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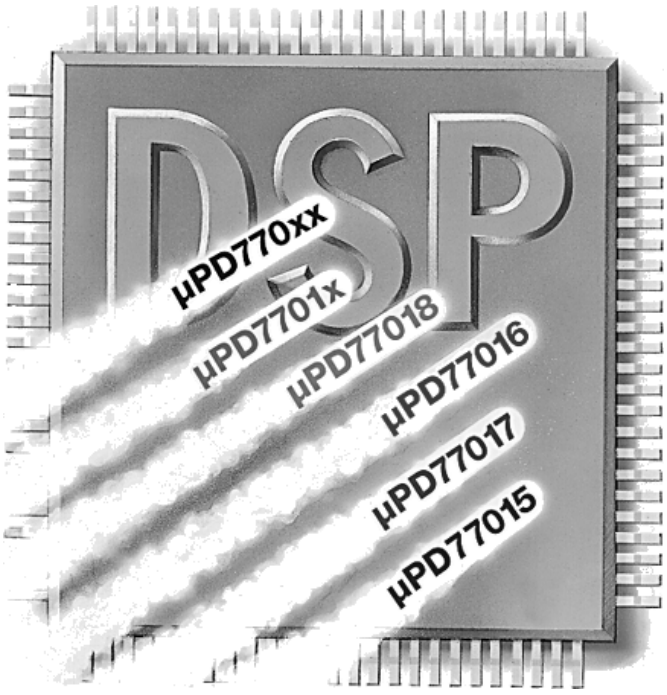


DTMF on µPD7701x

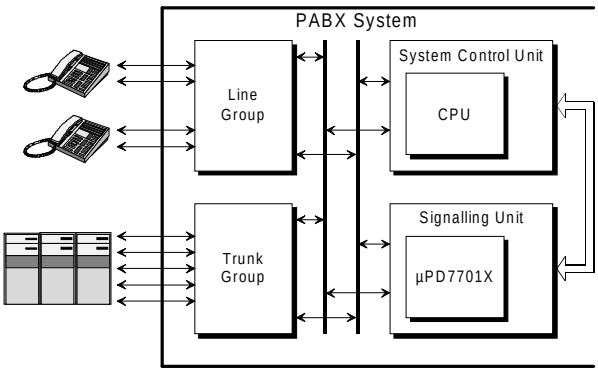
Dual **T**one **M**ulti **F**requency (DTMF) signalling is commonly used in all kinds of telecommunication switching equipment. The further introduced software for NEC's µPD7701x 16-bit fixed-point DSP family is well suited for private and public switched telephone networks, where it is of particular importance to combine multichannel DTMF receivers and transmitters with other functions like single tone receivers/transmitters or conferencing in a single device.

All of these functions are supported with ready made software for the µPD7701x family. The DTMF receiver and transmitter programs distinguish on functionality and flexibility, while the high performance and on-chip memory resources of this DSP family assure the potentiality to undertake also multiple tasks beside processing of DTMF signals.

2nd Edition

What is DTMF and where is it used?

In modern telephone systems manifold kinds of signalling functions are carried out by use of signalling tones. This holds true for private telephone exchanges (PABx) as well as for public switched telephone networks (CO).



This signalling serves on one hand for exchanging information between the subscriber and the switching equipment and on the other hand for establishing dedicated connections system internally and to external via the public networks.
The reception, i.e. the identification, of these signalling tones like also their generation is concentrated in a dedicated unit, the “Signalling Unit”. Upon detection of a signalling tone the System Control Unit will receive a message about the kind of the detected signal and will undertake appropriate actions , like, for instance, linking an internal subscriber (Line Group) to an external line (Trunk Group), which is not engaged.

The signalling tones may be of different kind, as there are pulsed or continuous single tones or also two-tone-pulses (DTMF: Dual Tone Multi Frequency). However most of them have one thing in common: the signalling tones consist of unique or linearly superposed sinewaves with frequencies lying in the speechband (300 Hz to 3.4 kHz).

