

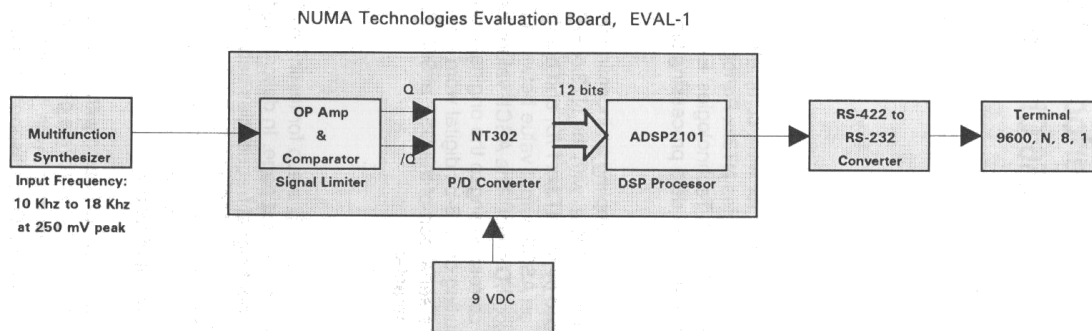
**Technical Brief****C. R. Crego  
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This Technical Brief serves as documentation for work completed on a "256 Channel Tone Decoder" ( 256 T/D ), using NUMA Technologies NT3xx Period-to-Digital Converter (P/D). The 256 T/D was set up and tested on NUMA Technologies' EVAL-1 Evaluation Board, which provides a comprehensive signal input / data processing test platform for evaluating NT3xx P/D processes.

The requirements for the system involved sampling an incoming frequency value, found within an 8 kHz bandwidth of 10 kHz to 18 kHz, with the NT3xx P/D. Based on the sampled frequency value, a count is produced by the NT3xx P/D, and handed off to a DSP Processor. In the DSP Processor, an ASCII output value between 0 and 255 is determined, which is dependent upon the NT3xx P/D count. The ASCII values between 0 and 255 represent a "channel" designator, corresponding to the original input frequency. The demodulated channel value, consisting of an 8-bit digital word framed by one start bit and one stop bit, is transmitted from the serial port of the DSP at 9600 bits per second, and concluded by a Carriage Return character.

**Test Hardware Description**

For reference, a Block Diagram of the 256 T/D setup for testing on NUMA Technologies' EVAL-1 Evaluation Board is shown on the next page. In describing the setup, we note that the EVAL-1 board is supplied with input signal frequencies between 10 and 18 kHz by a multifunction synthesizer at an input level of 250 mVolts Peak. The multifunction synthesizer's output is applied directly to the EVAL-1 board's input stage ( the "Limiter" ), which consists of an operational amplifier, and a comparator. Power is supplied to the EVAL-1 board by a DC power supply set at nine volts.



## Block Diagram: Channel Decoder Setup for NT302 P/D Converter

In describing the EVAL-1 board's operation, we begin with the Limiter input stage. In the Limiter, the operational amplifier's function is to provide gain to the incoming signaling frequency, while the comparator provides "limiting", with "Q" and "/Q" output (ie.: here, /Q is stated as "not" Q). In this representation, Q corresponds to negative-going zero-crossings, while /Q relates positive-going zero-crossings. The Q and /Q information is applied to the NT3xx P/D, which provides signal zero-crossing period measurement. The period measurements, which are output as 12-bit count values, serve as input to the DSP microprocessor. Once the DSP has performed its processing function on a given count input, data representing the channel's ASCII characters is output via the DSP's serial port as a 9600 bit-per-second, TTL-level serial bit stream. Just prior to leaving the EVAL-1 board, the TTL serial bit stream is converted to RS-422 compatible levels.

In order to visually observe the output channel on a PC, we provide an extra stage of data conversion. The extra stage of conversion is accomplished with an RS-422 to RS-232 converter, which provides the PC serial port with RS-232 compatible levels. The PC then displays the channel value with terminal emulation software.

