Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	)	
	)	
Amendment of the Commission's Rules to Establish New Personal Communications Services	)	**GEN Docket No. 90-314**
	)	**ET Docket No. 92-100**
	)	
	)	**RM-7140, RM-7617,**
	)	**RM-7618, RM 7782,**
	)	**RM-7860, RM-7978,**
	)	**RM-7979, RM-7980**
	)	
	)	**PP-35 through PP-40, PP-79**
	)	**through PP-85**
	)	
To: The Commission	)	

ORIGINAL FILE

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COMMENTS OF
PULSON COMMUNICATIONS CORPORATION

William S. Moorhead, President

PULSON COMMUNICATIONS CORPORATION
8280 Greensboro Drive
Suite 500
McLean, VA 22102-3807
703/848-4132

A. Thomas Carroccio

SANTARELLI, SMITH & CARROCCIO
Ninth Floor
1155 Connecticut Avenue, N.W.
Washington, D.C. 20036
202/466-6800

Attorneys for
PULSON COMMUNICATIONS CORPORATION

November 9, 1992

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COMMENTS OF PULSON COMMUNICATIONS CORPORATION

Pulson Communications Corporation ("Pulson"), by its attorneys, hereby submits its comments regarding the Notice of Proposed Rule Making and Tentative Decision, FCC 92-333, released August 14, 1992 ("NPRM"). For its comments, Pulson states as follows:

1. The NPRM sets forth proposals for the establishment and regulation of new Personal Communications Services ("PCS"). Pulson concurs in the Commission's determination of a need for PCS and urges the adoption of the rules proposed by the NPRM, with certain modifications and clarifications set forth below.

Need for Technical Flexibility

2. The rules proposed by the NPRM make no specific provision for the use of ultra-wideband ("UWB") technologies in PCS. Pulson

respectfully suggests that the report and order establishing PCS should specifically allow UWB technology to be utilized in the design and implementation of PCS systems. Pulson further suggests that UWB systems be allowed to operate utilizing "center frequencies" within the PCS spectrum allocations.

3. Throughout the Commission's consideration of PCS, Pulson has been working on the commercial development of the Impulse Radio technology for which it holds the exclusive licenses for civilian applications. Impulse Radio is a UWB technology designed to provide true spectrum reuse without interference to co-channel users.

4. Recent studies by consultants retained by Pulson indicate that Impulse Radio is capable of operation without interference (i) to conventional co-channel users; (ii) from conventional co-channel users; or (iii) between multiple users of Impulse Radio. (Analysis by Barrett Science & Engineering, Inc., Exhibit "A" hereto.) Studies also indicate Impulse Radio's capability for spectrum reuse without co-channel interference is enhanced through the use of existing orthogonal codes. (Statement of Dr. Robert A. Scholtz, Exhibit "B" hereto.)

5. Pulson-sponsored studies also have demonstrated that Impulse Radio technology is feasible, even in an in-building environment. An Impulse Radio transmission remains fully usable, even after distortion resulting from passage through and around various architectural obstacles. Conventional radio receivers are unable to process the individual impulses transmitted in an Impulse

Radio system, because such impulses are of too short duration for conventional receivers to detect. To conventional receivers, Impulse Radio signals remain buried in the ambient noise level. By contrast, Impulse Radio receivers are able to correlate sequences of such impulses, even when the impulses are distorted by propagation effects. The resulting "coherent integration" of pulse sequences allows the efficacious reception of Impulse Radio transmissions only by the Impulse Radio receivers for which they are intended. (Report of Raines Engineering, Exhibit "C" hereto.)

6. Pulson's developmental activities clearly indicate that UWB technologies and frequency-based technologies have the capacity to share spectrum without any interference between or among them. Accordingly, the PCS rules promulgated by the Commission should allow UWB-based systems to utilize frequencies within allocated PCS spectrum blocks as their "center frequencies". Such provisions would afford PCS providers maximum flexibility to utilize the most efficient technology, including UWB technology, in the development and operation of their PCS systems. The technical integrity of PCS would continue to be protected through equipment type-acceptance procedures and through the enforcement of appropriate interference standards.

