FM Synthesis

• What is FM? • What is DX-FM? • What are Operators and Algorithms? • Critical relationship between "M" and "C"• Non-coincident and Coincident Series • Series generated by M:C • Modulation Amount • FM Synthesizers • Converting between FM synths • Enharmonic Detuned Frequencies •

Definitions

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Oscillator   A device for generating waveforms
FM           Frequency (or Pitch) Modulation - Where the pitch or
frequency of an
             oscillator [the Carrier] is modulated by another
oscillator [the
             Modulator]
DX-FM        DX Synthesizer FM - Where both oscillators use Sine-
waves and are
             "musically-tuned" frequencies generated from a keyboard
"C"          Carrier Frequency- The frequency of the oscillator which
is being
             modulated
"M"          Modulator Frequency - The frequency of the oscillator
which modulates
             the Carrier
```

What is FM?

Frequency Modulation (FM) is where the output of one oscillator is used to modulate the pitch of another, the oscillators being called Modulator and Carrier respectively. "Modulate the Pitch"... that's the key phrase! The pitch of the Carrier is being changed (modulated) in tandem (in sync/ going up and down at the same time) by the Modulator.

Think of it as one person singing and another person grabbing the throat of the first and shaking him in a rhythmic manner; the singer being the Carrier and the throttler being the Modulator.

In analogue synthesizers, you can use an LFO (Low Frequency Oscillator) to modulate a VCO (Voltage Controlled Oscillator). Let's take a slow LFO and modulate the VCO... what happens is that the slowly rising and falling LFO makes the pitch of the VCO rise and fall also, giving you a sort of wobbly sound (referred to as VIBRATO). Increase the modulating LFO Amount and there's more wobbling. Increase the modulating LFO Speed and the wobbling gets faster. This is also commonly called "Pitch Modulation".

What is DX-FM?

On DX synthesizers (DX-FM), the only real difference is that the Modulator is a "musically-tuned frequency" (whose frequency is determined by the notes actually played on the keyboard). The other difference is that DX-FM oscillators are all Sine-waves.

Imagine an old analog synth with 2 VCOs... When you play the keyboard, both the VCOs will emit their respective waveforms, taking its pitch by reference of the notes played on the keyboard. Now imagine rerouting VCO1 into the modulation input for VCO2... Play the keyboard and both VCOs will play their respective notes but now the pitch of VCO2 is changing exactly in time with the frequency of VCO1. And there we have it ... one FM synth (VCO1=Modulator; VCO2=Carrier). Some synths already have this facility except it's commonly called "Cross-Modulation".

What are Operators and Algorithms?

Operators are just Oscillators. Your FM synth will have either 4 or 6 Operators. Why so many Operators? Because the sounds from one Modulator & one Carrier aren't exactly that overwhelming.

Algorithms are the preset combinations of routing available to you. Note that the Carriers are always the last Operators in any Algorithm chain and all other Operators are Modulators.

Critical relationship between "M" & "C"

Let's look at the one Modulator & one Carrier set-up.

[MODULATOR] ------> [CARRIER] -------> [sound output]

The carrier frequency "C" and the modulator frequency "M" will together determine which harmonics will exist (or have the possibility to exist) in the harmonic spectrum. The harmonic spectrum is a graphic representation of frequencies where "1" is the fundamental frequency and the other harmonics are just multiples of the fundamental.

```
The rules determining which harmonics can exist are as follows:-
a  There will always be a harmonic at "C", the Carrier frequency.
b  To the right of "C" (harmonics greater than "C"), there will be harmonics
   following the series C+M, C+2M, C+3M, C+4M etc.
c  To the left of "C" (harmonics less than "C"), there will be harmonics
   following the series C-M, C-2M, C-3M, C-4M etc.

So if "C"=9 and "M"=2,
(i)   there will be one harmonic at 9,
(ii)  on the right, there will be the harmonic series 11, 13, 15, 17 etc, and
(iii) on the left, there will be a similar series 7, 5, 3, 1 etc.

