Sources for a Simulcast Frequency Standard

Management Briefing

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ONE OF A SERIES OF NOTES ON
TECHNOLOGY FROM ADCOMM

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This short paper offers discussion on nontechnical issues related to 9-1-1 systems. It is done as an aid to managers and others with limited technical knowledge of communications. The use of some telephone jargon and terminology is unavoidable, but terms are explained as needed.

SOURCES FOR A SIMULCAST FREQUENCY STANDARD

GENERAL

The coverage of a two-way radio system can be improved by a variety of methods. One of the best methods is the use of simulcast technology and receiver voting. Unfortunately, simulcast systems have a reputation for being expensive to install and difficult to maintain. While some of these complaints are justified, some of the perceived negative aspects of simulcast can be reduced by the application of appropriate technology. A complete discussion of simulcast technology is beyond the scope of this management briefing. However, one critical aspect of implementing a simulcast system is maintaining frequency stability. A variety of methods have been used over the years. The most common has been the use of high-quality temperature controlled crystal oscillators. These can still be used effectively at VHF. However, at UHF the a crystal oscillator may need to be multiplied 24 to 36 times or more to reach frequencies in the 450 MHz range. Since any drift or frequency errors are also multiplied by the same number of times, crystal oscillators are at the limit when used at UHF. At 800 MHz, crystal oscillators are simply not stable enough to provide adequate frequency control. Therefore, some other method of controlling the frequency must be found. The most common method today is to use a crystal oscillator that is locked to a rubidium oscillator. Unfortunately, rubidium oscillators are expensive $5,000 to $25,000. Therefore, we decided to undertake a technology review to determine what other alternatives might be available.

The search results are tabulated and represent all the manufacturers contacted in the time allowed except for suppliers of standalone crystal oscillators. Crystal oscillators, in all their configurations, were found to be less stable than the threshold requirement of E-9 stability over 1 year. The only standalone oscillators capable of that performance, and of reasonable cost, are rubidium (Rb) types. Standalone oscillators have the distinct disadvantage of necessary periodic maintenance to account for inevitable oscillator drift.

A frequency standard disciplined by a highly accurate broadcast service such as one those described below has clear maintenance advantages. It is entirely possible for such a system to require no periodic maintenance at all, i.e., the system could run without adjustment for years.

GPS and LORAN-based systems are the most attractive units technically. Given that the time to repair a failed receiver is on the order of 24 to 48 hours, a disciplined oven-controlled crystal oscillator (OCXO) appears viable.

There are many variations on the themes shown in the table. Several manufacturers have equipment that addresses redundant system configurations (Spectracom, Ball, and Austron primarily). The modular systems, as well as Spectracom*s multibox solution, could be employed in a way that leaves room for such expansion. Also, the data represent the best information that could be obtained in the time allowed for the study. It may be that items shown as "N/A" (function/feature not available) are indeed available as a special perhaps. Likewise, data shown as "na" (information not available) were not obtained in the usual literature/rep presentations or by initial contact with an applications engineer, for instance, but may be obtainable by further factory contact.

A follow-on to this report might be to generate a "request for quote" based on the understanding of the products available, the transmitters to which the product will be applied, redundancy if desired, alarm configuration, MTBF desired, and so on. This would provide a vehicle for examining MTBF numbers, of which I am skeptical. For example, what is the source of the figure, calculated (how) or measured; compare calculated versus measured; characterize the population measured; and so on.

Products of interest are disciplined types:

Spectracom	8165
TrueTime	GPS-XL GPS-705
Datum 9390-52000	
Ball/Efratom	GPS-RR
FTS	2102

Note that Spectracom claims to be the frequency standard supplier to GE where Ball/Efratom is the supplier to Motorola. The success of the Spectracom relationship might be explored.

Time and Frequency Standard Sources

There are a number of systems available that discipline different oscillator technologies by using some generally available source of accurate time and frequency. These sources considered are:

GLOBAL POSITIONING SYSTEM (GPS)

A system of 24 satellites deployed by the DoD for military navigation purposes. Degraded performance is available to nonmilitary users. This is generally acknowledged to be the most accurate system available with virtually complete and dependable worldwide coverage. It should be noted that reception of only one satellite is needed for time and frequency applications, after a multiple satellite acquisition, so GPS offers some redundancy. Frequency accuracy >E-12 is possible.

