Experiences with VHF FM-FM Radio-Telemetry System in the Venezuelan Seismological Network

Florentina M. Prida A.
Electronic Instrumentation Department
Venezuelan Foundation for Seismological Research (FUNVISIS)
Prolongación Calle Mara, El Llanito
Caracas, Venezuela

Abstract

The Venezuelan Seismological Network (RESVAC) has been operating with a VHF FM-FM Radio-Telemetry System for several years. The network which started in 1981, initially with one station, now consists of 21 short-period and 1 long-period station, with 16 of the short-period stations being radio-telemetered. It is essential for seismological studies that high quality data be produced by these stations. Even though the cost of maintenance is high, we have tried to keep it to a minimum. We are applying an analogue frequency modulation radio-telemetry method with low-power carrier in our seismological network. The transmission band is 220-235 MHz. The maximum transmission power is 500 mW. The antennas are Yagi type with horizontal polarization. Our Voltage Control Oscillator sensitivity is 5 V pp input producing $\pm$125 Hz deviation in the sub-carrier. The system performs the following functions:

-It generates a multiplex of subcarriers of various frequencies ranging from 680 Hz to 3060 Hz.

-It encodes the information to be transmitted in the form of frequency modulation of the individual subcarriers.

-It transmits the multiplexed FM signals to the receiving station via an FM radio-frequency carrier.

-It separates and demodulates the subcarriers forming the multiplexed signal.

The seismic signals were initially written on paper by drum recorders. In order to improve our system and produce digital records, we adopted The Soufriere System in 1990 for collecting data. However, it was necessary to refine the quality of the transmitted signal because the noise can cause false triggers in the digital system. Also, for later processing, it is imperative to achieve a better quality of the seismic signal. Consequently, we have studied the noise sources, the radio links, the equipment, the filters, the frequency mixers and other important details of the radio-telemetry system. In order to reduce equipment costs, it was decided to build some of the components. These locally produced components have special specifications for the purpose of obtaining better data quality in a seismic network. The technical and economic experience garnered on several aspects of the telemetry system during the past 12 years will be described.

Introduction

FUNVISIS has been operating the Venezuelan Seismological Network (RESVAC) since 1981. Actually, this network is formed by 21 short period stations and one (1) long period station; 16 of the short period stations are operating by radio-telemetry. Figure 1 shows the seismological station distribution in Venezuela and Table 1 is a listing of their characteristics.

It was decided to use the FM-FM System for transmitting the seismological signals because this system is a simple and flexible technique for transmitting a number of analogue signals via a common radio-frequency (RF) link with reasonable accuracy. Furthermore, since the data values are encoded in the form of subcarrier frequencies, the system is insensitive to level changes in the RF transmission path (Albright et al., 1967).

The seismic signals were initially written on paper by drum recorders. In order to improve our system and produce digital records, we adopted the Soufriere System (Beckles et al., 1990) in 1990, because of its better data handling capabilities (Prida, 1990). However, it was necessary to refine the quality of the transmitted signal because the noise can cause false triggers in the digital system. Also, for later processing, it is imperative to achieve a better quality of the seismological signal.

The sources of dynamic error for telemetry can be interchannel crosstalk due to harmonic and intermodulation distortion products in the multiplexed signal, distortion arising from phase non-linearity in filters and noise arising from the transmission-system thermal fluctuations. We have studied the noise sources, the radio links, the equipment, the filters, the frequency mixers and other important details of the radio-telemetry system. In order to reduce equipment costs, it was decided to build some of the components. These locally produced components have special specifications for the purpose of obtaining better data quality in a seismic network.

During the installation and routine maintenance of stations, we have observed some important factors which play a significant role in improving network performance and reducing maintenance costs. The technical and economic experience acquired during the past twelve years will be described.