     [-------------Harmonic Series - "C"=9 and "M"=2--------------]
        |      |      |      |      |      |      |      |      |
        1      3      5      7      9     11     13     15     17
      C-4M   C-3M   C-2M   C-M   Carrier  C+M   C+2M   C+3M   C+4M
```

What is happening is that the energy of the modulation is transformed into "Sidebands" (the series of harmonics on both sides of the Carrier).

The appearance of Sidebands is always in pairs on each side of "C". These Sideband pairs are ranked by their "order" of separation from "C" (eg 1st pair is "M" distance apart from "C", 2nd pair is 2x"M" distance apart from "C"... etc).

```
Now, it is important to note the following:-
a  If "C" was detuned down to 8.5, then the whole harmonic spectrum would be
   shifted down by 0.5! So detuning "C" shifts the entire spectrum.
b  If "M" was detuned down to 1.5, then the Sidebands would move in closer and be
   separated by 1.5! So detuning "M" compresses or expands the Sideband separation.
c  IMPORTANT - Of the left-hand-side Sidebands, there comes a point where the
   Sidebands go beyond zero. Sidebands with negative values are "reflected
   Sidebands" (reflection point = 0, silence). Don't worry about this. Ignore the
   minus-sign and treat it as another Sideband.
```

Non-Coincident and Coincident Series

Let's look at a few examples. Reflected Sidebands are denoted by brackets. These examples only give frequencies up to the 6th Sideband but, of course, the number of Sidebands is, in theory, infinite. In general, the intensity of the higher Sidebands will decrease in intensity to a point where they become inaudible. At this point, don't worry about the heights (amplitude)of the harmonics because they haven't been determined yet.

```
   Examples
   M  :  C     Sidebands
   2  :  3     5     7     9     11     13     15
      :        1    (1)   (3)   (5)    (7)    (9)
   3  :  5     8     11    14    17     20     23
      :        2    (1)   (4)   (7)   (10)   (13)
   1  :  1     2     3     4     5      6      7
      :        0    (1)   (2)   (3)    (4)    (5)
```

a In M:C = 2:3, the reflected Sidebands are coincident with the non-reflected Bands. In this case, there are two components in each Sideband.
b In M:C = 3:5, the reflected Sidebands do not coincide with those of the non-reflected. In this case, each Sideband stands alone.
c In M:C = 1:1, the Sidebands are coincident except that there is a Band at the Zero frequency. Obviously, you cannot hear this particular frequency as it is silent.

When the sidebands are coincident, you'll notice that the separation between them is regular. With non-coincidental sidebands, you'll have an alternating separation (eg 1,2, ,4,5, ,7,8... etc). This sort of harmonic arrangement cannot be obtained using normal subtractive synthesis.

IMPORTANT NOTE - if you replace the Carrier value with that of any Sideband (reflected or not), you get the same Series. Try it!

Also note that detuning the Carrier Frequency (C) produces quite a remarkable change in the series. In M:C = 1:1 (with coincident sidebands), if we detune the Carrier to C=1.01, the unreflected bands will be at 2.01, 3.01, 4.01, 5.01 etc and the reflected bands will be at 0.99, 1.99, 2.99, 3.99, etc, so they no longer coincide.

Series generated by M:C

Below are 2 tables. In the first table, use "M" and "C" values to find out what Series is being generated. Then go to the second table to see the harmonic spectrum of that Series.
Certain series have a "x2" or "x3" on them. It is the same series except that it is transposed upward by that amount.

SERIES generated by Modulator-to-Carrier combinations ("M"=columns; "C"=rows)

C\M	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1:1	2:1	3:1	4:1	5:1	6:1	7:1	8:1	9:1	10:1	11:1	12:1	13:1	14:1	15:1	16:1
2	1:1	1:1x2	3:1	2:1x2	5:2	3:1x2	7:2	4:1x2	9:2	5:1x2	11:2	6:1x2	13:2	7:1x2	15:2	8:1x2
3	1:1	2:1	1:1x3	4:1	5:2	2:1x3	7:3	8:3	3:1x3	10:3	11:3	4:1x3	13:3	14:3	5:1x3	16:3
4	1:1	1:1x2	3:1	1:1x4	5:1	3:1x2	7:3	2:1x4	9:4	5:2x2	11:4	3:1x4	13:4	7:2x2	15:4	4:1x4
5	1:1	2:1	3:1	4:1	1:1x5	6:1	7:2	8:3	9:4	2:1x5	11:5	12:5	13:5	14:5	3:1x5	16:5
6	1:1	1:1x2	1:1x3	2:1x2	5:1	1:1x6	7:1	4:1x2	3:1x3	5:2x2	11:5	2:1x6	13:6	7:3x2	5:2x3	8:3x2
7	1:1	2:1	3:1	4:1	5:2	6:1	1:1x7	8:1	9:2	10:3	11:4	12:5	13:6	2:1x7	15:7	16:7
8	1:1	1:1x2	3:1	1:1x4	5:2	3:1x2	7:1	1:1x8	9:1	5:1x2	11:3	3:1x4	13:5	7:3x2	15:7	2:1x8
9	1:1	2:1	1:1x3	4:1	5:1	2:1x3	7:2	8:1	1:1x9	10:1	11:2	4:1x3	13:4	14:5	5:2x3	16:7
10	1:1	1:1x2	3:1	2:1x2	1:1x5	3:1x2	7:3	4:1x2	9:1	1:1x10	11:1	6:1x2	13:3	7:2x2	3:1x5	8:3x2
11	1:1	2:1	3:1	4:1	5:1	6:1	7:3	8:3	9:2	10:1	1:1x11	12:1	13:2	14:3	15:4	16:5
12	1:1	1:1x2	1:1x3	1:1x4	5:2	1:1x6	7:2	2:1x4	3:1x3	5:1x2	11:1	1:1x12	13:1	7:1x2	5:1x3	4:1x4
13	1:1	2:1	3:1	4:1	5:2	6:1	7:1	8:3	9:4	10:3	11:2	12:1	1:1x13	14:1	15:2	16:3
14	1:1	1:1x2	3:1	2:1x2	5:1	3:1x2	1:1x7	4:1x2	9:4	5:2x2	11:3	6:1x2	13:1	1:1x14	15:1	8:1x2

