PSAT2 DTMF Experiment
APRStt – Touchtone® Digital Communications
Using any Radio for Data Exchange

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DTMF (Dual Tone Multi Frequency) (aka Touchtone®) signaling has been built into almost all Amateur Radios for decades and more recently cellphones, yet most hams do not make use of this powerful data entry and data exchange capability for their special events. They continue to use laborious voice directed nets and hand transcribed data. Although APRS brings an ideal digital communications capability to such applications, not all volunteers have the more expensive APRS capable radios. But they all have DTMF!

APRStt has been around since 2001 [*http://aprs.org/aprstt.html*] and used by the author for several special events, but it has not caught on, even though now HT's with built in DTMF are down around $50 each, a fraction of the cost of an APRS radio. To wake things up and give a worldwide demonstration of the power and practicality of DTMF signaling for data exchange, the new PSAT2, on orbit since June 2019, has a primary mode for DTMF uplink and voice/APRS downlink. Although an entire APRStt protocol has been developed for almost any application that APRS can do, the implementation on PSAT2 consists of two DTMF formats that are practical in the space environment. One for worldwide position reporting by Grid Square and the other for sending APRS messages. [*http://aprs.org/psat2.html*]
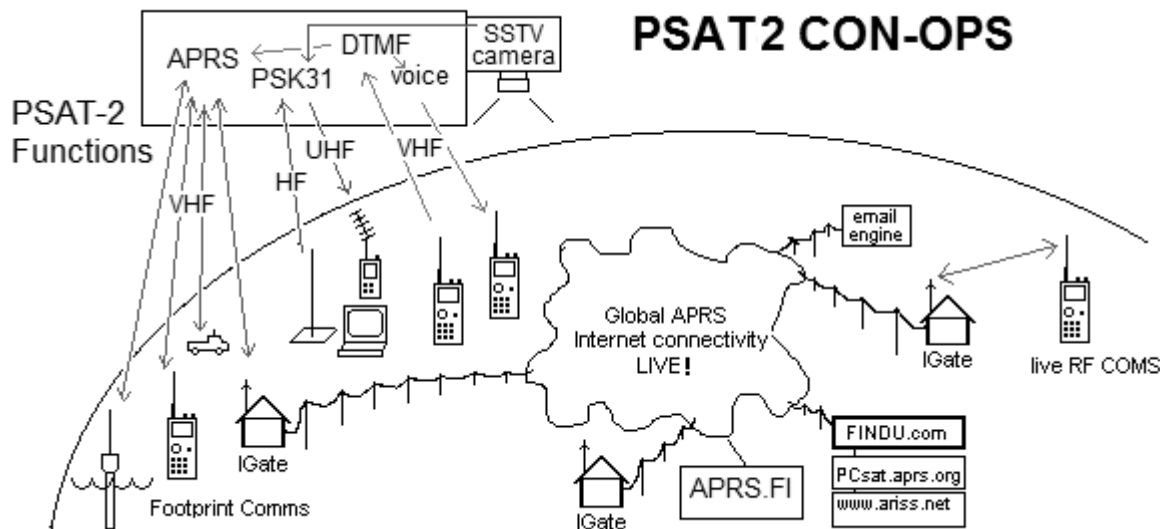

Figure 1. PSAT2 has Packet, PSK31, SSTV, Voice Synthesis and DTMF transponders.

As you can see in the Concept of Operations Figure 1, PSAT2 carries a number of experiments for a number of additional modes beyond just simple digipeating. In fact, these other unique

modes have higher priority compared to digipeating because they are new and different. These modes are a full duplex PSK31 transponder with HF SSB uplink and UHF FM audio waterfall downlink. Also included in the downlink audio passband every four minutes is an SSTV image either from memory or from the live camera if the view appears to be the Earth (ie, not full sun and not the blackness of space). And importantly for this paper, the first ever DTMF uplink-to-APRS downlink with Voice user feedback.

