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INTRODUCTION

This paper presents some of the results of current NASA developments in the area of low-cost ground receiving systems suitable for the reception of television signals transmitted from synchronous satellites. The systems described receive microwave signals from satellites and perform conversion on the carrier frequency and the modulation format to produce signals compatible with conventional VHF-UHF television receivers.

At the present time, the transmission of television signals from synchronous altitude to large numbers of terrestrial receivers is being studied by several groups, including the CCIR, the Indian government, the Canadian government, and NASA.[1-4] Studies[5,6] have shown that in applications such as television service for India, where there are over 500,000 villages, the placing of only one television set in each village causes the ground receiver costs to be a major portion of the total system cost. If satellite television systems are considered for Western Europe, where there are already over 100 million television receivers, the need for low-cost equipment to adapt the satellite transmitted signal to existing television sets becomes even more obvious. Realizing this imminent need for low-cost receiving stations, NASA has carried out several development programs in these areas.[7,8] The major results are presented in this paper.

The receiving systems studied connect to conventional VHF-UHF television sets. Satellite transmission frequencies near 2.5 and 12 GHz are considered, in order to cover the range of receiver technologies that might be required. The signals transmitted from the satellite might be either frequency modulated (FM) or amplitude modulated with vestigial sidebands (AM-VSB). Receivers to accommodate both modulation formats were designed.

Two different approaches to receiving system design are presented. In one design, the receiver electronics are mounted inside the receiving antenna feed housing. The receiving system then includes both the antenna and the electronics required for interfacing with the television set. In the second design approach, the electronics are packaged separately from the antenna. This system interfaces between the microwave antenna output connector and the user's television set. This report contains descriptions of the two receiving system designs, gives the designed performance characteristics, and presents estimates of the manufacturing cost per unit for various production quantities.

RECEIVERS WITH ELECTRONICS IN THE ANTENNA FEED

One approach to the design of receiving systems is to place the receiver electronics in the antenna feed horn. This approach has the advantage of (1) reduced rf cabling losses, (2) fewer microwave connectors, (3) reduced packaging costs. This type of design was used[7] together with a low-cost paraboloidal reflector design to produce a receiving system having the characteristics given in Table I.

The reflector of the antenna is a quasi-paraboloidal surface that is fabricated from 10 petal-shaped flat stampings. The petals are inserted into extruded rim segments, and are joined with rivets along their seams to form the reflector (fig. 1). The number of petals, the petal shapes, and the rivet hole placement were determined using a computer program to guarantee a high gain, high efficiency design. The antenna is shipped disassembled and weighs about 25 kg, (55 lb). Assembly can be made in about 2 hours by unskilled personnel.

The functions required of the electronics portion of the receiving system are shown in figure 2. The single diode mixer consists of a Schottky barrier diode mounted in the circular waveguide portion of the antenna feed assembly. The local oscillator is a 83.33 MHz crystal oscillator followed by a transistor tripler and a times ten, step recovery diode multiplier. An interdigital filter on the multiplier output eliminates the unwanted multiplier products. Low-cost discrete transistors are used in the transformer coupled IF chain. An IF noise figure of 1.6 dB is obtained at 120 MHz. The limiter is an integrated circuit. A transmission line type discriminator is used, and the line is formed using stripline techniques. Full improvement threshold of the discriminator is about 10 dB. The video amplifier and the remodulator are discrete transistor circuits. A diode ring modulator is used to amplitude modulate a 66 MHz carrier (channel 3). The electronics just described are mounted in the die-cast mixer-feed housing as shown in figure 3.

Power for the receiver is provided by a small, inexpensive, 15 volt dc power supply located in or near the user's television set. The power supply operates off 115 volts, 60 Hz line voltage, and sends the dc power up television twin lead to the antenna mounted electronics.

Audio signals appear as frequency modulation on a 4.5 MHz subcarrier that is added to the composite video signal that frequency modulates the satellite transmitter. When this signal is detected and remodulated in the ground receiver, the audio modulation fits the format for a CCIR type M television system.

Manufacturing cost estimates of the receiving systems are based upon the parts count, the materials required, the assembly techniques to be used, and the testing and alignment required. The resultant manufacturing costs are given in Table II.