```
15  1:1   2:1  1:1x3  4:1  1:1x5 2:1x3  7:1   8:1  3:1x3 2:1x5 11:4
4:1x3  13:2  14:1  1:1x15 16:1
16  1:1  1:1x2  3:1  1:1x4  5:1  3:1x2  7:2  1:1x8  9:2  5:2x2 11:5
3:1x4  13:3  7:1x2  15:1 1:1x16
```

] and [denote non-coincidental reflected bands.
If "C" appears on any "]", then "[" will be a reflected Band (and vice-versa).
"I" denotes coincidental reflected Bands.

```
Series of Harmonics generated
Series 1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21
22 23 24 25 26 27 28 29 30 31 32
 1:1   I  I  I  I  I  I  I  I  I  I  I  I  I  I  I  I  I  I  I  I  I
I  I  I  I  I  I  I  I  I  I  I
 2:1   I     I     I     I     I     I     I     I     I     I     I
I     I     I     I     I
 3:1   ]  [     ]  [     ]  [     ]  [     ]  [     ]  [     ]  [
]  [     ]  [     ]  [     ]  [
 4:1   ]     [     ]     [     ]     [     ]     [     ]     [     ]
[     ]     [     ]     [
 5:1   ]        [     ]        [     ]        [     ]        [     ]
[     ]        [     ]
 6:1   ]           [     ]           [     ]           [     ]
[     ]           [     ]
 7:1   ]              [     ]              [     ]              [
]              [     ]
 8:1   ]                 [     ]                 [     ]
[     ]                 [
 9:1   ]                    [     ]                    [     ]
[     ]
10:1   ]                       [     ]                       [     ]
[     ]
11:1   ]                           [    ]                          [
]                          [
12:1   ]                             [     ]
[     ]
13:1   ]                                [     ]
[     ]
14:1   ]                                   [     ]
[     ]
15:1   ]                                      [     ]
[     ]
16:1   ]                                         [     ]
[
Series 1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21
22 23 24 25 26 27 28 29 30 31 32
 5:2      ]  [           ]  [           ]  [           ]  [
]  [           ]  [           ]
 7:2      ]        [           ]        [           ]        [
]        [           ]
 9:2      ]              [           ]              [           ]
[           ]
11:2      ]                    [           ]                    [
]                    [
13:2      ]                          [           ]
[           ]
15:2      ]                                [           ]
[           ]
 7:3         ]  [                 ]  [                 ]  [
]  [                 ]  [
 8:3         ]     [                 ]     [                 ]     [
]     [
```

