Using Digital Signal Processor Technology to Simplify Deep Space Ranging

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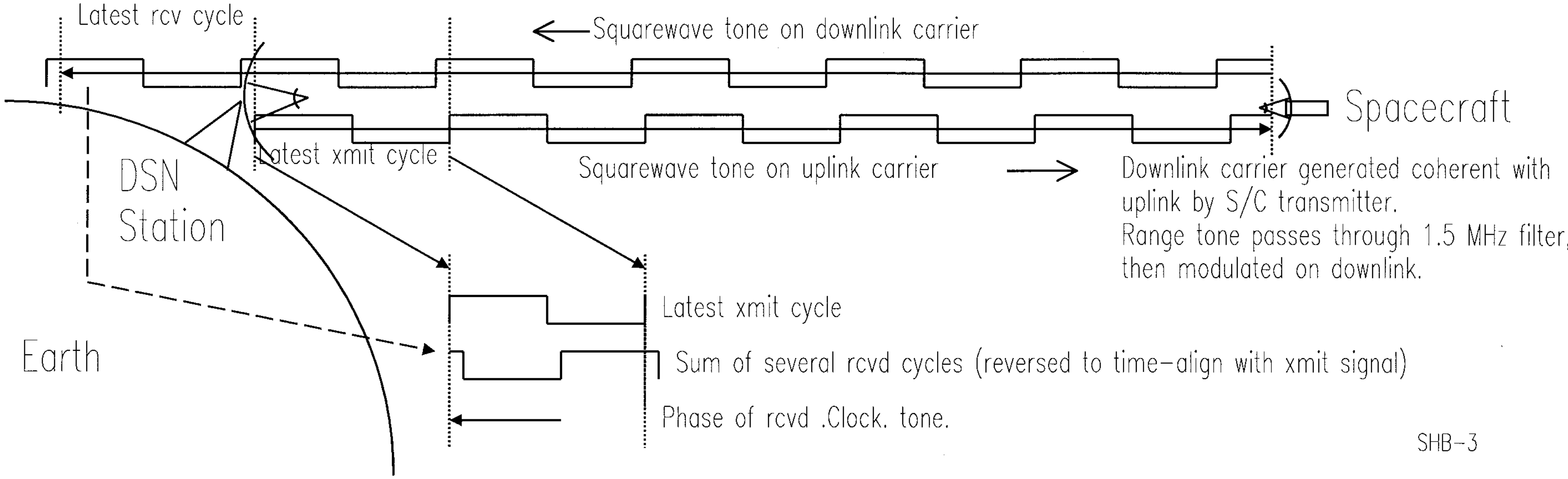
What is .Deep Space. Ranging?

- Ranging measures the distance from a ground station to a spacecraft
- Deep Space means:
  - Large distances. Anywhere from LEO (300 km) to Neptune (4.5 billion km).
  - Weak signal. Down to −20 dB−Hz. But must also handle up to +50 dB−Hz.
  - Precise measurements. Precision depend on the ranging SNR, but the ranging system error sources RSS must be less than 1.25 m 1−sigma (1−way distance in meters).
- Ranging measurements add to Doppler navigation
  - Doppler shift measures spacecraft velocity, but not distance. Spacecraft distance is inferred from an orbit solution. Doppler resolution limited by the carrier loop bandwidth.
  - Ranging measures absolute distance to a resolution limited by ranging signal strength.
  - Orbit solutions from Doppler and range have smaller error ellipses than doppler−only solutions.
- Spacecraft ranging is crucial to navigation in certain operations:
  - Flybys, landings, and aerobraking. Only one chance to get it right.
  - Reduced tracking operations while in cruise mode. One ranging measurement goes a long way.