The manufacturing cost is not the selling price. In a competitive situation with large quantity production of 10^5 per year, or greater, by each manufacturer, the "factory door price" might be 1.5 to 1.8 times the manufacturing cost. And the retail sales price might be 2.0 to 2.5 times the manufacturing cost. The final selling price depends heavily upon the quantity, the competition, and the marketing situation.

RECEIVERS THAT OPERATE BETWEEN THE MICROWAVE ANTENNA AND THE TELEVISION SET

If the satellite television receiver is to operate with a range of antenna designs, the conversion electronics are required to be separate from the antenna system. The second design approach used separates the receiver electronics into two electronics packages. One package, mounted near the antenna, to minimize rf losses, accepts the rf signal from the antenna and translates it to the IF frequency. The second package, mounted indoors near the television set, demodulates and remodulates the signal as required, provides dc power, and selects the signal, either satellite or terrestrial, to be sent to the user's television set. Several receiving systems were designed using this approach.[8] Their characteristics are given in Table III.

The block diagram for the FM receivers is shown in figure 4. The details of the 2.25 GHz FM receiver will be presented first.

At 2.25 GHz, the balanced mixer is constructed using two Schottky barrier diodes in a stripline circuit. The local oscillator is a direct transistor oscillator at 2.13 GHz, with thermistor compensators used to achieve frequency stability over the temperature range of -40° to $+54^{\circ}$ C. The 120 MHz low-noise IF amplifier is constructed using discrete transistors in a design having transformer coupled interstages. The antenna mounted portion of the IF amplifier has a 2.5 dB noise figure and 30 dB of gain. Conventional television twin lead carries the IF signal to the indoor unit. The indoor unit IF chain also uses discrete transistors in a transformer coupled interstage design. The limiter is a current-limiting differential amplifier with discrete transistors. Two microstrip transmission lines are used in the transmission line type discriminator. One line is shorted to the ground plane, and the other is open circuited. The video amplifier and the VHF remodulator are conventional, discrete transistor circuits. The receiving system output is a CCIR type M television signal at 83.25 MHz (channel 6). The power supply operates off 115 volts, 60 Hz, line voltage. The 20 volts dc required at the antenna unit is carried up on the twin lead. The antenna unit and the indoor unit for the 2.25 GHz receiving system are shown in figure 5.

The 12 GHz FM receiving system is identical to the 2.25 GHz system except that the mixer and the local oscillator are at higher frequencies and the IF filter has a wider bandwidth. Figure 6 is a photograph of the 12 GHz FM antenna unit. The stripline mixer's size is only 5 by 5 cm (2" by 2"), because of the higher frequency. The local oscillator is a Gunn diode mounted in a resonant cavity. Initial tuning adjustments are made at the factor by a temperature compensated tuning rod extending into the cavity. In the 12 GHz FM indoor unit, the IF filter bandwidth is increased by changing only the element values in the filter. This allows the indoor unit packaging and construction to be identical for both the 12 and 2.25 GHz FM receivers. The fabricated 12 GHz FM indoor unit appears the same as the indoor unit shown in figure 5.

The AM-VSB receiving system at 2.25 GHz is simpler than the FM receivers. This system is only required to alter the carrier frequency of the incoming signal, as the modulation format is already compatible with conventional television sets. The functional block diagram is shown in figure 7, and the fabricated antenna and indoor units are shown in figure 8. The balanced mixer uses two Schottky barrier diodes in a stripline circuit. Because of the high local oscillator stability required in the AM system, a crystal oscillator followed by a multiplier chain is used. The 72 MHz crystal oscillator is followed by a transistor tripler, and a times ten, step recovery diode multiplier. The rf stability is within ± 100 kHz. The multiplier output is filtered by a five-section, quarter wave, alternately shorted stripline filter. This filter is built on the same stripline board as the mixer. The IF frequency is 83.25 MHz, (channel 6). A 30 dB gain and 2.5 dB noise figure characterize the discrete transistor IF amplifier. The IF bandwidth is wide enough to allow three adjacent AM-VSB channels to be received. Channels can be selected by the VHF tuner in the user's television set. The indoor unit for the AM-VSB receiver functions as a power supply and a signal selector. The ac line voltage is converted to dc and carried up the twin lead to power the antenna unit. A switch allows the user to select either the signals from an antenna aimed at terrestrial stations or the signal from the electronics that process the satellite transmitted signal.