PSK31 and SSTV: The PSAT2 PSK31 and SSTV downlink is on 435.350 +/- Doppler using any UHF FM receiver (SSTV only when PSAT2 is in the Sun). You will see the audio waterfall with satellite telemetry at around 280 Hz, PSK31 users between 550 to 950 Hz and occasional SSTV images between 1200 to 2300 Hz. Using SSB uplink on ten meters and UHF FM downlink, the total Doppler shift of PSK31 users is only about 1 Hz per second average. On approaching and receding passes for a user, where Doppler changes very little, conventional PSK31 decoders can work OK.

Full Duplex, Doppler Corrected Uplink: But for serious two-way contacts, users should download the special Doppler corrected PSK31 uplink program written by Andy Flowers, K0XY. It not only adjusts your uplink Doppler automatically so you stay at a fixed location in the passband, but it also allows you to operate full duplex with your HF uplink for the full duration of the pass. You can chat with everyone in parallel as fast as you can type! Download: http://www.frontiernet.net/~aflowers/dopplerpsk/dopplerpsk.html

Packet Digipeater: PSAT2 becomes the 6th active APRS digipeater in space. The goal is to have enough digipeaters so that Ham users around the world are never more than a few minutes from position/status reporting and 2-way text messaging anywhere on Earth. Ten satellites would get close to users being no more than about 10 minutes from any next pass. The basis of the packet portion of PSAT2 is the re-packaged Byonics TinyTrack4 APRS transceiver that we call the SATT4 shown in Figure 2. In addition to digipeating, it does all the normal packet telemetry, and command and control as well. Initially, priority is being given to DTMF experiments and the digipeater is off. For live status and downlinks, see [*http://aprs.org/sats.html*].
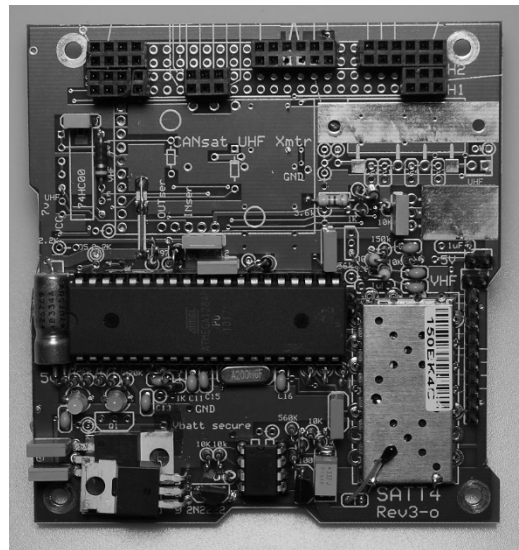

