NATIONAL RADIO ASTRONOMY OBSERVATORY

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PROTOTYPE IF TRANSMISSION SYSTEM

S. Weinreb

Introduction

Studies of the VLA IF transmission system have been presented in the following documents:

1) ITT Federal Labs Final Report — This report investigates and prices several cable distribution systems using single-sideband transmission of several IF signals per cable.
2) VLA Proposal, Chapter 13 — A cable distribution system in the 300-600 MHz range is described and priced.
3) VLA Electronics Memorandum No. 2 — An air-link transmission system is investigated.
4) VLA Electronics Memorandum No. 5 — Modulation systems for transmission through dispersive cables are examined.

As a result of these studies the system described in this memorandum has been selected for prototype development. A block diagram description of the system is given in the next section. Detailed descriptions of the system elements are given in Section III. Finally, a list of problems requiring further study is presented in Section IV.

II. System Description

The recommended system utilizes SSB transmission of signals in the 1-2 GHz range on 1 5/8" buried coaxial cables. Twelve 42 MHz bandwidth signals are carried on each cable. These signals are the 8-50 MHz IF signals arising from dual-frequency or dual-polarization outputs of 6 antennas.

The spectral distribution of the signals is shown in Figure 1. The two signals from a single antenna are transmitted as the lower and upper sidebands of carriers which range from 1125 MHz to 1875 MHz. The carriers have been chosen so that they can be harmonics of a 75 MHz crystal oscillator and so that harmonics of the 224.6 MHz signals in the LO system do not fall in signal bands. The transmission band has been restricted to an octave so that second harmonic signals do not fall in the signal band.

A specification of -23 dB has been adopted for the maximum cross-talk between channels. The cross-talk between signals from different antennas will be at different frequencies in the correlators and hence only causes a small increase in the noise level. The cross-talk between the two channels from a single antenna can appear at a proper frequency to give correlation. However, these correlations are not of importance in either the dual-polarization or dual-frequency modes of operation.

The layout of the baseline electronics is shown in Figure 2. The inputs to the system are the leveled front-end outputs from 2695 and 8085 MHz left-hand and right-hand polarization front-ends at each antenna. These inputs will be automatically leveled (ALC) and will have a pulsed system temperature monitor (ATM) in the front-end box. This is done in order to decrease the dynamic range, linearity, and amplitude stability requirements in the transmission system. The leveled outputs are connected to an Input Selector which allows different inputs or a test signal to be selected from the main control room for transmission on a channel. Two selected outputs then feed into a Dual SSB Modulator which translates both signals on to a carrier frequency.

The modulator output will be pre-equalized for approximately 0.4 km of 1 5/8" cab.e. This fixed equalization is adequate even though the actual cable length to the first repeater may vary between 0 and 0.8 km; the only effect will be the introduction of a 0.3 dB amplitude slope for 0 or 0.8 km of cable.

The antenna output signal will be coupled into the trunk transmission line thru a 10 dB coupler. This coupler will either be sealed for burial or will be installed in a waterproof box.

The trunk transmission line consists of buried 1 5/8" coaxial cable with a repeater spacing of 800 meters. (It may be possible to increase repeater spacing slightly through the use of lower-loss coax or repeaters with wide dynamic range; the economy of doing this will be investigated.) Each repeater will consist of a transistor amplifier, an equalization network, and a second amplifier. Pre-equalization will be used because the repeater power output can then be concentrated in the higher frequency end of the band. That is, the repeater input signal will be approximately -55 dBm and the output signal will taper from -24 dBm in a 42 MHz band at 1100 MHz to -16 dBm in a 42 MHz band at 1900 MHz.

The number and length of cables along each arm of the Wye cannot be specified until the array configuration is finalized and a reliability study has been performed. The reliability study will determine to what extent redundant repeaters and cables are required. At the present time it appears that one cable running the total 21 km and a second cable 10.5 km long will be sufficient. This will accommodate 12 antennas on each arm with no more than 6 antennas on the last 10.5 km of the arm.

At the central control station the signals in each cable must be separated and translated to the frequency range of the variable delay line. A block diagram of the control room electronics is shown in Figure 3. Each IF receiver extracts a desired carrier signal, adds or subtracts 100 MHz from this carrier in a phase-locked loop, and mixes this resultant with the filtered input signal to produce an output in the 50 to 92 MHz range (assumed to be the delay line frequency range). After passing through the delay line the signal is converted back to the original 8 to 50 MHz range by mixing with the 100 MHz signal.

Finally, the signal is applied to an adjustable, trimming equalizer and an ALC and monitor unit. The monitor unit will determine the gain and noise in the IF transmission system and the ALC will provide a constant level output to the correlators.

An error budget for amplitude variations with frequency and the non-linear difference in phase between signals from any two antennas is as follows (the figures apply to the 8 to 50 MHz frequency range):

TABLE I

SYSTEM AMPLITUDE AND PHASE ERROR BUDGET

Element	Peak Amplitude Variation	Phase Difference Nonlinearity
Front-End	± 0.3 dB	± 5°
SSB Modulator........	± 0.5 dB	± 10°
Repeater Link	± 1.0 dB	± 5°
IF Receiver	± 0.5 dB	± 10°
Variable Delay	± 0.7 dB	± 20°
Correlators	± 0.5 dB	± 5°
Total	± 3.5 dB	± 55°

The composite errors will not be as large as the total peak shown above because the errors will not add coherently and because the adjustment of the final trimming equalizer will reduce the composite error. A composite amplitude error of ± 1.5 dB and a phase difference nonlinearity of ± 30° are expected.