An extensive cost analysis was performed on the three receiving systems just described. Among the important assumptions made are the following.

1. The fabricated systems would be consumer quality items. There would be less emphasis on reliability, ruggedness, and performance than there is in military or commercial quality equipment.

2. High volume production techniques would be used.

3. Parts procurement procedures would be similar to those used for present day consumer electronics items, i.e., large lot purchases with minimum specifications and little testing by the part manufacturer.

4. There would be a competitive manufacturing environment.

The manufacturing cost estimates are prepared in the following manner. From the fabricated prototypes of the receivers, parts lists are compiled, and volume price quotes are obtained from parts manufacturers for the individual parts. To these are added labor costs for assembly and test. The resulting cost (parts plus labor), is termed the "manufacturing cost". The manufacturer could not sell the items at a price equal to the manufacturing cost. He must provide for facilities, tooling, engineering, overhead, and profit. As for the receiving systems described earlier, it is estimated that the manufacturer would sell the receivers at a price that is 1.5 to 1.8 times the manufacturing cost, and the retail price would be 2.0 to 2.5 times the manufacturing cost.

The manufacturing costs as a function of the quantity of receivers produced per year are shown in figure 9, for the year 1970.

Those of us who work in the aerospace industry might at first have difficulty accepting the cost figures given. After all, the 12 GHz receiver has a Gunn diode local oscillator, a Schottky barrier diode stripline mixer, a 120 MHz IF, and several other features for which we are accustomed to paying high prices. The costs of several receiver components are given in Table IV to indicate the low cost of some of the items required. For production rates of 10^5 and 10^6 per year, the item by item costs are even lower than those given in Table IV. Costs for 10^3 units per year would be slightly higher.

In addition to the variation of receiver cost with quantity, there is also a cost variation with time. Factors that affect receiver costs with time are (1) changing semiconductor costs, (2) generally increasing costs for labor and standard parts, and (3) improved production techniques. Costs of newly introduced semiconductors with limited markets, are estimated to decrease at a rate of 25% per year for the first three years. Semiconductors with partially established markets are estimated to decrease in cost at 15% per year. For well established semiconductor products the rate of decrease is set at 5% per year. The costs of labor and standard parts are assumed to increase at 3% per year due to inflation. Production improvements and periodic receiver redesigns are estimated to cause a yearly net decrease of 10% in the cost of labor and standard parts. This product improvement decrease of 10% is in addition to the effect of inflation.

Estimated receiver costs in subsequent years are calculated using the cost trends just discussed. The results are shown in figures 10 and 11 for 10^3 and 10^6 units per year, respectively. The year corresponding to the beginning of each curve, is the year of the start of production. Costs are given for 1970 and 1972 production starts. Costs for a given year are higher for a later production start, because the product improvement factor of -10% has been operating for a shorter time.

The projected cost estimates shown in figures 10 and 11 use cost adjustment factors based upon a period when the average inflation rate (r) was about 3%. To estimate the costs for a different expected inflation rate (r'), the following approximation may be used.

$$\text{COST}'\ (\text{Year}) \approx \text{COST}\ (\text{Year}) \cdot [1 + (r' - r)\ (\text{Year} - 1970)]$$

where

r = assumed inflation rate for figures 10 and 11 = +3%

r' = expected inflation rate

year = calendar year for which cost is to be calculated

COST (Year) = manufacturing cost as shown in figure 10 or 11

COST' (Year) = manufacturing cost with the expected inflation rate

Thus, the manufacturing costs in 1975, if one expects a 6% inflation rate, would be approximately 1.15 times the costs given in figures 10 and 11.

The analysis of the cost variation versus time was conducted only for the receiving systems that do not include the antenna. However, the electronics portion of the 2.62 GHz FM receiving system described in the first part of this paper is very similar to the 2.25 GHz FM receiver just described. As an approximation, the percentage cost reductions shown in figures 10 and 11 for the 2.25 GHz FM receiver may be extended to the electronics portion of the receiving system with the electronics in the antenna feed. Because the antenna reflector is composed only of mechanical parts, with no electronics, the same cost reduction factors cannot be applied to the antenna portion of the receiver.