## Technical Details

In assessing the 256 T/D system's requirements, we note that an 8 kHz bandwidth, with  $F_{min}$  equal to 10,000 Hz and  $F_{max}$  equal to 18,000 Hz, can be divided into 256 equi-spaced channels of 31.25 Hz. However, by selecting a frequency spacing of 31 Hz, starting at 10,048 Hz ( $F_{lo}$ ), we can provide 256 integer-based equi-spaced channels, ending at 17,953 Hz ( $F_{hi}$ ). This ad hoc scheme sets 47 Hz between the lower frequency limit and the first channel frequency, and 46 Hz between the last channel frequency and upper frequency limit. To illustrate the concept, an excerpt from the Channel Table for 256 Channel Tone Decoder, included as Appendix 1, is shown below.

| Freq. ( Hz ) | Channel |
|--------------|---------|
| -----        |         |
| 10,000       | none    |
| 10,048       | 0       |
| 10,079       | 1       |
| .            | .       |
| .            | .       |
| .            | .       |
| 17,953       | 255     |
| 18,000       | none    |

The frequency values in the Channel Table are the channel "center frequencies" which serve as input to the NT3xx P/D. Given these inputs, the NT3xx will respond with a "count" value proportional to the input frequency's period. In order to determine the output count values generated by the NT3xx P/D, we must first determine Fclock, the master system clock frequency, using the "Ideal Clock" formula,

$$F_{\text{clock}}(\text{MHz}) = 2 * 4.095 * F_{\text{min}}(\text{kHz}). \quad (1)$$

In the Ideal Clock equation, we set Fmin equal to 10.0 kHz ( as previously noted ), and calculate a value of 81.90 MHz for Fclock ( in the above equation, the "4.095" factor represents the maximum count number the P/D's 12-bit counter can obtain, and the factor "2" is representative of two zero-crossings per signal period ). In order to simplify matters, and conform to a readily available, industry-standard oscillator frequency, we selected the nearby value of 80.00 MHz for Fclock.

When the NT3xx P/D is used in a bounded frequency system, such as that described above, there exists count extrema defined as "Nmin" and "Nmax". The Nmin and Nmax count extrema values are inversely proportional to the frequency values Fhi and Flo, respectively, and are defined by the following equations:

$$N_{\text{min}} = F_{\text{clock}} / ( 2 * F_{\text{hi}} ), \quad (2)$$

and

$$N_{\text{max}} = F_{\text{clock}} / ( 2 * F_{\text{lo}} ). \quad (3)$$

By inserting the values for Fclock, Fhi, and Flo into Equations (2) and (3), we find Nmin equal to 2228 and Nmax equal to 3980.

From the results just obtained for  $N_{min}$  and  $N_{max}$ , we can calculate  $N$ , the maximum, valid number of counts available in the NT3xx P/D "count range",  $\mathbf{N}$ , to be

$$N = N_{max} - N_{min} + 1, \quad (4)$$

noting that the valid NT3xx P/D "count range",  $\mathbf{N}$ , is formally defined by the vector

$$\mathbf{N} = [ N_{max}, N_{max} - 1, N_{max} - 2, \dots, N_{min} + 1, N_{min} ]. \quad (5)$$

From Equation (4) we determine that  $N$  is equal to 1753, and from Equation (5), we note that  $\mathbf{N}$  is comprised of the following values: [ 3980, 3979, 3978, ... , 2229, 2228 ]. For reference, the channel center frequency counts,  $\mathbf{N}(F_c)$  -- with  $F_c$  defined as the channel center frequency -- are tabulated in the "Count" column in the "Channel Table for 256 Channel Tone Decoder" in Appendix 1. Each value of  $\mathbf{N}$  is determined by a variant of Equation (2), where  $\mathbf{N}$  is substituted for  $N_{max}$ , and  $F_c$  is substituted for  $F_{lo}$ . The calculated results are "rounded" to obtain integer count values.

With 256 discrete frequencies, comprised of a bandwidth of 8000 Hz, we can determine the average "channel count bandwidth" to be  $\pm 15.6$  Hz. However, for the NT3xx P/D processor, the "count bandwidth" about a given channel count is inversely proportional to the frequency limits and is not a constant value; Each individual channel will span a unique range of counts, with the widest count range occurring for the "lowest" frequencies, and the narrowest count range occurring for the "highest" frequencies. The count bandwidth for the "ith" channel is represented by the following range of counts:

$$R_i = [ (M_i + \frac{1}{2} \Delta_{i+1}), (M_i + \frac{1}{2} \Delta_{i+1} - 1), \dots, M_i, \dots, (M_i - \frac{1}{2} \Delta_{i+1}), (M_i - \frac{1}{2} \Delta_{i+1} - 1) ]. \quad (6)$$