The error budget will be revised as more is learned about the individual elements. A quantitative calculation of the effects of these errors will also be made.

III. System Element Description

(301) ALC and Monitor Unit

This unit accepts an 8 to 50 MHz noise input at a level between -20 dBm and +5 dBm and produces a constant level output of -15 ± 0.2 dBm. The input signal will contain a 400 cps amplitude modulation which is obtained by modulating a small (~ 5 °K) noise signal injected at the front-end input. The level control loop will be too slow to react to this 400 cps signal. The 400 cps signal at the level-sensing detector output will be synchronously detected to given an output inversely proportional to the system temperature. This output, as well as the voltage-controlled attenuator control signal, should be supplied to the monitor system.

(302) Input Selector

The input selector will contain two 4-position coaxial relays and a pulse generator for use as a test signal. A four-bit control signal will be used to control the two inputs to the SSB modulator in the following manner:

Lower Sideband	
Bits 1 and 2	Input
00	2695 RHP
01	8085 LHP
10	Termination
11	Pulse Gen

Upper Sideband	
Bits 3 and 4	Input
00	2695 LHP
01	8085 RHP
10	Termination
11	Pulse Gen

The switch-cross-talk must be < 40 dB. The pulse generator should supply a 22 mV (-20 dBm peak power in 50 ohms) pulse with a duration of 10 ns. and a repetition rate of 2 MHz; the pulse generator should be turned off when it is not selected.

(310) Dual Single-Sideband Modulator

This unit accepts two input signals and translates these signals to the lower and upper sidebands of a carrier between 1125 MHz and 1875 MHz. The input signals are broadband noise signals at a power level of -15 dBm and will have a flat spectrum to within ± 0.30 dB over the 8 to 50 MHz band. The input noise band may extend beyond this range and the 3 dB points will be approximately 4 and 75 MHz; however, only the band between 8 and 50 MHz need be passed by the transmission system.

Two methods can be used for SSB modulation. The first method is to DSB modulate with a mixer and then remove the unwanted sideband with a filter. The second method requires the uses of quadrature phase shift networks and two mixers to cancel the unwanted sideband. The sharp cutoff filters required by the first method may be difficult to phase match. However, it is a much simpler system than the phase-shift method which gives good control of phase match. The first approach should be with the filter method as is shown in Figure 4.

The bandpass filter shown in Figure 4 must have flat response for the desired sideband and must provide > 25 dB rejection of the unwanted sideband. A 4-pole 0.1 dB Tschebyscheff filter can give the following response if the internal resonator Q's are sufficiently high (f_o is the carrier frequency):

Frequency	Response
$f_o + 5$	- 3 dB
$f_o + 8$	- 0.5 dB
$f_o + 29$	0 dB
$f_o + 50$	- 0.5 dB
$f_o + 53$	- 3 dB
f_o	-12 dB
$f_o - 3$	-19 dB
$f_o - 8$	-28 dB

The phase shift between 3 dB points will be approximately 360°. It appears reasonable to match the nonlinear portion of this phase shift to within ± 10°. This match must, of course, be obtained for filters at different center frequencies.

The carrier frequencies must be transmitted along with the sideband signals since they are needed for demodulation. Less power is required, however, because the carriers can be extracted with very little bandwidth. Values of 10 dB to 30 dB below the sideband power are appropriate.

The output power of the modulator is prescribed by the requirement to supply -55 dBm per channel at the input of the first repeater following the antenna. The attenuation budget and output power calculation are shown in Table II. The required output level varies between +1 dBm and -44 dBm dependent on the antenna location and carrier frequency.

The variable length of line between the antenna and first repeater requires a varying amount of equalization. However, if no equalization was applied, the only harmful result would be an attenuation of 0.6 dB across a 42 MHz band. It appears, then, that the reasonable procedure will be to insert a fixed equalizer for the average length of cable; the slope will then be a maximum of 0.3 dB which can be removed in the final adjustable equalizer.

TABLE II

ATTENUATION BUDGET AND OUTPUT POWER REQUIREMENTS FOR ANTENNA TO TRUNK CONNECTION

	Maximum	Minimum
Trunk Cable Attenuation	32 dB (0.8 km at 1904 MHz)	0 dB
Loss from Couplers to Other Antennas	3 dB (5 x 0.6 dB)	0 dB
Attenuation Variation	3 dB	-1 dB
Coupling Loss	10 dB	10 dB
Antenna to Trunk Cable	5 dB (70 m of 7/8" at 1904 MHz)	2 dB (40 m of 7/8" at 1096 MHz)
Total Attenuation	53 dB	11 dB
Output Power per Channel for -55 dBm at Repeater	-2 dBm (+1 dBm for both channels)	-44 dBm (-41 dBm for both channels)
Intermodulation S/N*	36 dB	120 dB

* The intermodulation S/N is based on an amplifier with a 3rd order intermodulation tone intercept of +20 dBm. See ITT Final Report, Appendix 10.

(330) Repeater

The repeater design starts with the specification of overall signal-to-noise for the repeater chain; a figure of 20 dB will be adopted. The noise in the chain arises from amplifier noise and intermodulation noise. It is shown in the ITT Final Report (p. 4-14) that optimum signal level arises when the overall amplifier noise is twice the overall intermodulation noise. Thus, values of 22 dB and 25 dB (giving 20 dB total) are adopted for overall amplifier and intermodulation signal-to-noise, respectively.

The amplifier noise adds incoherently from one repeater to the next. Since there will be a maximum of 26 repeaters on a single link, the noise power increases by 26 times = 14 dB. Thus, the signal level at each repeater input must be 22 + 14 = 36 dB above the amplifier noise. Assuming a 6 dB maximum noise figure and a noise bandwidth of 50 MHz for each signal channel the minimum input level at each repeater must be -91 + 36 = -55 dBm per channel.