Number of Providers - Reservation of Block

7. The NPRM indicates the Commission will allocate three 30 MHz blocks of spectrum per geographic area for licensed services.[1/]

[1/] NPRM at para. 38.

The NPRM also addresses the possibility that the Commission will allocate "four or five PCS licenses per area."[2] Whatever number of providers the Commission ultimately decides to be appropriate, Pulson recommends that one allocated spectrum block for licensed services be reserved in each geographical area for utilization by an innovative technology.

8. The Commission recognizes that "many PCS concepts are still being developed and that many PCS technologies are at their inception."[3] In its recent Tentative Decision in GEN Docket No. 90-314,[4] the Commission tentatively denied several requests for pioneer's preferences in PCS. The pioneer's preference requests of twelve requesters, including Pulson, were tentatively denied because they had not yet either demonstrated the feasibility of their technologies, or brought them to a more advanced and effective state.[5] In addition, it must be anticipated that other technologies particularly suitable for PCS may be in early stages of experimentation or development. It would be foolhardy for the Commission to effectively foreclose the use of more efficient PCS

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[2] NPRM at para. 37.

[3] NPRM at para. 105.

[4] Tentative Decision and Memorandum Opinion and Order, FCC 92-467, released November 6, 1992 ("Tentative Decision").

[5] Tentative Decision, para. 25.

technologies through the early commitment of all allocated spectrum blocks to existing technology.[6]

9. One allocated spectrum block for licensed services in each geographic area should be reserved for an initial period of at least five years, plus a secondary period of an additional five years.[7] During the initial reserve period, an application for the use of a reserved spectrum block should be accepted only from an entity which has developed an innovative technology to the point it is capable of providing PCS service in a timely fashion.[8] That entity should be allowed to apply for the reserved spectrum block in only one geographical area.[9] In order to discourage applications based upon inadequately developed technologies, an entity should be precluded from filing repetitious applications in the event its initial application for a reserved spectrum block is denied.

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[6] It is unreasonable to anticipate that a PCS provider will abandon its recent investment in current technology in order to utilize the more efficient technologies which promise to become fully developed before the turn of the century.

[7] Pulson suggests that the reserve period for all geographical areas run concurrently, beginning from the date on which the nation's first PCS system actually initiates service to the public.

[8] Such technologies may include, but should not be limited to, the technologies for which pioneer's preferences were requested in GEN Docket No. 90-314.

[9] In the unlikely event that two applications are simultaneously filed for the same geographical area, the competing applicants should be afforded a reasonable opportunity to negotiate a withdrawal of one application without prejudice, or some other resolution consistent with the public interest.

10. If the reserved spectrum block in any geographical area is not the subject of a pending new-technology-based application at the time the initial reserve period expires, that spectrum block would be available during the secondary reserve period only if an applicant demonstrates the existence of either of the two following criteria: (a) the development of an innovative technology as described above; or (b) upon a showing of an actual need for additional PCS capacity in that geographical area. If no supported application for the reserved spectrum block in a geographical area is not pending at the time the secondary reserve period expires, the spectrum block would become generally available for application.

11. Pulson submits that a technology reserve such as proposed above would provide substantial incentive for continued development of technologies applicable to PCS, and thereby increase the likelihood that the public will receive the benefit of maximum technological enhancement of PCS.

CONCLUSION

In light of the foregoing, Pulson respectfully submits that the Commission, in its report and order establishing PCS, should make it clear that it is not foreclosing the utilization of ultra-wideband technologies within the spectrum blocks allocated for PCS. In addition, the Commission should encourage continuing development of technologies applicable to PCS by reserving at least one allocated spectrum block in each geographical area for award to an applicant which demonstrates it has significantly advanced PCS technology.

Respectfully submitted,

PULSON COMMUNICATIONS CORPORATION

By: _____
William S. Moorhead, President

PULSON COMMUNICATIONS
CORPORATION
8280 Greensboro Drive
Suite 500
McLean, VA 22102-3807
703/848-4132

By: _____
A. Thomas Carroccio
Edward J. Smith, Jr.