CONCLUSIONS

Low cost receiving systems for television signals transmitted from synchronous satellites have been designed and fabricated. The receiving systems described convert the satellite transmitted signals to a frequency and modulation format that is compatible with VHF/AM-VSB television sets. One system, with the receiver electronics mounted in the feed of a 2.1 meter (7 ft) diameter antenna, was estimated to cost $65 for both the antenna and electronics, in large quantity production. This system receives FM television signals at 2.62 GHz. Other receiving systems, not including the antenna, operate with FM signals at 2.25 and 12 GHz, and AM-VSB signals at 2.25 GHz. The unit manufacturing cost of these receivers ranges from $11 to $33 for large quantities. The cost depends upon the frequency, the modulation type, and the year of manufacture.

The described developments in ground receiving system technology indicate that low-cost ground receivers are available to provide maximum utilization of the high power communications satellites that will be developed over the next decade. The estimated receiving system costs are low enough that the advantages of satellite television transmission can be afforded by small communities, schools, hospitals, and even individual television set owners.

REFERENCES

1. Anon.: Feasibility of Direct Sound and Television Broadcasting From Satellites. CCIR Rep. 215-2, Documents of the XII th Plenary Assembly, New Delhi, 1970.

2. Prasada, Birendra, and Singh, Jai P.. ACME-A Hybrid Airborne Satellite Television and Communications System for India. Paper 70-472, AIAA, Apr. 1970.

3. Parkinson, Peter. An Experimental Earth Station for Domestic Television Reception. Paper 70-432, AIAA, Apr. 1970.

4. Kuhns, Perry W.. The Technological Problems of Television Broadcast Satellites. Aviation and Space: Progress and Prospects. ASME, 1968, pp. 103-110.

5. Hesselbacher, R. W.: Television Broadcast Satellite (TVBS) Study. Vol. 1. General Electric Co. (NASA CR-72578), Aug. 1, 1969.
Hesselbacher, R. W.: Television Broadcast Satellite (TVBS) Study, Research and Technology Implications Report. Vol. 2. General Electric Co. (NASA CR-72511), Oct. 6, 1969.
Hesselbacher, R. W.: Television Broadcast Satellite (TVBS) Study. Vol. 3. General Electric Co. (NASA CR-72579), Nov. 15, 1969.

6. Jansen, J.; et al.: Television Broadcast Satellite Study. Rep. 08848-6002-RO-00, TRW Systems Group (NASA CR-72510), Oct. 24, 1969.

7. Lusignan, B. W.; Bulkeley, P. S.; Janky, J. M.; and Taggart, R. B., Jr.: The Design and Development of a Low-Cost Microwave Adaptor Suitable for Television Reception from High-Power Communications Satellites. Rep. SU-SEL-70-075, Center for Radar Astronomy, Stanford Univ. (NASA CR-72773), Oct. 31, 1970.

8. Anon.: Ground Signal Processing Systems, Summary Reports on Analysis, Design and Cost Estimating. General Electric Co. (NASA CR-72709), June, 1970.

TABLE I. - RECEIVING SYSTEM CHARACTERISTICS

Frequency	2.62 GHz
Modulation type	FM
Signal bandwidth	25 MHz
rf Tuning	None
Receiver noise figure	7 dB
Antenna diameter	2.1 m (7 ft)
Antenna gain	32 dB
Antenna efficiency	55%
Receiving system G/T	0.4 dB
Video S/N (CCIR weighted)	47 dB (at C/N = 15 dB)
Receiver output	VHF/AM-VSB

TABLE II. - MANUFACTURING COST ESTIMATES

	Quantity manufactured			
	10^2	10^3	10^4	10^5
Antenna	$ 89	$ 42	$33	$32
Electronics	164	75	49	33
Total	$253	$117	$82	$65

TABLE III. - RECEIVING SYSTEM CHARACTERISTICS

Frequency (GHz)	2.25	12.00	2.25
Modulation Type	FM	FM	AM
Signal bandwidth (MHz)	30	40	6
rf Tuning	None	None	None
Receiver noise figure (dB)	9	11	9
Video S/N (CCIR weighted) (dB) (C/N = 15 dB in FM systems)	47	51	41
Receiver output	VHF/AM	VHF/AM	VHF/AM-VSB