The system is subject to selective availability. This allows the government to encumber the signal so that users without the proper means of decoding are, in effect, denied use of the satellites. This is unlikely since GPS has been deeply integrated into the country*s communication infrastructure. Enemy jamming is another possibility; however, the system is spread-spectrum and inherently resistant to such measures.

GEOSTATIONARY OPERATIONAL ENVIRONMENTAL SATELLITES (GOES)

This system is comprised of three satellites!two operational with one spare. They are operated by NOAA and provide time data referenced to Coordinated Universal Time (UTC). The two operational satellites are located at 135° and 75° west longitude providing coverage to the western hemisphere. GOES West transmits on 468.825 Mhz and GOES EAST on 468.8375 MHz.

The system has the advantage of universal coverage for the United States. However, there is only one satellite on each frequency. It is not known how long the backup would take to place. Also, the operating frequencies might encounter interference from land mobile radios. The satellites are also subject to outages because of sunspots. The only equipment found provided an accuracy on the order of E-7; consequently, this system is not included.

WWVB

The National Institute of Standards and Technology maintains radio station WWVB as a UTC standard. It broadcasts from Fort Collins, Colorado, at 60 kHz providing coverage over the North American continent. Frequency accuracy $E-9 is possible.

WWVB is subject to a number of perturbations that account for the claim of E-9 accuracy for a signal theoretically capable of much greater accuracy (E-11). These perturbations include:

A largely predictable diurnal phase shift that changes the skywave propagation path from day to night

60 Hz interference, which is generally not a problem except in close proximity to power systems

Electrical disturbances caused by weather

It seems that the method for combatting these errors is a long-term averaging scheme, such that, for sky-wave reception in particular, it may be necessary to average for 24 hours at the site in order to attain maximum accuracy.

In addition, destructive interference can be encountered between the WWVB skywave and groundwave at approximately 750 miles from Fort Collins. All these contributions are claimed to be accounted for, at least in the case of Spectracom, resulting in an overall accuracy spec of E-9.

LORAN C

This is a low-frequency, pulsed, hyperbolic radio aid to coastal navigation. It operates in the 90 kHz to 110 kHz band. It is also used for time and frequency reference purposes. The system is maintained by the United States Coast Guard. LORAN C has been expanded to cover the midcontinent area as well, essentially providing coverage over the continent. Frequency accuracy to E-12 should be possible.

Since LORAN C is a pulsed system, skywave/groundwave interference is avoided. Its second priority is to provide a highly accurate and redundant time standard. With respect to range, the groundwave from a given station is considered reliable over a 1.000-mile distance. With respect to the Twin Falls, Idaho, site, there are LORAN C facilities at George, Washington, Gillette, Wyoming, Fallon, Nevada, and Havre, Montana, that can provide adequate service.

OMEGA

The Omega system is a hyperbolic navigational system designed to provide worldwide coverage in the VLF band from approximately 10 kHz to 14 kHz. While organized differently than LORAN C, its navigational operation and time and frequency management characteristics are similar.

Frequency accuracies to E-11 are possible over a few days of measurement. This system, like WWVB, is subject to a variety of propagational problems. There are few receivers available for use as frequency standards so they are not included here.

TRANSIT

This is a satellite-based navigational system deployed by the Navy. Five satellites operate in polar orbits such that a satellite is in view approximately once every 90 minutes. They operate on two frequencies, approximately 400 MHz and 150 MHz. While widely used for civilian navigation, it has not gained acceptance as a time and frequency standard and is not considered here.

Frequency Distribution

Several amplifiers are tabled below. Another approach, however, might be to use a modular power amplifier along with a power splitter to distribute frequency at an adequate level to multiple transmitters. Depending on the dynamic range of a transmitter*s frequency input, a configuration using a Mini-Circuits amplifier such as a ZFL-500HLN with a four-way splitter might be considered. This configuration would apply somewhat more than 9 dbm to each transmitter at a part cost around $200 (excluding power supply and packaging). Other configurations are certainly possible, which may require attenuation or a different splitter with terminations, but the cost would still be hundreds of dollars.

Note that the Datum 9390-52000 should be able to distribute its +20 dbm 10 MHz output to four transmitters via a passive splitter alone.

