

DIGITAL RECEIVER SIMULATION

Mr. Carl Hinrichs - McDonnell-Douglas Corporation

MR. HINRICHS: The simulation is summarized on Figure 7-26 and was for the Saturn-Uranus design that you have heard so much about in the last day and a half. This design is 40 watt, 400 MegaHertz, 44 bit-a-second link and, as has been pointed out, is a power starved link and uses convolution coding. As far as the simulation itself goes, parameters such as the power level, the bit rate, and the range are relatively insignificant. These are taken into the simulated signal-energy-to-noise-density ratios. The center frequency is, in the simulation, relatively unimportant because the simulation is entirely in complex amplitude so that the center frequency is just a normalization.

As was pointed out, we were interested in encoding this link and this is one of the reasons that the simulation became particularly attractive. For convolutional codes we do not have to concern ourselves with some typical simulation problems such as very low symbol error rates. We will be looking primarily for symbol error rates that are around .05. And if we get down to .01 or .001, this is very solid for the code. This makes simulation quite attractive.

Fine, it is attractive but why simulate this particular link? As we have heard from the previous speakers, this link has several unique aspects. First of all, atmospheric scintillation. We are in an atmosphere here today, we transmit radio waves back and forth, why don't we have that problem? Well, primarily because we are not at a ten or thirty bar level. We are only in a one bar level here. If the pressure were higher, we would start seeing scintillation problems.

Secondly, the center frequency certainly enters into this, our Doppler to data rate ratio is very high. What I mean by this is that relative to the bandwidth of the data, the

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TYPICAL LINK

- 40 WATTS
- 400 MHz
- 44 BPS
- 10^5 km RANGE
- CONVOLUTIONAL CODE

UNIQUE ASPECTS

- ATMOSPHERIC SCINTILLATION
- DOPPLER/DATA RATE ≈ 450

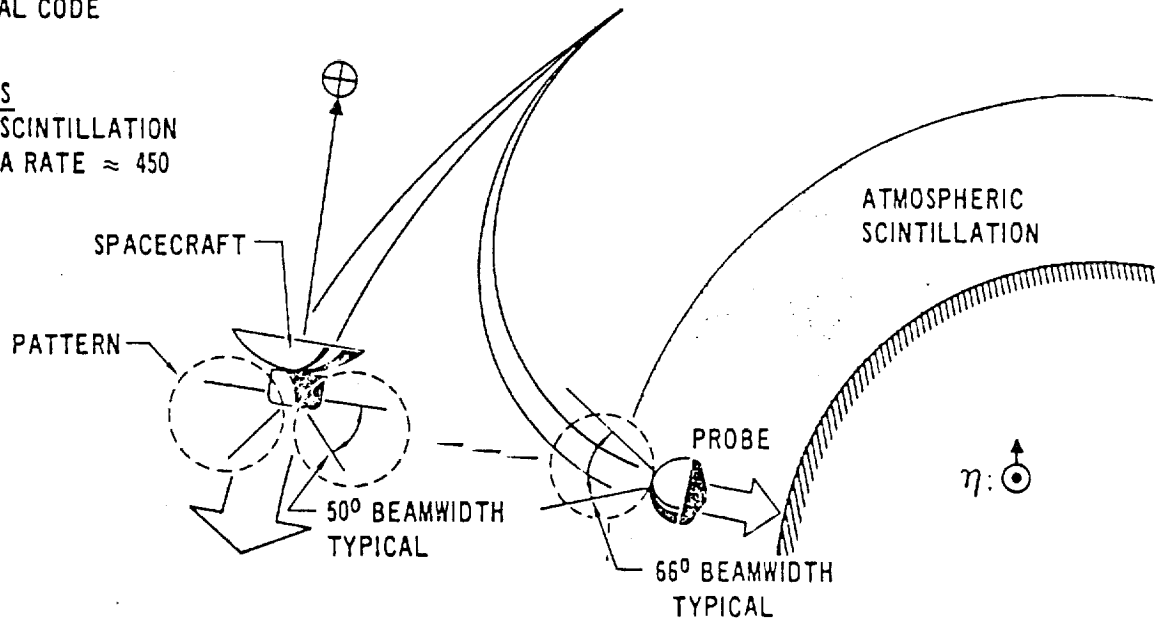


Figure 7-26

frequency uncertainties due the Doppler are quite wide. So we have a unique aspect in this sense. Because of the uniqueness of the link, the unique problems and because we are only looking for fairly high symbol error rates as opposed to an uncoded system, simulation appears to be a good technique to determine the applicability of candidate designs.

