Multiplex *Touch-Tone*® Detection Using Time Speed-Up

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A signal may be read from a storage medium faster than the rate that would correspond to real time reconstruction of the signal; this process has been named time compression or time speed-up. Cheap serial shift registers make time speed-up an attractive means to detect **Touch-Tone**® *calling (or other format) signals on a multiplicity of channels using a single detector.*

I. BACKGROUND

Time speed-up (TSU) of a signal consists of reading the signal from a store faster than the rate at which it was recorded. (This is generally faster than real time reconstruction of the signal, thus the name). I propose this process for multiplexing several voiceband channels in time, so that one multifrequency receiver can detect *Touch-Tone*® signaling on a multiplicity of channels.

Processing of a single signal using TSU configurations based on electric or acoustic delay lines (called DELTIC systems, for delay line time compression) has been done since the 1950's.[1,2] At Bell Laboratories, TSU is being investigated for multiplexing *Picturephone*® visual telephone channels on slightly nonlinear microwave radio systems.[3]

The inherent simplicity and versatility of a digital TSU signal processing system is enhanced by the availability of inexpensive serial shift registers based on the insulated gate field effect transistor. These registers typically store 64 bits, and are sufficiently fast to permit a single detection circuit to serve eight to 16 *Touch-Tone* voiceband signaling channels or hundreds of channels in a low frequency application, such as 20 Hz ringing detection.

The attractiveness of TSU multiplex tone detection is demonstrated by, and most of this article treats of, the *Touch-Tone* detection case.

If the system is realized as a digital multiplexer (concentrator) in tandem with an analog frequency detector, it will become apparent that the frequency detector can (but need not) be exactly the type of circuit now used, but with a scaling applied to all reactances. This scaling is to raise all spectral features by a constant factor which is the ratio of time compression. Thus, all the linear and nonlinear signal processing now used can be included in a TSU system and its performance would simulate that of present *Touch-Tone* receivers. By adding additional data smoothing, which could involve using the signal samples more than once, the present tolerance to digit simulation by speech can be exceeded.

II. SIXTY-FOUR CHANNEL TSU RINGING DETECTOR

An exploratory key telephone system must detect the presence of 20 Hz ringing on 64 central office lines. This detection could be performed on each channel, but the availability of 64 bit serial shift registers has made centralized TSU detection economically more attractive.

Figure 1 shows the TSU arrangement to be used in this exploratory system. A transducer V_i, $i = 1, 2 \ldots 64$ at each channel slices (limits) the ringing signal and presents a rectangular wave at logic level to the sampling gates S_{ai}. Binary data is sufficient to specify the input signal because it is basically a single tone; there are interfering tones from power line cross-coupling but are suppressed to a large extent by the larger 20 Hz signal and the limiting operation. (It will be apparent that a multitone format such as *Touch-Tone* signaling would not be well represented by binary coded signal samples.) The sampling gates load the long serial register SR1 with a sequence of samples V_x from all the channels. The order of the samples is the same as the order of the channels: $\ldots, 1, 2, \ldots 63, 64, 1, 2, \ldots.$

The register SR1 has taps every 64 bits, however, and at these m taps (including the input and output) the samples at any instant are all for the same channel, as shown by V_y. These samples can be processed in a high speed detector, and the result registered in either a common or per-channel answer depository. A digital detector, for instance, could examine the m samples in a time consisting of a few logic gate delays. Alternatively, the m samples can be placed in an independent register SR2 as shown in Fig. 1, from which they can be clocked into an analog frequency discriminator of any type, such as a two-pole resonator. With this system, the SR2 read-out clock is in-