The intermodulation noise determines the maximum signal level in a repeater. The intermodulation noise adds coherently from one repeater to the next and thus increases in power by $(26)^2$ = 28 dB in the chain. The intermodulation noise per repeater must then be 25 + 28 = 53 dB below the signal level. The intermodulation signal-to-noise is specified by twice the difference in dB between the "noise intercept level" and the amplifier power output. This concept is discussed in the ITT Final Report, Appendix 10. The noise intercept level is 1 dB below the tone intercept level which is specified at +20 dBm for commercially available transistor amplifiers in the 1-2 GHz range. Thus the maximum amplifier total power output is +20 - 1 - 1/2(53) = -7.5 dBm.

We must next relate the total power to the power per channel. There are 12 channels per cable and if the power were distributed uniformly, the total power would be 11 dB above the power per channel. (The power required in the carriers is negligible.) However, the dynamic range can be increased slightly by pre-equalization, i.e., higher power output in the channels at the high frequency end of the band. If this is done, the distribution of channel power outputs will be as shown in Table III, where the channel powers have been selected to give a -8 dBm total power and a flat spectrum after passing through 0.8 km of cable.

TABLE III

CABLE ATTENUATION AND REPEATER OUTPUT POWERS

Channel	Center Frequency MHz	Cable Attenuation* dB/800 m	Output Power dBm	Output Power μW
1	1096	24.5	-23.7	4
2	1154	25.1	-23.1	5
3	1246	26.1	-22.1	6
4	1304	26.5	-21.7	7
5	1396	27.6	-20.6	9
6	1454	28.1	-20.1	10
7	1546	29.0	-19.2	12
8	1604	29.5	-18.7	13
9	1696	30.4	-17.8	17
10	1754	30.9	-17.3	19
11	1846	31.7	-16.5	22
12	1904	32.2	-16.0	25
Total -----------------------------			-8.3	149

* Attenuation for 800 meters of aluminum-outer, copper-inner conductor 1 5/8" coaxial cable at 20 °C. Values may differ slightly from one manufacturer to another.

The maximum attenuation between repeaters is determined by the channel output powers and the specified repeater input level of -55 dBm. It can be seen from Table III that nominal cable attenuation will produce a -48 dBm input level. The 7 dB of additional attenuation is allowed for the following effects:

Coupler loss — 6 - 10 dB couplers at 0.6 dB per coupler	3.6 dB
Cable temperature change — 20 °C to 35 °C change at 0.2%/°C	1.0 dB
Cable "snake" — 3% elongation...............	1.0 dB
Cable attenuation tolerance	1.4 dB
Total	7.0 dB

The annual temperature variation of the buried cable could cause a cumulative power level variation in the repeater link. A 20° annual change would cause a 1.3 dB change per repeater or ~ 32 dB of power variation at the end of the link. A manual adjustment of approximately once per week of all repeater gains would be required to keep the power level within 1 dB of nominal. In order to avoid this, the repeater gain should be temperature compensated. This can be accomplished by a thermistor attached to the buried cable and controlling a PIN diode attenuator in the repeater. An ALC or AGC circuit could also be used but would be unnecessarily complex.

The equalizer in each repeater will be a transmission line type network presently being developed by D. Buhl.

A block diagram of the complete repeater is shown in Figure 5.

(340) Cable Distributor

A block diagram of the cable distributor is shown in Figure 6. This unit provides RF amplification, automatic level control, and power division to provide 16 isolated outputs. Twelve of these outputs are used to drive IF receivers; one output is used in the ALC loop; and three outputs are for monitor purposes.

(350) IF Receivers

The IF receiver must select one channel of data and translate this data to the delay line operating frequency which is assumed to be 50 to 92 MHz. A system for performing this task is shown in Figure 7.

The appropriate carrier is selected and offset by means of the phase-locked loop shown in the lower half of the figure. This loop can be designed to have no locking problems because the input signal level is fairly high and the frequencies are fixed. The VCO should be a cavity stabilized transistor oscillator with a frequency stability of the order of .01%.

The most critical component in the IF receiver is the bandpass filter (351). This unit is identical to the filter (313) discussed in the SSB modulation section.

(360) Variable Delay

The prototype variable delay line is described in specifications dated April 21, 1967.

(370) Down-Converter

This unit is simply a balanced mixer followed by a low-pass filter ($\sim$ 70 MHz cutoff) and buffer amplifier. The most serious problem will be the feed-thru of the 50 to 92 MHz signal in the mixer. With a well balanced mixer it should be possible to provide > 20 dB rejection of this signal. The leakage of the 100 MHz LO signal should be > 40 dB below the output level. This signal will produce a correlator output but the output is at DC and is thus rejected by the computer filter at the lobe rotation frequency.

(380) Trim-Equalizer

An adjustable amplitude and phase equalizer will be useful for a final trimming of phase and amplitude. The specifications of this equalizer will not be known until the prototype performance of the remainder of the system is known.

At this time it appears that a reasonable equalizer will have two adjustments affecting amplitude and phase (say amplitude slope and curvature) and two more adjustments affecting only phase. The amplitude adjustments could be made by observing the output with the built-in sweep generator applied in the appropriate front-end. The phase adjustments could be made by observing the pulse response with the IF transmission test-pulse generator applied. It may be feasible to make final adjustments by peaking up on a point radio-source.

It may be easier to realize the trimming equalizer in the 50-92 MHz or even the 1-2 GHz portions of the system.