System Description

For the transmission of the seismological signals, we apply an analogue frequency modulation radio-telemetry method with low-power carrier in our seismological network (Prida and Mendoza, 1988). The transmission band is 220 MHz to 235 MHz. The maximum transmission power is 500 mW. The antennas are yagi type with horizontal polarization. Our Voltage-Controlled Oscillator (VCO) sensitivity is 5 V pp input producing ± 125 Hz deviation in the subcarrier. The system performs the following functions:

- It generates a multiplex of subcarriers of various frequencies ranging from 680 Hz to 3060 Hz.

- It encodes the information to be transmitted in the form of frequency modulation of the individual subcarriers.

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Figure 2 shows the block diagram with the links used for the seismological signals transmission. Figure 3 shows a block diagram of the central receiving station that is situated in the FUNVISIS building in Caracas. The telemetered station signals are transmitted by seven channels which correspond to seven repeaters used around Caracas. It is necessary to use these repeaters for carrying the signals to the central station because Caracas is a valley encircled by mountains. These repeaters are: ALTOS DE PIPE, EL VOLCAN, ALTOS DE IRAPA, AVILA I, AVILA II and OPSIS. Channel six is a VHF repeater for a seismological

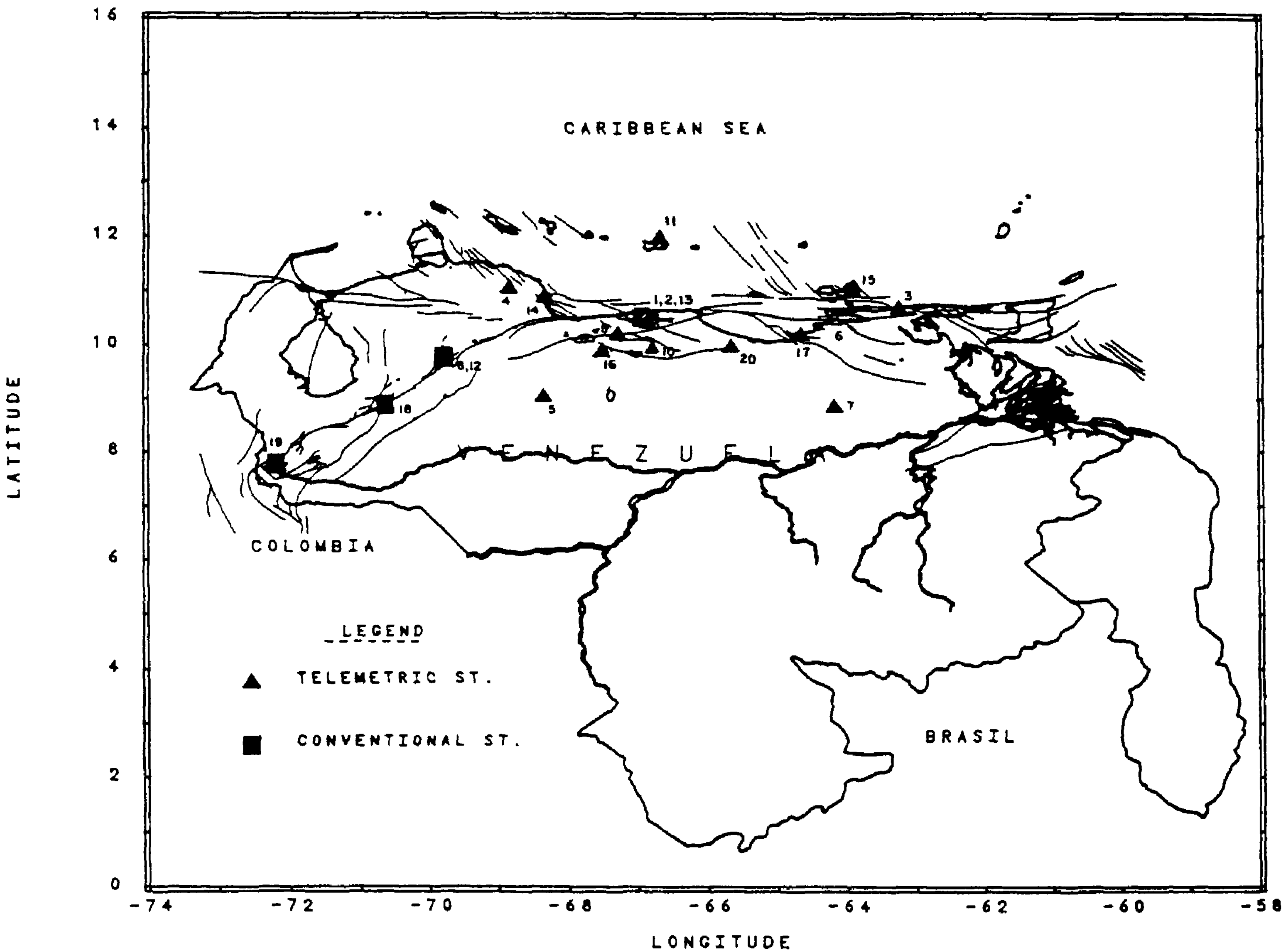

Figure 1: Venezuelan Seismological Network: Station Distribution

Table 1: Venezuelan Seismological Network: Station Characteristics.

ESTACION	CODE	LATITUDE (°N)	LONGITUDE (°W)	GAIN	TYPE	PERIOD	COMPONENTS
CARACAS (01)	CAR	10.5068	66.9275	54	T	SHORT	1
CARACAS (02)	CAR	10.5068	66.9275	54	C	LONG	3
CARUPANO (03)	CRUV	10.6748	63.2363	60	T	SHORT	1
CERRO ANTONIO (04)	CANV	11.039	68.828	60	T	SHORT	1
CERRO EL OSO (05)	CEOS	09.0307	68.3341	60	T	SHORT	1
CUMANA (06)	CUM	10.4650	64.1694	60	T	SHORT	1
EL TIGRE (07)	TGRV	08.8400	64.1683	54	T	SHORT	3
EL TOCUYO (08)	TOV	09.7925	69.7925	60	C	SHORT	2
GUACAMAYA (09)	GUAC	10.1920	67.2711	66	T	SHORT	1
LAS OLLAS (10)	OLLA	10.0190	66.8040	60	T	SHORT	1
LOS ROQUES (11)	LORO	11.9578	66.6742	60	T	SHORT	1
LAGUNETA (12)	LAGU	09.7700	69.7650	54	C	SHORT	1
LLANITO (13)	LLAV	10.4750	66.8080	60	C	SHORT	3
MORROCOY (14)	MORO	10.8728	68.3291	60	T	SHORT	1
PALMA REAL (15)	PALR	11.0000	63.9110	66	T	SHORT	1
PLATILLON (16)	PLAT	09.8740	67.5024	60	T	SHORT	1
PUERTO LA CRUZ (17)	PCRV	10.1762	64.6361	54	T	SHORT	1
SANTO DOMINGO (18)	SDV	08.8861	70.6333	60	C	SHORT	2
SAN CRISTOBAL (19)	SCRV	07.7889	72.1917	54	C	SHORT	1
VALLE DE GUANAPE (20)	GUAN	09.9575	65.6478	60	T	SHORT	1

