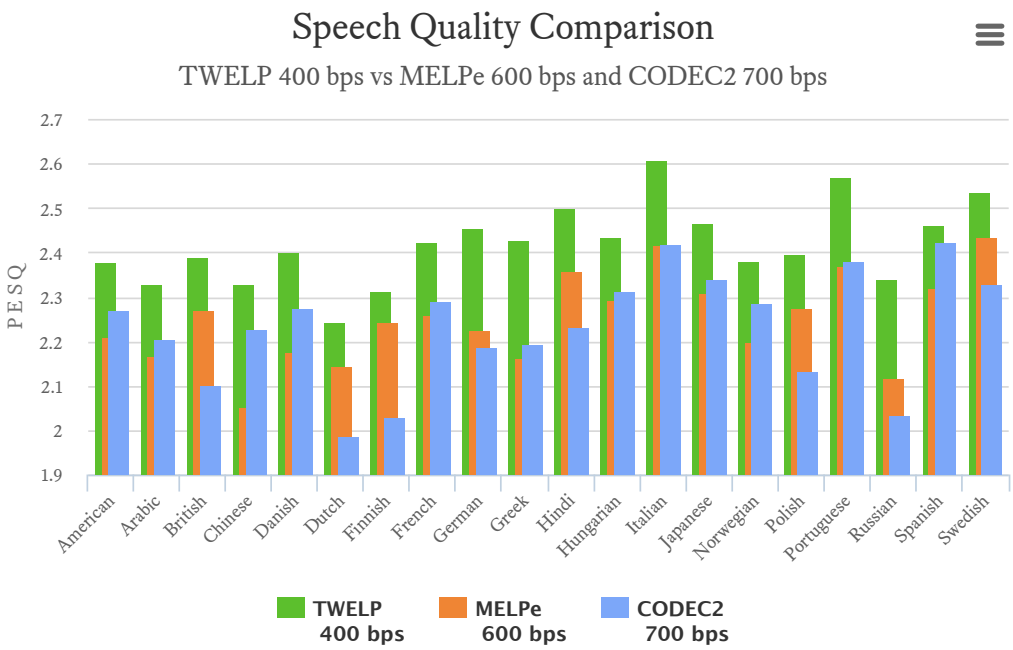
Thanks to these unique features, TWELP technology provides significantly better speech quality than other well-known technologies—including AMBE+2, MELPe, ACELP, and others—at equivalent bit rates ranging from 300 bps to 4800 bps and beyond.

Additionally, unlike other low-bitrate vocoders (such as MELPe, for example), TWELP delivers much higher quality for non-speech signals, including sirens, background music, and similar audio.

Speech Quality. This is a comparison with the MELPe vocoder, which operates at 600 bps.
The TWELP 400 bps and MELPe 600 bps vocoders were tested using the ITU-T P.50 speech base in 20 different languages.

Note:
We have updated the speech database by minimizing inter-speech pauses to eliminate their impact on the evaluation results. Therefore, the numbers obtained from the quality measurements using this updated speech database differ from those previously obtained with the original speech database, where speech pauses were not removed.

The ITU-T P.862 tool was used to evaluate speech quality in terms of PESQ scores:

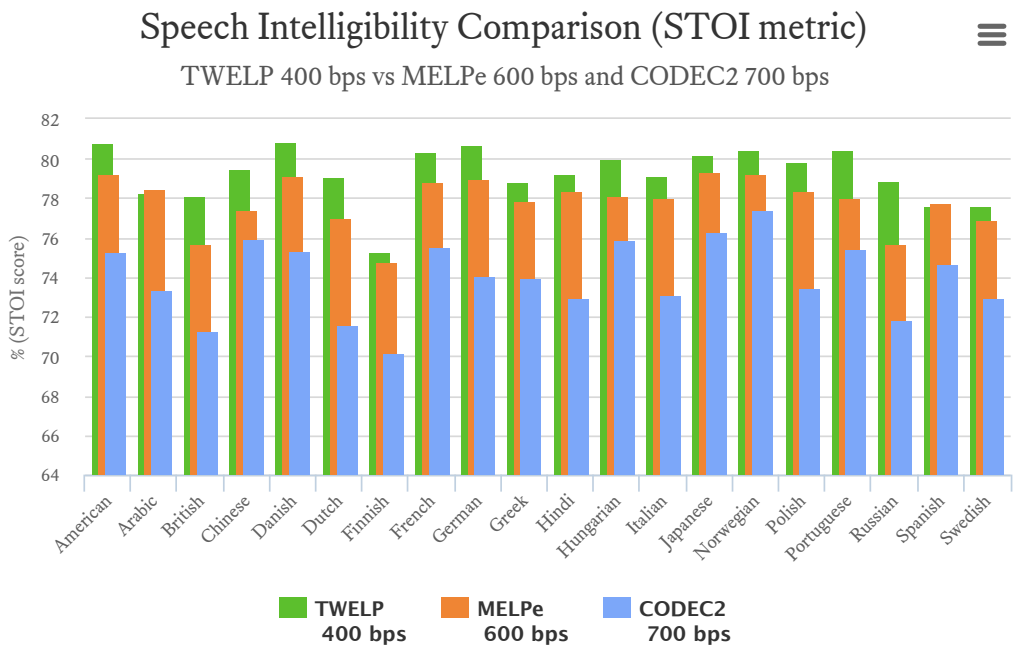


The diagram demonstrates a significant difference in speech quality between the TWELP 400 and MELPe 600 vocoders.
We've also included numbers for the free CODEC2 700 bps vocoder for comparison. The exact values are shown in the table below.

Language	**TWELP 400 bps**	**MELPe 600 bps**	**CODEC2 700 bps**
American	2.379	2.211	2.272
Arabic	2.329	2.168	2.207
British	2.389	2.270	2.103
Chinese	2.329	2.055	2.228
Danish	2.401	2.174	2.276
Dutch	2.245	2.145	1.987
Finnish	2.315	2.243	2.031
French	2.425	2.258	2.292
German	2.454	2.227	2.186
Greek	2.427	2.164	2.193
Hindi	2.502	2.358	2.234
Hungarian	2.436	2.293	2.314
Italian	2.608	2.417	2.422
Japanese	2.467	2.308	2.340
Norwegian	2.384	2.197	2.285
Polish	2.399	2.274	2.134
Portuguese	2.571	2.370	2.381
Russian	2.340	2.119	2.033
Spanish	2.463	2.322	2.425
Swedish	2.534	2.437	2.327
Average	**2.421**	**2.251**	**2.234**

Superiority of the TWELP 400 over MELPe 600 and CODEC2 700 is on average 0.17 and 0.187 PESQ appropriately

Speech Intelligibility. Here is a comparison with the MELPe vocoder, which operates at 600 bps. The TWELP 400 bps vocoder and the MELPe 600 bps vocoder were tested using the ITU-T P.50 speech database, covering 20 different languages.
STOI (Short-Time Objective Intelligibility) and ESTOI (Extended Short-Time Objective Intelligibility) metrics were used to assess speech intelligibility:



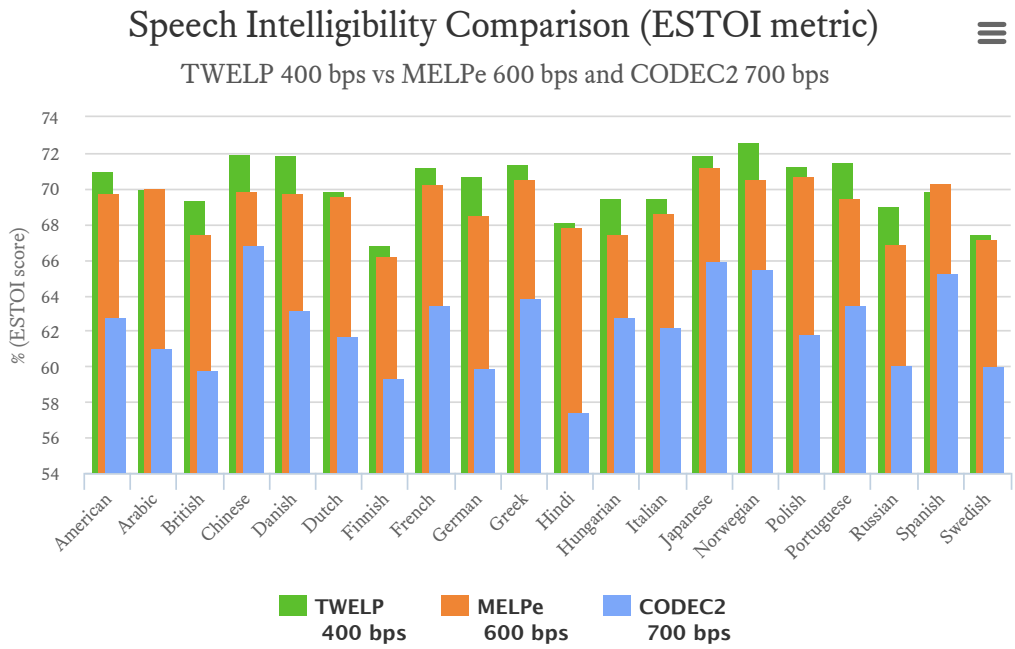
The diagram illustrates a difference in speech intelligibility between the TWELP 400 and MELPe 600 vocoders in the STOI metric. We've also included numbers for the free CODEC2 700 bps vocoder for comparison. Exact values are provided in the table below:

Language	TWELP 400 bps	MELPe 600 bps	CODEC2 700 bps
American	80.78	79.24	75.31
Arabic	78.31	78.50	73.42
British	78.14	75.67	71.36
Chinese	79.51	77.40	75.93
Danish	80.86	79.12	75.41
Dutch	79.10	77.04	71.54
Finnish	75.29	74.76	70.16
French	80.36	78.79	75.52
German	80.74	79.00	74.04
Greek	78.82	77.89	73.97
Hindi	79.27	78.35	72.92
Hungarian	79.99	78.14	75.90
Italian	79.19	78.03	73.10
Japanese	80.22	79.30	76.34
Norwegian	80.48	79.24	77.41

Polish	79.87	78.37	73.48
Portuguese	80.47	78.04	75.44
Russian	78.93	75.74	71.81
Spanish	77.61	77.82	74.64
Swedish	77.63	76.89	73.00
Average	**79.28**	**77.90**	**74.04**

Superiority of the TWELP 400 over MELPe 600 and CODEC2 700 is on average 1.38% and 5.24% appropriately

Considering that a low-bitrate vocoder is a nonlinear device that significantly distorts the spectrum of the original speech signal, the ESTOI metric provides more accurate assessments of speech intelligibility after vocoding:



The diagram shows a difference in speech intelligibility between the TWELP 400 and MELPe 600 vocoders in the ESTOI metric. We've also included numbers for the free CODEC2 700 bps vocoder for comparison. Exact numbers are shown in the table below.

Language	**TWELP 400 bps**	**MELPe 600 bps**	**CODEC2 700 bps**
American	71.05	69.76	62.80
Arabic	69.99	70.04	61.07
British	69.40	67.54	59.80
Chinese	71.96	69.85	66.83
Danish	71.93	69.81	63.20
Dutch	69.91	69.58	61.78
Finnish	66.79	66.23	59.38
French	71.27	70.28	63.46
German	70.78	68.55	59.96
Greek	71.45	70.59	63.81

Hindi	68.13	67.87	57.40
Hungarian	69.47	67.46	62.84
Italian	69.50	68.60	62.20
Japanese	71.91	71.22	65.94
Norwegian	72.62	70.59	65.52
Polish	71.28	70.79	61.89
Portuguese	71.50	69.53	63.49
Russian	68.98	66.88	60.10
Spanish	69.85	70.33	65.32
Swedish	67.46	67.17	60.05
Average	**70.26**	**69.13**	**62.39**

Superiority of the TWELP 400 over MELPe 600 and CODEC2 700 is on average 1.13% and 7.87% appropriately

Speech intelligibility testing confirms that the TWELP 400 bps vocoder has a slight advantage over the MELPe 600 bps vocoder and a significant advantage over the CODEC2 700 bps vocoder, despite operating at a much lower bitrate.

