A COST-EFFECTIVE MODULAR DOWNCONVERTER FOR S-BAND WEFAX RECEPTION

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Abstract

The relocation of weather satellite facsimile downlinks from VHF into S-band has generated a requirement for reliable, low cost microwave receiving equipment. This paper explores many of the design trade-offs encountered in developing one such receiver system.

Introduction to WEFAX

For the past decade, meteorological agencies around the world have received periodic weather facsimile (WEFAX) and Automatic Picture Transmission (APT) printouts from a network of polar orbiting and geosynchronous satellites. [1,2] The products available from these satellites are diverse, but generally include computer-gridded cloud cover maps such as the one shown in Figure 1, derived from satellite-borne optical and infrared sensors. [3] Ground reception of such signals supports not only weather prediction, but also geological resource assessment and agricultural planning activities.

WEFAX coverage is currently limited to the Western Hemisphere, while APT is a worldwide, direct broadcast service. Users depending upon these transmissions include underdeveloped nations, operating their ground receiving stations on an extremely limited budget and under the most adverse environmental conditions. The challenge facing the designer of WEFAX and APT receiving equipment thus involves assuring the utmost in reliability, ease of operation by unskilled personnel, and of course absolute minimum cost.

Frequency Allocations

Several generations of weather satellites have transmitted frequency-modulated downlink signals in the 135 to 138 MHz frequency region. A degree of standardization has begun to emerge with regard to modulation characteristics and image formatting, enabling users to recover multiple satellite products on a single receiver and display device, with minimum equipment modification. Perhaps a thousand commercial VHF weather satellite receiving stations now exist worldwide. Countless other, less elaborate systems have been fabricated by individual hobbyists and experimenters. [4]

Spectrum allocation requirements have dictated the assignment of downlink frequencies in the microwave region for the latest series of meteorological satellites. The first two of these, designated SMS/GOES (Synchronous Meteorological Satellite/Geostationary Operational Environmental Satellite) have been deployed by the U. S. National Oceanic and Atmospheric Administration (NOAA). They will be joined shortly by three additional geostationary satellites now being developed by the USSR, Japan, and the European Space Agency (ESA). The five spacecraft will be positioned approximately seventy degrees apart, thus providing nearly global WEFAX coverage.

All of these satellites will transmit WEFAX at a frequency near 1.7 GHz, with modulation characteristics and image format being fully compatable with present VHF WEFAX transmissions. In order to assure maximum utilization of existing equipment, linear downconversion of these 1.7 GHz signals to the 135 MHz region has emerged as an accepted technique for developing worldwide S-band WEFAX receiving capability.

Path Calculations and System Margin

System noise margins for a proposed S-band WEFAX receiver are derived in Table 1. Significant assumptions are the satellite's Effective Isotropic Radiated Power (EIRP), the use of a small (1.2 metre) parabolic reflector and feed as the ground-station antenna, an IF bandwidth of 26 KHz in the VHF receiver, and a receiver overall noise factor of 2.2 (which represents a Noise Figure of 3.4 dB), a design goal for the proposed downconverter. Under these conditions, the system's Signal-to-Noise Ratio (SNR) approaches 17 dB.

Since a 10 to 12 dB SNR will yield relatively noise free WEFAX images, it can be seen that the proposed receiver will tolerate at least 5 dB of signal degradation without significantly impacting overall system effectiveness.

System Modularization

During initial development of the WEFAX downconverter, numerous mixers, bandpass filters, single stage amplifiers, local oscillators and multipliers were fabricated, each in a separate shielded enclosure, all with input and output ports connectorized and matched to a fifty ohm, nonreactive interface impedance. Circuitry for each of these modules was based upon various of the author's previously published designs, adapted to the frequency of interest. [5,6,7,8] It should be pointed out that an analytical design approach based upon scattering-parameter analysis was employed; more simplistic design techniques based upon frequency scaling are frequently fraught with difficulty.

Performance of individual modules was generally optimized empirically prior to their inclusion in a system prototype. This modular approach allowed maximum flexibility in configuring the system for optimum performance consistent with minimizing costs. Wherever possible, it was decided to cascade identical modules rather than develop a wide variety of circuits. The resulting system, shown in Figure 2, satisfied the major sensitivity, selectivity, stability and spectral purity criteria, proved readily repeatable, and required little or no realignment of the individual circuits following system integration.