Figure 2. The SATT4 Packet System

APRStt and DTMF: But the real fun and unique experiment is the DTMF uplink, which lets anyone with almost any inexpensive FM radio participate in the usual APRS style contacts. This mission is not so much to demonstrate some kind of great idea for satellites, but more so, to demonstrate to APRS users worldwide the power of DTMF data from-any-radio into the global APRS-IS (internet system). The DTMF downlink from PSAT2 is visible on this web page: http://www.aprsat.com/dtmf
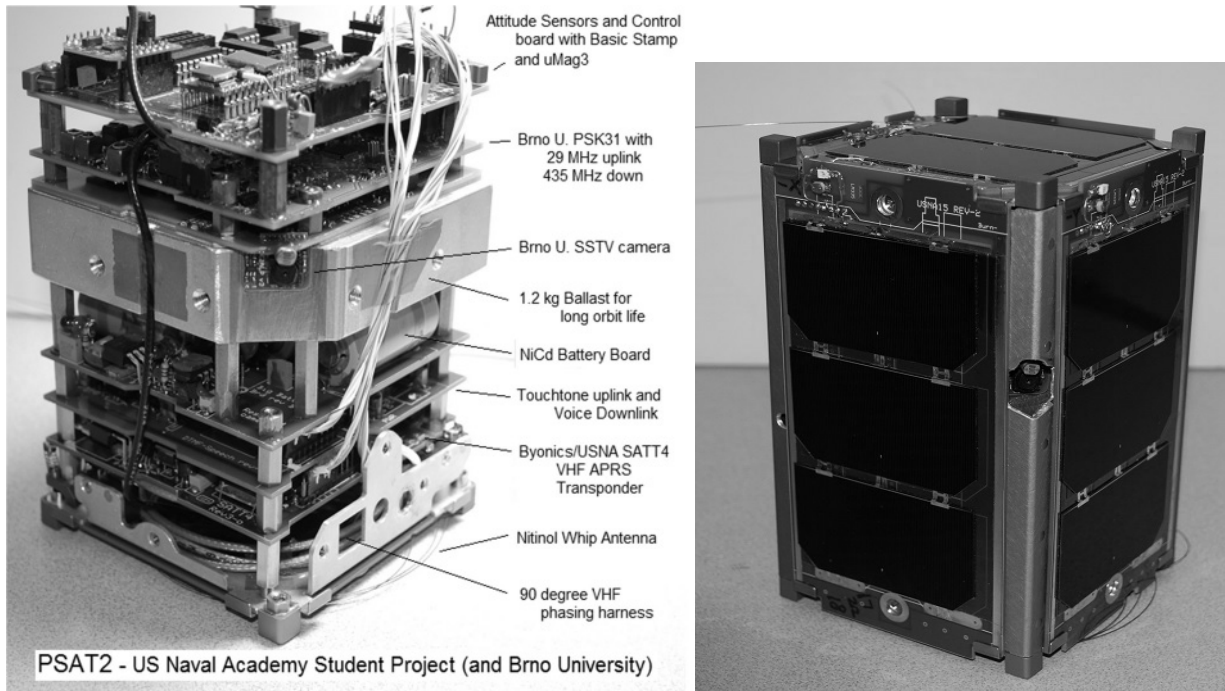
Figure 3. The PSAT2 internal and external views. The camera peeps through a hole in the rail.

Operating Pecularities: PSAT2's 28 degree inclined elliptical orbit with apogee at 860 km and low perigee at 300 km means it never gets higher than 28 degree latitude which makes it difficult to work in Northern states. But the significant difference is the footprint between apogee and perigee shown in Figure 4, which can make a 20 degree or so elevation difference on the horizon. When apogee circulates to be over the northern hemisphere, then more northern stations can work it. The apogee goes through a complete cycle every 34 days.
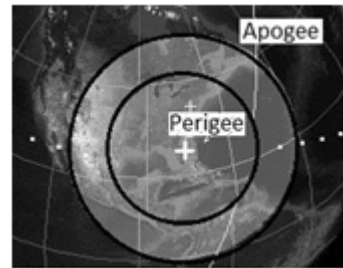
Figure 4. Footprint sizes

Pass Timing for Mobiles: Another interesting thing about the orbit is that it is almost time synchronous; meaning that a pass will occur almost the same time every day (though five minutes later). But then, an earlier pass will appear 90 minutes or so earlier every other day. This makes it very easy to do mobile/portable operations without any computer once you hear one pass and remember the offsets.

Figure 5. PSAT2's easy to remember pass times.

Camera: By default, the HF/UHF PSK31 and SSTV modes have been enabled from launch and available to users. During the in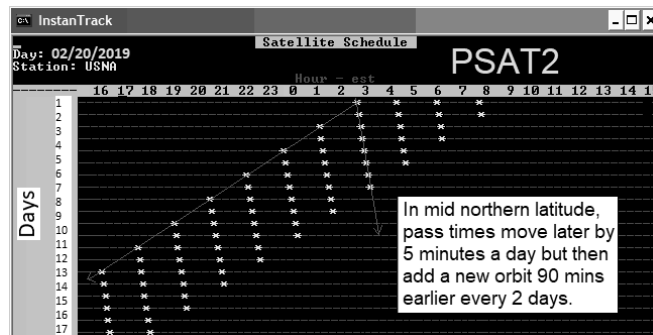itial activation, the camera took some images to file. It has been sending them down over time. The best earth photo is shown here. Later, live camera and other modes were enabled.
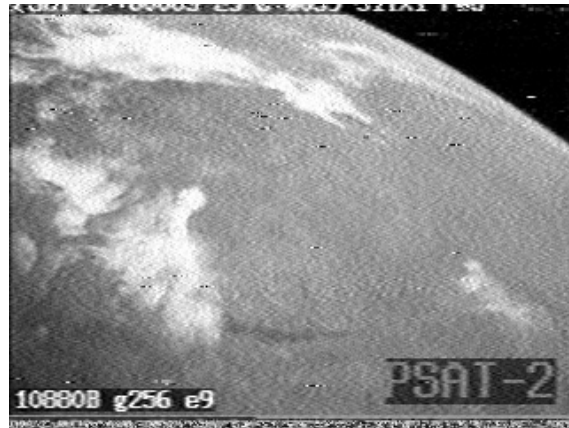
Figure 6. One of the best early SSTV camera images from the Brno University camera.

