CRYSTAL-CONTROLLED HIGH-G TRANSMITTER

KENNETH L. LANGE
Hewlett-Packard

MAX V. SCHELL
Sandia Laboratories

Summary Continuous telemetering during and after a 10,000 to 16,000g shock pulse experienced by the telemeter is a requirement that is frequently not met. In most cases a free-running oscillator is used in the transmitter while a very wide band receiver is used to acquire and provide leeway for the drifting and shifting RF signals.

This paper describes a crystal-controlled L-band transmitter which performs in such a way as to minimize most of the above operational problems. It has minimal short-tem drift, predictable output frequency, and makes a low noise transition through the high g shock pulse. RF power is 60 to 100 milliwatts. For analog data bus compatibility, phase modulation is employed.

Sandia Laboratories has developed an L-band transmitter for telemetering data from the inside of an artillery shell. The original need was for information during the in-barrel portion of the flight. Later requirements were for information over the whole flight envelope.

An examination of some detailed requirements is in order to show how they steered the design:

1) The physical environment is very vigorous. Launch of the shell is accompanied by a 10,000 to 16,000g setback shock in conjunction with spin-up and centrifugal accelerations of 6,000 to 12,000g orthogonal to the setback shock.

2) In-barrel telemetry employing the wave-guide effect made L-band the lowest usable frequency range.

3) RF frequency pulling by variable in-flight VSWR should be avoided.

4) Frequency was required to be sufficiently stable to keep the RF signal within the passband of standard telemetry receivers.

5) Temperature range of operation was expected to be -40°C to 60°C.

6) Power consumption was to be as low as possible. Transmitter to operate from 24 to 32 VDC.

7) A small size was indicated.

An examination of the physical characteristics of hybrid microcircuits led to an early decision to develop the transmitter around that fabrication technology. Basic ruggedness is the first attribute achieved through low mass components and interconnections plus high strength bonds. The alumina substrate is fragile only if flexed.

Further on down the list of hybrid microcircuit attractive features are: Repeatability (once the design is firm). Careful design of RF circuitry can keep size down to the same range as handwired units. All circuits - dc, modulation, and RF - can be put down on one substrate. Excellent heatsinking of components is afforded, as well as rapid internal thermal equilibrium

Free-running oscillators (VCO's) for transmitter use do not offer the kind of frequency stability held to be desirable for Sandia flight tests. They are, however, relatively easy to design, build, and modulate. DC to RF efficiency is probably higher than for a crystal-controlled oscillator. All the attributes of the free-running oscillator do not offset the range

Crystal oscillators simply cannot operate at the required L-band frequency. However, frequency multiplication by harmonic generation is pretty commonplace today. A step recovery diode circuit set-up to accept the oscillator output will provide an output in L-band. Such a circuit also affords a decent amount of reverse isolation. Exploration of the literature provided the information that modulation could be impressed via the step recovery diode bias circuit.

The unit initially was inteaded for use only during barrel transit. Experimental measurements were made of the loop loss between a projectile antenna in a barrel and a receiving antenna placed a safe distance away. Decent signal-to-noise ratio indications were obtained with 10 milliwatts at 1500 MHz.

A frequency multiplication factor of 10 to 15 seemed reasonable, considering the needed conversion efficiency, range of crystal frequencies for oscillators, and so on. It was fairly natural to choose a 100 MHz crystal frequency and a X15 factor to arrive at a 1500 MHz output.

The first transmitter design was comprised of the following elements: a voltage regulator to provide a constant 21.5 VDC internal voltage while accepting 24-32 VDC external; a 100 MHz crystal-controlled oscillator; a frequency multiplier circuit incorporating a step recovery diode and X15 harmonic selection for 1500 MHz output; a bias and modulation amplifier circuit for the diode in the X15 multiplier. All parts except the TO-5 contained crystal, and input and output connectors were mounted on the substrate.

Mounting techniques were exploited to assure survival and operation of the substrate and crystal. First, placement of the substrate flat against the inside of the case was selected. Its orientation was such that the setback (axial) inertial reaction would force the substrate more firmly against the mounting face. Similarly the substrate mounted components would place their adhesive in compression. The spin-produced inertial reactions of the substrate and mounted parts will load their restraints in shear. These areas are where the strengths are. It was learned that solder was the only acceptable structural adhesive to use for securing.the substrate to the housing. Electrical and structural bonding of the metalized bottom of the substrate was accomplished by sweat-soldering the entirety of it to the inside of the tin-lead plated brass housing. Successful RF performance hinged on achieving a marriage of the substrate to the housing.

Second, the TO-5 contained crystal was suspended by a conventional printed wiring board. The internal crystal is supported by pins through the header. Orientation of this device was such that the circular plane of the crystal is forced against the top of the pins by the setback inertial reaction. Again, the adhesive is placed in shear by the spin-produced inertial reactions.

A small number of tests conducted in heavy-shock producing equipment chased out major bugs. Firing tests subsequently demonstrated that the concept was sound. Especially noteworthy was data clarity during the shock pulse.

Partial consequence of the successful barrel-length flight performance was development of a requirement to provide telemetry during the entire flight. Considerably more power was indicated to be necessary. What could be more simple than to connect an L-band amplifier? This approach was expected to provide the required gain and power while increasing the dc to RF efficiency.

Continuing respect for the environment led to a relatively simple hybrid microcircuit amplifier. Circuit design was low Q, heavily weighted toward survival, no noise, and fixed tuning. Stub transmission lines tuned during alignment are used here. A consequence is that harmonic content of the spectrum is higher than the current IRIG criteria. We have experienced no operational difficulties as a result of this.

In conjunction with the addition of the amplifier, the board-mounted crystal was moved to a cavity in the housing bottom and hard-mounted there. This is the design as it stands in June, 1973.

DC input 24-32 VDC at 125-140 milliamperes; reverse polarity protection provided.

200 milliwatt 100 MHz crystal-controlled oscillator working into X15 step recovery diode coupled into 1500 MHz amplifier with 60-100 milliwatt output, assuming VSWR less than 1.5:1.

Modulation frequency capability 20kHz to 200kHz at 3 radians peak deviation. True phase modulation.

Load Mismatch: VSWR up to 7:1 with no harm to the transmitter.

Spectrum: Not per IRIG 106-71 for harmonic content. Very little effort was made to suppress harmonics that occur every 100 MHz 100 to 1700 MHz to a level more than 15-20 dB below the carrier.

Selected crystals have withstood 16,000g shock. Nearly a dozen successful flight tests have been conducted in artillery pieces.

Size, less connectors is 1.375 by 1.636 by 0.9 inch high.