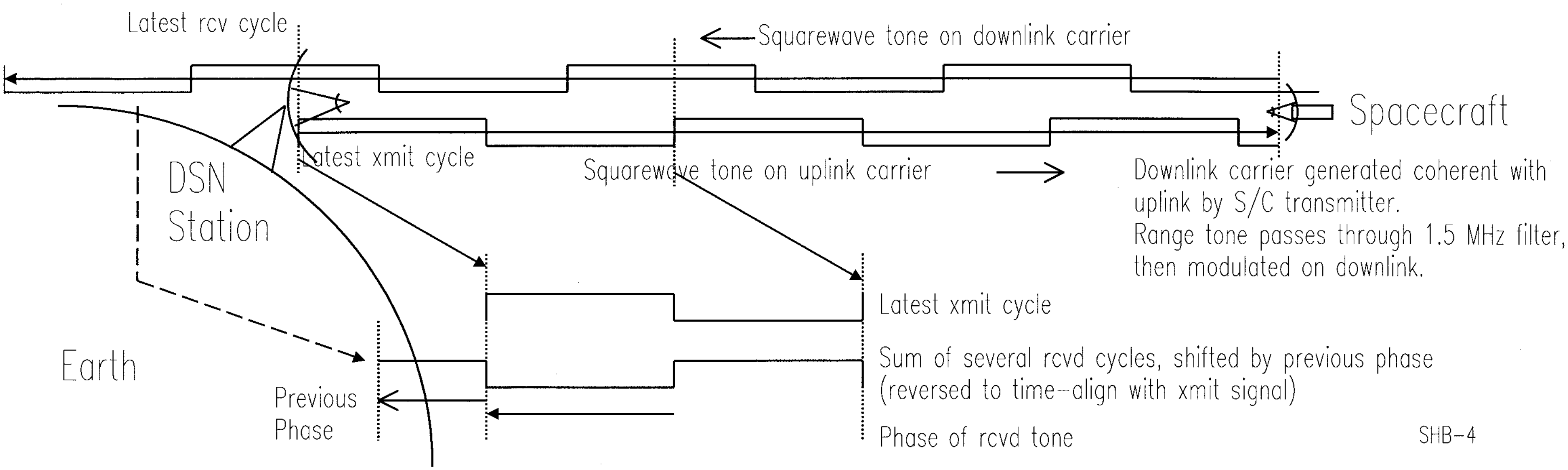
How DSN Ranging Works Today

- The Sequential Ranging Assembly, SRA, measures the phase delay of a sequence of squarewave tones modulated on the carrier.
  - First tone (.Clock. tone) is a 1 MHz squarewave.
  - The spacecraft demodulates the tone, filters it, and remodulates it onto the downlink carrier.
  - The ground receiver demodulates the range tone, sends back to SRA.
  - The SRA integrates many cycles of the received tone, then correlates against the tone being transmitted.
  - The phase shift that maximizes the correlation is the phase delay introduced by the Round Trip Light Time (RTLT) traveled.



How DSN Ranging Works Today (Cont.)

- The phase of the .Clock. tone is only the RTLT modulo 1 cycle of the .Clock. tone, or about modulo 300 meters.
- After the .Clock. tone, the SRA sends a sequence of lower-frequency tones in order to resolve the ambiguity of the .Clock. tone.
- Each tone is exactly ½ the frequency of the previous tone.
  - The SRA does a simplified correlation to determine if the received tone is in-phase or out-of-phase with the current transmit tone.
  - A phase of 0 or +1/2 the tone length is added to the RTLT being resolved.
  - After the .Last. tone, the sequence repeats beginning with the .Clock..



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New Ranging Design to Replace the SRA

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- JPL's Network Simplification Project (NSP) will make significant changes to the DSN's receiver and exciter operations.
- Simplify DSN operations of the Block V Receiver (BVR) and Block V Exciter (ETX) by consolidating related subsystems under single controllers.
- Make each receiver independent of an antenna by using an Intermediate Frequency (I/F) switch assembly. Any receiver can be used with any antenna front end.
- Provide a new, simpler ranging design to meet new requirements:
  - Support Pseudo-random Noise (PN) and sequential squarewave tones. The SRA provides squarewave tones only.
  - Allow an antenna's uplink ranging hardware to work with any downlink channel selected via the I/F switch assembly. The SRA requires hardwiring between the uplink and downlink hardware.
  - Simplify ranging operations by reducing number of controllers to an Uplink Controller (ULC) and a Downlink Tracking and Telemetry (DTT) channel. The SRA requires BVR, ETX, SRA, and Metric Data Assembly (MDA) inputs for control.