In Equation (6),  $M_i$  corresponds to the "ith" count value in the range of  $N_{min}$  to  $N_{max}$ ,  $\Delta_i$  represents the inter-channel count difference between counts  $M_i$  and  $M_{i-1}$ , and  $\Delta_{i+1}$  represents the inter-channel count difference between counts  $M_{i+1}$  and  $M_i$ . The inter-channel count difference,  $\Delta_i$ , is defined by the following relation:

$$\Delta_i = M_{i+1} - M_i. \quad (7)$$

Using the maximum and minimum range values in Equation (6), the count bandwidth, " $B_i$ ", about the "ith" count value can be easily shown to be

$$B_i = \frac{1}{2} ( \Delta_{i+1} + \Delta_i ) \text{ counts.} \quad (8)$$

Using Equation (8), a table of count bandwidth values for all count values in the range  $N_{min}$  to  $N_{max}$  was generated. An excerpt from the "Table of Count Bandwidth Ranges", included as Appendix 2, appears below to provide an example of several count bandwidth ranges, and the associated channel ( included for reference here only ):

| <b>Chan.</b> | <b>R<sub>hi</sub></b> | <b>R<sub>lo</sub></b> | <b>Count</b> |
|--------------|-----------------------|-----------------------|--------------|
| 0            | 3985                  | 3974                  | 3980         |
| 1            | 3973                  | 3962                  | 3968         |

|     |      |      |      |
|-----|------|------|------|
| 2   | 3961 | 3950 | 3956 |
| .   | .    | .    | .    |
| .   | .    | .    | .    |
| .   | .    | .    | .    |
| 254 | 2232 | 2230 | 2231 |
| 255 | 2229 | 2226 | 2228 |

While it is not immediately obvious, we have to re-calculate a new value,  $N'$ , corresponding to the number of counts available in the extended NT3xx P/D count range, determined as result of the count bandwidth range limits. The new  $N'$  value may be determined by calculating

$$N' = R_{hi}(0) - R_{lo}(255) + 1, \quad (9)$$

From Equation (9) we find that  $N'$  is 1760.

### Data Processing Details

Once the NT3xx P/D has "handed off" a count value, "M", to a DSP Processor ( ie: a Digital Signal Processor such as the Analog Devices ADSP2101 ), the value is processed by a software-based "Transfer function". The Transfer Function determines the appropriate "channel" output value -- between 0 and 255 -- by employing a "count-averaging" routine, followed by a "lookup-table" (LUT) procedure. The count-averaging process will mitigate noise, frequency variations, or frequency drift about a given channel's expected frequency bandwidth. The LUT process determines the "index" value into a data array stored in RAM, whose contents span the entire range of  $N'$  values, and correspond to the 256 individual channel values.

The Transfer Function determines the LUT index from the incoming count value by obtaining a data "offset" value. The offset value may be found by subtracting the lowest expected count value, which is  $R(255)_{lo}$ , from the averaged count value,  $M_{avg}$ :

$$\text{Offset} = M_{avg} - R(255)_{lo} + 1. \quad (10)$$

Once a given channel value has been obtained from the LUT, the value is converted from HEX to "n" corresponding ASCII values, using a second LUT. This LUT is a table of 658 ASCII values representing the individual digits in a given channel ( for 256 channels, n can only be 1, 2, or 3 ). The ASCII channel values, framed by "Start" and "Stop" bits ( ie: a 1 for a "stop" bit and 0 for a "start" bit ), are subsequently sent out of the DSP at 9600 bps ( or 960 words per second for 10-bit words ), via the Serial Port coupled to an RS422 driver. Finally, a "Carriage Return" is sent to conclude the transmission of a given channel value. To simplify data reception and to facilitate testing, the data is converted to an RS232 format by an RS422 - to - RS232 Converter,

for reception by an external PC ( N.B.: one could, however, employ any asynchronous compatible serial I/O device ).

Since it is beyond the scope of this report to elaborate on the DSP programming requirements necessary to effect the aforementioned data processing in detail, a separate technical note addressing those aspects of the system will be drafted.