T = Telemetric
C = Conventional

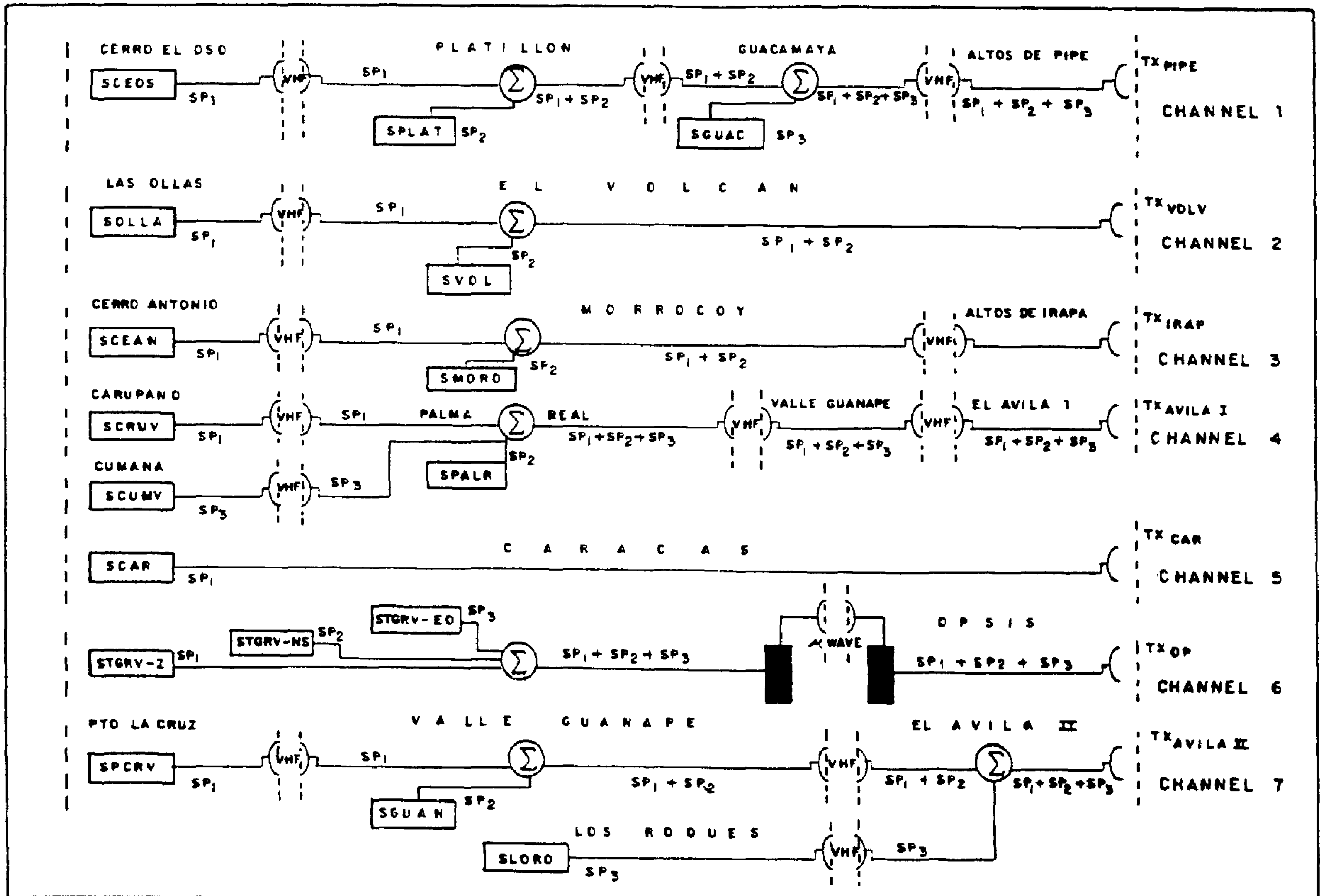

Figure 2: Venezuelan Seismological Network: Radio Telemetry-System. Transmission diagram block.