The standardised DTMF signals are assembled by an addition of two sinewave pulses of a defined duration. Each sinewave pulse is originated from two groups (row and column frequency group) with each of it containing four distinctive frequencies. Consequently 16 combinations are possible which represent 16 different signs (0...9,A,B,C ,D,#,∗).

The µPD7701x as a signalling processor: system integration

The Signalling Unit has to communicate with other system components of different nature in manifold ways:

- receiver input data from Trunk Group and Line Group
- generator output data to Trunk Group and Line Group
- report of detected signalling tones to the System Control Unit
- commands from the System Control Unit, e.g. to generate a signalling tone, initialisation, parameters, etc.

In most cases input and output of receiver and generator data is applied by means of serial synchronous lines (TDMA: Time Division Multiple Access, PCM Highway), connection to the System Control Unit may be established either via serial lines (Signalling Highway) or via parallel data paths. The plentiful equipment of peripheral interfaces of the µPD7701x DSPs leaves all options: No matter how the system configuration looks like, adaptation to the existing environment is possible without any problems.

During development of the receiver/transmitter programs it has been considered to strictly separate the data processing modules from those handling the data I/O in order to secure easy adaptation to different system environments. For synchronising data exchange e.g. with the host CPU (Handshake) and the µPD7701x offers solutions by S/W (polling) or H/W (interrupt). The DSP internal synchronisation of data I/O is interrupt controlled, but can be changed to other methods easily.

The Signal(ling) processor software

The Signalling Unit has to provide an appropriate quantity of receivers and generators, whereas “appropriate” can be derived from the number of connected lines and their occupation rate. The µPD7701x DSP family offers for that an optimum solution. Due to its forward-looking architecture, high computational power and on-chip memory resources it is capable to process a remarkable amount of channels simultaneously. Even the “smallest” member of the family, the µPD77015, is capable to operate up to 14 DTMF receivers and generators simultaneously, without any need to spend external memory expansion.

DTMF receiver/transmitter: The by far most complicated function to implement is the DTMF

receiver, since the requirements for 100% recognition rate and sufficient immunity against speech signals and other signals are extremely high. This DTMF receiver implementation for NEC's µPD7701x DSP family was developed on the base of several years experience with DTMF receivers implemented on the µPD77C25 DSP devices, which have confirmed their performance in practice and have been approved in several European countries.

The DTMF receiver fully complies to the CEPT recommendation T/CS 46-02, even under worst conditions, i.e. yields 100% detection rate if all signal conditions in terms of level, twist, frequency deviation, tone- and pause-duration and signal-to-noise-ratio are at their tolerance limits.

detection level:	A...A-25 dB (A = -22 dB...-30 dB country specific)
max. twist:	±6 dB
max. frequency deviation:	±(1.5%+2 Hz)
min. pause length:	40 ms
min. tone length:	40 ms
pause length to be ignored:	≤20 ms
tone length to be ignored:	≤20 ms
max. additional noise:	20 dB below the row frequency level or A-16 dB, whichever is higher
max. additional dial tone:	A+22 dB (with dial tone protection) A-16 dB (without dial tone protection)

CEPT recommendation T/CS 46-02

Since there is no standardised speech immunity test available the receiver was tested with an analogue test tape that carries 30 minutes of condensed telephone conversations of various kinds. The result, i.e. the number of fail detections induced by the speech, appeared well under the permissible maximum.

Despite of different existing standards for signalling tones a multitude of different requirements for receivers exist, which take for instance specifications in different countries into account. Therefore it is not only desirable to realise multichannel receivers and generators within one unit but also, to adapt them to different specifications easily. This aspect played an important role during the program development and the way to adjust the receiver to dedicated needs has been paved in advance.