## **In Conclusion**

NUMA Technologies has developed a "256 Channel Tone Decoder". The process provides a method for digitizing an incoming frequency, known to exist in a pre-specified bandwidth, and computing a corresponding output channel value. The channel values, which lie in the range of 0 to 255, are computed in a DSP Processor using a software transfer function. Once determined, the channel's "n" numerical digits are transformed into individual ASCII characters -- each framed by Start and Stop bits -- creating "n" representative 10-bit words. Each 10-bit word representing a digit in the channel value is sent out of the DSP via the serial port at 9600 bps, with the transmission concluded by a Carriage Return.

**Appendix 1: Channel Table for 256 Channel Tone Decoder**

| <u>Freq.</u> | <u>Count</u> | <u>Channel</u> | <u>Freq.</u> | <u>Count</u> | <u>Channel</u> | <u>Freq.</u> | <u>Count</u> | <u>Channel</u> |
|--------------|--------------|----------------|--------------|--------------|----------------|--------------|--------------|----------------|
| 10000        | 4000         | none           | 11443        | 3495         | 45             | 12869        | 3108         | 91             |
| 10048        | 3980         | 0              | 11474        | 3486         | 46             | 12900        | 3100         | 92             |
| 10079        | 3968         | 1              | 11505        | 3476         | 47             | 12931        | 3093         | 93             |
| 10110        | 3956         | 2              | 11536        | 3467         | 48             | 12962        | 3085         | 94             |
| 10141        | 3944         | 3              | 11567        | 3458         | 49             | 12993        | 3078         | 95             |
| 10172        | 3932         | 4              | 11598        | 3448         | 50             | 13024        | 3071         | 96             |
| 10203        | 3920         | 5              | 11629        | 3439         | 51             | 13055        | 3063         | 97             |
| 10234        | 3908         | 6              | 11660        | 3430         | 52             | 13086        | 3056         | 98             |
| 10285        | 3898         | 7              | 11691        | 3421         | 53             | 13117        | 3049         | 99             |
| 10296        | 3885         | 8              | 11722        | 3412         | 54             | 13148        | 3042         | 100            |
| 10327        | 3873         | 9              | 11753        | 3403         | 55             | 13179        | 3035         | 101            |
| 10358        | 3881         | 10             | 11784        | 3394         | 56             | 13210        | 3028         | 102            |
| 10389        | 3850         | 11             | 11815        | 3385         | 57             | 13241        | 3020         | 103            |
| 10420        | 3838         | 12             | 11846        | 3376         | 58             | 13272        | 3013         | 104            |
| 10451        | 3827         | 13             | 11877        | 3367         | 59             | 13303        | 3006         | 105            |
| 10482        | 3816         | 14             | 11908        | 3359         | 60             | 13334        | 2999         | 106            |
| 10513        | 3804         | 15             | 11939        | 3350         | 61             | 13365        | 2992         | 107            |
| 10544        | 3793         | 18             | 11970        | 3341         | 62             | 13396        | 2985         | 108            |
| 10575        | 3782         | 17             | 12001        | 3333         | 6a             | 13427        | 2979         | 109            |
