Adding a High-Quality Telemetry Channel onto the Standard 1680 MHz Radiosonde

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ABSTRACT

A description is given of how the surplus bandwidth of the standard radiosonde can be used for an additional high-quality telemetry channel. Bounds imposed on the channel by the existing radiosonde signal are discussed, as well as an FM/FM subcarrier system which fits into these bounds. Also given are detailed circuit diagrams of the voltage-controlled oscillator added to the radiosonde, and the phase-locked loop used in the ground station.

1. Introduction

In sounding the upper atmosphere, or testing instruments at high altitudes it is convenient to use the standard radiosonde as a data bus for additional sensors. The radiosonde is a very inexpensive package which contains a power source, a transmitter and basic meteorological sensors (pressure, temperature and humidity). Furthermore, radiosonde ground stations, with tracking antennas, are evenly distributed throughout the country, and are usually idle 70% of the day.

We describe here a simple addition to the standard radiosonde which will yield an additional high-quality analog channel without jeopardizing normal performance of the radiosonde. A complete ground station for the added channel is also described. The only interference with the existing ground station is the insertion of a passive power divider between the antenna and the standard radiosonde receiver. The power divider diverts half of the RF signal to the second ground station. The loss of 3 dB in the received signal is tolerable in most cases.

2. Bounds imposed by the radiosonde

The standard 1680 MHz radiosonde (VIZ 1292) utilizes a pencil tube power oscillator as a continuous wave (CW) transmitter. The modulation is in the form of short carrier interruptions, $\tau=70$ μs in length, whose repetition rate f_p is a function of the sensor output. The highest repetition rate is 200 Hz. The tube cutoff is implemented by a transistor switch in series with the tube cathode. The rise time of the RF signal amplitude after the cutoff period is instantaneous. However, the initial frequency is offset about 5 MHz, and the carrier frequency will show an exponential rise time of about 300 μs before reaching the steady-state frequency. A typical radiosonde signal, as detected by a wide bandwidth intermediate frequency (IF) Amplitude Modulation (AM) receiver, is shown in Fig. 1a. The same signal detected on a Frequency Modulation (FM) receiver is shown in Fig. 1b. The latter signal is also typical of the result of a detection on an AM receiver with a narrowband IF, since the slope of the response of the IF amplifier serves as a frequency detector. By narrowband IF, we mean a bandwidth of $\sim$1 MHz, and, by wideband IF, a bandwidth of more than 5 MHz.

The spectrum of the signal shown in Fig. 1a is a sequence of the harmonics of the 200 Hz frequency, whose envelope behavior is $x^{-1}\sin x$ with the first zero at the inverse of the cutoff duration $1/\tau$, i.e., near 14 kHz. To prevent crosstalk from the radiosonde signal to the added channel, a practical lower limit on the frequency, f_m, of the added channel is set at

$$f_m > \frac{1}{2\tau} = 28\ \text{kHz}. \tag{1}$$

The cutoff duration τ also imposes an upper limit on the information frequency f_i. Intuitively, one can see that the cutoff duration cannot occupy a significant part of the information period. From the Nyquist criteria the information will not be recovered if the cutoff duration is larger than one-half the information

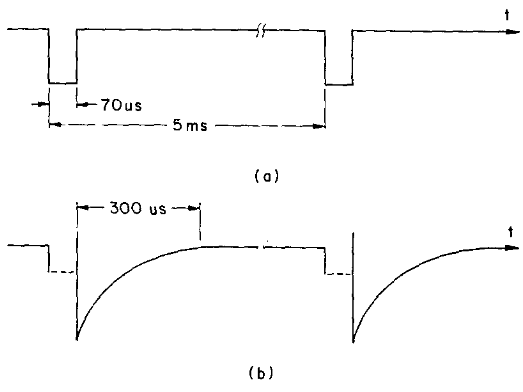

FIG. 1. The radiosonde signal (a) as detected by an AM receiver with wideband IF amplifier and (b) as detected by an FM receiver or by an AM receiver with narrowband IF amplifier.

period. A more practical rule would be one-third or

$$f_i < \frac{1}{3\tau}. \qquad (2)$$

Worst-case design requires that the longest τ be used in (2). In Fig. 1b, it is shown that in FM reception the effective τ is equal to 370 μs yielding

$$f_i < 900 \text{ Hz}. \qquad (3)$$

The two bounds (1) and (3) imply that the information signal, whose upper frequency cannot exceed 900 Hz, should first be modulated on a subcarrier, whose frequency should be above 28 kHz, before being modulated onto the radiosonde carrier. Signal-to-noise ratio considerations dictate that the information be frequency-modulated onto the subcarrier. To prevent crosstalk from the added channel to the radiosonde data, the level of the cathode modulation due to the subcarrier should be well below the level which will cause tube cutoff. The modulation level cannot be too low, however, since it also determines the level of the detected signal at the ground station. A level of 20% of the cutoff level was found to be a good compromise. It was achieved by applying a modulating signal, with a 0 to +12 V peak-to-peak amplitude, through a 68 kΩ resistor, to the modulation line (Fig. 2).