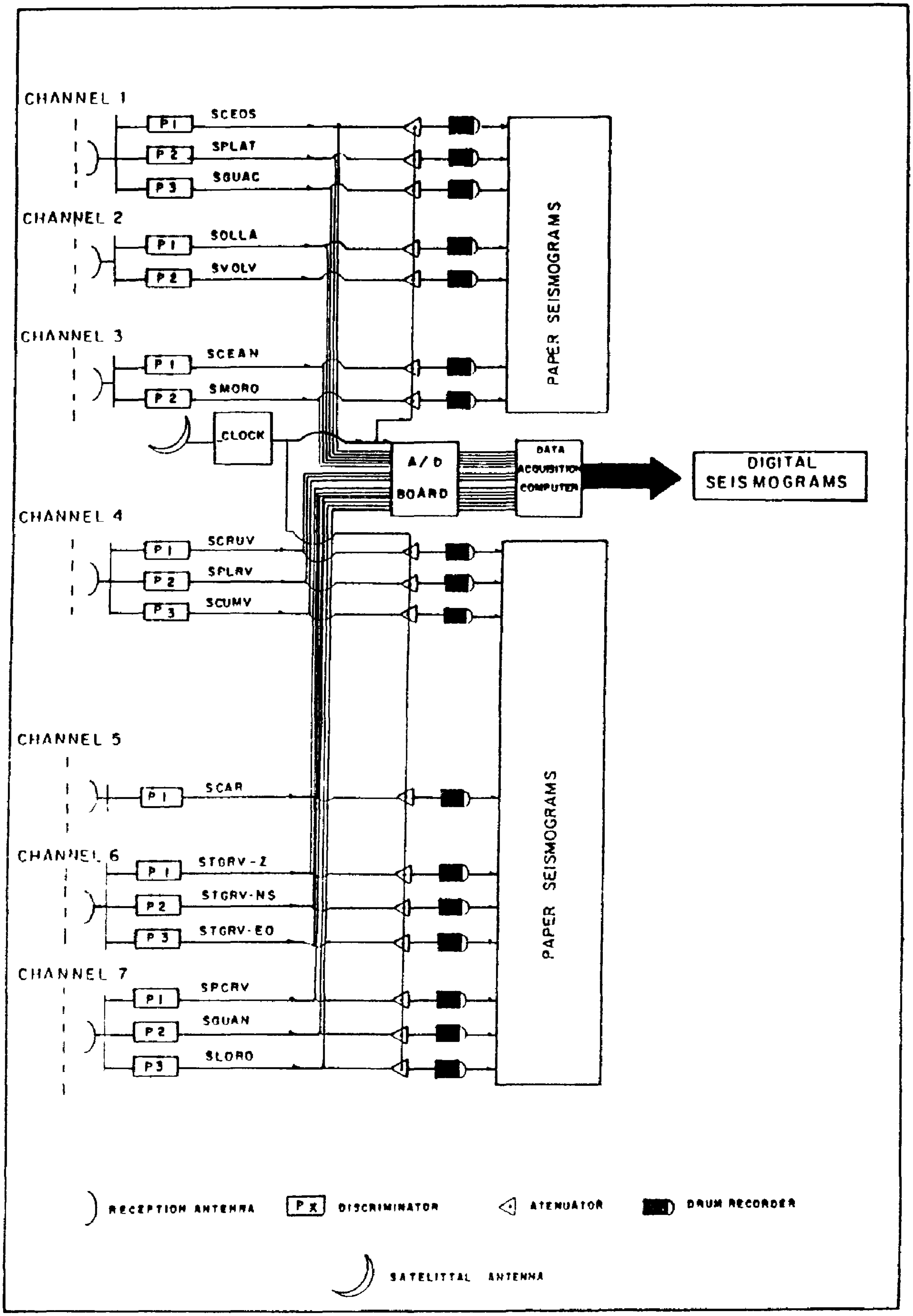

Figure 3: Venezuelan Seismological Network: Radio Telemetry-system. Central reception station diagram block.

signal which is first transmitted via microwaves from station El Tigre to the OPSIS building in Caracas.

Methods and Observations

We have tested all the telemetry equipment in the laboratory in order to improve the quality of the signal transmission. The equipment was tested by changing various features and the results analyzed. We have also installed a test seismological telemetered station and a test conventional seismological station in the laboratory and their behaviour analyzed with different components. The best results from these tests are currently being used in the operational telemetry equipment.