SANTARELLI, SMITH & CARROCCIO
1155 Connecticut Avenue, N.W.
Suite 900
Washington, D.C. 20036
202/466-6800

Its Attorneys

November 9, 1992

EXHIBIT A

Barrett Science & Engineering, Inc.

1453 Beulah Road
Vienna, VA 22182
(703) 759-4518

5th November 92

Federal Communications Commission
1919 M Street NW
Washington D.C. 20554

To whom it may concern:

I have been retained by Pulson Communications, Inc., for over one and one half years to assist Pulson in the development of impulse communications technology. I was specifically asked to address the issue of interference with respect to this technology.

Interference can be broadly categorized into three kinds: (i) interference by users of impulse technology to other conventional users of the electromagnetic spectrum; (ii) interference to users of impulse technology by other conventional users of the electromagnetic spectrum; and (iii) interference to a user of impulse technology by other users of impulse technology.

With respect to (i) and (i), analysis has shown minimum to negligible interference. With respect to (iii), the development of orthogonal coding will permit multiuser access to impulse technology with mininum interference.

To support our conclusions concerning interference (i) and (ii), two Appendices are attached. Appendix A contains a detailed analysis of state of the art conventional receivers and emitters and concludes that these receivers cannot respond to the transient nature of the impulse radio signal and that conventional emissions are out of band with respect to impulse radio reception. Appendix B contains a detailed analysis and historical introduction to the philosophy underlying the design of conventional receivers. The analysis explains the technical rationale for the emergence of the conventional design philosophy and again shows that conventional receivers cannot respond to the transient nature of the impulse radio signal. In illustration of this major point, Fig. 1 is shown here. The figure graphically depicts the fast onset and offset of the impulse radio signal and the slow onset of conventional receivers, all of which are set at the nominal average frequency of the impulse signal.

To support our conclusions concerning interference (iii), Appendix C is attached, which contains a detailed analysis of codes which provide minimum cross-interference between users of impulse radio.

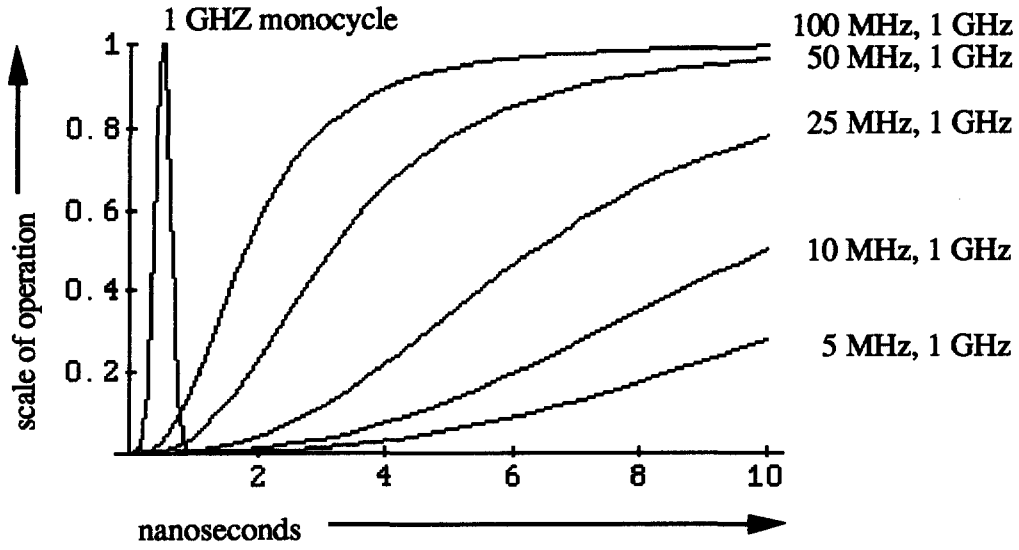

Fig. 1. A representation of the transient onset response of synchronous frequency domain receivers with respect to that of a time domain 1 GHz pulse of 1 nsec. Representative transient responses are shown with the transient onset frequency represented. All receivers shown have a steady state response of 1 GHz. From Appendix B.