New Design is Primarily COTS–based

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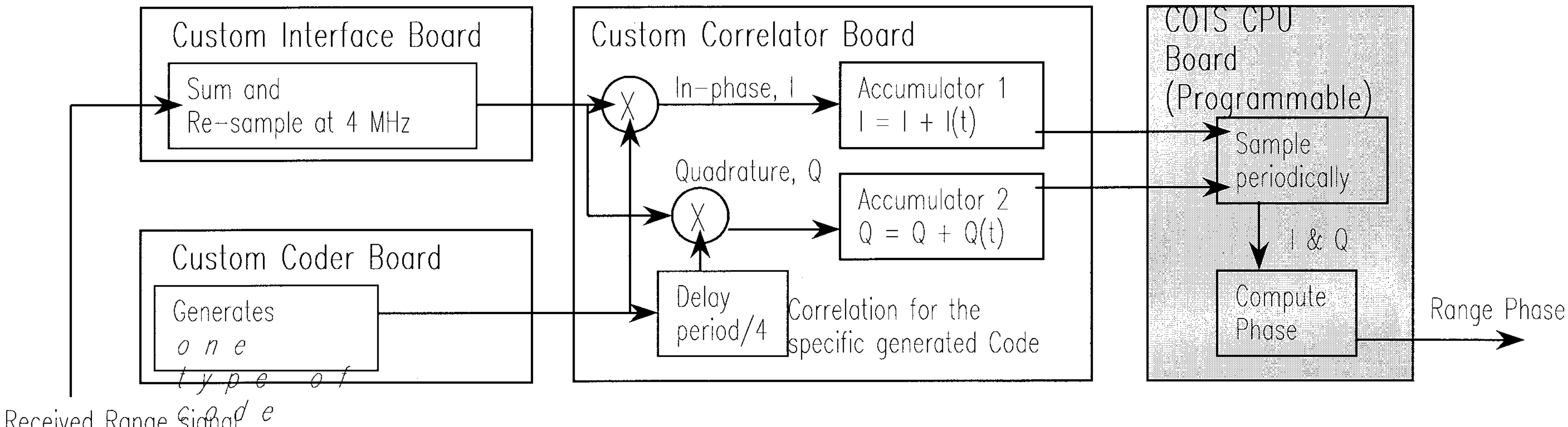
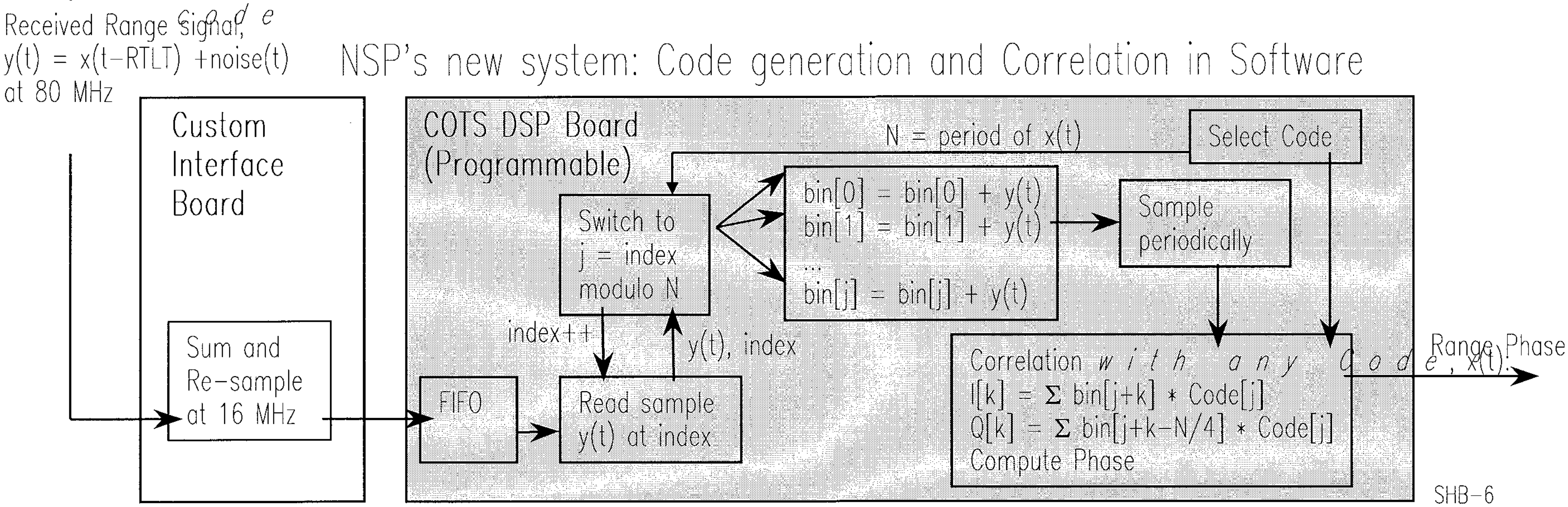
SRA's Old system: Code generation and Correlation in Hardware



NSP's new system: Code generation and Correlation in Software



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New Design Will Provide Old SRA Tones