You can download the P.862 and STOI/ESTOI utilities, along with all speech samples, by using the links in the 'Downloads' section at the bottom of the page, and then check all the numbers presented above.

Speech Samples (WAV-files).

A few independent experts compared the TWELP 400 bps vocoder with the MELPe 600 bps vocoder using the preference method.
Although opinions were split, most listeners preferred the TWELP vocoder, noting its more natural sound, even despite the noticeable presence of artifacts in some speech transitions.

You can play and listen to short samples of the source speech, as well as the speech processed by the MELPe 600 bps vocoder and the TWELP 400 bps vocoder, using the links in the table below. We've also included samples for the free CODEC2 700 bps vocoder for comparison.

For the best listening experience, we recommend using high-quality headphones or premium audio equipment to hear the nuances and differences in the vocoder sound more clearly.

You can also download the complete set of P.50 samples as zip files for all languages simultaneously by using the links in the 'Downloads' section at the bottom of the page.

Language	**Source speech**	**CODEC2 700 bps**	**MELPe 600 bps**	**TWELP 400 bps**
American	▶	▶	▶	▶
Arabic	▶	▶	▶	▶
British	▶	▶	▶	▶
Chinese	▶	▶	▶	▶
Danish	▶	▶	▶	▶
Dutch	▶	▶	▶	▶
Finnish	▶	▶	▶	▶
French	▶	▶	▶	▶

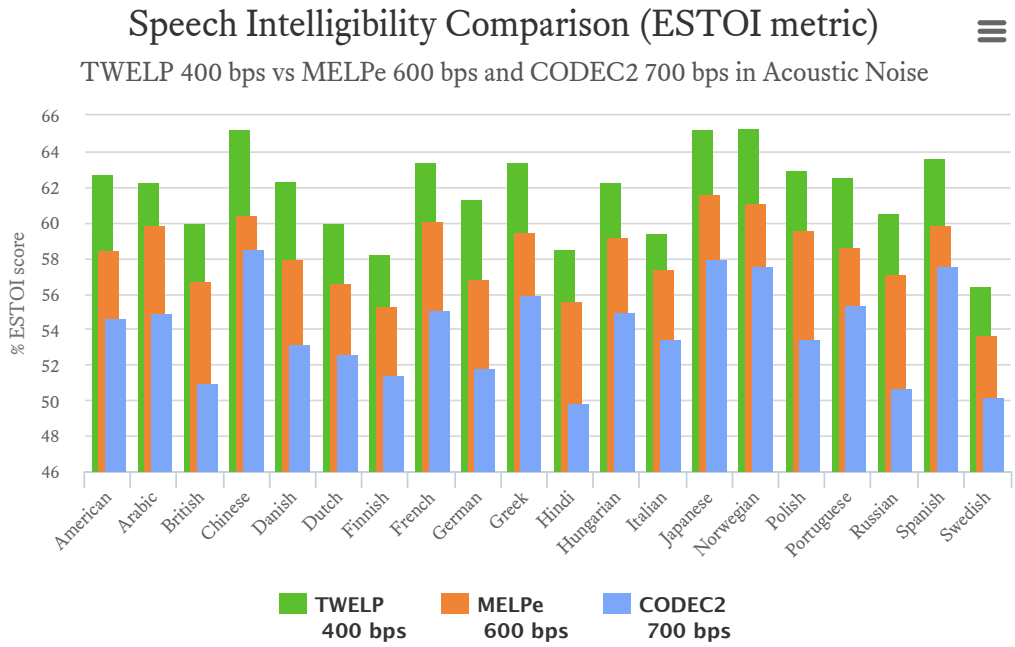
German	▶	▶	▶	▶
Greek	▶	▶	▶	▶
Hindi	▶	▶	▶	▶
Hungarian	▶	▶	▶	▶
Italian	▶	▶	▶	▶
Japanese	▶	▶	▶	▶
Norwegian	▶	▶	▶	▶
Polish	▶	▶	▶	▶
Portuguese	▶	▶	▶	▶
Russian	▶	▶	▶	▶
Spanish	▶	▶	▶	▶
Swedish	▶	▶	▶	▶