```
10:3         ]           [                 ]           [
]           [
11:3         ]              [                  ]             [
]              [
13:3         ]                    [                 ]
[                 ]
14:3         ]                       [                 ]
[                 ]
16:3         ]                             [                 ]
[
Series 1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21
22 23 24 25 26 27 28 29 30 31 32
 9:4            ]  [                       ]  [
]  [                       ]  [
11:4            ]        [                       ]        [
]        [
13:4            ]              [                       ]
[                       ]
15:4            ]                    [                       ]
[
11:5               ]  [                             ]  [
]  [
12:5               ]     [                             ]     [
]    [
13:5               ]        [                             ]        [
]
14:5               ]           [                             ]
[
16:5               ]                 [                             ]
[
13:6                  ]  [                                   ]  [
]
15:7                     ]  [
]  [
16:7                     ]     [
]     [
```

Also note the series from "5:2" onward share one strange property in that they do not have a harmonic at the fundamental frequency (ie 1).

Modulation Amount

The Modulation Amount determines the loudness/ amplitude of the Carrier and each "order" of Sidebands. "Order" refers to the sideband's ranking from the Carrier (ie 1st, 2nd, 3rd sideband) and they are always in pairs. The resultant FM output will be symmetrical for each "order" of sideband pairs.

The exact amplitudes are very difficult to calculate and, quite frankly, you only need to know how the bands are affected (rather than go through the messy calculations).

Very basically, as you increase the Modulation Amount, more and more sidebands will appear. The way in which the sidebands appear is what gives DX-FM its characteristic sound.

```
a  When there is no modulation, only the Carrier frequency exists (no
sidebands).
b  At low levels of modulation, the amplitude distribution (the
heights is the
   harmonic spectrum) is sort of tent-like with the apex being "C".
c  As the modulation is increased to moderate levels, the
distribution becomes more
   bell-shaped (centred around "C").
d  From here, small increases in modulation make the bell-shape wider
(ie more
   sidebands).
```

e As the modulation is increased to much higher levels, the distribution changes
   into a pair of bell-shapes at the middle orders with a "spike" at "C".

The table below shows the distribution changes as the Modulation Amount is increased (Top graph is least modulation and bottom graph is most modulation). The graphs serve only as guides and are not accurate.

The examples given are

i   M:C = 1:7 [with no reflected sidebands],
ii   M:C = 3:4 [with reflected sidebands which are non-coincident], and
iii M:C = 1:1 [with reflected sidebands which are coincident].