An important consideration is the behaviour of the equipment in the field. For this reason, we have implemented a systematic maintenance programme for each station. A database with the station performance and its evolution in time has been built. For this database, several factors about the stations have been taken into account including, for example, equipment features, station's environment, frequencies and filters used at the stations, topography of the radio-link, transmission power, antennas, antenna polarization, theoretical models for the links, radio line-of-sight estimations, energy, etc. Also, many observations have been made on some characteristics of the receiving signals, for example, receiver signal power spectral levels, noise levels, receiver signal duration time, receiver signal-noise, etc.

Comparing all the measurements, results and data for each station, some inferences have been drawn on how to improve the behaviour for each station.

Consideration about the System

In order to improve the quality of the telemetry system, the following considerations should be taken into account.

The voltage-controlled oscillator must be very stable to avoid drift or false signals (VanSchaack, 1992). Additionally, its frequency subcarrier stability is definitive for the signal demodulator at the central recording site, because the voltage-controlled oscillator subcarrier and the discriminator central frequency should be exactly the same for obtaining a good modulation-demodulation process. For VanSchaack (1992), one of the most critical specification is the sine wave distortion in the VCO; he suggested maximum distortion of less than 1% in order to get good dynamic range, because if this distortion exceeds 1%, it is possible to get beat frequencies in a multiplexed system. Also, VanSchaack (1992) recommended the VCO sensitivity of 5 V pp input producing $\pm$ 125 Hz deviation in the carrier; decreasing it may be good for having more station signals in one transmitter channel and for getting better signal to noise ratio. VanSchaack (1992) also suggested a linearity of 1% or better and 1% as maximum distortion for the voltage-controlled oscillator.

For increasing the signal-to-noise ratio in the system, the preamplifiers should have a bandpass filter, but it is very important to choose adequate cut-off frequencies for the filters. Furthermore, the gain selection is essential for obtaining good records. These selections (gain and filter cut-off frequencies) should be determined by the types of earthquakes to be recorded and the area coverage desired.

The transmitter-receiver specifications are very important for obtaining a good quality of telemetered signals. VanSchaack (1992) suggested that the distortion level in the transmitter-receiver system is perhaps the single most important specification in the entire telemetry system and he proposed that transmitters and receivers should have less than 2% audio distortion each; he has explained that when the distortion reaches a level of about 3% in either unit, it is possible that the dynamic range will be reduced and if it reaches a level of even 5%, it will result in serious problems. VanSchaack (1992) noted that distortion is cumulative over the various telemetry devices and for this reason, each part of the system must have very low distortion. It is, therefore, imperative to keep the total distortion low. For having a clean system, the total distortion in the system must be below 3%. For total distortion around 1%, the dynamic range is about 60 dB; if the percentage distortion rises to 4 or 5%, the dynamic range decreases to about 30 dB. Also VanSchaack (1992) proposed that in a congested area, it is possible to put an RF bandpass filter in the system in order to reduce interference from adjacent channels. Albright et al. (1967) proposed that the carrier frequency stability for the transmitter must be below ± 0.003% and its linearity should be 2%.

A favourable factor for the transmitter-receiver system is the effect of the yagi antenna. This effect is pretty much the same as multiplying transmitter power by a factor that is dependent on the antenna gain. Another advantage of using a highly directional antenna is that it may be able to refuse the same frequency off the side lobes of the antenna, since the signal is so strongly attenuated there (VanSchaack, 1992).

The subcarrier discriminator is the demodulator we use at the central recording site. Its output, ideally, reproduces the original seismic signals, which can be digitized or fed to a drum recorder, etc. The discriminator stability should be about the same as the VCO stability, even if you are in an air conditioned building (VanSchaack, 1992). Following demodulation, the output is filtered in order to remove undesired noise and subcarrier components and amplified to suitable output level (Albright et al., 1967). The filter characteristics are important for having a good quality for the signal records. VanSchaack (1992) recommends that the filters provide 18 to 20 dB attenuation at the edge of adjacent bands because if a channel is modulated at 100% there will still be an allowable dynamic range greater than 40 dB without cross-talk.