Superiority In Quality Of The Non-speech Signals. In contrast to other LBR vocoders (MELPe, AMBE+2, etc.), TWELP vocoders provide high quality of non-speech signals, including police, ambulance, fire sirens, etc. This feature in conjunction with high quality natural human-sounding of voice makes TWELP vocoders well suitable for replacement of analog radio by digital radio and also for other applications where high quality transmitting of non-speech signals is relevant along with high quality transmitting of speech signals.

Source signal	**CODEC2 700 bps**	**MELPe 600 bps**	**TWELP 400 bps**
▶	▶	▶	▶

Note:
Of course, at such an ultra-low bitrate 400 bps, the quality of non-speech signal processing is worse than at higher bitrates and is not so much better than that of MELPe 600 bps.

High Robustness To Acoustic Noise. In contrast to other LBR vocoders, TWELP vocoders are highly robust to acoustic noise due to a reliable pitch estimation method and other features of TWELP technology.



The diagram demonstrates a difference in speech intelligibility for noisy speech (SNR = 10 dB) between the TWELP 400 and MELPe 600 vocoders, based on the ESTOI metric. We've also included numbers for the free CODEC2 700 bps vocoder for comparison. Exact numbers are shown in the table below.

Language	**TWELP 400 bps**	**MELPe 600 bps**	**CODEC2 700 bps**
American	62.77	58.47	54.62
Arabic	62.31	59.83	54.92
British	59.96	56.73	51.00
Chinese	65.22	60.42	58.58
Danish	62.39	57.98	53.15
Dutch	60.01	56.63	52.64
Finnish	58.23	55.25	51.43
French	63.39	60.07	55.05
German	61.28	56.79	51.85
Greek	63.39	59.48	55.95
Hindi	58.58	55.59	49.80
Hungarian	62.26	59.22	55.00
Italian	59.37	57.39	53.43
Japanese	65.21	61.64	57.94
Norwegian	65.32	61.09	57.60
Polish	62.98	59.62	53.47
Portuguese	62.60	58.66	55.35
Russian	60.55	57.10	50.68
Spanish	63.58	59.90	57.62
Swedish	56.43	53.69	50.23
Average	**61.79**	**58.28**	**54.02**

Superiority of the TWELP 400 over MELPe 600 and CODEC2 700 is on average 3.51% and 7.77% appropriately

The fact that the difference in speech intelligibility between the TWELP and MELPe vocoders is larger for noisy speech (3.51%) than for clean speech (1.13%) indicates better resistance of the TWELP vocoder to acoustic noise.

Additionally, the TWELP vocoder features an NCSE (Noise Cancellation Speech Enhancement) preprocessor, which cleans the input speech signal from noise and enhances speech quality.
Below, you can listen to a short fragment of heavily noisy English speech after passing through MELPe and TWELP vocoders, with NPP (Noise Pre-Processor) and NCSE disabled and enabled, respectively.