Now in the next chart, (Figure 7-27), I would like to review a little bit about atmospheric scintillation. Sometimes we tend to say that these problems are non-analytic. Certainly in the past, there have been a number of articles, at least that I am familiar with, that deal with fading. In the bulk of the fading articles, the amplitude is generally considered Raleigh or Ricean and the phase is assumed to be uniform. In atmospheric scintillation, neither of these is necessarily the case.

Atmospheric scintillation arises when one has a blob, as it is called in the literature, of atmosphere with an index of refraction slightly different from the remaining atmosphere. This blob may have been generated in a number of ways but generally, it is some form of thermal instability that creates it. The blob is unstable and breaks into smaller blobs. The smaller blobs continually break until the Reynolds number is finally sufficient and it can dissipate. So there is a range of inhomogeneities in the index of refraction.

As an electromagnetic wave passes through this range of inhomogeneities, the larger inhomogeneities tend to affect the phase of the signal and the smaller inhomogeneities tend to affect the amplitude of the signal. Thus, we see the amplitude in the phase characteristics of the signal are independent.

As Mr. Grant pointed out, for this simulation we have modeled the scintillation amplitude as some value A, with a 4/3rds fall off

SCINTILLATION FILTERING

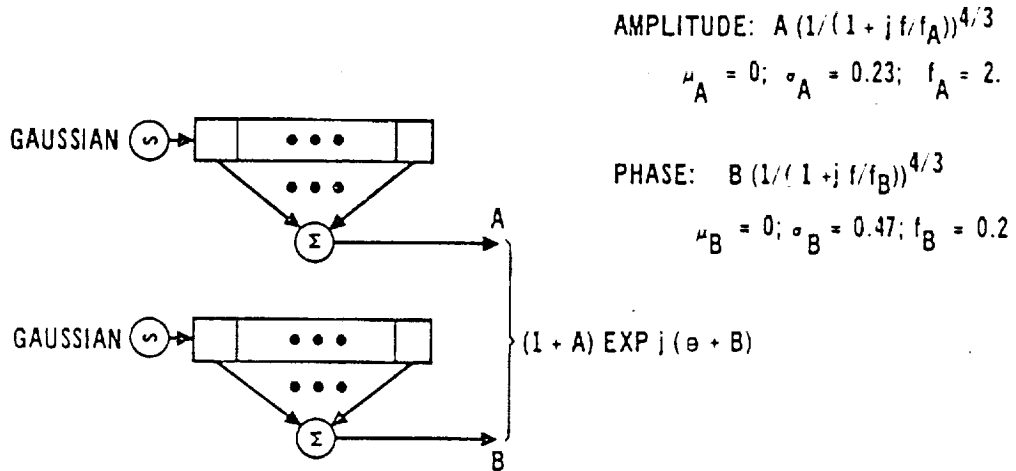


Figure 7-27

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at a corner of two Hertz. This amplitude is modeled, in this case, as having a zero mean and a root variance of .23.

The phase, the other independent variable, again, has a 4/3rds filter roll off. Four-thirds is basically from the Russian Tatarski. The phase has, again, a zero mean and a root variance of .47 radians and rolls off at a much lower corner, 2/10ths of a Hertz.

Typically, in digital simulations, we like to use Z transforms but as one can fairly readily show, when one has a non-integer number of poles, the Z transform series doesn't collapse into a closed form. So we spent a fair amount of effort in modeling the exact characteristics of the scintillation in terms of tapped delay lines. We took independent Gaussian numbers and ran them through the delay lines to form the amplitude and the phase. For this simulation we modeled the amplitude as simply unity plus the Gaussian number. A better simulation might utilize a log normal.