Mode Status Bits: The 8 bits on the end of every one minute telemetry packet indicates the status of the various modes. Normal digipeater operations will show a pattern of x1xx1xx. But if DTMF is enabled, the DTMF bits are 1101xxxx as shown here. Generally, PSAT2 will be in DTMF mode with the digipeater off to keep the DTMF uplink exclusive for DTMF users on 145.980 MHz.

Figure 7 Default mode Status Bits

Narrowband Uplink Modulation is Required: Unfortunately, PSAT2 uses a low cost off-the shelf receiver with modern narrowband channelization. This causes distortion on all uplinks that are not Doppler compensated. Don't even think about transmitting to PSAT2 with normal USA model radio not set to narrowband and using 5KHz channel steps except for the center few seconds as the Doppler passes rapidly through zero offset. Do not transmit otherwise because PSAT2 will never decode you and you are only jamming others.

Operating Frequencies:

 - APRS/DTMF/Voice downlink: 145.825 1200 baud
 - APRS digi uplink 145.825 if enabled
 - DTMF uplink 145.980 when enabled
 - PSK31 Downlink: 435.350 MHz +/- 5 kHz FM (300 mw)
 - PSK31 Uplink: 29.4815 MHz PSK31 SSB (25 W and omni vertical typical)

Overall APRS Satellite live Web Page: http://aprs.org/sats.html

APRStt GRID MAP Encoding: The map and table below encodes the 99 grids that have 99% of the worlds ham population into only 4 DTMF digits by converting the first two letters into two digits from the 00-99 table. You can see that our Maryland FM19 grid becomes 1819 in DTMF. A table is also shown below that simplifies finding your grid. Notice that three grids for Indonisa OI, OJ, and PI appear in the Canada, USA and Central America blocks.