```
           M:C = 1:7            -        M:C = 3:4
- M:C = 1:1
                                -
- |
             |                  -          |
- |  |
             |                  -          |
- |  |
             |                  -          |
- |  |
          |  |  |               - |        |        |
- |  |  |
          |  |  |               - |        |        |
- |  |  |
       |  |  |  |  |            - |  |     |        |        |
- |  |  |  |
    |  |  |  |  |  |  |         - |  |     |  |     |        |
| - |  |  |  |  |
2  3  4  5  6  7  8  9 10 11 12 - 1  2  3  4  5  6  7  8  9 10 11 12
13 - 1  2  3  4  5  6  7
                                -
-    |
             |                  -          |
- |  |
             |                  -          |
- |  |  |
             |                  -          |
- |  |  |
          |  |  |               - |        |        |
- |  |  |  |
       |  |  |  |  |            - |  |     |        |       |
- |  |  |  |
    |  |  |  |  |  |  |         - |  |     |  |     |       |      |
- |  |  |  |  |
 |  |  |  |  |  |  |  |  |      - |  |     |  |     |  |    |      |
- |  |  |  |  |  |
2  3  4  5  6  7  8  9 10 11 12 - 1  2  3  4  5  6  7  8  9 10 11 12
13 - 1  2  3  4  5  6  7
                                -
-       |
                                -
-       |
             |                  -          |
- |  |  |  |
             |                  -          |
- |  |  |  |
       |     |     |            -    |     |                 |
- |  |  |  |  |
```

```
    |  |  |  |  |  |  |       - |  |     |  |     |        |
| - |  |  |  |  |
  |  |  |  |  |  |  |  |  |   - |  |     |  |     |  |     |
| - |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  | - |  |     |  |     |  |     |  |
| - |  |  |  |  |  |  |
2  3  4  5  6  7  8  9 10 11 12 - 1  2  3  4  5  6  7  8  9 10 11 12
13 - 1  2  3  4  5  6  7
                                -
-          |
                                -
-          |
                                -
-       |  |  |
               |                -          |
- |     |  |  |
    |        |        |         -   |      |                 |
| - |     |  |  |
  |  |  |     |     |  |  |     -   |      |  |        |     |
| - |     |  |  |  |
|  |  |  |     |     |  |  |  | -   |      |  |        |     |  |
| - |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  | - |  |     |  |     |  |     |  |
| - |  |  |  |  |  |  |
2  3  4  5  6  7  8  9 10 11 12 - 1  2  3  4  5  6  7  8  9 10 11 12
13 - 1  2  3  4  5  6  7
```

In DX-FM synthesizers, the modulation amount is controlled by envelope generators so quite dramatic timbral changes can be achieved. Having a visual picture of how the modulation amount changes the amplitude distribution helps us understand what is going on.

For more details on the calculating the amplitudes, see DX Spectrum Amplitudes. To look at FM amplitudes graphically, see FM Spectrum Graphs (contains animated GIFs).

FM Synthesizers

FM synthesizers (mainly by Yamaha) underwent 3 stages of evolution.
It started with the classic DX-7 and DX-9. These were intricate synths and were designed for performance. The parameters available were very flexible allowing subtle nuances to be controlled. However, they were very complex to programme.
Next came the affordable DX-21 and DX-100. They were designed to have a wider variety of sounds and simplified parameters. Programming was easier but the finer detail was lost.
Finally came the CX-5 and FB-01. They were FM for computers and a few minor design changes only. These designs were later used for computer sound-cards.

We can analyse the design differences into basically 4 types of FM synthesizers, as follows:-