TABLE IV. - 1970 COSTS OF SELECTED ITEMS FOR 12 GHz FM RECEIVER,

10^4 PER YEAR MANUFACTURING RATE

Item	Cost Each
Gunn diode	$22.00
Mixer diode	4.75
Mixer board material	.63
IF transistor	.15
Resistor	.01
Fixed capacitor	.01
Variable capacitor	.20
Balun	.065
Antenna unit enclosure	.40
Total parts cost for indoor unit - (IF amplifier, limiter, discriminator only)	4.59
Total labor (assembly and Test)	4.90

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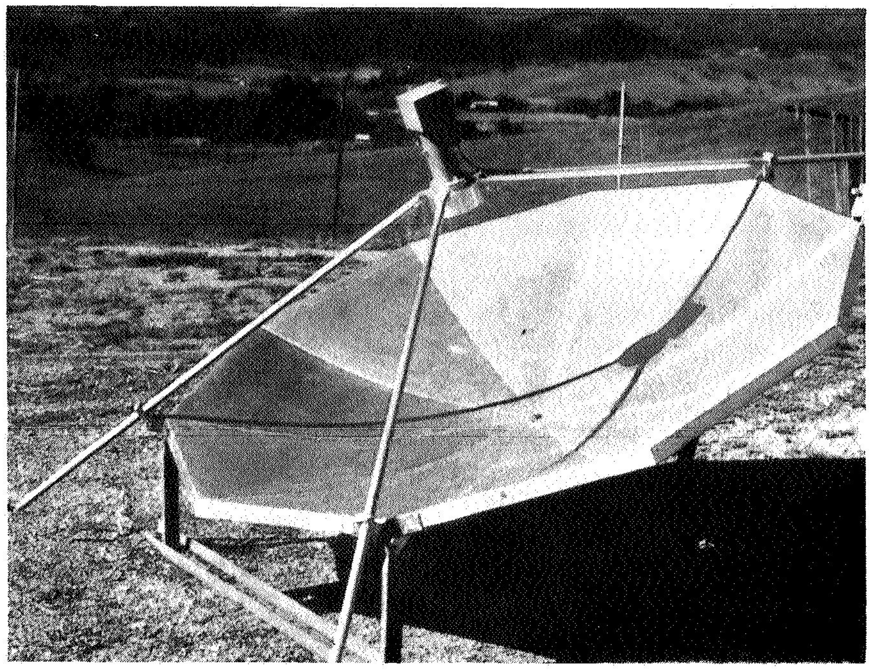

Figure 1. - Assembled antenna with electronics in the feed.

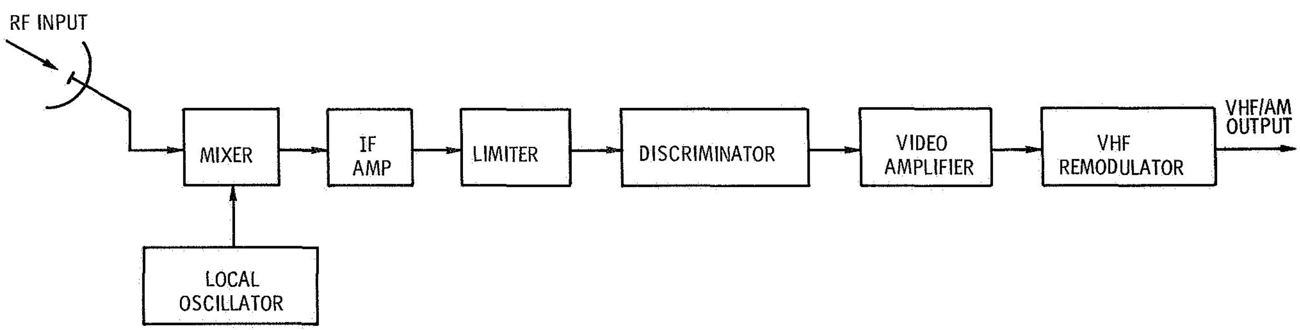

Figure 2. - Block diagram of FM receiver with electronics in the antenna feed.