| 10606        | 3771         | 18             | 12032        | 3324         | 64             | 13458        | 2972         | 110            |
| 10637        | 3760         | 19             | 12063        | 3315         | 65             | 13489        | 2965         | 111            |
| 10688        | 3749         | 20             | 12094        | 3307         | 66             | 13520        | 2958         | 112            |
| 10699        | 3738         | 21             | 12125        | 3298         | 67             | 13551        | 2951         | 113            |
| 10730        | 3727         | 22             | 12156        | 3290         | 68             | 13582        | 2945         | 114            |
| 10761        | 3717         | 23             | 12187        | 3282         | 69             | 13613        | 2938         | 115            |
| 10792        | 3706         | 24             | 12218        | 3273         | 70             | 13644        | 2931         | 116            |
| 10823        | 3695         | 25             | 12249        | 3265         | 71             | 13675        | 2925         | 117            |
| 10854        | 3685         | 26             | 12280        | 3257         | 72             | 13706        | 2918         | 118            |
| 10885        | 3674         | 27             | 12311        | 3249         | 73             | 13737        | 2911         | 119            |
| 10916        | 3684         | 28             | 12342        | 3240         | 74             | 13788        | 2905         | 120            |
| 10947        | 3653         | 29             | 12373        | 3232         | 75             | 13799        | 2898         | 121            |
| 10978        | 3643         | 30             | 12404        | 3224         | 76             | 13830        | 2892         | 122            |
| 11009        | 3633         | 31             | 12435        | 3216         | 77             | 13861        | 2885         | 123            |
| 11040        | 3623         | 32             | 12466        | 3208         | 78             | 13892        | 2879         | 124            |
| 11071        | 3613         | 33             | 12497        | 3200         | 79             | 13923        | 2872         | 125            |
| 11102        | 3802         | 34             | 12528        | 3192         | 80             | 13954        | 2866         | 126            |
| 11133        | 3592         | 35             | 12559        | 3184         | 81             | 13985        | 2860         | 127            |
| 11164        | 3582         | 38             | 12590        | 3177         | 82             | 14016        | 2853         | 128            |
| 11195        | 3573         | 37             | 12621        | 3169         | 83             | 14047        | 2847         | 129            |
| 11226        | 3563         | 38             | 12652        | 3161         | 84             | 14078        | 2841         | 130            |
| 11257        | 3553         | 39             | 12683        | 3153         | 85             | 14109        | 2835         | 131            |
| 11288        | 3543         | 40             | 12714        | 3146         | 86             | 14140        | 2828         | 132            |
| 11319        | 3533         | 41             | 12745        | 3138         | 87             | 14171        | 2822         | 133            |
| 11350        | 3524         | 42             | 12776        | 3130         | 88             | 14202        | 2816         | 134            |
| 11381        | 3514         | 43             | 12807        | 3123         | 89             | 14233        | 2810         | 135            |
| 11412        | 3505         | 44             | 12838        | 3115         | 90             | 14264        | 2804         | 136            |