This type of cathode modulation generated both FM and AM signals (≈2.5 dB MHz^{-1}). Thus either an AM or an FM receiver can be used at the ground station. Our experience shows that an FM receiver yields slightly better results.

3. System overview

A block diagram of the system is given in Figs. 2 and 3. Fig. 2 indicates the interface point with the VIZ Radiosonde type 1292. The electrical connection is made to an external wire, modulation line, which connects the modulator section to the RF section, and is therefore easily accessible. The electrical ground is also available on an external wire.

A 0 to +12 V amplitude square wave (or almost any other waveform) is applied to the interface point through a 68 kΩ resistor. The square-wave frequency is dependent on the telemetered information and may come directly from a sensor having a frequency output. If the sensor yields an analog voltage, a voltage-controlled oscillator (VCO) is required.

The ground station (Fig. 3) includes a regular radiosonde station with its tracking antenna. Half of the power of the 1680 MHz signal coming from the antenna is diverted to an additional 1680 MHz receiver. A 3 dB power divider is used (e.g., Microlab/FXR type D2-2TN). The 1680 MHz receiver has to have an IF bandwidth of at least 1 MHz and a video bandwidth of at least 100 kHz. The receiver used in our applications was an ACL type SR-209, with an RF tuning head, type SH-205-P, and an IF amplifier, type IF-212-1000. Both FM and AM detection are possible with this receiver.

The heart of the receiving system is a phase-locked loop (PLL) which locks onto the subcarrier and tracks its instantaneous frequency. The loop bandwidth should be comparable to the information bandwidth.

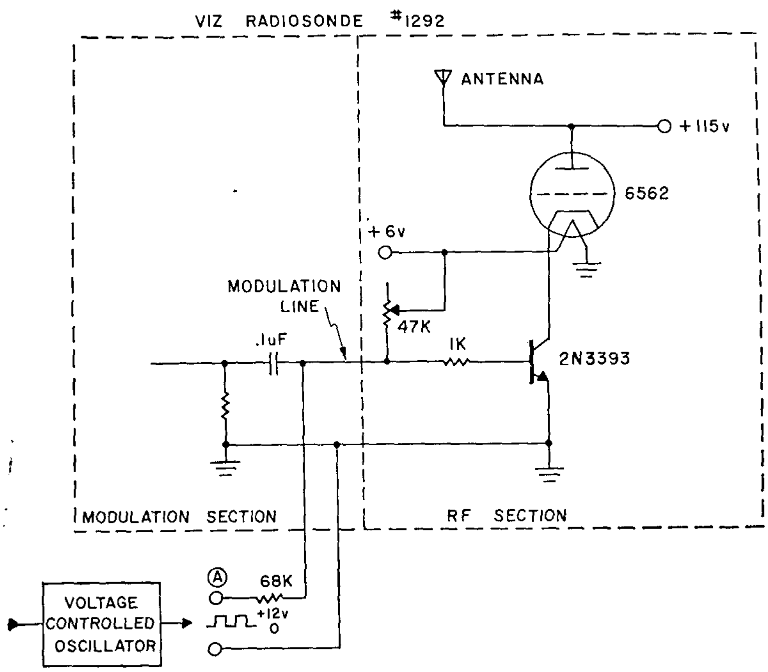

FIG. 2. Radiosonde interface.