Technical Explanations

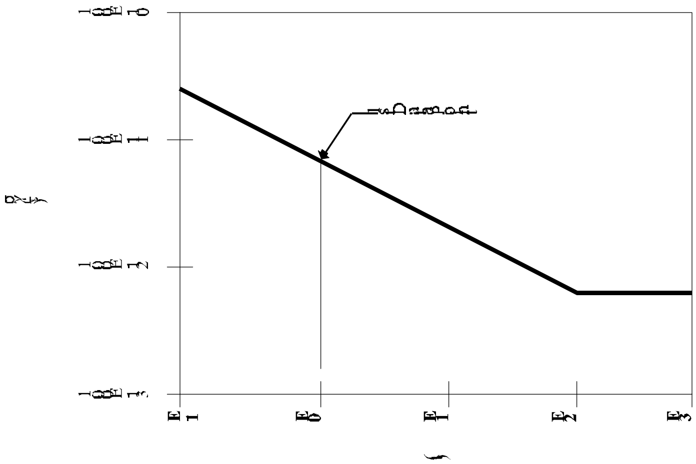
ALLAN VARIANCE

The two-sample deviation or square root of the Allan Variance is the standard method of describing short-term stability of oscillators in the time domain. It is usually described by

$$\sigma_{y}\,\tau = \frac{\qquad}{\mid}\sum_{=}^{-}\ -\ +\ -\ -$$

A graph of Allan Variance could be drawn using the following process. This abbreviated procedure assumes m samples of instantaneous frequency taken at 1s intervals. The process is usually done over a range of (J) and that range can be defined as short-range stability, for instance:

Number of data values available: m=9
Sampling time interval: J=1s



Sampled data values (parts in E-13) might be:

Data Values (y)	First Differences $(\overset{!}{y}_{k+1}\ !\overset{!}{y}_{k})$	First Differences^2 $(\overset{!}{y}_{k+1}\ !\overset{!}{y}_{k})^2$
892		
809	-83	6889
823	14	196
798	-25	625
671	-127	16129
644	-27	729
883	239	57121
903	20	400
677	-226	51076

So:

$$\sum_{=}^{-} \ \overline{} \ {}_{+} \ - \ \overline{} \qquad =$$

Based on these data:

$$\sigma_{\gamma}\ \tau = \frac{\qquad}{} =$$

$$\left[\sigma_{\gamma}\ \tau\right] = \sqrt{\qquad\qquad}$$

$$\sigma_{\gamma}\,\tau = \qquad \tau = \ \varsigma$$

Data values are in 10^{13} (E13)

PHASE NOISE

This is a somewhat elusive specification in this application. It is usually mentioned for rubidium oscillators that typically exhibit this phenomenon to a greater degree than quartz oscillators, particularly close to the fundamental frequency. For 900 MHz, this does not appear to be a concern, at least for certain models of Rb oscillators; it becomes important for much shorter wavelength radar systems.

In a synthesized transmitter, this spec may be overshadowed by the synthesizer*s closed loop and filter performance rather than being simply a matter of multiplying the frequency and its spurs.

RETRACE

This generally refers to the frequency change from one power cycle to the next, usually after some "off" period. It is the frequency error, or hysteresis, encountered from the frequency value at the last power turnoff. It is not considered important, by the manufacturers at least, in a disciplined system where frequency accuracy will always approach a figure much better than 1 part in 10^{-9} after a relatively short averaging time.

Quartz oscillator manufacturers seem to spec this as a short-term aging number that represents the time for an ovenized oscillator to settle. Also, crystal oscillators will tend to age quickly in their early operation (on the order of weeks to several months) settling to reasonably good numbers. Thus, retrace, as such, is a hard number to get for quartz oscillators. While retrace for Rb oscillators is typically satisfactory for this application, it may be wise to consider battery backup for a crystal oscillator if power interruptions may occur.

MTBF

The basic formulas are:

$$= \frac{-}{} \qquad = \frac{-}{}$$

$$= \frac{- \quad -}{}$$

where: MTBF = Mean time between failures
t = Operation time
R = Probability of survival or reliability

These formulas apply for the useful life of the device excluding failures because of infant mortality or a specific wearout mechanism, i.e., random failures only.