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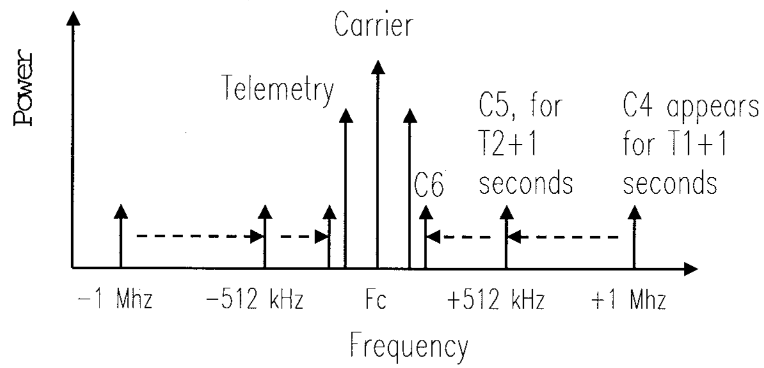
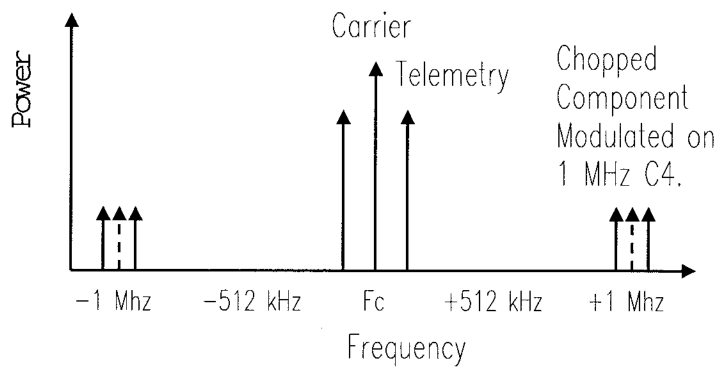
- The SRA produces a sequence of squarewave tones identified by .Component Number..
- Highest frequency tone, .Clock. tone, is about 1 MHz and is called Component 4 (C4).
- The next tone in the sequence, C5, has exactly ½ the frequency of C4 (about 512 KHz). Similarly CN+1 is ½ the frequency of CN.
- Low frequency Components are .chopped. by mixing them with a copy of the .Clock. Component. This keeps them from interfering with telemetry or the receiver's carrier lock.
- NSP ranging will produce and correlate the same tones as SRA.





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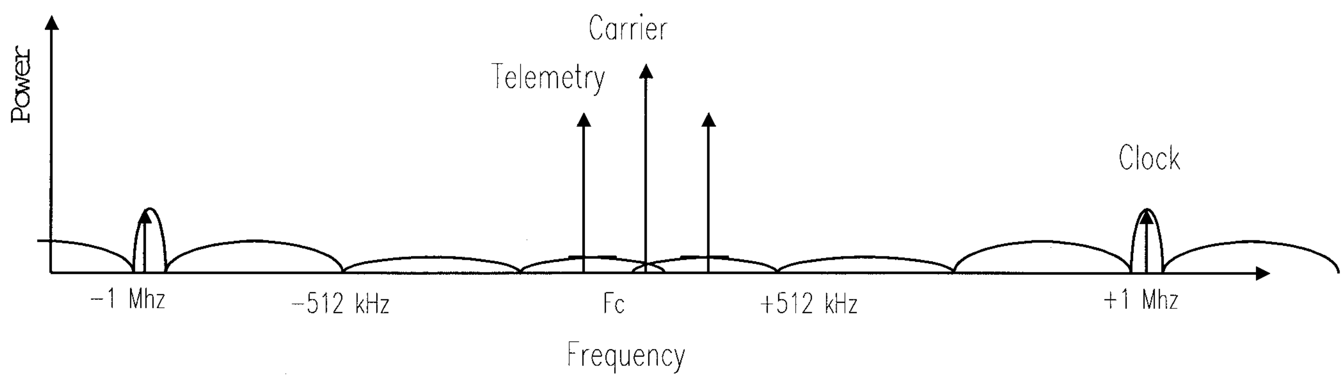
New Design Provides More Types of Ranging

- The NSP ranging can also produce and correlate PN tones.
- These PN tones are configurable by the user, providing many 'chip' sizes and tone lengths. Future needs for specific tones and correlation patterns can be supported with minimal software changes.
- NSP ranging can support the Spacecraft Transponder Modem (STM) ranging tone. The tone is an ANDed set of PN patterns ORed with a 1 MHz .Clock..
- The spread-spectrum nature of the PN tones allows them to share the spectrum with the telemetry tones. This eliminates the need for chopping. All tones are transmitted all the time, simplifying design.



Advantages for Operations & Spacecraft Designers

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- Less custom hardware = cheaper to implement.
- Less hardware and DSP boards that are smaller than older processors means less rack space, fewer spares, fewer cables, less cooling needs.
- The NSP design puts the ranging code generation into the software.
  - One set of H/W will support the old sequential tones and the PN tones.
  - Provides PN tones needed to support new spacecraft transponders with regenerative ranging. PN tones require fewer project-controlled inputs.
- The DSP in new design has 16 MHz FIFOs.
  - Supports upgrade to 4 MHz range tones for future spacecraft that use a 4+ MHz ranging filter.
  - A 4 MHz range tone measurement sigma is ¼ the sigma with 1 MHz tones.
- Using DSP FIFOs and COTS I/O control provide a very clean interface agreement between the COTS hardware and custom hardware.
  - Allows for future changes to one without changing the other.
  - Can easily upgrade to future DSP COTS products.
- DSP boards are programmed in 'C' and have good development tools.
- Programmers can be found for DSP platforms, helping maintenance.