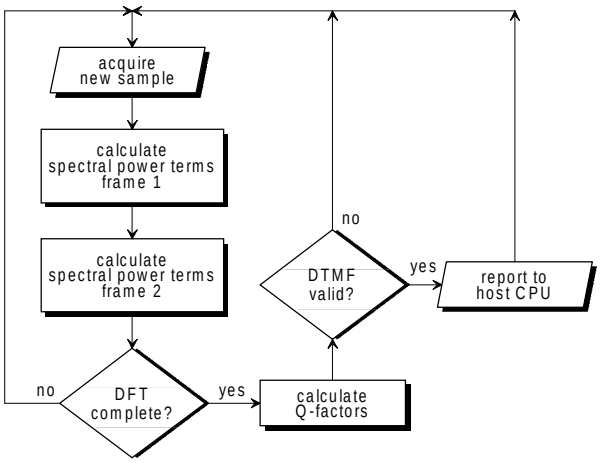
The detection characteristic of the receiver may be varied in numerous ways, as for example the dynamic of the input levels, the minimum detection level, the acceptable twist and the dial tone rejection. All important parameters determining the receiver's properties are held in the internal data RAM and may be downloaded e.g. from the host CPU to equip the receivers with country specific parameter sets.

The DTMF transmitters offer a similar degree of flexibility like the receivers. The levels of the row and column frequencies may be adjusted separately, the duration of the generated tones can be programmed.

The DTMF receiver and transmitter algorithm

The cyclic incoming samples are passed through a dial tone rejection filter, after they have been linearised from A-Law or µ-Law format if necessary. Since the highest DTMF frequency is 1633 Hz, the receiver is adjusted for 4 kHz sampling rate. Although this sampling rate yields aliasing of the speech signals it is sufficient for the DTMF signals.

The DTMF receiver is based on a spectral analysis of the input signal. Therefore the spectral power terms of the eight relevant DTMF frequencies are calculated by use of a dedicated variant of the Discrete Fourier Transform (DFT) called Goertzel Algorithm. The DFT stretches over 103 samples (25.75 ms at 4 kHz). To increase the time resolution of the calculation a second set of spectral power terms is obtained in parallel, but interleaved by 13 ms to the first one. After a complete set of power terms is available the maxima of the row and column frequency group are examined to target a proper decision whether a valid DTMF signal was applied.



µPD7701x DTMF receiver program flow

For that purpose “quality factors” are determined as a measure of the “quality” of the supposed DTMF tone. A DTMF tone is judged as valid only if its “quality factors” have reached a certain level for some time. If this is the case the DTMF tone, completed with the dedicated channel number, has to be reported to the System Control Unit. This may take place by applying an interrupt to the host CPU to force it to pick up the report message from the DSP. Then the System Control Unit will take the required actions.

The DTMF transmitters employ a phase-increment algorithm to calculate the samples with 8 kHz sampling frequency from the previously calculated one. Rounding errors due to the limited data word width are reduced to a negligible measure by a level correction routine.

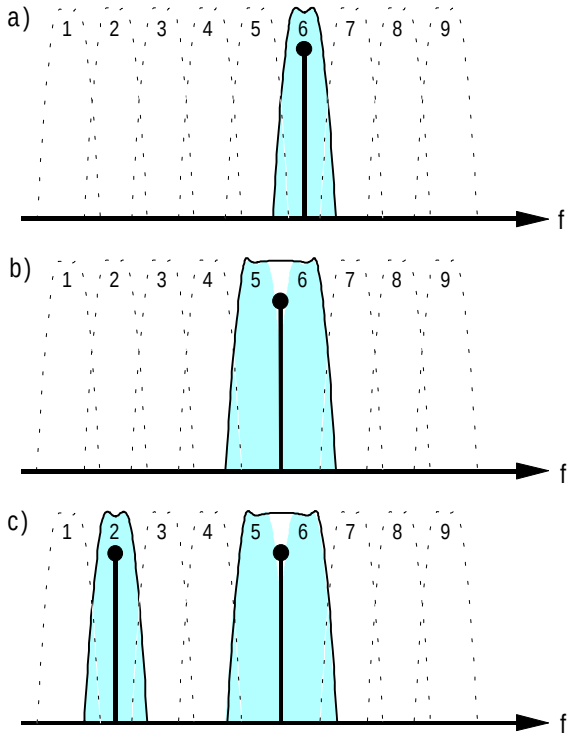
The single tone receiver/transmitter algorithm