| <u>Freq.</u> | <u>Count</u> | <u>Channel</u> | <u>Freq.</u> | <u>Count</u> | <u>Channel</u> | <u>Freq.</u> | <u>Count</u> | <u>Channel</u> |
|--------------|--------------|----------------|--------------|--------------|----------------|--------------|--------------|----------------|
| 14295        | 2798         | 137            | 15814        | 2529         | 186            | 17333        | 2307         | 235            |
| 14326        | 2792         | 138            | 15845        | 2524         | 187            | 17384        | 2303         | 238            |
| 14357        | 2786         | 139            | 15876        | 2519         | 188            | 17395        | 2299         | 237            |
| 14388        | 2780         | 140            | 15907        | 2514         | 189            | 17426        | 2295         | 238            |
| 14419        | 2774         | 141            | 15938        | 2509         | 190            | 17457        | 2291         | 239            |
| 14450        | 2768         | 142            | 15989        | 2504         | 191            | 17488        | 2287         | 240            |
| 14481        | 2762         | 143            | 16000        | 2500         | 192            | 17519        | 2283         | 241            |
| 14512        | 2756         | 144            | 16031        | 2495         | 193            | 17550        | 2279         | 242            |
| 14543        | 2750         | 145            | 16062        | 2490         | 194            | 17581        | 2275         | 243            |
| 14574        | 2744         | 146            | 16093        | 2485         | 195            | 17812        | 2271         | 244            |
| 14605        | 2738         | 147            | 16124        | 2480         | 196            | 17643        | 2267         | 245            |
| 14636        | 2732         | 148            | 16155        | 2476         | 197            | 17674        | 2263         | 246            |
| 14667        | 2727         | 149            | 16188        | 2471         | 198            | 17705        | 2259         | 247            |
| 14698        | 2721         | 150            | 18217        | 2486         | 199            | 17736        | 2255         | 248            |
| 14729        | 2715         | 151            | 16248        | 2481         | 200            | 17787        | 2251         | 249            |
| 14760        | 2710         | 152            | 16279        | 2457         | 201            | 17798        | 2247         | 250            |
| 14791        | 2704         | 153            | 18310        | 2452         | 202            | 17829        | 2243         | 251            |
| 14822        | 2898         | 154            | 16341        | 2447         | 203            | 17880        | 2239         | 252            |
| 14853        | 2693         | 155            | 16372        | 2443         | 204            | 17891        | 2235         | 253            |
| 14884        | 2687         | 156            | 16403        | 2438         | 205            | 17922        | 2231         | 254            |
| 14915        | 2681         | 157            | 16434        | 2433         | 206            | 17953        | 2228         | 255            |
| 14946        | 2676         | 158            | 16465        | 2429         | 207            | 18000        | 2222         | none           |
| 14977        | 2670         | 159            | 16496        | 2424         | 208            |              |              |                |
| 15008        | 2665         | 160            | 18527        | 2420         | 209            |              |              |                |
| 15039        | 2659         | 161            | 16558        | 2415         | 210            |              |              |                |
| 15070        | 2654         | 182            | 18589        | 2411         | 211            |              |              |                |
| 15101        | 2648         | 163            | 16620        | 2406         | 212            |              |              |                |
| 15132        | 2843         | 164            | 16651        | 2402         | 213            |              |              |                |
| 15163        | 2638         | 165            | 16682        | 2397         | 214            |              |              |                |
| 15194        | 2632         | 168            | 16713        | 2393         | 215            |              |              |                |
| 15225        | 2627         | 167            | 16744        | 2388         | 218            |              |              |                |
| 15258        | 2621         | 168            | 16775        | 2384         | 217            |              |              |                |
| 15287        | 2616         | 169            | 16806        | 2380         | 218            |              |              |                |
| 15318        | 2611         | 170            | 18837        | 2375         | 219            |              |              |                |
| 15349        | 2606         | 171            | 16868        | 2371         | 220            |              |              |                |
| 15380        | 2800         | 172            | 18899        | 2367         | 221            |              |              |                |
| 15411        | 2595         | 173            | 16930        | 2362         | 222            |              |              |                |
| 15442        | 2590         | 174            | 16981        | 2358         | 223            |              |              |                |
| 15473        | 2585         | 175            | 16992        | 2354         | 224            |              |              |                |
| 15504        | 2579         | 178            | 17023        | 2349         | 225            |              |              |                |
| 15535        | 2574         | 177            | 17054        | 2345         | 226            |              |              |                |
| 15566        | 2569         | 178            | 17085        | 2341         | 227            |              |              |                |
| 15597        | 2564         | 179            | 17118        | 2336         | 228            |              |              |                |
| 15628        | 2559         | 180            | 17147        | 2332         | 229            |              |              |                |
| 15659        | 2554         | 181            | 17178        | 2328         | 230            |              |              |                |
| 15890        | 2549         | 182            | 17209        | 2324         | 231            |              |              |                |
| 15721        | 2544         | 183            | 17240        | 2320         | 232            |              |              |                |
| 15752        | 2539         | 184            | 17271        | 2318         | 233            |              |              |                |
| 15783        | 2534         | 185            | 17302        | 2311         | 234            |              |              |                |