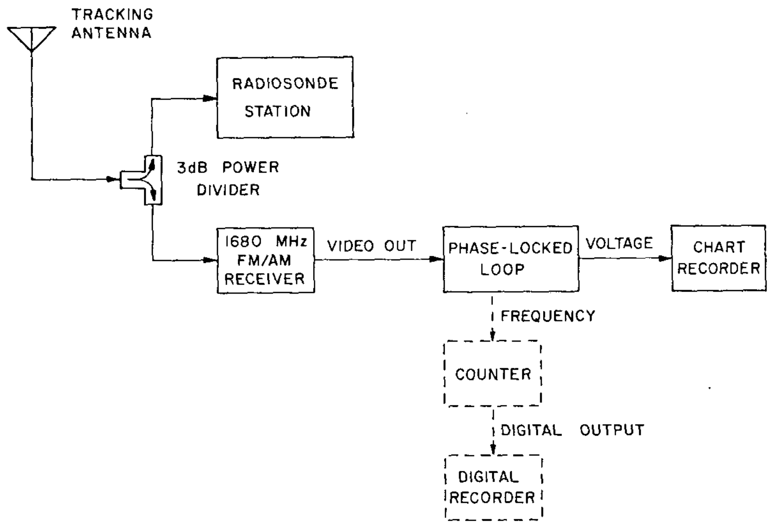

FIG. 3. Block diagram of the ground station.

The PLL provides a noise-free square wave whose frequency is equal to the subcarrier instantaneous frequency. The PLL also provides an analog output voltage which is related to the subcarrier instantaneous frequency. The voltage output can be plotted directly on a chart recorder. The frequency output has to be counted before it can be displayed on a printer or on any other digital decorder.

Nothing in the system described above requires that the added channel be continuously dedicated to one sensor. As in the original radiosonde data, time multiplexing may be used to allow the high-quality channel to serve several sources (sensors and references). The only impact of time multiplexing is on the bandwidth of the PLL at the ground station. A higher bandwidth may be required to follow the step functions involved in switching from one source to another, on board the radiosonde.

An example of time-multiplexed data telemetered via the added channel is given in Fig. 4. The data represent a 3 min recording, half an hour into a radiosonde flight, launched from Madison, Wisc., at 2045 CST 13 March 1974. The major part of the time (the square-wave like waveform) is devoted to a net flux radiometer flipping between upward and downward positions. The radiometer readings are interrupted for 12 s every 2 min to transmit information from seven additional sources. In this particular case the sources are, in order, 0 V reference, +5 V reference, ambient temperature, electronics temperature point 1, electronics temperatuie point 2, 0 V reference, and another 0 V reference.

4. Detailed circuitry

This section describes in detail a specific VCO and accompanying circuitry added to the radiosonde, and the PLL with its accompanying circuitry as used in the ground station. The circuits described will telemeter, with excellent fidelity, a 0 to +5 V amplitude signal

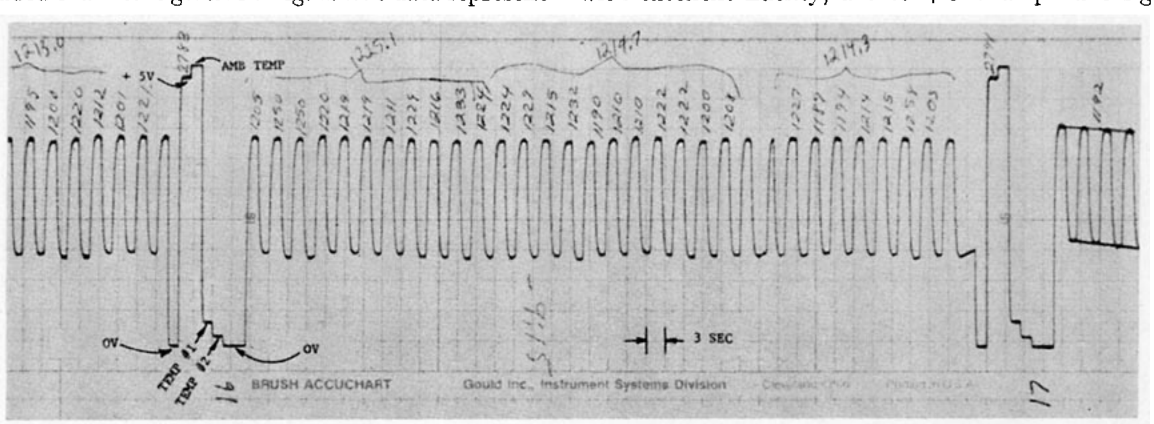

FIG. 4. Three minutes of data recorded via the added channel during a radiosonde ascent. The square-wave like waveform is from a radiometer flipping between upward and downward positions. A 12 s interruption every 2 min is devoted to seven additional sources (see text).

whose small-signal frequency does not exceed 200 Hz and whose large-signal slew rate does not exceed 0.04 V ms^{-1}.

Other designs of a VCO and a PLL may be used and the authors make no claim that the design presented here is an optimal one. The main advantage of this design is that it has been tested successfully during several radiosonde flights.