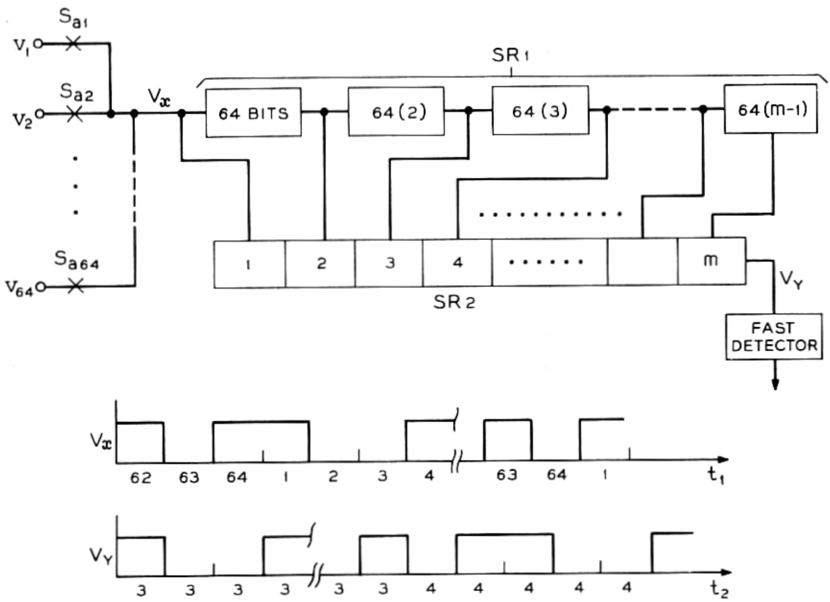

Fig. 1 — 64 Channel TSU single frequency detector.

herently a part of the detection process, since it controls the ratio of time speed-up; if the channels are sampled at rate f_s per second and the SR2 register is read at kf_s per second, then k is the ratio of time compression (and spectral expansion).

Modifications to the Fig. 1 TSU tone detector permit detection of a single tone of unspecified frequency. To do this, more detectors could be added at the output of SR2. The same result would be attained by using only one detector with various clock rates to read out SR2, and a return path from SR2 output to input, so that the samples for a particular channel could be processed repeatedly.

In the exploratory key telephone ringing detector the 64 channels are sampled at seven times per cycle of the input 20 Hz wave and a digital detector is used to examine the samples from one cycle ($m = 7$). The detector stores this tentative result in another serial shift register, and when enough 50 msec intervals appear to have ringing present, a RING output is delivered to the common controller. This detection operation is low Q, but this is by design, and is not dependent on either the TSU structure or the technology. An analog detector in this system would need $m \gg 7$ but would not require the added integration. As always, an appropriate trade-off between selectivity (high Q) and fast detection (low Q) must be made.

The effectiveness of the detector in suppressing frequencies other than 20 Hz is a function of the sampling rate, as well as the parameters of the detector. Waveform preservation is not necessary for detection, so the sampling theorem requirement (two samples per cycle at the highest frequency of interest) need not be met. As few samples as possible should be handled to conserve storage, but the lower limit is set by the signal duty cycle variation and the size and frequency of the interfering signals. The equivalence between periodic sampling and modulation permits intelligent selection of the sampling rate.

III. EIGHT CHANNEL TSU *Touch-Tone* DETECTOR

The TSU configuration of Fig. 1 could be adapted to multifrequency detection by means of a few additions. First, incorporate at the register SR1 input an analog to digital converter to code the signal samples sufficiently accurately to preserve the information content, say b bits per sample. Replace shift register SR1 by b parallel shift registers, one for each bit at the analog-digital output. Finally, add a digital to analog converter at the output of the b parallel read-out registers (SR2 in Fig. 1). No change in principle is involved; the added circuitry only preserves the signal amplitude through the TSU system. A delta coder with a (longer) single shift register could be used for the digitizing operation; the type of code is a detail.

However, the structure of Fig. 1 is not well suited to *Touch-Tone* detection. The serial registers are conveniently available in 64 bit and larger sizes. (Smaller sizes would be economically wasteful; adding taps increases the lead count perilously.) Only seldom is there a need to detect 64 *Touch-Tone* signals simultaneously, and reliability requirements would be excessively difficult, even if the need existed. By using the Fig. 2 TSU configuration, the 64 bit registers are used very efficiently.