The single tone receiver uses similar techniques than it’s DTMF equivalent. To achieve a maximum of configurability the incoming signal is analysed with 9 parallel bandpass filters using the Goertzel algorithm. The centre frequencies of these filters are determined with a predefined coefficient set, but can also be tuned by the user.

These 9 filters open up a kind of analysis window for the tone to be detected. The user has total control over shape and width of the window by selecting the position of the filters on the frequency axis. Additionally the filters can be switched on or off separately. Some examples illustrate the possibilities:

a) A single tone that fits ideally into one of the analysis passbands should be detected. In this case it is possible to switch 8 filters off to reduce the timeload for the DSP, and only one Goertzel filter is calculated.

b) A single tone that does not fit into one of the analysis passbands should be detected. Now the user has two alternatives: He can tune the filters by changing their coefficients or he can calculate two filters which are located “in the neighbourhood” of the respective tone. This is the most realistic configuration.



c) A combination tone should be detected (as required in the UK). This situation can be handled by activating 2...4 filters for the upper and lower frequency.

The minimum tone duration for a valid detection can be set in 25 ms steps from 50 ms onwards. To reduce the time load the receivers can be operated at 4 kHz sampling frequency if the detected frequency is below 2 kHz.

To summarise: The single tone receivers for the µPD7701x devices can be programmed in terms of frequency, bandwidth, sensitivity and minimum duration. They can also be adapted to the recognition of combination tones.

Their counterpart, the single tone transmitters offer a comparable flexibility level: Frequency and amplitude are programmable, combination tones are possible. They can also generate continuous output which is switched on or off under control of a host CPU or an internal timer.

Conferencing

Conferencing is used to let several persons that are connected to a single PABx communicate with each other. Therefore the DSP has to sum up several speech input signals. To provide a reasonable intelligibility individual gain controls for each speech input are required.

The gain controls emphasise the input channels with the highest levels (subscribers talking) while the low-level inputs (subscribers listening) are attenuated. Another effect of the gain control is to guarantee that there is no distortion due to overflow at any output. The configuration of conferences is done on-line under control of a host CPU that transfers the respective commands to the DSP via it's parallel host interface.

NEC's conferencing software for the µPD7701x devices allows to build up conferences with any given number of subscribers and is only limited by the processor's computing power.

The Processor Load

The program structure has been shaped in the way that the number of DTMF receivers and transmitters can be varied in a quasi automatic manner, just two constants have to be redefined.

Due to the fact that all channels are utilizing identical program modules the instruction memory load is independent of the operated number of channels.

Each receiver and transmitter channel occupies of course a separate data X-RAM area. The Y data memory holds just constants which can be completely placed also in an internal data ROM if a ROM device is used.

The table below specifies memory and time loads with additional relative figures for the µPD77015. I/O and A/µ-law coding is not included. The relative figures are given for a single Rx/Tx function.

Time and memory loads for the single tone receiver depend on the number of Goertzel filters that have to be calculated. In the table they are specified for a realistic basic load of 2 filters; N is the number of extra filters that exceeds 2.