Discussion

Due to our experience, and the considerations that will subsequently be mentioned, the telemetered stations in the Venezuelan seismological network are working with the following features:

An important consideration is getting power to the site. If electricity is available at the site, then a battery connected to a charger is probably the most reliable method. If this option is not available, solar panels can be used.

Other important aspects are the operating conditions surrounding the stations. If possible, unfavourable operating factors such as electromagnetic fields adjacent to the station, populated areas, insecurity conditions, etc. should be eliminated or the station relocated.

We use different kinds of preamplifiers and VCOs: commercial and homemade equipment. Our homemade amplifiers have gains of the order of 48 to 66 dB switch selectable in 6 dB steps. They use a band-pass filter from 0.1 Hz to 20 Hz designed for 12 dB per octave cutoff. Neither frequencies lower than 0.1 Hz nor frquencies higher than 20 Hz are of interest to us because the telemetered signals originate from short-period seismometers. We use the differential input configuration in the pre-amplifiers because we have obtained better behaviour in common-mode noise with this configuration. We have found that the highest level of system noise referred to the input will be 0.5 microvolt peak-to-peak. Some of the commercial amplifiers that we use have gains of the order of 48 dB to 90 dB; others have gains from 60 dB to 120 dB switch selectable in 6 dB steps. Most of them have a common mode rejection input greater than 60 dB and the noise level referred to input in the bandpass filter from 0.2 Hz to 12.5 Hz is around 0.2 microvolt rms referred to input. Some of them have a low pass filter with switch selectable higher frequency cutoffs at 5, 12.5, 25, 50 and 100 Hz and a high pass filter with switch selectable cut-off frequencies of 0.2, 5 and 10 Hz. Usually, we set the switches at 0.2 Hz frequency cut-off for the high pass filter and 12.5 Hz frequency cutoff for the low pass filter, thus obtaining a bandpass filter from 0.2 Hz to 12.5 Hz. The other commercial amplifiers have a fixed bandpass filter from 0.1 Hz to 30 Hz, with 12 dB per octave rolloff above 30 Hz and 18 dB per octave rolloff below 0.1 Hz. Usually, our short-period stations have gains of 54, 60 or 66 dB.

All of the commercial voltage-controlled oscillators employ standard constant bandwidth channels: subcarrier centre frequencies spaced at 340 Hz with ± 125 Hz deviation. The first carrier is 340 Hz, the next is 680 Hz, etc. We have built VCOs employing this constant bandwidth and with these subcarrier frequencies. The homemade VCO has a lineariy of 0.2% of full bandwidth as output frequency with respect to input voltage and the VCO frequency drift is less 0.035% of centre frequency per °C. The range subcarrier output level for the homemade VCO is 0 to 4 volts. For the commercial VCOs that we use, the linearity is 0.2% to 0.25% max of full bandwidth and its drift is less than 0.05% per °C. For homemade and commercial VCOs, the sensitivity is ± 5 Vdc for full scale deviation producing ± 125 Hz. All of the preamplifiers-VCOs that we use have a power requirement lower than 200 mW with 8 V dc to 15 V dc.

The multiplexers are homemade in order to decrease the cost of the equipment. The mixer supplies the summing output of up to four channels into a single output. Its power requirement is 8 V dc to 15 V dc. According to the pattern of subcarrier frequencies used by the telemetry system and its bandwidth, it is not possible to produce mixed signals by either a combination with multiples of subcarrier frequencies or by a combination of differences of subcarrier frequencies because these combinations create beat effects and noise. For example, 2040 Hz minus 1020 Hz gives the channel frequency of 1020 Hz, this difference frequency can beat against the 1020 Hz carrier and produce a noisy signal (VanSchaack, 1992). Even if the constant bandwidth multiplexing system allows the use of eight signals on one line, due to the beat effects, the maximum number of subcarriers that it is possible to mix at the multiplexer for later transmission on one line is four, therefore, it is not necessary to employ more than four input channels for the multiplexer. Each multiplexer input channel must have a separate level control and a disconnect switch in order to minimize noise and cross-talk effects. It is essential for obtaining a suitable multiplexing output signal to be careful with the levels of the multiplexer input signals, the power levels should be similar. It is suggested that the output signal from the multiplexer be viewed with a spectrum analyzer in order to facilitate the adjusting and checking of power levels and centre frequencies.