Given the problem, we need a candidate design. In the first portion of the Saturn-Uranus study, TRW supported McDonnell Douglas in defining the hardware impacts of various candidate system designs. In the latter portion of the study, they took the resultant system design and performed a detailed receiver design. That receiver design is shown on Figure 7-28.

In the receiver, the lower loop is the frequency tracking loop. This loop tracks the tones of the transmitter. It is a continuous phase, FSK transmitter. The upper loop is the automatic gain control loop which serves to hold the voltage for the AFC loop at a constant value. The automatic gain control loop provides a signal strength indication from the coherent amplitude detector. If it is not locked to the signal, it can initiate the sweep circuitry.

CANDIDATE DESIGN (TRW)

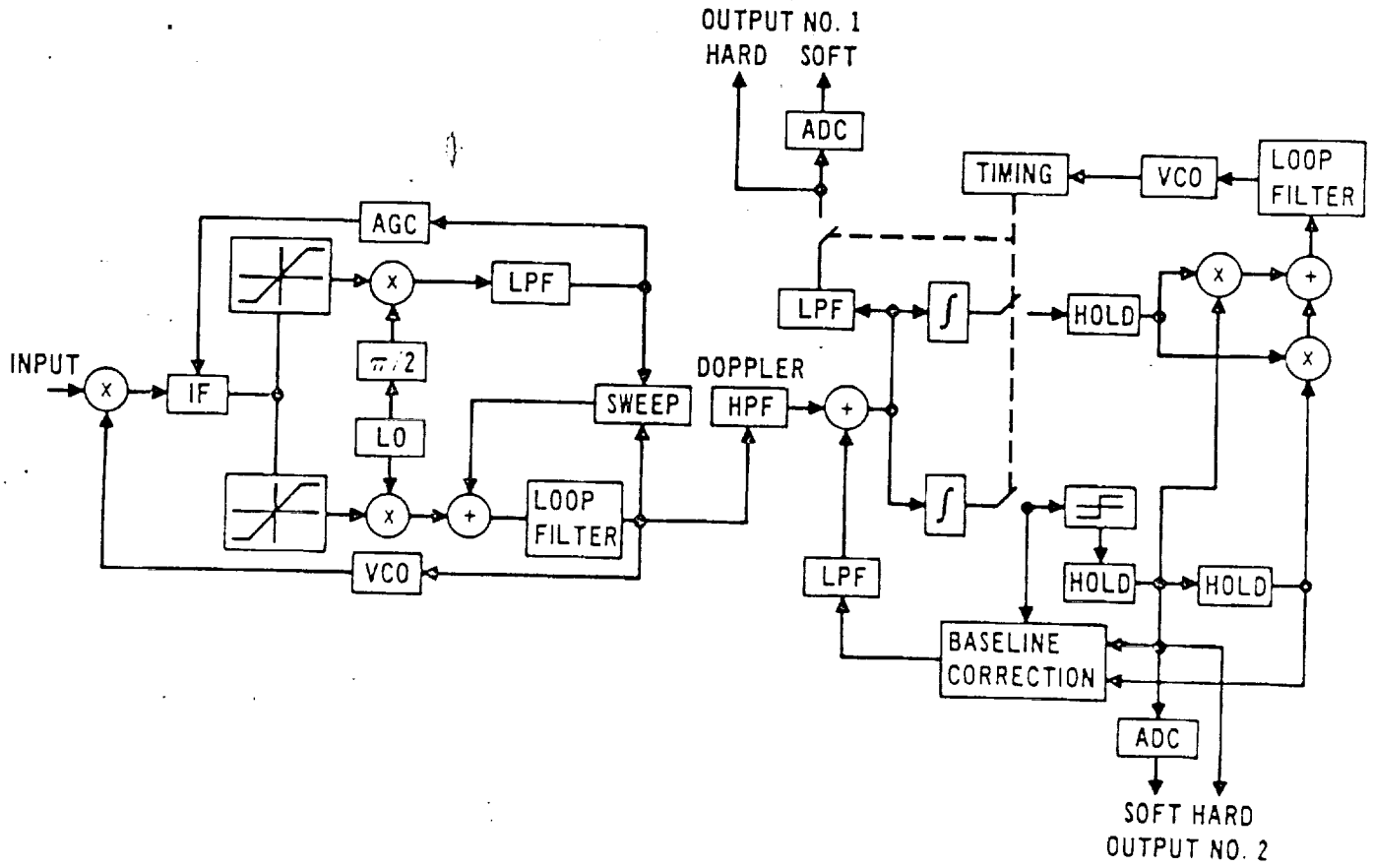


Figure 7-28

The signal feed back from the tracking loop filter indicates when it may have gone beyond the specified sweep or anticipated Doppler range. It will then reverse the sweep direction.

The bit synchronizer, is a relatively straightforward in-phase, quadrature phase, bit synchronizer. It has a baseline correction circuit to correct for "drifts," i.e., long successive strings of either plus ones or minus ones.

Fairly early in the simulation efforts, it appeared that it would be easy in the simulation, since the bulk of the work in a digital simulation is in the receiver (relatively little of the work in terms of computing time takes place in the bit synchronizer) to look at two different type of detectors: a sampled filter detector and the in-phase integrator (as a detector). For both of these detectors, we look at both a hard decision; (that is either a plus or minus one) or soft decision (the relative level of confidence of a level). This is the candidate design that we have investigated.

This chart (Figure 7-29) represents an abbreviated computer flow diagram. We actually generated two routines, one for the error rate and one for the acquisition. Unfortunately, we never got a set of curves of the acquisition probabilities as every time we tried to acquire, we did. Perhaps if we go lower in E/No (we only went down to 7 db) we could start to define the curve. Above 7 db, the receiver acquired every time.

Basically, in the computer flow after initializing the problem, we may or may not step the scintillation. We are taking approximately 40 samples per bit in the simulation. Because the scintillations are only two Hertz and 2/10ths of a Hertz compared to 88 symbols per second, it was not necessary to step the scintillation lines every time that we stepped a sample for a bit. Thus we saved some time here. The simulation data is a 63 bit PN sequence.