```
Synth        | DX-7,5,1      | DX-9      | DX-21,27,100 | CX-5,7,11     |
             | TX-7,816,802  |           | TX-81Z       | FB-01         |
-------------|---------------|-----------|--------------|---------------|
Mod.Output   | {---- Orig (0~99) ----}   |   X (0~99)   |  CX (0~127)   |
Parameters   | {---- Rate/Level -----}   | {--------- ADSDR ---------}  |
Algorithms   |     6-op      | {--------4-op---------}  |   CX 4-op     |
```

Note - Elka EK-44 and EM-44 fall under the DX-21 category.

MOD. OUTPUT - This is the output level of the Modulator into the Carrier. Basically, there are 3 types (I've made up the names). The Orig (0~99) could output a Modulation Index from 0~13.1 (Mod.Index is the scientific measurement of the Modulator output value). The X (0~99) could output a higher range 0~25.1 Modulation Index. The CX (0~127) was similar to the Orig with a range 0~12.6 Modulation Index but the bias was different.
PARAMETERS - The classic FM synths used Rates and Levels for most of their parameters. The subsequent generations were simplified to the more "normal" synthesizer paramenter like ADSDR for envelopes.
ALGORITHMS - Algorithms are the combinations of Modulation and Carrier Operators available on

the synth. The classic FM synths used 6-operators and had 32 algorithms. The exception was the DX-9 with 4-operators and 8 algorithms. This 4-op design was carried forward onto the subsequent synths. The CX/FB computer range also used the same 4-op design except that the operators were numbered in reverse order.

Converting between FM synths

Direct conversion between the different FM synths can be a bit tricky. Below are some conversion tables for the various FM synths. Please note that there are limitations to conversion (eg Conversion from 6-op to 4-op ~or~ from a complex Rate/Level envelope to ADSDR may not be ideal).

MODULATION OUTPUT CONVERSION

Orig :	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75
X :	3	6	11	15	19	23	28	33	38	43	48	53	58	63	68
CX :	21	32	42	49	54	59	64	69	74	79	84	89	94	99	104

continued...

Orig :	80	82	84	86	88	90	91	92	93	94	95	96	97	98	99
X :	73	75	77	79	81	83	84	85	86	87	88	89	90	91	92
CX :	109	111	113	115	117	119	120	121	122	123	124	125	126	127	127

ENVELOPE PARAMETERS

Attack (A) ~ Rate (R) Conversion

DX-7 R:	15	21	27	34	40	47	54	60	67	74	80	85	89	93	96	99
DX-21 A:	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31

Decay (D) ~ Rate (R) Conversion

DX-7 R:	10	16	21	27	33	39	45	51	57	63	69	75	81	87	93	99
DX-21 D:	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31

Sustain (S) ~ Level (L) Conversion

DX-7 L:	35	39	44	48	53	57	62	66	71	75	80	84	89	93	99
DX-21 S:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Release (R bottom) ~ Rate (R top) Conversion

DX-7 R:	21	27	32	38	43	49	54	60	65	71	76	82	87	94	99
DX-21 R:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Certain parameters like Feedback and Frequency are the same (although Frequency may take some fiddling to convert). However, most other parameters are not the same.

Enharmonic Detuned Frequencies

The frequency of an operator is dependent on 3 parameters (1) the Coarse Frequency, (2) the Fine Frequency, and (3) Detune. So far, we have dealt mainly with the Coarse Frequency which is the main integer ratio of the base frequency (eg M:C = 2:1). We have also looked at Detune and its effects where (a) detuning the Carrier shifts the entire spectrum, and (b) detuning the Modulator changes the separation between the sidebands.