CallSign Software - Grid Square Map
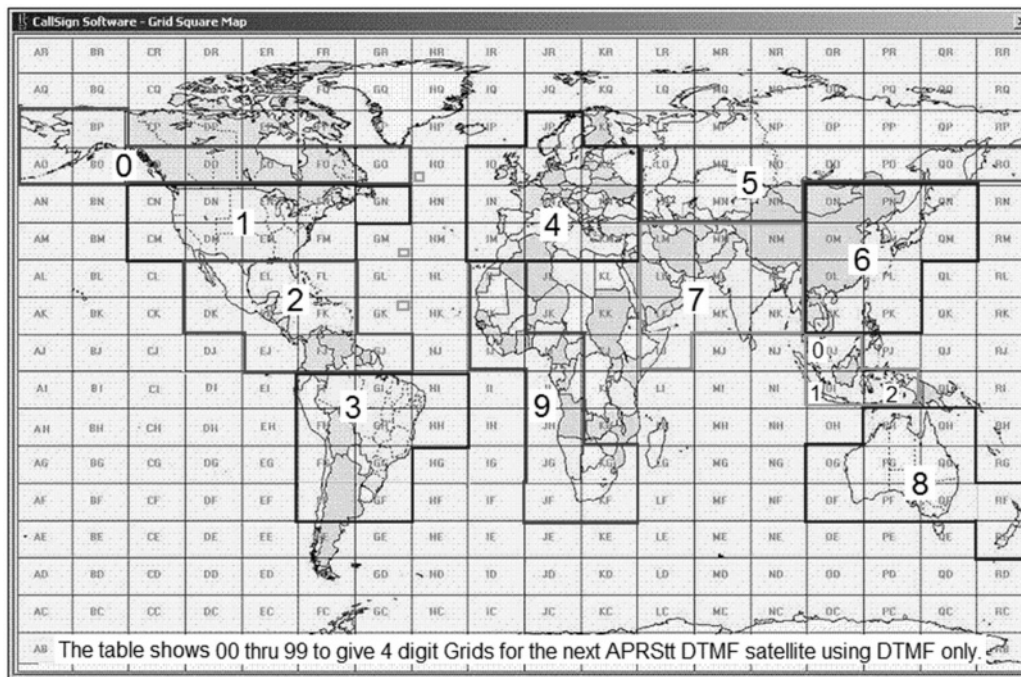
	0	1	2	3	4	5	6	7	8	9
0x Canada										
	00: AP, BP, AO, BO, CO									
	05: DO, EO, FO, GO, OJ									
1x USA										
	10: CN, DN, EN, FN, GN									
	15: CM, DM, EM, FM, OI									
2x C America										
	20: DL, EL, FL, DK, EK									
	25: FK, EJ, FJ, GJ, PI									
3x S. America										
	30: FI, GI, HI, FH, GH									
	35: HH, FG, GG, FF, GF									
4x Europe										
	40: JP, IO, JO, KO, IN									
	45: JN, KN, IM, JM, KM									
5x Russia										
	50: LO, MO, NO, OO, PO									
	55: QO, RO, LN, MN, NN									
6x Japan, China										
	60: ON, PN, QN, OM, PM									
	65: QM, OL, PL, OK, PK									
7x India										
	70: LM, MM, NM, LL, ML									
	75: NL, LK, MK, NK, LJ									
8x Aus/NZ										
	80: PH, QH, OG, PG, QG									
	85: OF, PF, QF, RF, RE									
9x Africa										
	90: IL, IK, IJ, JJ, JI									
	95: JH, JG, KG, JF, KF									

The table shows 00 thru 99 to give 4 digit Grids for the next APRStt DTMF satellite using DTMF only.

Other Grids: Due to popular demand for hams that were left off that map (ie, Hawaii), we can (with the efforts of WA7MXZ and KB6EBR) make adjustments. For Hawaii, we have designated the grid of HI and can distinguish it from the real HI in Brazil by comparing where PSAT2 is at the time of the contact and then correct for it on the DTMF downlink page.

Region		0	1	2	3	4	5	6	7	8	9
Canada / Alaska	0	AP	BP	AO	BO	CO	DO	EO	FO	GO	OJ
United States	1	CN	DN	EN	FN	GN	CM	DM	EM	FM	OI
Central America	2	DL	EL	FL	DK	EK	FK	EJ	FJ	GJ	PI
South America	3	FI	GI	HI	FH	GH	HH	FG	GG	FF	GF
Europe	4	JP	IO	JO	KO	IN	JN	KN	IM	JM	KM
Russia	5	LO	MO	NO	OO	PO	QO	RO	LN	MN	NN
Japan /China	6	ON	PN	QN	OM	PM	QM	OL	PL	OK	PK
India, MidEast	7	LM	MM	NM	LL	ML	NL	LK	MK	NK	LI
Australia/New	8	PH	QH	OG	PG	QG	OF	PF	QF	RF	RE
Africa	9	IL	IK	IJ	JJ	JI	JH	JG	KG	JF	KF

APRStt Callsign Encoding: PSAT2 cleverly compresses a 6 character call into only 10 digits following the 4 digit grid noted above. The first six digits of the call are the matching single keys for the callsign letters, EG: 924227 for WB4APR. The next 4 digits encode the 2 bit location of each of the 6 call letters on each of the 6 keys used. For example, the 6 letters of


```
FM 19 W B 4 A P R
* 18 19 9 24 277 1558 #
      1 2 0 1 1 2
six 2 bit nos showing locations of 6 letters on keys
then converted to 4 digit decimal ———→
                                        wb4apr
```