Frequency Standards

Brand	Model	Standard	Price/ Qty	Output	Batt?/ Price/Qty	Rack?/ Size/ Price	Ant?/ Price	MTBF (Hrs.)	Trim-Range/ Resol	Stab., Long (locked if disc.)	Stab., Short (unlocked if disc.)	Retrace	Phase Noise/ Hz	Pwr V/I	T opr ºC	) over T	BITE[a]
Ball Efratom	FRK-L (Rb osc. only)	Rb osc.	$5.8k/4 $4.93K/9	1 10 Mhz sine	N/A	N/A	N/A	100k	2E-9/ 1E-11	4E-11/ mo.	3E-11/s	3E-11	na/10 -120/100 -145/1k	22-32VDC 1.8Apk	-25 to +65	3E-10	Rb lock, OC
Ball Efratom	GPS-RR	GPS 6 Rb	$12819	4 10 Mhz sine	Yes/?	Yes	Yes/ incl.	na	N/A	E-12	E-11	3E-11	@10Mhz-125/10 -155/100 -155/1k	Std AC 22.5-32VDC	0 to 50	3E-10	RS-232
Ball Efratom	MFS	Rb	$7600	4 1,5,10 Mhz sine	Yes/$1500	Yes	N/A	na	See FRK	See FRK	See FRK	See FRK	See FRK	AC/DC module (MPS)	-25 to 50	See FRK	Relay/ TTL/ CMOS module
Ball Efratom	MFS	GPS or VLF6Rb	$12250	4 1,5,10 Mhz sine	Yes/$1500	Yes	Yes/ incl.	na	2E-9	E-12	4E-11/mo	2E-11 1 hr @25ºC after 48 hr off	na/10 -120/100 -145/1k	AC/DC module (MPS)	-25 to 50	3E-10 -25 to 50	Relay/ TTL/ CMOS module
Ball Efratom	MFS	GPS or VLF6 XTAL	$9225	4 1,5,10 Mhz sine	Yes/$1500	Yes	Yes/ incl.	na	na	E-11	5E-10/day	na	-120/10 -150/10k	AC/DC module (MPS)	-25 to 50	E-8 -55 to 95	Relay/ TTL/ CMOS module
Spectracom	8165	WWVB6 XTAL	$5450	5 10 Mhz sine	Yes/$540	Yes/ $155	Whip/ $190, loop/ $395	160k	30 steps /6.6E-9	1E-9	2E-9/ wk 5E-10/day	<2E-8 1hr after 48hr pwr loss	na	Std AC 12,24, 48VDC opt. 24W	-30 to 50	<5E-10/ºC[g]	Relay 2A@30 VDC, RS422
TrueTime	GPS-DC Mk III	GPS6 XTAL	$12250	1,5,10 Mhz opt. @$200/ output	No	Yes/ 1.75 in.	Yes/ incl.	26k	N/A	1E-11	1E-10	N/A	@10Mhz -110/10 -100/100 -120/1k	95-260 VAC, 45W. 10-32VDC opt./$475	0 to 50	3.4E-11/ºC[d]	RS-232
TrueTime	GPS-DC Mk III	GPS6 Rb	$14750	1,5,10 Mhzopt. @$200/ output	No	Yes	Yes	26k	N/A	5E-12	1E-10/ / t, 1≤t≤100s	N/A	@10MHz -115/10 -115/100 -115/1k	95-260 VAC, 45W.10-32VDC opt./$475	15 to 35	4E-12/°C[e]	RS-232
TrueTime	GPS-705	GPS6 XTAL	$4995 base	1,5,10 Mhz TTL opt.	No	No	Incl.	na	na	<5E-12 tracking	E-9/1S E-0/100S 3E-12/day	na	na	12 or 24 VDC, 3W	0 to 60	na	RS-232
TrueTime	GPS-XL	GPS6 XTAL	$2995 base	1,5,10 Mhz TTL opt.	No	No	Incl.	na	na	<5E-12 tracking	E-9/1S E-10/100S 3E-12/day	na	na	5VDC@800ma 12VDC@80ma 12 or 24 VDC opt.	0 to 60	na	RS-232

Frequency Standards (Cont.)