ERROR ROUTINE FLOW CHART

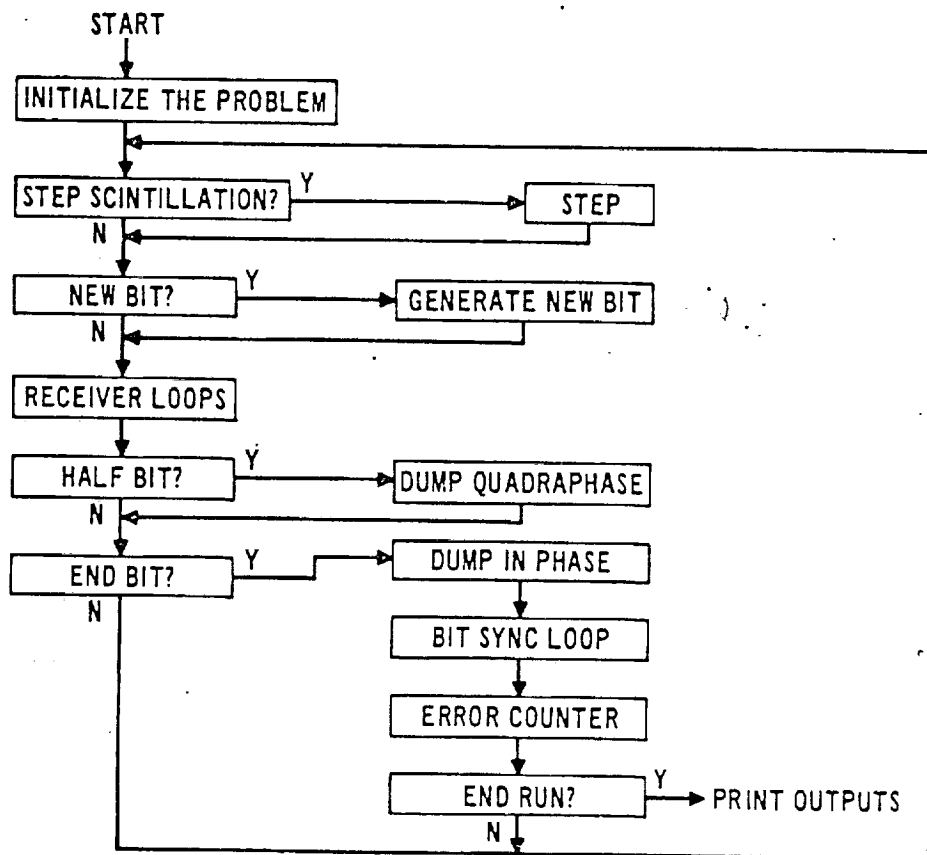


Figure 7-29

One of the interesting things in the simulation was that we simulated to the lowest feasible component in the receiver. Each filter in the receiver, the band-pass filters, the tracking filters, were individual Z transforms, the gain constant of the VCO's were independently variable; each multiplier occurred (the front end of the receiver) as a complex amplitude multiplication.

We ran some interesting parametrics, Figure 7-30. We looked at varying the modulation index and, the old 7/10ths modulation index still holds good. The initial design was for a 1,000 Hertz IF. It looks like slightly larger IF's might be more advantageous. In the future we will be looking at 1,500 or 2,000 Hertz. The IF has to be wide enough so that there won't be any phase distortion in the receiver; but if it is very wide, it is not necessary. One curious thing that we discovered was that the dynamic range of the automatic gain control could be increased somewhat. By this, the AGC tries to keep the voltage level to the AFC loop constant. What one normally does in a design is when the signal hits the threshold, the gain stops. If the gain were a bit greater, the performance improves.

Finally, looking at the two different types of detectors, in all of the runs that we made, the integrator detector - that is, the in-phase integrator in the bit synchronizer, outperformed the sample filter detector. It appears that the integrator detector is the best design.

One of the things that we always like to look at is error rate. The No scintillation and scintillation data shown here are compared to the original specification which was an FSC BT=2 receiver. The candidate design is performing well within that bound.

In conclusion (Figure 7-31), in terms of the mean error rate, this is an acceptable design. However, when considering convolution