The modular concept was carried forward into production, thus minimizing manufacturing costs, maximizing isolation between stages, and enhancing both user flexibility and maintainability. For example, each downconverter contains three identical amplifiers, as well as three identical bandpass filter modules. Thus the required inventory of field-replaceable assemblies is minimized, and trouble-shooting by stage substitution becomes a viable means of reducing system downtime.

Figure 3 depicts an assembled downconverter, patterned after the block diagram of Figure 2, along with interior views of several of the modules employed. Detailed specifications on these modules are available from the author.

Cost Considerations

NOAA, in a recent Technical Memorandum, described a workable downconverter for S-band WEFAX reception, based upon readily available standard microwave assemblies.[9] It appeared clearly possible to reduce the cost of this converter by at least a factor of three, while significantly improving system performance, by developing the most cost-effective circuits tailored to the particular application.

Link analysis (see Table 1) confirmed the feasibility of recovering noise free images with a much smaller antenna than the one used by NOAA, by somewhat upgrading receiver performance requirements. Two stages of bipolar amplification preceeding a passive balanced mixer proved practical to achieve the required receiver sensitivity. Conjugately matched amplifiers were used, thus simplifying their design and assuring improved stability. Of course it was necessary to confirm by noise-circle analysis that such impedance-matched preamplifiers would not degrade system noise figure beyond the 3.4 dB design goal.[10]

Bandpass filtering at the various mixer ports made it possible to use a singly balanced mixer configuration, while maintaining the same system spurious rejection as the NOAA system had exhibited with its more costly double-balanced mixer. Filtering in the preamplifier chain also eliminated image noise, while significantly enhancing dynamic range.

Although frequency stability requirements demand the use of a crystal-controlled local oscillator chain, it was found that employing Automatic Frequency Control in the VHF receiver could compensate for minor LO drift. Thus the temperature stability requirements of the oscillator were relaxed somewhat, resulting in further cost savings.

By applying a predetermined DC bias to the LO multiplier diode, its conduction angle was optimized to enhance third-harmonic output (while reducing other spectral components). This technique reduced the filtering requirements of the local oscillator chain.

To minimize module fabrication costs, micro-stripline construction was employed throughout. However, rather than etch these circuits on the traditional (and costly) controlled ϵ_r microwave substrates, low-cost fiberglass-epoxy printed circuit stock was used. Dissipative losses were clearly measurable, but tolerable, while anomolies due to substrate discontinuities were readily compensated by tuning adjustments. Several hundred of these modules have been successfully fabricated, using photo-etching techniques along with artwork such as that shown in Figure 4.

Summary

A method has been described for downconverting S-band WEFAX, for reception by an existing VHF weather satellite groundstation. Prudent design tradeoffs have held total costs, including the required antenna and feed, RF modules, and interconnecting cables, to around $1200.

References

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9. J. J. Nagle, "A Method of Converting the SMS/GOES WEFAX Frequency (1691 MHz) to the Existing APT/WEFAX Frequency (137 MHz)," NOAA Technical Memorandum NESS 54, April 1974.

10. "Noise Parameters and Noise Circles for the HXTR-6101, -6102, -6103, -6104, and -6105 Low Noise Transistors," Application Bulletin 17, Hewlett-Packard Company, January 1977.

Table 1

System Signal-to-Noise Calculations

1. Given: EIRP (Satellite) = +54.4 dBm

2. Path Loss (dB) = $92.5 + 20 \log_{10} d + 20 \log_{10} f$

   where f = 1.7 (GHz)
   and d = 35,788 (Km)
   thus Path Loss = -188.2 dB

3. Power to Antenna = EIRP + Loss = -133.8 dBm

4. Given: a 1.2 m dia. parabolic reflector, with 55% feed efficiency.
   Antenna Gain = +25 dBi

5. Recovered Power = Power to Antenna + Gain = -108.8 dBm

6. Assuming that $T_o = 290^o$ K,
   Minimum Discernible Signal (MDS) = $-174 \text{ dBm} + 10 \log_{10} BW + 10 \log_{10} F$

   where $BW = 2.6 \times 10^4$ (Hz),

   and F = 2.2

   thus MDS = -126.4 dBm.