The subcarrier added to the radiosonde in this application is 30 kHz. An input voltage of 0 to +5 V is converted to a frequency which varies between 27 to 33 kHz, respectively (Fig. 5). An Intersil integrated circuit VCO type ICL 8038 AM was chosen for its good temperature stability. Since the 8038 requires an input voltage referenced to the +12 V supply, a transistor (2N2222)–operational amplifier (741) configuration was employed as a controlled-current voltage shifter to shift the 0 to +5 V input to the levels required by the VCO (e.g., 9.6 V for the 30 kHz center frequency) for minimal temperature dependence. Ahead of the operational amplifier a diode clipper is employed to prevent the input signal from rising above 6 V since such voltage levels would saturate the transistor and bring the collector up to the input voltage. This circuit was used in conjunction with a time-multiplexing circuit. Full swing transition may occur when the system is switched from one sensor to another. Such a step function may be beyond the "pull out" range of the PLL at the ground station. To prevent temporary loss of lock, the rise time of the incoming signal is slowed down by an RC low-pass filter in series with the input.

The ground station PLL (Fig. 6) is preceded by a 4-pole bandpass filter having 6 dB points at 27 and 33 kHz. The filtered signal is then squared up by the third operational amplifier operating as a Schmitt trigger. The hysteresis of the Schmitt trigger was adjusted to provide an additional noise deadband. The squared signal is fed to the MC 1596 multiplier where its phase is compared to the phase of the signal generated by the VCO of the PLL. The output of the multiplier is buffered by the fourth operational amplifier and is fed to the loop low-pass filter (MC 1539). The output of the filter controls the VCO. The low-pass filter (LPF) stage contains a sweep circuit which accelerates lock acquisition by searching for the signal when not in lock. The output of the LPF is swept from 0 to +5.5 V. At 5.5 V the integrating capacitor is discharged to about 0 V and another sweep begins. The sweeping rate is controllable.

The ground station VCO is identical to the VCO added to the radiosonde, except, as a safety factor, its frequency vs voltage ratio is doubled (24–36 kHz is produced by 0–5 V, or 27–33 kHz will produce 1.25–3.75 V). The correct ratio is restored in the active low-pass filter which provides a voltage gain of 2 and an offset to give the desired 0 to +5 V range. This filter also attenuates any remnants of the subcarrier frequency. The loop natural frequency f_n is 350 Hz and its damping factor ξ is 0.6. The "pull out" range Δf_{p0} given by (Gardner, 1966)

$$\Delta f_{p0} \approx 1.8 f_n(\xi+1), \qquad (4)$$

is thus equal to 1 kHz. This means that the largest step function of input frequency which the loop can track without skipping cycles is 1 kHz which is less than the maximum frequency step that may occur. It is for this reason that the slow-down RC filter is added in front of the transmitting VCO.

5. Summary and conclusions

The standard U. S. radiosonde was designed in the fifties with a considerable unused bandwidth. Relatively recent techniques, such as the phase-locked loop,

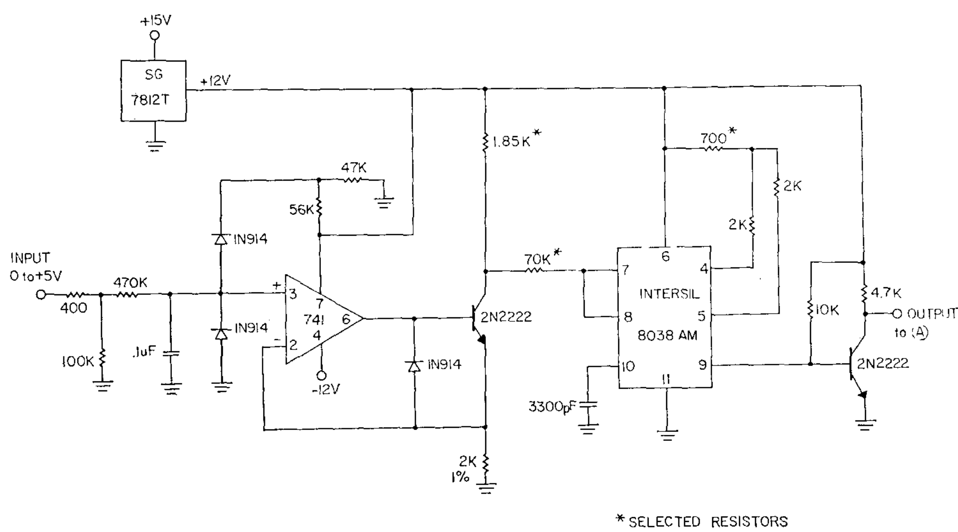

FIG. 5. The VCO circuit diagram.