PARAMETRICS

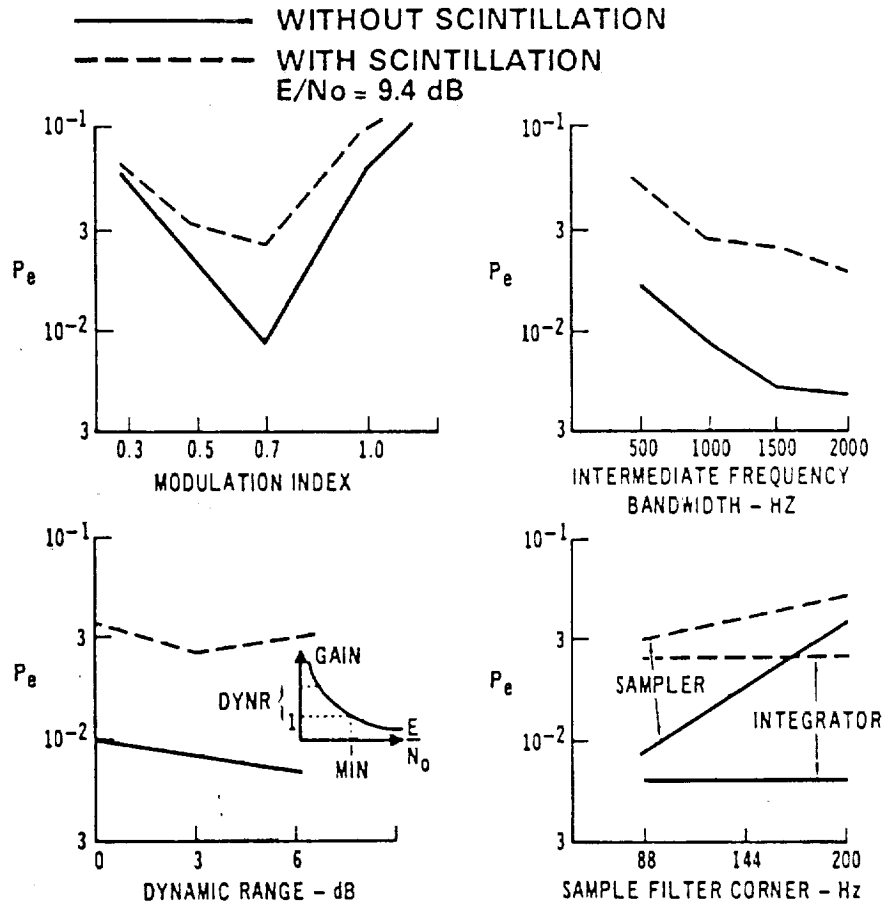
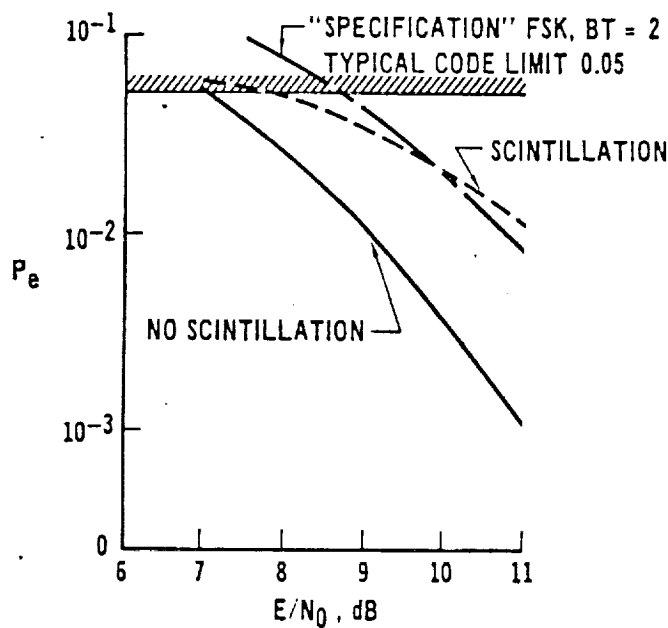


Figure 7-30

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CONCLUSIONS



CONCLUSIONS -

- CANDIDATE ACCEPTABLE FROM THE MEAN ERROR RATE VIEWPOINT
- COMPLETE VERIFICATION AWAITS ARC CODING ANALYSIS

RECOMMENDATIONS -

- INTERMEDIATE FREQUENCY BANDWIDTH ≈ 1500 Hz
- AUTOMATIC GAIN CONTROL DYNAMIC RANGE ≈ 3 dB BELOW " MINIMUM SIGNAL"
- USAGE OF INTEGRATION RATHER THAN SAMPLING FILTER DETECTOR
- FURTHER EXPLORATION OF SCINTILLATION MODEL EFFECTS

Figure 7-31

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codes, the mean error rate is only one of the criteria. The code is sensitive to not only the distribution of errors but the actual pattern of the errors. At the conclusion of this study, we cut magnetic tapes for ARC to analyze for different coding algorithms. The tape records the different detector performance via soft decisions.

We recommend an IF frequency a little bit greater than 1,000 Hertz; an AGC something below the usual definable minimum signal, and integration detector rather than a sample filter detector, and now that we have the tools available to us, investigate a variety of scintillation models.

Thank you.

MR. GRANT: Our next speaker is Dr. James Modestino, Associate Professor in the Systems Engineering Division at Rensselaer Polytechnic Institute. Dr. Modestino will report on convolutional code performance in fading channels.