7. SNR = Recovered Power - MDS = 17.6 dB

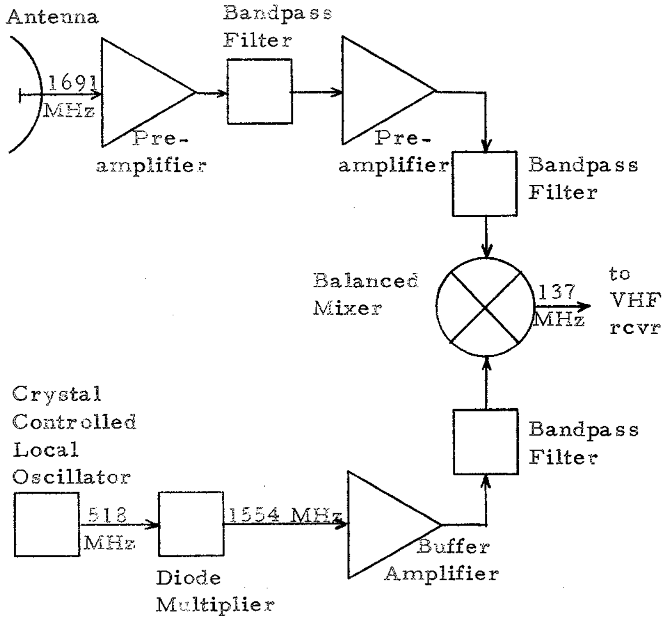

Fig. 2 - System Block Diagram of the Microcomm modular S-band WEFAX downconverter.

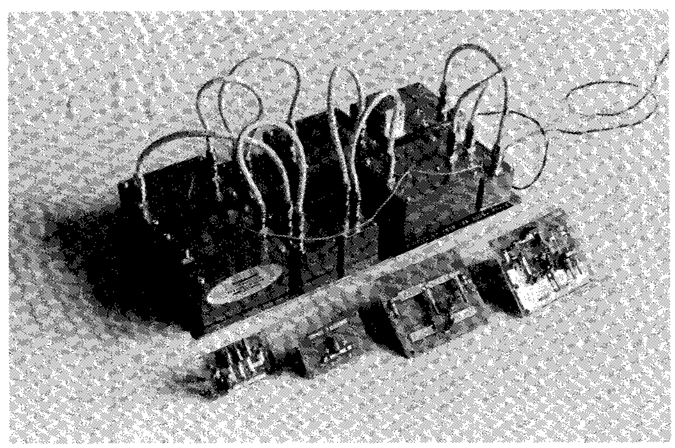

Fig. 3 - Completed downconverter assembly, with individual modules in foreground.

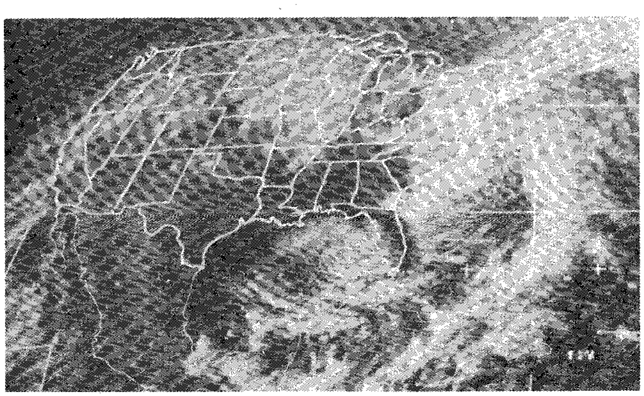

Fig. 1 - Representative WEFAX/APT printout.

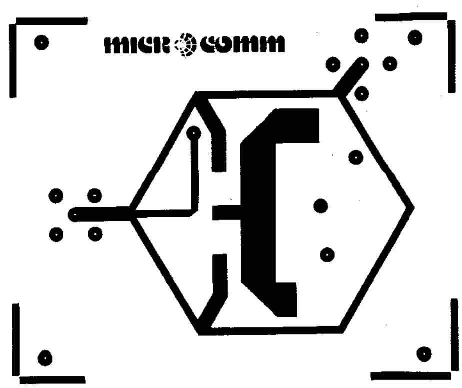

Fig. 4 - Typical microstripline artwork.