WB4APR on the 6 keys are key locations 120112. Since each location is between 0 and 3, they can be encoded in 2 bits each (powers of 4) and assembled left to right into a 12 bit binary number. To convert to decimal, take the first 2 bits times 1024, the next 2 bits times 256, the next 2 bits times 64, the next times 16, the next times 4 and the last 2 bits times 1. Then add them up and get the 4 digit decimal "key code" (1558 in this example).

This 4 digit decimal number we call your callsign key code. For those that are 12-bit-challenged, Bob Wood WA7MXZ has written an *DTMF Callsign Encoder* to do this 4 digit number for you.

For shorter calls, right-pad to 6 with spaces. A space is encoded as the "0" key with the key location code of 1. The entire Grid and call report adds a "*" at the beginning and a "#" at the end for the full 16 DTMF key report.   See: [*http://aprs.org/PSAT2Translator.html*]

Other than your gridsquare, you only need to memorize the last four digit special code because your call is simply spelled out with the letters on the keys.

DTMF Robustness: The combined 16 key combination is then stored in the DTMF memory of the users radio so that it can be transmitted in a single 3 second burst. Since the entire code is self contained, is always 16 keys, is sent at a standard speed, always begins and ends with known keys and all keys in-between are decimal only, then any other combinations will be ignored. Also the usual failure mode of DTMF is duplication of digits or omission of digits which will be ignored by the mentioned constraints. A successful uplink will be ACK-ed by voice since the DTMF user cannot see the APRS downlink.

Hints: Since the hardest thing for a DTMF decoder to recognize is two of the same digits in a row, check your own code. If there are no duplicate digits in a row, then you *might* be able to select fast DTMF on your radio. But otherwise, we have found that slower DTMF works best (100 ms). The most important thing of course is using narrowband FM and tracking Doppler within a few hundred Hz. Also, the DTMF receiver goes to sleep after 5 minutes of no use. If you are the first user on your continent, press and hold a key for 3 seconds to wake it up.

DTMF MESSAGES: The DTMF decoder will also accept encoded Messages. Since everything in ham radio has already been said, we simply stored the top 99 common ham radio messages on the spacecraft and you select the appropriate message with a two-digit message number (00 to 99). These messages are the standard ARL radiograms plus some other special ones (such as 40,41 and 42 for QSL's) for this satellite. To send one of these messages in the same 16 key DTMF memory use either the C or B format. These are 16 key DTMF strings that begin with the *"C"* key to indicate a message, and then a 2 digit message number and then a 2 digit modifier xx, followed by the above encoded CALLSIGN. If the message is an actual ARL **Emergency message**, then the modifier should be 99 and the speech will include the word "EMERGENCY". If the modifer is anything over 90, then it will not say Emergency but will say TEST. If the modifier is less than 90, then the modifier will only be used if the template for that message has a blank in it for insertion of the modifier.

DTMF ARL Radiogram Message Format:	*CMMxxCCCCCCXXXX#*
DTMF special reversed QSL Message Format:	*Bxx40CCCCCCXXXX#*

For messaging it is assumed that you will generally just key in the first 3 digits and then finish the uplink with the remaining stored callsign from memory. The **C** format is when you want to send multiple messages from your callsign. Type in the CMM and then have the rest stored in a DTMF memory. The **B** format is when you want to send the same message (such as one of the 3 QSL messages) but easily modify the modifier. In this case, you key in Bxx and then store the remainder of the message and call in a DTMF memory.

In either case, the *"xx"* digits are a numeric modifier that will replace any *"__"* blank in the message text. See the *Actual Flight list of messages* and for background the *standard ARL radiograms* and a copy of the *Maritime Emergency Codes* that are also included.