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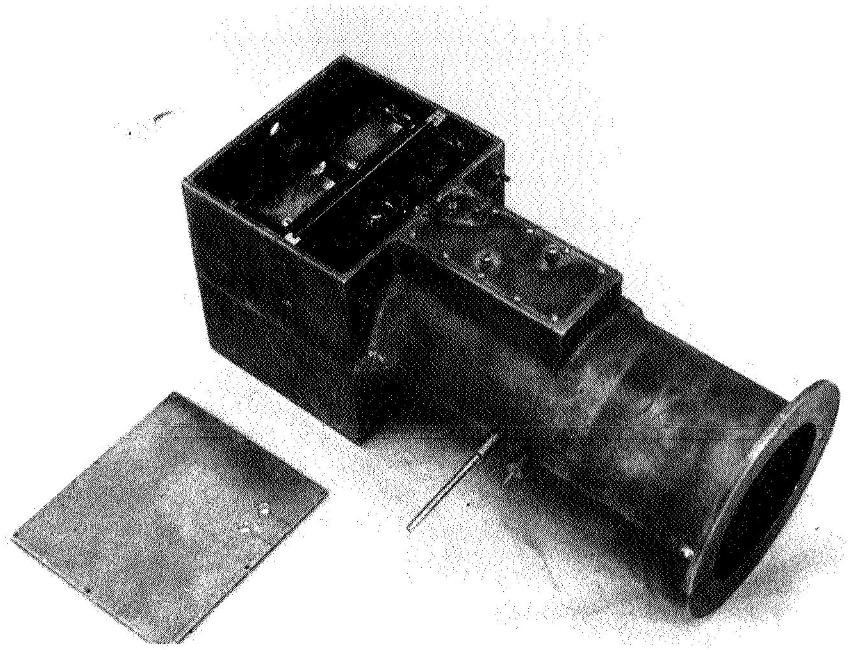

Figure 3. - Feed with electronics.

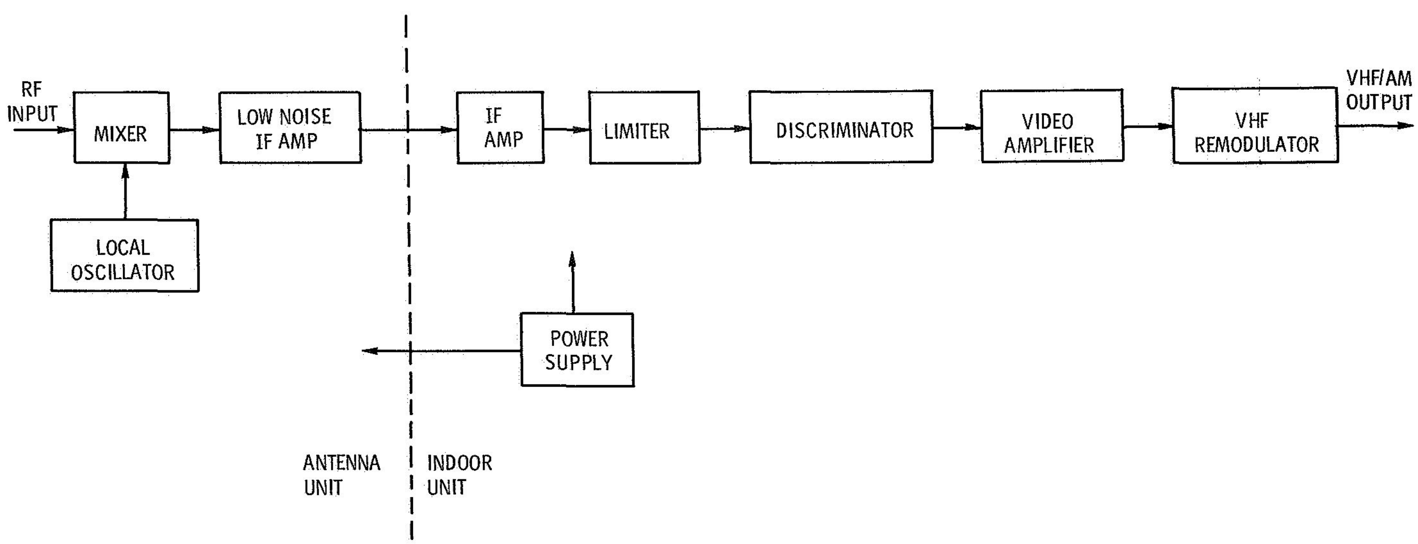

Figure 4. - Block diagram of FM receivers, electronics only.