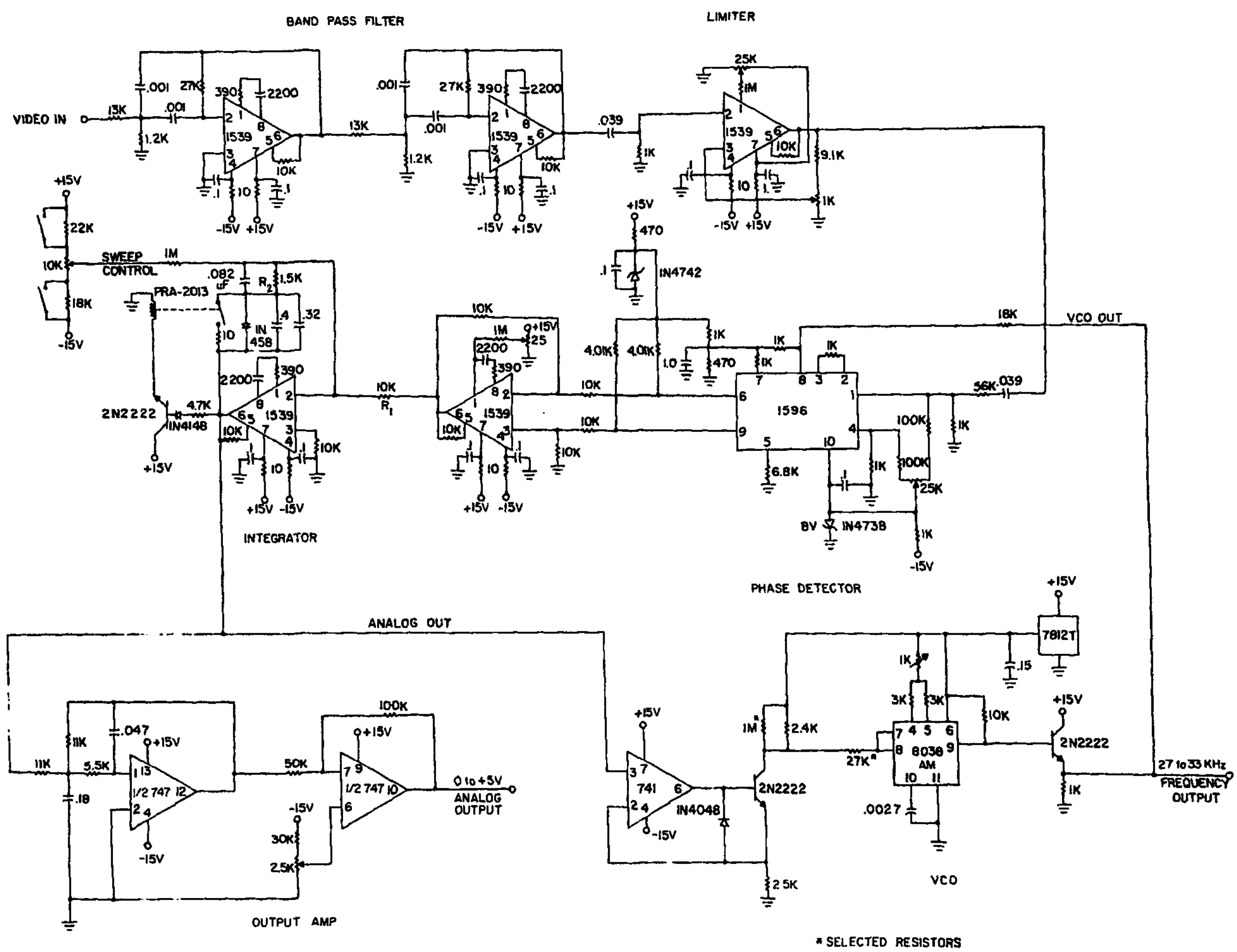

FIG. 6. The PLL circuit diagram.

allow this unused bandwidth to be utilized by inserting an additional telemetry channel. General bounds on this channel are discussed, and a specific design is described. This design was successfully tested in more than 15 flights serving two different applications.

While the additional circuitry may double the price of the radiosonde, the total package is still very inexpensive, and may prove to be a useful telemetry system for balloon-borne experiments.

REFERENCE

Gardner, F. M., 1966: *Phaselock Techniques.* Wiley, Sec. 4.2.