IV. Unresolved Questions

The system design that has been presented in this memorandum needs detailed design, prototyping, and modification where necessary. In addition to this task, the following questions need investigation:

1) Are the equalization requirements significantly different for 1 5/8" cable supplied by different manufacturers? This is likely to be the case because the cable construction is quite different from one manufacturer to another. It is also necessary to determine whether the 1 5/8" coax can be accurately simulated by a much shorter length of small, flexible coax. This information is needed for simulation tests and for repeater test sets. In summary, accurate loss and time delay measurements are needed for several types of coaxial cable.

2) What is the cross-talk between long lengths of 1 5/8" coax laid in a trench? This is probably not a problem but more certainty is needed before a large investment is made.

3) What is the expected reliability of the IF transmission system? Are redundant cables and/or repeaters needed? How do we switch faulty repeaters? These questions need to be answered by an analysis of system reliability (as defined in Chapter 19 of the VLA Proposal — essentially fraction of available Fourier components) in terms of repeater and cable failure rates.

4) How do we monitor the repeaters? A measure of the power output of each repeater is almost certainly needed at the main control room. This data could be obtained by running a twisted pair to each repeater or by transmitting tones in the IF transmission system.

5) What is the repeater environment? At present, it appears that a small waterproof and insulated box, mounted a few feet above the ground, and temperature stabilized at 40 °C, will be adequate. The cables would come up to this box in a broad 90° arc. This looks to be less expensive and more accessible than manholes for repeaters.

6) Should the data link for the control and monitor system be integrated into the IF transmission system? This link must operate in two directions and therefore cannot use the one-way 1-2 GHz repeater system. However, the IF (or LO) cables provide a low loss path (~ 15 dB for 21 km at 1 MHz) for a low frequency transmission system. On the other hand, a twisted pair data link is not very expensive and may be simpler.

7) Can we integrate the underground coaxial cable system with AC power distribution? Is there a danger of 60 ~ pickup or damage from faults? How do we get AC power to repeaters?

8) An analysis of the effects of amplitude variations (with frequency) and phase nonlinearity mismatch is needed. This is not too difficult, but the information needs to be presented in a clear and useful form. The use of pulse testing of the system should be investigated.

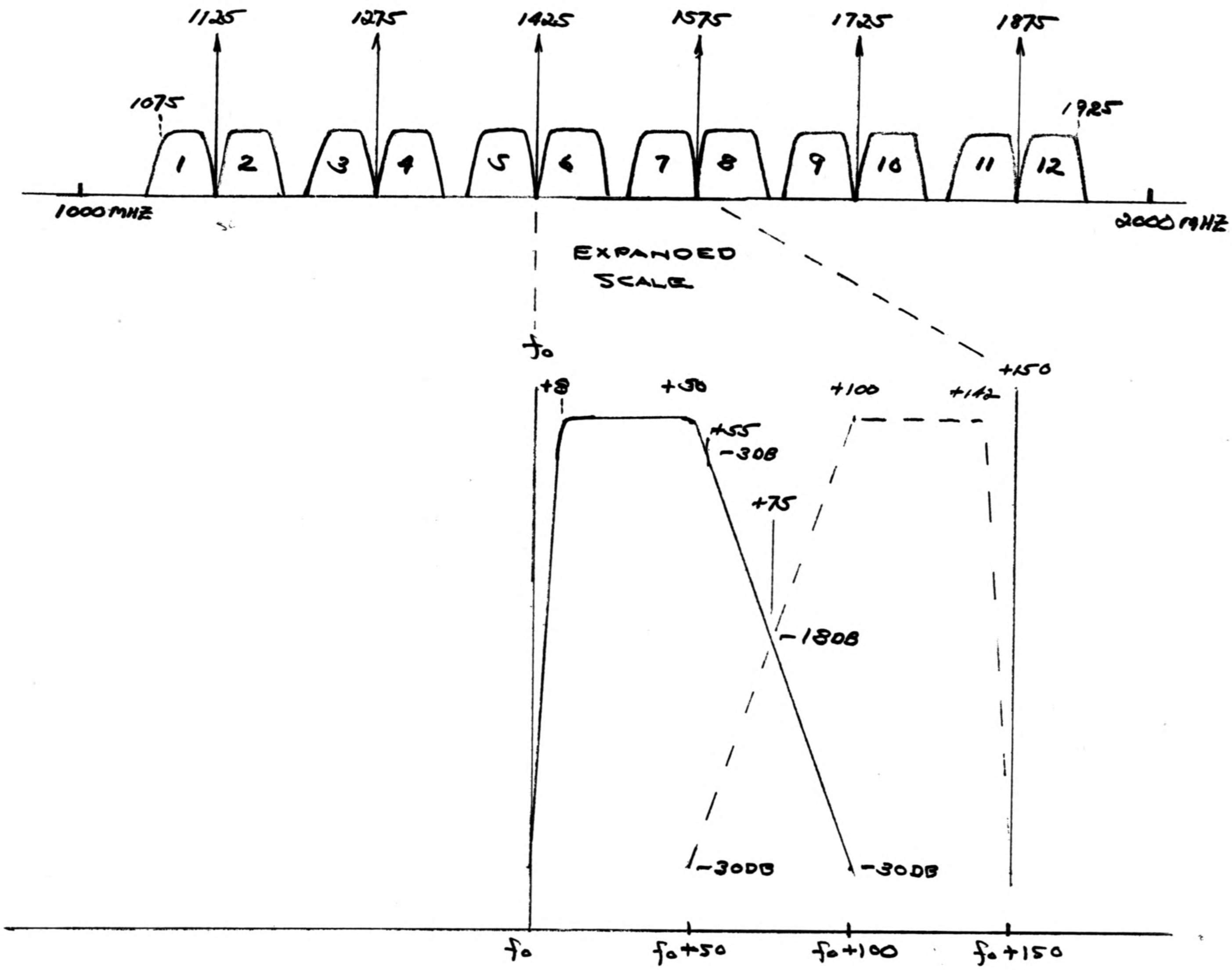

Figure 1 — Spectral distribution of signals in the IF transmission system. Twelve 42 MHz bandwidth signals are transmitted in the 1000-2000 MHz range on a buried 1 5/8" coaxial cable.