The radio-system uses a band transmission from 220 MHz to 235 MHz, 100 mW for the output power and frequency modulating (FM). Although most of the transmitters are running with the output power of 100 mW, some of them are operating with 200 mW and 500 mW, and one is working with 2 Watts. The modulation distortion typical for the transmitter is around 0.25% @ 1KHz and its maximum is 1.5%. The typical audio distortion for the receivers is 1% with 3% maximum. The carrier frequency stability for the transmitter is ± 0.0005% of assigned frequency and for the receivers is ± 0.001% of centre frequency. The modulation frequency band is 300 Hz to 4 kHZ and the frequency response for both (transmitter and receiver) is ± 0.6% dB typical,with ± 2.5 dB maximum. The modulation limit for the transmitter is 5 KHz deviation maximum and its deviation sensitivity is 5 KHz with 1.0 V rms modulation. The receivers have a squelch adjustable 0.3 microvolt to 1.0 microvolt RF input, its typical sensitivity for 5 kHz deviation is 25 dB @ 1 microvolt, its audio output level is 0 to 6 dB ± 1.5 dB adjustable and its RF input is -113 dBm to 0 dB. The input power for the transmitter and the receiver is 10 V dc to 15 V dc.

In the situation where it is necessary to use two or more antennas on the same pole, with at least one transmitting, it may be necessary to mount them about 10 m apart in order to reduce any potential distortion.

The discriminator has the same sensitivity as the VCO: ± 125 Hz deviation subcarrier producing 5 V pp. Its input sensitivity is 30 mV to 2 V rms and its dynamic range is 60 dB for 0 Hz - 25 Hz bandwidth. Its linearity is 0.2% maximum deviation and the dc stability is 0.02% of centre frequency per °C. They have a 3-pole Butterworth low pass output filter, with the majority having a 25 Hz cutoff frequency while noisy stations have a cutoff frequency of 12.5 Hz.

All of the frequency bands used require line-of-sight radio paths. There are, however, some radio-band wave paths that follow the curvature of the earth (Horn, 1977; Prida and Mendoza, 1988; VanSchaack, 1992). Although the prediction of radio wave propagation, at least in the vicinity of the spherical earth and its turbulent atmosphere, is not an exact science (Horn, 1977), it is possible to predict it with some practical techniques. Utilizing line-of-sight radio path studies, 150 mW power output, a 10 dB gain antenna at each end and receiver signal strength -110 dB, we have reached radio paths about 200 km long (Prida and Mendoza, 1988).

The number of repeaters in a telemetry path has a significant consequence on the total distortion because every time that a signal is repeated, a distortion factor is added to the total receiver distortion. It can be proved that a repeated signal has a high cumulative distortion even though the levels of distortion for individual components are low. VanSchaack (1992) recommended that the number of repeaters be limited to a maximum of two. In our case, this number is impossible because Caracas is in a valley and we need at least two repeaters for each station. By our experience, we have limited the number of repeaters to four.

Conclusions

Based on work previously described and with experience from the continuous operation of the Venezuelan telemetered network, the following conclusions have been made.

In order to optimize the maintenance of the telemetered seismological stations, it is convenient to be systematic in the way plans for preventive as well as corrective maintenance are made. These plans should take into consideration the condition and characteristics of each station in order to establish priorities for maintenance visits to the stations.

It is essential for the optimum operation of the stations that care be taken in the calibration of all the equipment forming the system; this permits the elimination of noise and distortion factors that alter the seismological records and, therefore, the studies acomplished with the data.

Furthermore, it is suggested that elaborate spectral signal-to-noise relationsips that characterize each of the stations be determined everytime there is a change in any component of the station equipment.

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