FM synths will have some form of Fine Frequency. The Fine Frequency allows the selection of non-integer multiples of the base frequency. Normally, this would yield something clangorous or enharmonic. This brings another dimension into FM sounds because a new set of overtones are introduced. Typically, this would be used for bell-type or percussion sounds. You can also obtain very unique and strange timbres too (a great source of experimentation).

Specifically for the original DX-7 (and DX-9) range, the Fine Frequency can also be used to obtain "extra" detuning for the operator. Basically the Fine Frequency had a range of 0~99 where each increment increased the Frequency by 1 percent. The table below shows the frequencies which are within 0.05 of a Coarse frequency; achieved by a combination of the CF [Coarse Frequency selected] and FF [Fine Frequency increments].

Freq	CF	FF	Freq	CF	FF	Freq	CF	FF	Freq	CF	FF	Freq	CF	FF
0.505	0.5	1	4.95	3	65	11.97	7	71	18.96	12	58	25.95	15	73
0.510	0.5	2	4.96	4	24	11.97	9	33	18.98	13	46	25.96	22	18
0.515	0.5	3	4.98	3	66	11.99	11	9	19.03	11	73	25.99	23	13
0.520	0.5	4	5.01	3	67	12.04	7	72	19.04	14	36	26.01	17	53
0.525	0.5	5	5.04	4	26	----	--	--	19.04	16	19	26.03	19	37
0.530	0.5	6	5.04	3	68	12.95	7	85	19.04	17	12	26.04	14	86
0.535	0.5	7	5.05	5	1	12.96	9	44	19.05	15	27	26.04	21	24
0.540	0.5	8	----	--	--	12.96	8	62	----	--	--	----	--	--
0.545	0.5	9	5.95	5	19	12.96	12	8	19.95	19	5	26.98	19	42
0.550	0.5	10	5.96	4	49	12.98	11	18	19.95	15	33	27.02	14	93
----	---	--	5.97	3	99	13.02	7	86	19.98	18	11	27.03	17	59
0.950	0.5	90	6.04	4	51	13.04	8	63	20.02	11	82	27.04	16	69
0.955	0.5	91	6.05	5	21	13.05	9	45	20.02	13	54	27.04	26	4
0.960	0.5	92	----	--	--	----	--	--	20.02	14	43	----	--	--
0.965	0.5	93	6.95	5	39	13.95	9	55	20.04	12	67	28.05	17	65
0.970	0.5	94	6.96	6	16	13.97	11	27	----	--	--	28.05	15	87
0.975	0.5	95	6.96	4	74	14.04	12	17	20.96	16	31	----	--	--
0.980	0.5	96	7.02	6	17	14.04	9	56	21.01	11	91	28.95	15	93
0.985	0.5	97	7.04	4	76	14.04	13	8	----	--	--	28.96	16	81
0.990	0.5	98	7.05	5	41	----	--	--	21.96	12	83	28.98	18	61
0.995	0.5	99	----	--	--	14.95	13	15	21.96	18	22	28.98	21	38
1.01	1	1	7.95	5	59	14.96	11	36	21.97	13	69	28.98	23	26
1.02	1	2	7.96	4	99	14.96	8	87	21.98	14	57	29.04	24	21
1.03	1	3	7.98	6	33	14.98	14	7	22.04	19	16	29.04	22	32
1.04	1	4	7.98	7	14	15.03	9	67	22.05	15	47	----	--	--
1.05	1	5	8.04	6	34	15.04	8	88	22.05	21	5	29.96	28	7
----	---	--	8.05	5	61	----	--	--	----	--	--	29.97	27	11
1.95	1	95	8.05	7	15	15.95	11	45	22.95	15	53	30.02	19	58

1.96	1	96	----	--	--	15.96	12	33	22.95	17	35	30.03	21	43
1.97	1	97	8.95	5	79	15.96	14	14	22.96	14	64	----	--	--
1.98	1	98	8.96	7	28	15.99	13	23	22.99	19	21	30.96	18	72
1.99	1	99	8.96	8	12	16.02	9	78	23.01	13	77	30.96	24	29
2.02	2	1	9.03	7	29	16.05	15	7	23.04	12	92	30.97	19	63
2.04	2	2	9.04	8	13	----	--	--	23.04	16	44	31.02	22	41
----	---	--	9.05	5	81	16.95	15	13	23.04	18	28	31.03	29	7
2.96	2	48	----	--	--	16.96	16	6	----	--	--	31.04	16	94
2.98	2	49	9.95	5	99	17.01	9	89	23.97	17	41	31.05	27	15
3.02	2	51	9.96	6	66	17.03	13	31	23.98	22	9	31.05	23	35
3.03	3	1	9.99	9	11	17.04	12	42	24.05	13	85			
3.04	2	52	10.01	7	43	17.05	11	55	----	--	--			
----	---	--	10.02	6	67	----	--	--	24.96	13	92			
3.96	2	98	----	--	--	18.02	17	6	24.96	16	56			
3.96	3	32	10.96	8	37	18.04	11	64	24.96	24	4			
3.98	2	99	10.98	6	83				24.99	17	47			
3.99	3	33	10.98	9	22				24.99	21	19			
4.02	3	34	10.99	7	57				25.02	18	39			
4.04	4	1	11.04	6	84				25.05	15	67			
4.05	3	35	11.04	8	38									

These "near integer" or "extra detuned" frequencies are not available for the other DX-21 variants nor the CX variants.