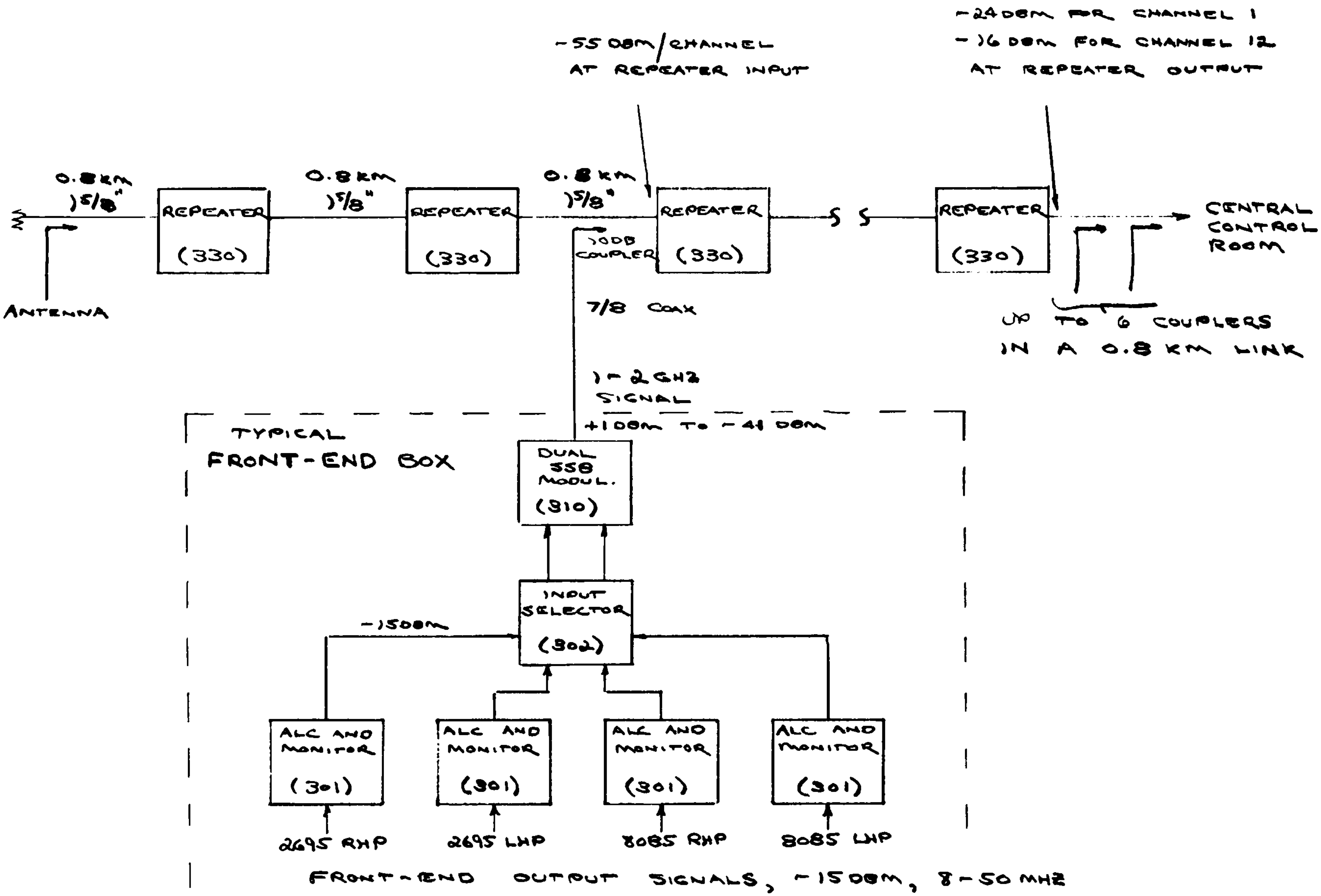

Figure 2 — Baseline and front-end box configuration.