	DTMF receiver		DTMF transmitter		Load for µPD77015
	fixed	per channel	fixed	per channel	
Instruction memory	554	-	52	-	14.9% (of 4.25k)
Data X-Memory	16	69	-	8	RAM load: 4.5% (of 2k)
Data Y-Memory	84	-	65	-	ROM load: 3.6% (of 4k)
Mips	-	1.356	-	0.58	5.9% (of 33 Mips)
	Single tone receiver		Single tone transmitter		
	fixed	per channel	fixed	per channel	
Instruction memory	226	-	52	-	6.4% (of 4.25k)
Data X-Memory	-	10 + 4·N	-	8	RAM load: 0.9% (of 2k)
Data Y-Memory	-	6 + 2·N	-	2 (per frequency)	ROM load: 0.2% (of 4k)
Mips	-	0.5 + 0.15·N	-	0.58	3.3% (of 33 Mips)

µPD7701x time and memory loads of DTMF receivers/transmitters

How to get CO/PABx functions for µPD7701x?

The complete µPD7701x software in form of the assembler source can be obtained from NEC. A Programmer's Manual describes in detail the programs and provides information how to suit them to certain requirements.

For evaluation purposes the package is completed with some test S/W for the DTMF and single tone receivers/transmitters. It downloads the DTMF S/W to the debugger board IE-77016-PC, equipped with a DSP module IE-77016-CM-EM6

or similar. In a digital test mode the S/W allows to generate freely conditioned test tones, which may also be impaired by scaleable noise and spurious frequencies, to feed them to the receiver and to monitor the detection results on the PC's monitor in a comfortable manner.

Alternatively the debugger board may also be equipped with an Analog Front End in order to run receiver tests with analogue test signals generated by any kind of test generators. Moreover NEC guides with intensive support to suit the µPD7701x program to special needs for S/W as well as H/W implementation.

µPD7701x Family Overview

		µPD77016	µPD77015	µPD77017	µPD77018	7701x core*
Internal memory	Instruction ROM	-	4k x 32 bit	12k x 32 bit	24k x 32 bit	user defined
	Instruction RAM	1.5k x 32 bit	256 x 32 bit			user defined
	Data ROM	-	2 x 2k x 16 bit	2 x 4k x 16 bit	2 x 12k x 16 bit	user defined
	Data RAM	2 x 2k x 16 bit	2 x 1k x 16 bit	2 x 2k x 16 bit	2 x 3k x 16 bit	user defined
External memory	Instr. memory	48k x 32 bit	-			-
	Data memory	2 x 48k x 16 bit	2 x 16k x 16 bit			user defined
ALU bus		40 bit				
Multiplier		16 x 16 --> 31 bit				
Barrelshifter		40 bit				
Working registers		8 x 40 bit				
Loop/repeat counter		1 repeat counter / 4 nested loop counters				
Host I/F, max. throughput		8 bit, 8.25 Mbytes/s				user defined
Serial I/F, max. throughput		2 SIOs, 8/16 bit, 16.6 Mbits/s				user defined
Interrupts		4 external, 6 internal				10
Min. instruction cycle time		30 ns				< 20 ns
Master clock for 33 Mips		66 MHz	33, 16.5, 8.25, 4.125 MHz (int. PLL)			t.b.f.
Power supply		+5 V	+3 V			
Typical power dissipation		0.7 W	90 mW	120 mW	150 mW	t.b.f.
Power down modes		0.4 W (halt)	3 mW (halt), 3 µW (stop)			t.b.f.
Packages		160 QFP	100 TQFP			user defined

**under development*

NECs new µPD7701x 16-bit fixed-point DSP family offers one of the most advanced architectures on the market. Their members are characterised by a clearly structured Harvard architecture with:

- Two identical memory banks (X, Y) with separate address computation units
- Powerful 16/40-bit arithmetic operation unit
- Program control unit with high performance loop counter
- Memory-mapped peripherals
- JTAG-based on-chip debug hardware and boundary scan facilities

All µPD7701x devices share the same core architecture but have a couple of device specific characteristics which are summarised in the table.

Devices under development will extend this family with a DSP core and more variants in performance/speed.

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