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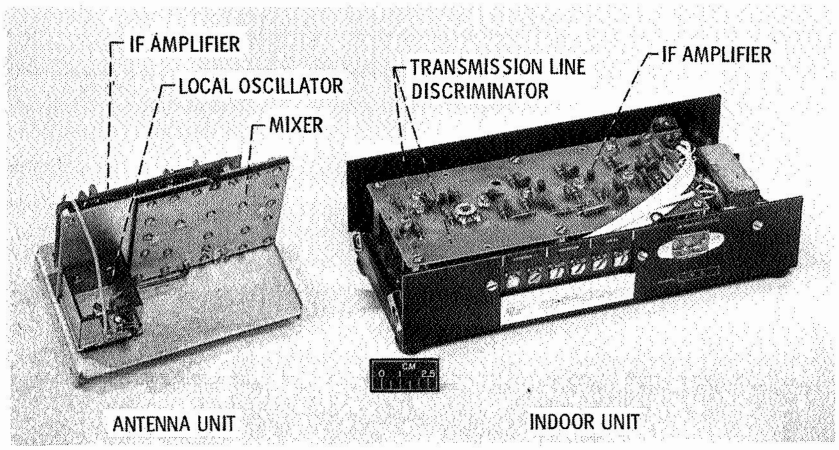

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Figure 5. - Antenna unit and indoor unit for 2.25 GHz, FM receiving system.

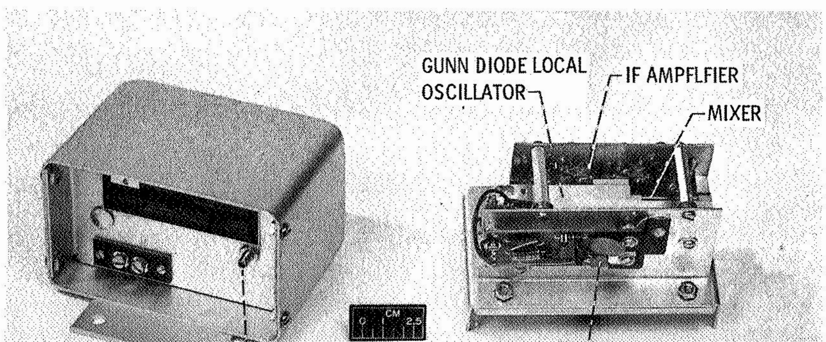

Figure 6. - 12 GHz, FM antenna unit.

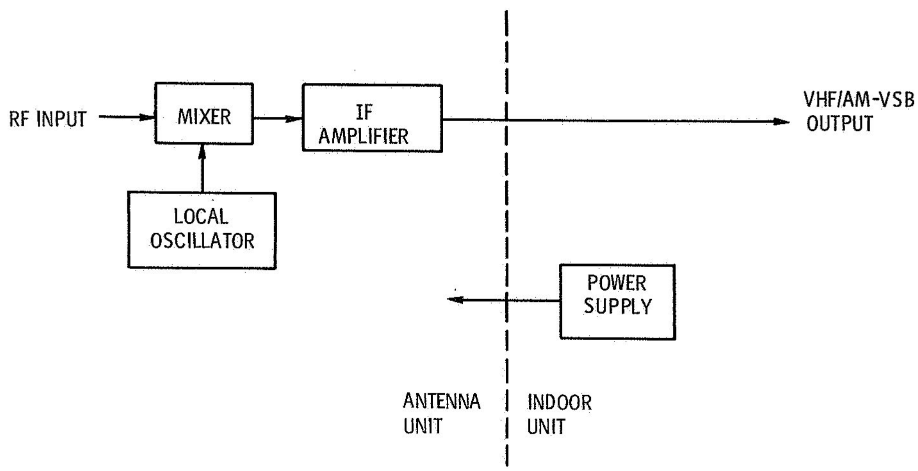

Figure 7. - Block diagram of 2.25 GHz AM-VSB receiver.