Making a Contact: When you send your grid and call by DTMF the spacecraft will say *"GRID FM19 from WB4APR, QSO number xx"*. The QSO number increments with each new station up to 99 and rolls over. To complete a contact with such a grid, send the QSL message number 40 (or 41,42) with the QSO number xx. The spacecraft will say *W3XYZ says message number 40 QSL your QSO number xx, my number is yy"* to complete the contact. Of course, an APRS copy of each of these messages will also come down on the downlink for those with APRS radios and be captured by the http://www.aprsat.com/dtmf page.

------------------------------   **APRStt General Use**   ---------------------------------------

Extrapolation of APRStt and DTMF to other local Applications and Events: The full APRStt spec has many formats for position reporting and callsigns, all to fit within the 16 key DTMF memory limit. When data blocks are 4 digits, then full callsigns can be used (10 digits). When up to 7 digits of data are needed (say Marathon runner numbers), then callsign suffixes can be used (5 digits). When up to 9 digits of data are needed, then a 3 digit locally assigned user ID (3 digits) can be used.

Examples of 4 and 6 digit data:

- XXYY gives positions to the nearest mile over a 100 mile square grid area

- XXYY gives positions to the nearest 500' over a 10 mile square grid area

- XXYY gives positions to the nearest 50' in a local event covering a mile (same as GPS)

- XXYY as minutes of Lat/Lon can give 1 mile precision. See Dayton map at right.

- XXXYYY gives positions to the nearest 500' over a 100 mile grid area

- XXXYYY gives positions to the nearest 50' over a ten mile grid area, (GPS resolution)