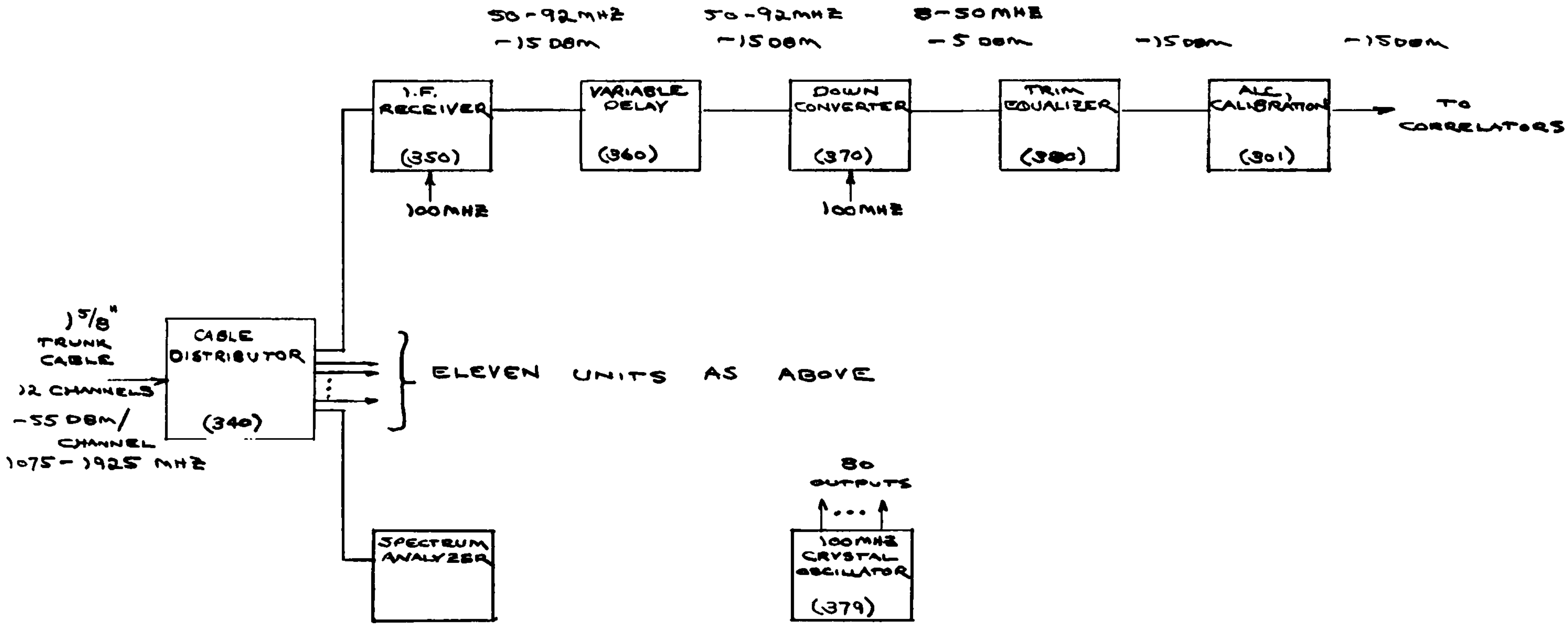

Figure 3 — Control room IF transmission system components.

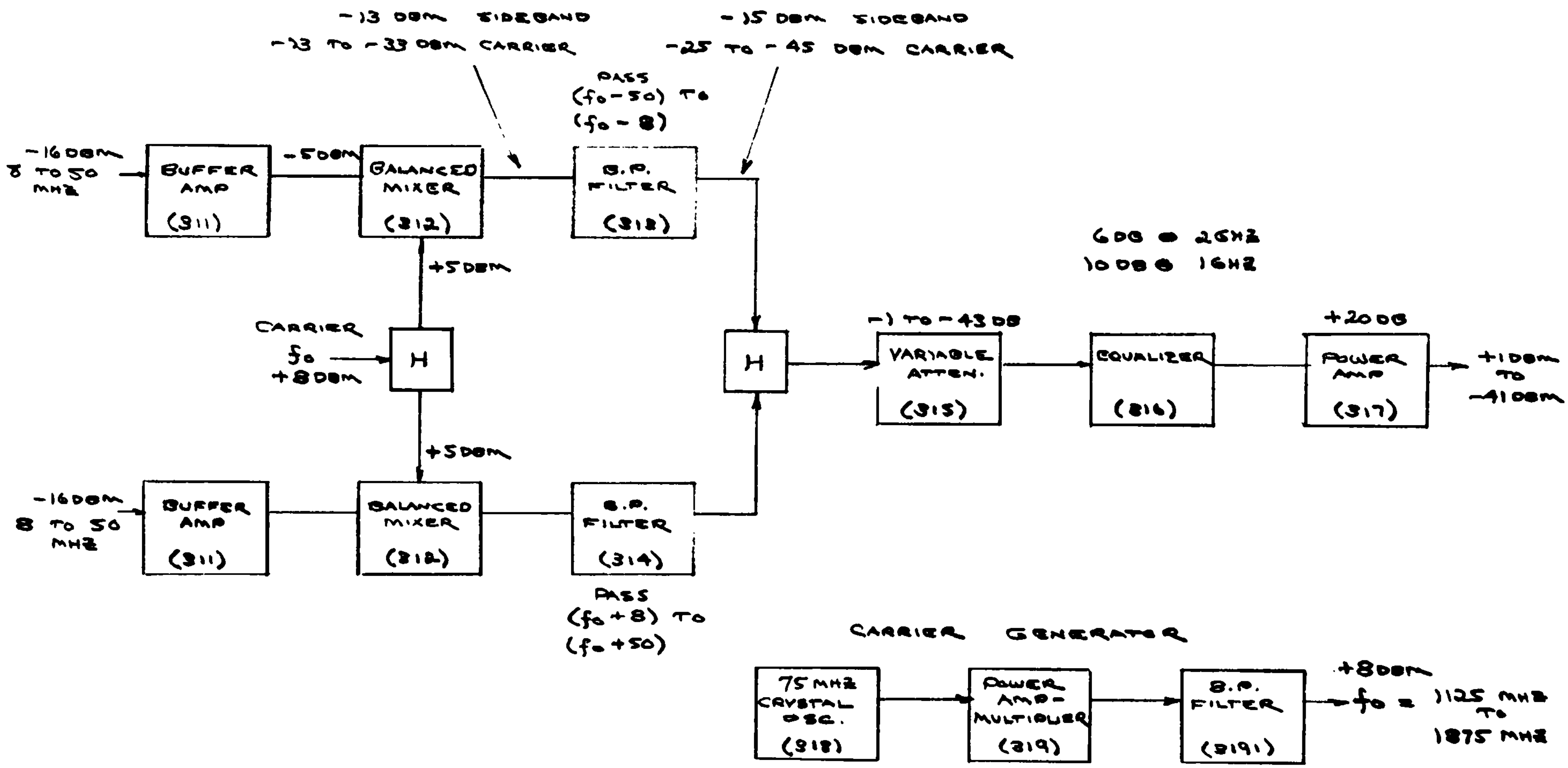

Figure 4 — Dual single-sideband generator.