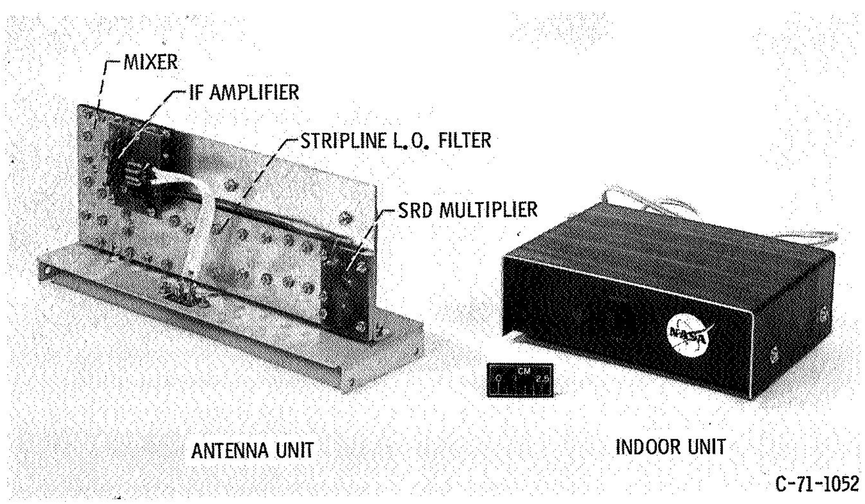

Figure 8. - Antenna unit and indoor unit for 2.25 GHz, AM-VSB receiving system.

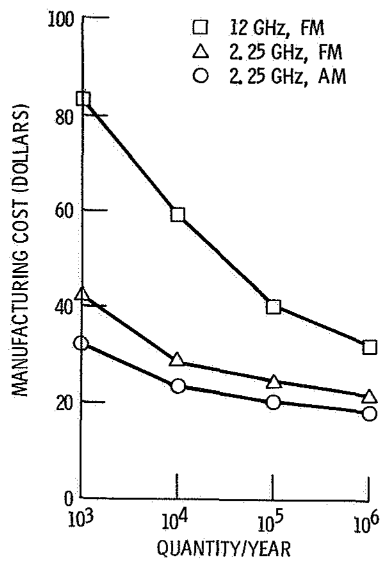

Figure 9. - Estimated 1970 manufacturing costs versus quantity produced per year.

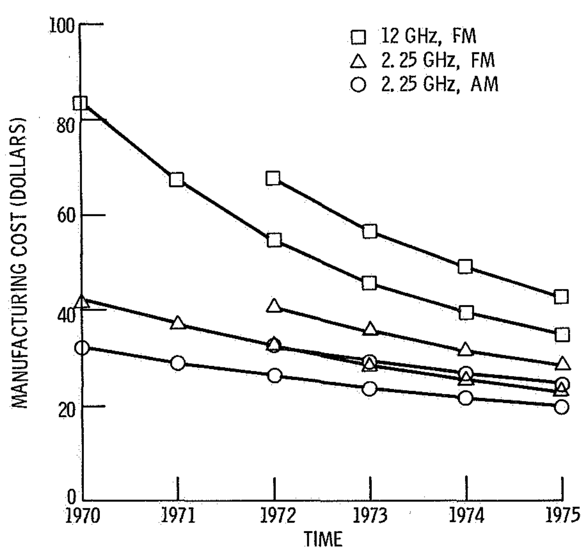

Figure 10. - Estimated manufacturing cost versus time for 10^3 units per year.

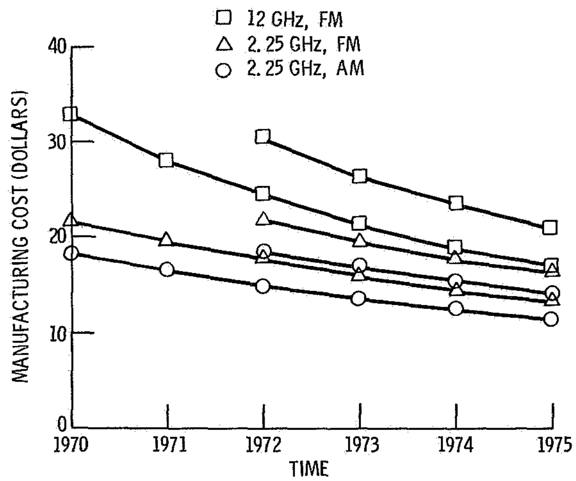

Figure 11. - Estimated manufacturing costs versus time for 10^6 units per year.