In Fig. 2, each channel has a private b-register store. The channel $i (i = 1, 8)$ inputs are sampled in multiplex by switches S_{ai} and coded by a common analog-to-digital converter. The coded samples are steered by logic gates S_{bi} to the registers for channel i. Sometime between (or synchronized with) input samples, the registers are read at high speed into the digital-to-analog converter, which is assumed to be simple enough to build for each channel. Transmission gate S_{ci}

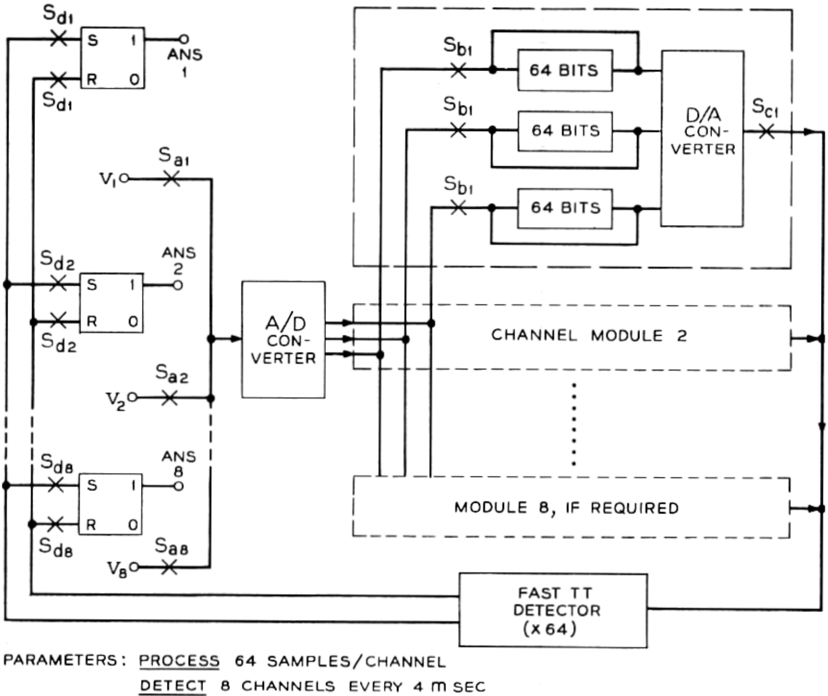

Fig. 2 — Eight channel TSU *Touch-Tone®* dialing detector.

simultaneously connects the (per channel) converter output to the detector input bus, so that the detector is time shared by all channel circuits. This detector can be a carbon copy of any of the standard receivers, but with all reactances scaled up in frequency by the time compression ratio. Or, it could be all-digital. In either case, the read-out of the channel register bank must be sufficiently fast to permit the detector to answer and return to quiescence before the next channel is examined.

An important feature of the Fig. 2 parallel register TSU system is that the channel registers need be supplied only for as many channels as are actually required. The Fig. 1 serial system must be built entirely in order to operate at all.

An 8-channel *Touch-Tone* receiver using 3 bit ($b = 3$) coding has been built and operated by Mr. R. J. Violet of Bell Telephone Laboratories. In this demonstration system, the channel sampling is done at 4000 Hz with 64 samples being stored per channel. Each channel is examined every 4 ms, and the detection requires 0.5 ms. Half of this 0.5 ms is to allow the receiver to become quiescent. The time compression ratio is the sampling interval divided by the sample read time, or 64. The detector is thus constructed for input frequencies at 64 times the normal *Touch-Tone* frequencies. This simple demonstration system immediately registers the detected results through gates S_{di} in a per-channel flip-flop bank (shown in skeletal form). An attractive feature of TSU detection is that further processing, such as delay or data format conversions, can be made by common equipment. Thus, *Touch-Tone* signal to dial pulse translators for conversion of step-by-step switching machines could be very effectively built using TSU multiplexing.

If the input signal can vary considerably in amplitude, either a per-channel automatic gain control or more accurate sample coding would be required to preserve the signal waveform through coding and decoding. Also, a sampling rate higher than 4000 Hz and a larger number of samples per detection might be used in a production circuit. In compensation, a rate of more than 8 channels is within the speed capability of the circuitry; additional signal integration to improve the tolerance to digit simulation is easy to incorporate.

The economic advantages of large scale production can be gained through the use of 64 bit serial shift registers in many of the digital systems. Preliminary economic analysis indicates that the marginal cost of one *Touch-Tone* detector in a TSU multiplex system would be less than the equivalent single channel receiver; a cost crossover can be expected at about three channels. In comparison with multiplex receiving based on digital filtering, TSU offers easier maintenance, per-channel modularity, and the ability to incorporate future improvements in the detector circuitry.

REFERENCES

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