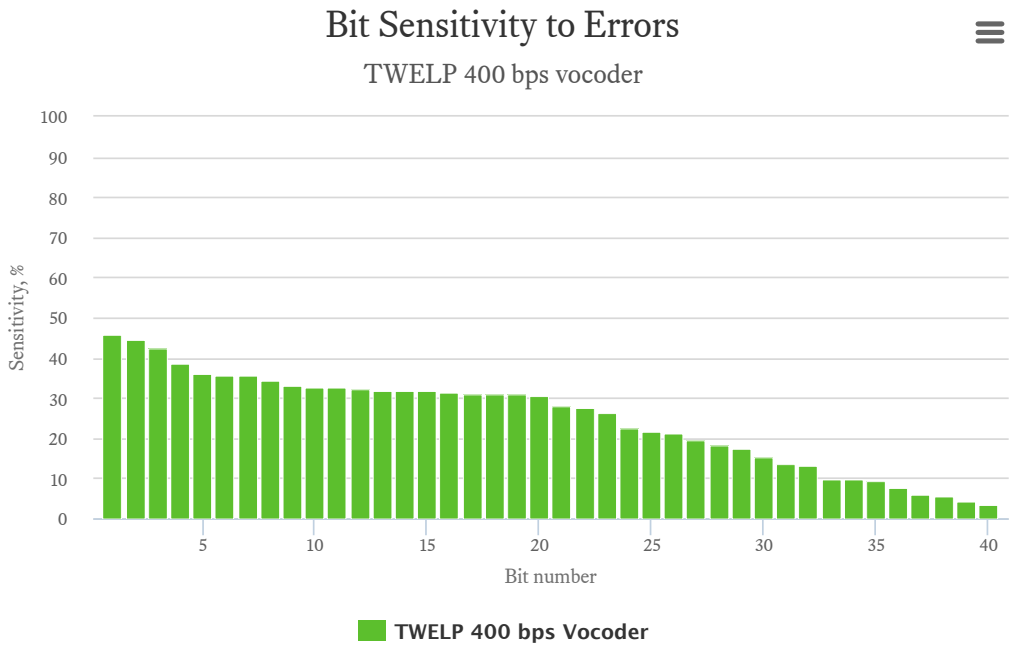
NPP NCSE	**Input speech (SNR=10dB)**	**CODEC2 700 bps**	**MELPe 600 bps**	**TWELP 400 bps**
Disabled	▶	▶	▶	▶
Enabled	▶		▶	▶

The NCSE integrated into the TWELP vocoder is described in more detail on the webpage for our standalone product, 'NCSE-AGC Preprocessor'.

High Robustness To The Channel Errors.
The TWELP technology offers highly efficient speech compression by eliminating redundancy while preserving excellent quality and intelligibility. To enhance robustness against transmission errors, we provide specialized versions called **TWELP Robust**.
These vocoders are based on an effective Joint Source-Channel Coding approach. Each vocoder is equipped with a custom-designed FEC, tailored to its specific characteristics and operational conditions.
TWELP Robust vocoders provide high speech quality simultaneously in noisy channel as well as in noiseless channel. FEC can operate with "soft decisions" as well as with "hard decisions" from a modem. "Soft decisions" mode provides much better robustness in comparison with the "hard decisions" mode.

For all users of our non-robust vocoder versions, we offer the following recommendations.

The diagram below illustrates the sensitivity of bits at the output of the vocoder to communication channel errors.
Essentially, the diagram shows by what percentage speech quality/intelligibility is reduced when a specific bit is distorted. The first bits in order cause catastrophic distortions, while the latter bits have significantly less impact on quality/intelligibility.



We strongly recommend using FEC (Forward Error Correction) with unequal protection of the bits in strong accordance with their sensitivity to errors and utilizing 'Soft Decisions' decoding. This will provide the highest robustness of the vocoder against errors in the channel.

Additional Functionalities. The following additional functionalities are developed by DSPINI and integrated into TWELP vocoders:

- Noise Cancellation Speech Enhancement (NCSE)
- Automatic Gain Control (AGC),
- Voice Activity Detector (VAD),
- Discontinuous Transmission (DTX),
- Tone Detection/Generation (Single tones and Dual tones). The tones are transmitted by the vocoder facilities.

Note:
The Tone Detector/Generator functionalities are not integrated into the code by default but can be added free of charge upon request.

Each functionality has unique features, performance and characteristics, providing significant superiority over any well-known implementations on the market.