- NNNNNc can report a runner code "c" for any marathon runner etc
- MMmS can report Status at any tenth of a mile mark in a Marathon
- TTTSSS can report the troop number and score during a jamboree
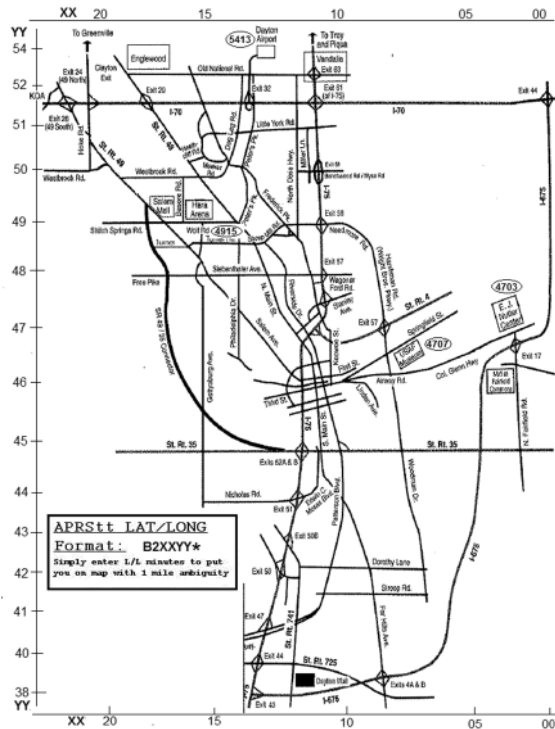
The applications of APRStt are as many and as varied as ham radio itself when there is specific data that needs to be quickly and accurately reported. And any code can be invented for any purpose because all local events are local. Once the code is received at the local APRStt engine, the code is converted to normal APRS packet so that everyone at the event with APRS can see what is going on, and since the APRS-IS then distributes that data worldwide, there is no limit to what can be done.

```
'****************************************************************************|
'***                   PSAT2 list of FLIGHT Messages          18 Nov 2015|
'****************************************************************************|
DTMF messages are sent in 16 key strings starting with the "C", ending in #
BxxMMCCCCCCkkkk# Where CCCCCCkkkk are your callsign keys and key code or
CMMxxCCCCCCkkkk# Where CCCCCCkkkk are your callsign keys and key code and
MM is the message number below and xx is a modifier number spoken in place
of __
Note: Wierd spellings attempt to get the voice on PSAT2 to sound better


'****************************************************************************|
'*                    ARL Emergency Standard Messages         18 Nov 2015|
'****************************************************************************|
 01 Everyone is safe, Do not worry.
 02 I am Coming home as soon as posseble.
 03 In hospetal, Receiving care and recovering.
 04 Only slight property damage here, Do not worry.
 05 I am moving to a new location, Will make contact then.
 06 Will contact you as soon as possible.
 07 Please reply by Amatur Radio.
 08 Need additionel radio equipment for emergency use.
 09 Additionel _ radio operators needed.
 10 Please standby for further information.
 11 Establish Amatur Radio contact on _ meeters.
 12 Ankchus to hear from you.
 13 Medicel emergency sit uation egsits here.
 14 Sit uation here is worsening and becoming criticel.
 15 Please adv eyeze your condition and what help is needed.
 16 Property damage is very significant.
 17 RE ACT communications are on channel _.
 18 Please contact me as soon as posseble.
 19 Request halth and welfare report.
 20 Temporarily stranded, Will need some assistance.
 21 Serch and Rascue assistance is needed.
 22 Need accurate information on conditions at your location.
 23 Report accessebility and best way to reach your location.
 24 Evacuation of razidents from here is urgently needed.
 25 Please adv eyeze weather conditions at your location.
 26 Need help and care for evacuation of sick and injured.
 27 Hi, This was Dove in spaice, anni verse air E
 28 There are _ of us here.
 30 Marytime Emergency Code number _.
 31 We are operating on emergency power.
 32 We are operating on sowlar power.
 33 This is a voice test.
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```
'****************************************************************************|
'*                      ARL GENERAL Standard Messages        18 Nov 2015|
'****************************************************************************|
 40 Q S L, your number _, my number is %. (% is the next number 'CQ msg
 41 Q S L, your C Q number _. 'CQ msg
 42 Q S L, your C Q number _ and thanks for the contact. 'CQ msg
 43 Go Navy, beet Army!. '''
 44 Navy Beets Army by _. ''
 45 I am _ years old.
 46 Greetings on your berthday. 'birthday to bertday
 47 Got your message number _.
 48 I am in school grade _. ''
 49 Celebrating _ munths in spaice.
 50 Greetings by Amatur Radio. 'Amateur to Amatur
 51 Am having a wonderful time.
 52 Really enjoyed visiting with you.
 53 Received your package, Thank you.
 54 Many thanks for your good wishes.
 55 Very delighted to hear your good newze.
 56 Congratulations on your worthy achievement.
 57 Wish we could be twog ether.
 58 Have a wonderful time, Let us know when you return.
 59 Congratulations on the new arrivel, Hope all are well.
 60 Wishing you the best.
 61 Wishing you happy holidays and New Year.
 62 Greetings and best wishes for the holiday season.
 63 Our best wishes are with you, Hope you win.
 64 Arrived safely at _ hours.
 65 Please meet me on arrival at _ hours.
 66 D X Q S Ls are on hand at the Q S L Bureau.
 67 Your message _ is undelivereble.
 68 Best wishes for a speedy recovery.
 69 Welcome, We hope you will enjoy the fun and fellowship.
 70 Call me ON my cell at _ Oh clock.
 71 No cell phone service here.
 72 My Cell phone battery is dead.
 73 Greetings from AMSAT, Keeping ham radio in spaice fo _ years.
 74 My Cell phone charging opportunitees are limited.
 75 Call my cell phone on the hour.
 76 My Radio power charging capabilities are limited.
 77 My next contact time will be in _ minutes.
 78 My next contact time is tomorrow.
 79 Please send items number _.
 80 I am on schedule.
 81 I may be delayed by _ hours.
 82 I may be delayed by _ days.
 83 I may be earlyer by _ hours.
 84 I May be earlyer by _ days.
 85 I may quit earlyer by _ stops.
 86 I may go further by _ stops.
 87 We are camping and enjoying it greatly.
 88 Sending love and kisses!.
 89 Contact me on the _ meeter band.
 90 There are _ of us here.
 91 Celebrating _ weeks in spaice.
```