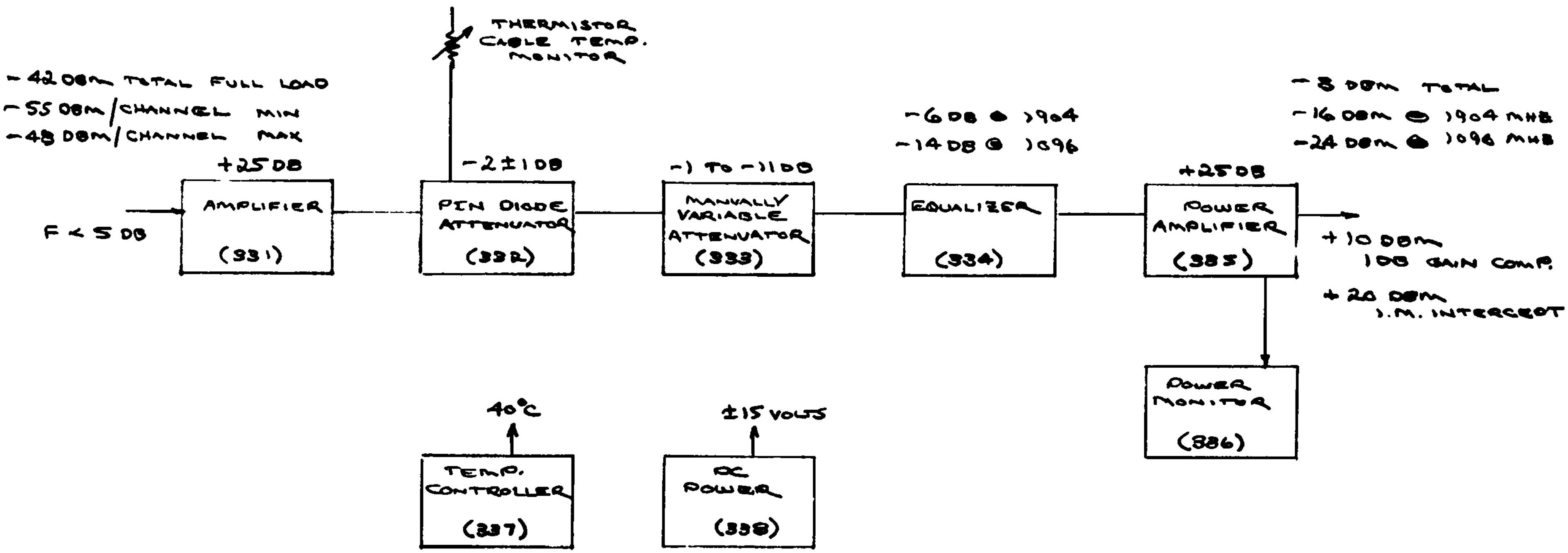

Figure 5 — Repeater block diagram.