Technical Characteristics And Resource Requirements:

Technical characteristics

Bit Rate (bps)	Algorithm	**Frame size** (ms)	**Algorithmic delay (including frame size)** (ms)	**Sampling rate** (kHz)	**Signal format**	**Bit stream format**
400	TWELP	100	120	8	Linear 16-bit PCM	40

Additional functionalities

Name	**Functionality**	**Technical characteristics**	
		Name	**Value**
AGC	Automatic Gain Control	Control range:	0 ... +42 dB
NCSE	Noise Canceller - Speech Enhancer	SNR increasing	20 dB
		Speech quality improvement	> 0.1 PESQ
Tone Detector	Single/Dual tones detection	In accordance with international standards	
Tone Generator	Single/Dual tones generation	Special generator, kept continuity of signal (phase and amplitude of signal of previous frame)	
DTX	Discontinuous Transmission	Reduces bit rate down to 110 bps in pauses between active speech regions	
VAD	Voice Activity Detection	High reliability even with pink noise at an SNR < 0 dB.	
CNG	Comfort Noise Generation	Type of noise	"white"
		Level	- 60 dB

The NCSE and AGC integrated into the TWELP vocoder are described in more detail on the webpage for our standalone product, 'NCSE-AGC Preprocessor'.

Resources for ARM Cortex-M4 platform

Module	**MIPS* peak**	**Memory** (KBytes)				
		Program	**Data**			
			Constants	**Channel**	**Heap**	**Stack**
Voice Encoder	49	42	196	4.7	6.7	1.0
NCSE	6.0					
AGC	0.5					
Voice Decoder	19					
Voice Encoder + Voice Decoder	68					
Total	74.5					

Resources for TI′s C64 DSP platform

Module	**MIPS* peak**	**Memory** (KBytes)				
		Program	**Data**			
			Constants	**Channel**	**Heap**	**Stack**
Voice Encoder	17.6	81	196	4.7	6.7	1.0
NCSE	2.6					
AGC	0.3					
Voice Decoder	5.3					
Voice Encoder + Voice Decoder	22.9					
Total	25.8					

Resources (estimated) for TI's C55 DSP platform

Module	**MIPS* peak**	**Memory** (KBytes)				
		Program	**Data**			
			Constants	**Channel**	**Heap**	**Stack**
Voice Encoder	30	26	196	4.7	6.7	1.0
NCSE	6.2					
AGC	0.4					
Voice Decoder	13					
Voice Encoder + Voice Decoder	43					
Total	49.6					

* DSPINI continues optimization of the TWELP algorithm and code in order to minimize computational complexity of the vocoder.

Software Integrity and Security. DSPINI guarantees the ABSOLUTE integrity of its software, free from any undocumented features, undeclared capabilities, or hidden functions. Our customers can be assured that none of our software/code contains any secret features or functionalities concealed from the user. If necessary, we are ready to provide the source code of our software products for appropriate certification. Moreover, our software is available in source code form—you simply need to purchase the appropriate license to use it.

Guarantee And Support. DSPINI guarantees a quality and accordance of all technical characteristics of the product to requirement of current specifications. Testing and other method of quality control are used for guarantee support.

Any Platforms. DSPINI can port this vocoder software into any other DSP, RISC or general- purposes platform inshort time: 1-2 months.

Licensing Terms. To use the vocoder, customer should obtain a license from DSPINI only.

Customization. The vocoder can be customized under any specific requirements- other bit rate, frame size, any other robustness to channel errors, etc. Please contact with us for details.

Prospects. DSPINI is impoving and developing continuously a set of new vocoders with range from 300 bps up to 9600 bps, based on TWELP technology.

Related Software. This vocoder may be effectively used in a bundle with other DSPINI's products:

- Linear and acoustic echo cancellers,
- Multichannel noise cancellers (including two-microphone adaptive array),
- Wired or radiomodems for any types of channels and bitrates,
- Other products.

Downloads:

- Datasheet (pdf)

- ITU-T P.50 source speech samples (zip)
- CODEC2 700 bps speech samples (zip)
- MELPe 600 bps speech samples (zip)
- TWELP 400 bps speech samples (zip)
- P.862 and STOI/ESTOI utilities
- P.862 and STOI/ESTOI utilities (macOS, Linux) - on request
- PC-evaluation package (zip) — on request
- User's Guide document (pdf) — on request

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