**Appendix 2: Table of Count Bandwidth Ranges**

| <u>chan.</u> | <u>R-hi</u> | <u>R-lo</u> | <u>chan.</u> | <u>R-hi</u> | <u>R-lo</u> | <u>chan.</u> | <u>R-hi</u> | <u>R-lo</u> |
|--------------|-------------|-------------|--------------|-------------|-------------|--------------|-------------|-------------|
| 0            | 3985        | 3974        | 46           | 3490        | 3481        | 92           | 3103        | 3097        |
| 1            | 3973        | 3962        | 47           | 3480        | 3472        | 93           | 3098        | 3089        |
| 2            | 3961        | 3950        | 48           | 3471        | 3483        | 94           | 3088        | 3082        |
| 3            | 3949        | 3938        | 49           | 3462        | 3453        | 95           | 3081        | 3075        |
| 4            | 3937        | 3926        | 50           | 3452        | 3444        | 98           | 3074        | 3087        |
| 5            | 3925        | 3914        | 51           | 3443        | 3435        | 97           | 3066        | 3080        |
| 6            | 3913        | 3902        | 52           | 3434        | 3426        | 98           | 3059        | 3053        |
| 7            | 3901        | 3891        | 53           | 3425        | 3417        | 99           | 3052        | 3046        |
| 8            | 3890        | 3879        | 54           | 3416        | 3408        | 100          | 3045        | 3039        |
| 9            | 3878        | 3867        | 55           | 3407        | 3399        | 101          | 3038        | 3032        |
| 10           | 3866        | 3858        | 56           | 3398        | 3390        | 102          | 3031        | 3024        |
| 11           | 3855        | 3844        | 57           | 3389        | 3381        | 103          | 3023        | 3017        |
| 12           | 3843        | 3833        | 58           | 3380        | 3372        | 104          | 3016        | 3010        |
| 13           | 3832        | 3822        | 59           | 3371        | 3383        | 105          | 3009        | 3003        |
| 14           | 3821        | 3810        | 60           | 3362        | 3355        | 106          | 3002        | 2996        |
| 15           | 3809        | 3799        | 61           | 3354        | 3346        | 107          | 2995        | 2989        |
| 16           | 3798        | 3785        | 62           | 3345        | 3337        | 108          | 2988        | 2982        |
| 17           | 3787        | 3777        | 63           | 3338        | 3329        | 109          | 2981        | 2976        |
| 18           | 3776        | 3766        | 84           | 3328        | 3320        | 110          | 2975        | 2969        |
| 19           | 3765        | 3755        | 65           | 3319        | 3311        | 111          | 2988        | 2962        |
| 20           | 3754        | 3744        | 66           | 3310        | 3303        | 112          | 2961        | 2955        |
| 21           | 3743        | 3733        | 67           | 3302        | 3294        | 113          | 2954        | 2948        |
| 22           | 3732        | 3722        | 88           | 3293        | 3288        | 114          | 2947        | 2942        |
| 23           | 3721        | 3712        | 69           | 3285        | 3278        | 115          | 2941        | 2935        |
| 24           | 3711        | 3701        | 70           | 3277        | 3269        | 116          | 2934        | 2928        |
| 25           | 3700        | 3690        | 71           | 3288        | 3261        | 117          | 2927        | 2922        |
| 26           | 3689        | 3880        | 72           | 3260        | 3253        | 118          | 2921        | 2915        |
| 27           | 3679        | 3889        | 73           | 3252        | 3245        | 119          | 2914        | 2908        |
| 28           | 3668        | 3659        | 74           | 3244        | 3238        | 120          | 2907        | 2902        |
| 29           | 3658        | 3848        | 75           | 3235        | 3228        | 121          | 2901        | 2895        |
| 30           | 3647        | 3638        | 76           | 3227        | 3220        | 122          | 2894        | 2889        |
| 31           | 3637        | 3628        | 77           | 3219        | 3212        | 123          | 2888        | 2882        |
| 32           | 3627        | 3618        | 78           | 3211        | 3204        | 124          | 2881        | 2876        |
| 33           | 3817        | 3608        | 79           | 3203        | 3196        | 125          | 2875        | 2889        |
| 34           | 3607        | 3597        | 80           | 3195        | 3188        | 126          | 2868        | 2863        |
| 35           | 3596        | 3587        | 81           | 3187        | 3181        | 127          | 2862        | 2857        |
| 36           | 3586        | 3578        | 82           | 3180        | 3173        | 128          | 2856        | 2850        |
| 37           | 3577        | 3568        | 83           | 3172        | 3165        | 129          | 2849        | 2844        |
| 38           | 3587        | 3558        | 84           | 3164        | 3157        | 130          | 2843        | 2838        |
| 39           | 3557        | 3548        | 85           | 3156        | 3150        | 131          | 2837        | 2832        |
| 40           | 3547        | 3538        | 88           | 3149        | 3142        | 132          | 2831        | 2825        |
| 41           | 3537        | 3529        | 87           | 3141        | 3134        | 133          | 2824        | 2819        |
| 42           | 3528        | 3519        | 88           | 3133        | 3127        | 134          | 2818        | 2813        |
| 43           | 3518        | 3510        | 89           | 3128        | 3119        | 135          | 2812        | 2807        |
| 44           | 3509        | 3500        | 90           | 3118        | 3112        | 136          | 2808        | 2801        |
| 45           | 3499        | 3491        | 91           | 3111        | 3104        | 137          | 2800        | 2795        |