Brand	Model	Standard	Price/ Qty	Output	Batt?/ Price/Qty	Rack?/ Size/ Price	Ant?/ Price	MTBF (Hrs.)	Trim-Range/ Resol	Stab., Long (locked if disc.)	Stab., Short (unlocked if disc.)	Retrace	Phase Noise/ Hz	Pwr V/I	T opr ºC	) over T	BITE[a]
Frequency Electronics	FE-5650A	Rb osc.	$3150/9	1 10 Mhz sine	N/A	N/A	N/A	na	2E-7/ 1E-11	2E-9	3E-11	5E-11	-90/10 -125/100 -145/1k	15-18VDC	-5 to 50	3E-10	RS-232 option
Stanford Research[c]	FS700	LORANC 6XTAL	$4950 US list	4 10 Mhz sine	No	N/A	Incl.	N/A		E-12 locked	E-10	na	50E-12/s Allan	Std AC	na	na	No
Datum	9390-5500	GPS6XTAL	~$10K	Opt.	Opt.	Yes/3.5 in	Incl.	na	N/A	E-11 locked/ 10s ave.	Depends on opt. osc.	na	na	DC pwr std AC opt.	0 to 50	na	RS-232
Datum	9390-52000	GPS6 XTAL	$4000/1	1 10 Mhz sine (+20dbm) +3@$300 ea.	No	Yes/ 1.75 in.	Incl. -40 to 50°C	na	N/A	5E-10	#3E-9/day std osc, 5E-10@$600	na	na	10-32 VDC <20W, 100-250VAC opt.	0 to 50	E-7	RS-232 relay/ TTL
FTS/ Austron	2100F[f]	LORAN C	$8310/1														
FTS/ Austron	2100R[f]	LORAN C	$7655/1														
FTS/ Austron	2102	LORAN C6 XTAL	$9500/1	2 10 Mhz (+13dbm)	na	Yes/3.5 in hi	Incl.	na	na	E-12	na	na	na	-48VDC, AC opt.	0 to 50	na	Relay
FTS/ Austron[i]	1295D modular	external6 XTAL	$5925/1 - frame,AC -10Mhz PLL	4 10 Mhz module $835	na	Yes/ 5.25 hi	N/A	133k[j]	na	Depends on source	3E-9/day, init. <E-9/day, 90 days	na	-125/10 -160/10k	AC/DC module, Dconly and redundant versions available	0 to 50?	5E-10 -55 to 60	From C relay
FTS/ Austron[i]	1295D modular	external6 Rb	$13755/1 -frame -Rb	4 10 Mhz module $835	na	Yes/ 5.25 hi	N/A	133k[j]	na	Depends on source	E-11/mo	na	-105/10 -145/10k				
Trak Systems[b]	8821	GPS	$4200/6	4 10 Mhz sine or TTL/box	Backup for osc.	Yes/ 1.75 in.	Yes/incl.	28k est.	N/A	1E-9 while tracking	N/A	na	N/A	85-265 VRMS.100-370 VDC 25 W	0 to 50	10E 8	Relay & TTL

Distribution Amplifiers

Brand	Model	Price/Qty	Outputs- Conn. Type, Level	Output VSWR	Output Distortion	Input- Conn. Type, Level	Input VSWR	Frequency Range	MTBF (Hrs.)	Power	T opr ºC
Spectracom	8143	$2240/1	12 BNC, 600 mv sine @ 50S	na	na	2 BNC, .1-1.0 Vrms@ 50S	na	10 Mhz, 1 or 5 Mhz opt.	??	115 VAC +/- 15%, 60 Hz, 12W. 12/24/48 VDC opt.	
Stanford Research Systems	FS710	$950/1	7 BNC, 1 Vpp 50S, 10% 2 Vpp 10KS, 10%	< 1.2 at 10 Mhz	< -25dbc	1 BNC, 50 mv to 5 Vpp	< 1.2 at 10 Mhz	10 Mhz +/- 100kHz	??	100/12/220/ 240 VAC 50/60 Hz 3 W.	??
Mini-Circuits (modules)[h]	ZFL-500HLN amp with ZFSC-4-1 splitter	~$200/1								Needs separate DC supply	
Ball/Efratom[a]	MTS										
FTS/Austron[a]	1295D										

[a] Manufacturers only form of distribution. Part of high-end, modular systems whose total cost, with RX and osc, starts >$10k.
[b] Trak representative characterized theirhardware as "low-end." It has been used in paging applications, no tesimonials.
[c] This unit appears to be a laboratory instrument. Technical help was not conversant in redundacy issues, simulcast, MTBF. Note lack of temp specs.
[d] Maximum temperature change 10ºC/day.
[e] Maximum temperature change 5 ºC/day.
[f] Receivers only. Separate disciplined oscillators and distribution amps are available.
[g] Maximum temperature change 5ºC/hr.
[h] See discussion above.
[i] These modular systems require an external receiver to discipline the oscillator.
[j] Data from QA report on a population of 2712 units of various configurations.

Key: N/A = Function/feature not applicable.
na = Information not available, either the information was not known by the manufacturer or could not be obtained in a timely fashion.
?? = Data pending.