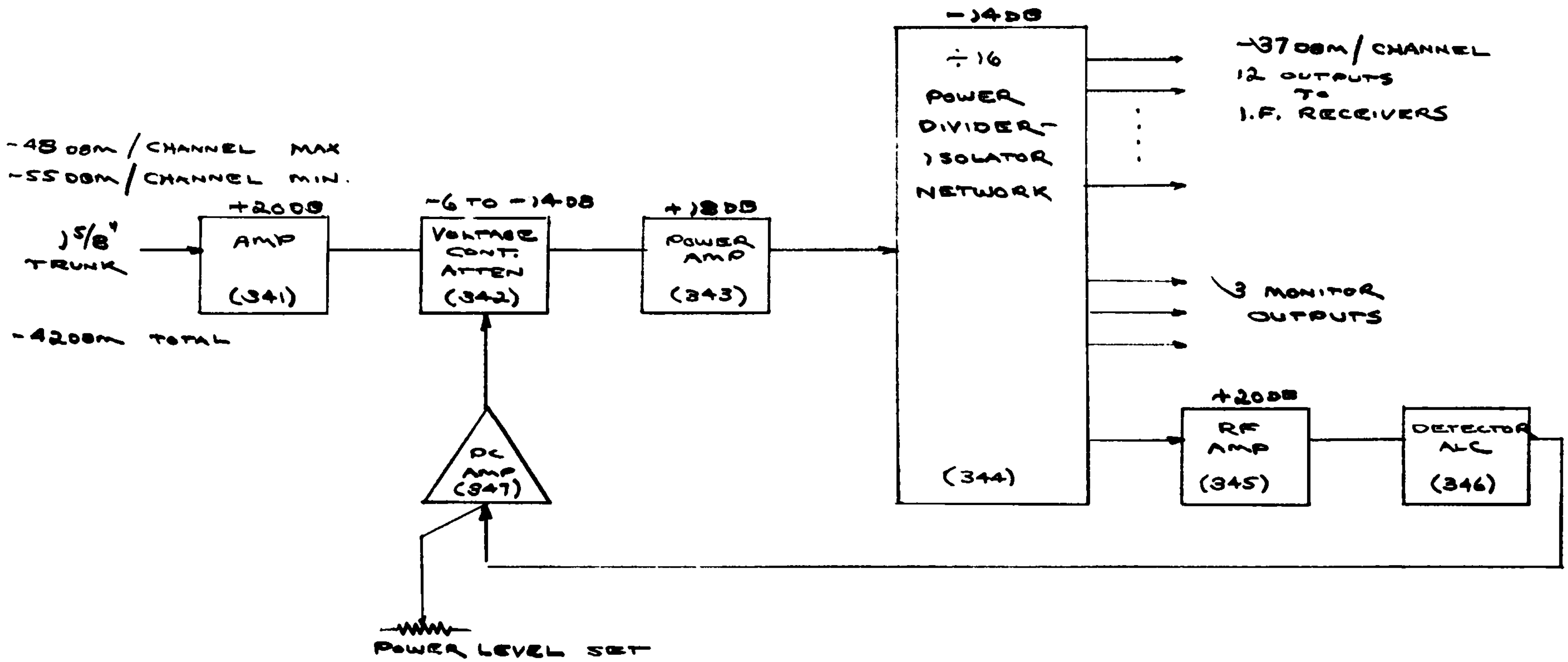

Figure 6 — Cable distributor. This unit provides amplification, power division, and a first ALC to the total received power.

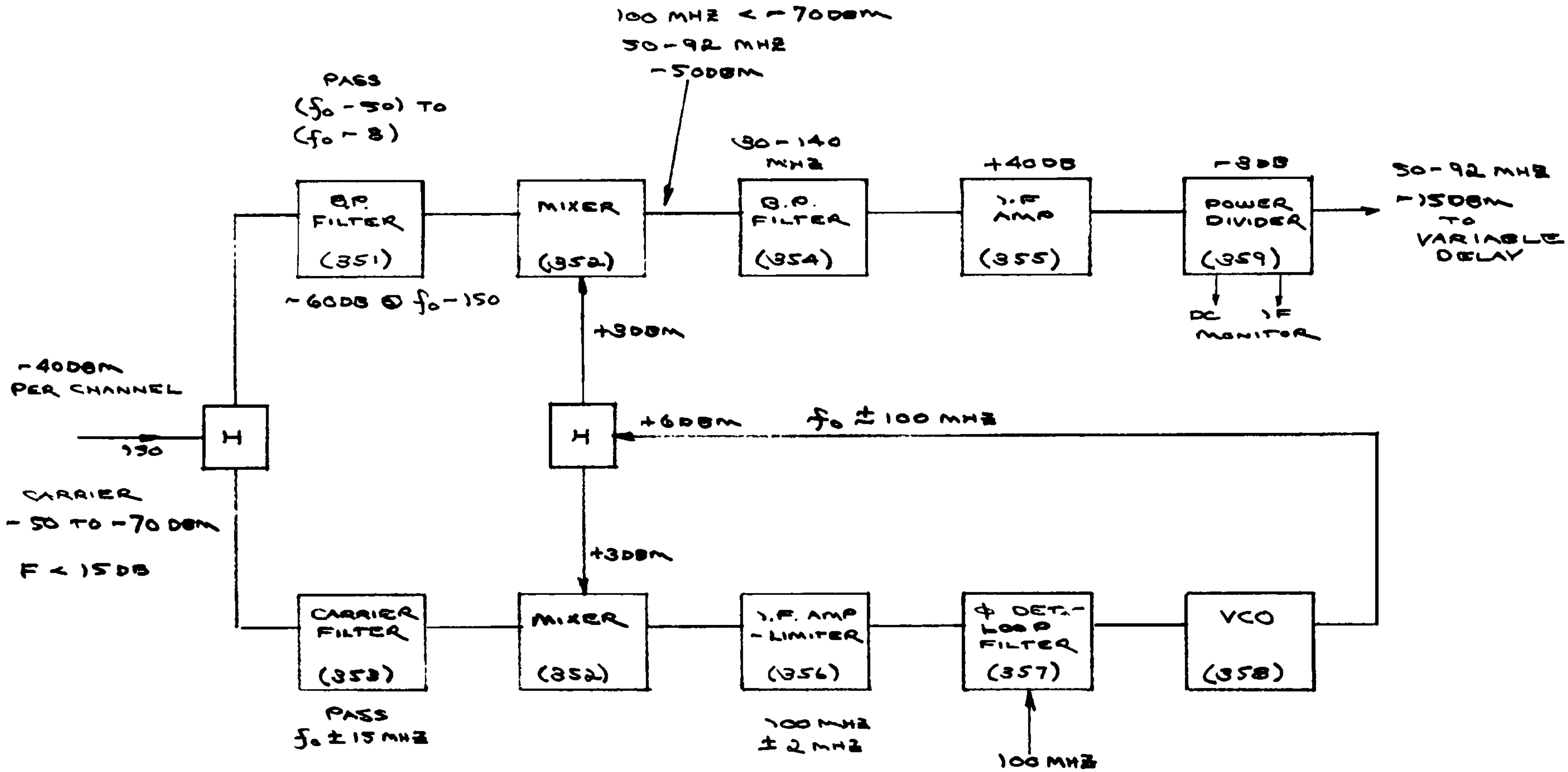

Figure 7 — A block diagram of the IF receiver is shown above. The carrier signal is extracted and offset by 100 MHz by the phase lock loop in the lower half of the diagram. The offset carrier is then mixed with the filtered composite signal to produce the desired sideband in the 50 to 92 MHz band.