| <u>chan.</u> | <u>R-hi</u> | <u>R-lo</u> | <u>chan.</u> | <u>R-hi</u> | <u>R-lo</u> | <u>chan.</u> | <u>R-hi</u> | <u>R-lo</u> |
|--------------|-------------|-------------|--------------|-------------|-------------|--------------|-------------|-------------|
| 138          | 2794        | 2789        | 186          | 2531        | 2527        | 234          | 2313        | 2309        |
| 139          | 2788        | 2783        | 187          | 2526        | 2522        | 235          | 2308        | 2305        |
| 140          | 2782        | 2777        | 188          | 2521        | 2517        | 236          | 2304        | 2301        |
| 141          | 2776        | 2771        | 189          | 2516        | 2512        | 237          | 2300        | 2297        |
| 142          | 2770        | 2765        | 190          | 2511        | 2507        | 238          | 2296        | 2293        |
| 143          | 2764        | 2759        | 191          | 2506        | 2502        | 239          | 2292        | 2289        |
| 144          | 2758        | 2753        | 192          | 2501        | 2498        | 240          | 2288        | 2285        |
| 145          | 2752        | 2747        | 193          | 2497        | 2493        | 241          | 2284        | 2281        |
| 146          | 2746        | 2741        | 194          | 2492        | 2488        | 242          | 2280        | 2277        |
| 147          | 2740        | 2735        | 195          | 2487        | 2483        | 243          | 2276        | 2273        |
| 148          | 2734        | 2730        | 196          | 2482        | 2478        | 244          | 2272        | 2269        |
| 149          | 2729        | 2724        | 197          | 2477        | 2474        | 245          | 2268        | 2265        |
| 150          | 2723        | 2718        | 198          | 2473        | 2459        | 246          | 2264        | 2261        |
| 151          | 2717        | 2713        | 199          | 2468        | 2464        | 247          | 2260        | 2257        |
| 152          | 2712        | 2707        | 200          | 2463        | 2459        | 248          | 2256        | 2253        |
| 153          | 2706        | 2701        | 201          | 2458        | 2455        | 249          | 2252        | 2249        |
| 154          | 2700        | 2696        | 202          | 2454        | 2450        | 250          | 2248        | 2245        |
| 155          | 2695        | 2690        | 203          | 2449        | 2445        | 251          | 2244        | 2241        |
| 156          | 2689        | 2684        | 204          | 2444        | 2441        | 252          | 2240        | 2237        |
| 157          | 2683        | 2679        | 205          | 2440        | 2436        | 253          | 2236        | 2233        |
| 158          | 2678        | 2673        | 206          | 2435        | 2431        | 254          | 2232        | 2230        |
| 159          | 2672        | 2668        | 207          | 2430        | 2427        | 255          | 2229        | 2226        |
| 160          | 2667        | 2662        | 208          | 2426        | 2422        |              |             |             |
| 161          | 2661        | 2657        | 209          | 2421        | 2418        |              |             |             |
| 162          | 2656        | 2651        | 210          | 2417        | 2413        |              |             |             |
| 163          | 2650        | 2646        | 211          | 2412        | 2409        |              |             |             |
| 164          | 2645        | 2641        | 212          | 2408        | 2404        |              |             |             |
| 165          | 2640        | 2635        | 213          | 2403        | 2400        |              |             |             |
| 166          | 2634        | 2630        | 214          | 2399        | 2395        |              |             |             |
| 167          | 2629        | 2624        | 215          | 2394        | 2391        |              |             |             |
| 168          | 2623        | 2619        | 216          | 2390        | 2386        |              |             |             |
| 169          | 2618        | 2614        | 217          | 2385        | 2382        |              |             |             |
| 170          | 2613        | 2609        | 218          | 2381        | 2378        |              |             |             |
| 171          | 2608        | 2603        | 219          | 2377        | 2373        |              |             |             |
| 172          | 2602        | 2598        | 220          | 2372        | 2369        |              |             |             |
| 173          | 2597        | 2593        | 221          | 2368        | 2365        |              |             |             |
| 174          | 2592        | 2588        | 222          | 2364        | 2360        |              |             |             |
| 175          | 2587        | 2582        | 223          | 2359        | 2356        |              |             |             |
| 176          | 2581        | 2577        | 224          | 2355        | 2352        |              |             |             |
| 177          | 2576        | 2572        | 225          | 2351        | 2347        |              |             |             |
| 178          | 2571        | 2567        | 226          | 2346        | 2343        |              |             |             |
| 179          | 2566        | 2562        | 227          | 2342        | 2339        |              |             |             |
| 180          | 2561        | 2557        | 228          | 2338        | 2334        |              |             |             |
| 181          | 2556        | 2552        | 229          | 2333        | 2330        |              |             |             |
| 182          | 2551        | 2547        | 230          | 2329        | 2326        |              |             |             |
| 183          | 2548        | 2542        | 231          | 2325        | 2322        |              |             |             |
| 184          | 2541        | 2537        | 232          | 2321        | 2318        |              |             |             |
| 185          | 2536        | 2532        | 233          | 2317        | 2314        |              |             |             |