The issue of whether a broadband conventional receiver would suffer interference type (i) can also be understood from the perspective offered by Fig. 1. Conventional receivers, whether narrow or broadband, have onset times many orders of magnitude slower than impulse radio signals. Therefore the predicted interference is negligible.

Sincerely yours,

Terence W. Barrett, Ph.D.

Attached: Appendices A-C.

Appendix A.

Abstract: This appendix examines the possibility of interference of impulse communications to conventional receivers. As a model conventional systems, UHF receivers are considered. The conclusion reached is that the slow onset time of conventional reeivrs precludes impulse signal interference.

Although the FCC studies, FCC/OST R-83-1[1] and FCC/OST R-84-1[2], address the possibility of the opening up of UHF bands to more users by using a new receiver design which is less susceptible to interference[3], these studies also provide valuable pointers concerning how interference is engendered and the performance characteristics of TV receivers. The new receiver design uses a surface acoustic wave (SAW) filter resulting in much better selectivity than present commercial filters. Yet, the phase response of this filter is still orders of magnitude slower than that of time domain communications. A major conclusion of the present report is that, on the one hand, *yes*, time domain *individual* signals could interfere with TV receivers in many different ways, but, on the other hand, due to the slow phase response of those receivers, that, *no*, that interference from *individual* signals is unlikely to be of any noticeable magnitude. The obtaining of a synchronous TV receiver with a phase response which would permit 1 nsec. pulse interference would require state-of-the-art filters and be very, very expensive. The following analysis applies to single pulse interference.

This analysis tabulates the ways in which time domain communications pulse effects *could* interfere with TV receivers, such interference being ultimately denied by the poor phase response of such receivers, i.e., the real interference engendered is severely attenuated.

The major innovation provided by the new FCC-required receiver design is the elimination of receiver intermediate frequency interference. The first receiver design contract for interference rejection was designed by Texas Instruments Inc. (TI) and implemented a new IF amplifier and which would have permitted the relaxation of UHF allocation taboos[4]. The TI receiver achieved improved performance by replacing the tuner and IF of a conventional TV receiver with (i) a high dynamic range, wideband, silicon MESFET mixer and (ii) UHF, low-loss, surface acoustic wave (SAW) IF bandpass filters. These high dynamic range, wideband devices, permit the use of wider front-end filters. This means that even the entire low VHF TV band (channels 2-6) passes through the RF amplifier and mixer simultaneously, but interfering signals are rejected by the SAW IF filter directly following the mixer and without distortion of the desired signal. This eliminates most IF-related effects.

Although the TI receiver was pronounced a success with respect to interference rejection, it was felt that additional improvements in noise figure and internally generated spurious products were desirable. So the FCC let another contract for a receiver addressing those issues which was awarded to RF Monolithics (RFM). Essentially, the receiver is a

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[1]H. Davis Advanced Technology UHF Receiver Study Part 1, Receiver Performance Measurements, OST Report FCC/OST R-83-1, February 1983.

[2]G.S. Kalagian, R.P. Eckert and W.D. Daniel, Advanced Technology UHF Receiver Study Part 2. Effect on the UHF Television Allotments, OST Report FCC/OST R-84-1, March, 1984.

[3]Using the new receiver design, 43 TV channels could be added to the top 10 U.S. cities.

[4]D.L. Ash, C.S. Hartman, High performance TV receiver, Texas Instruments Inc., FCC/OCE CE 78-01, March 1978.

consumer-type receiver (Magnavox Model RK4245) modified by RFM[5]. The improvements made by RFM which make this receiver superior to present production models are:
(1) Whereas conventional receivers use an IF band of 41-47 MHz, the RFM receiver employs (i) a first IF band of 444-450 MHz and (ii) a second IF band of 41-47 MHz for low cost IF gain and pseudo-synchronous demodulator circuitry. The first IF band is achieved with surface acoustic wave (SAW) filter technology and results in rejection of UHF taboo channels with low loss.
(2) Gallium arsenide varactor filters.
(3) A high performance double-balanced RF mixer.

The RFM receiver also uses the following protection from interference:
(1) tuner selectivity.
(2) radar frequency trap (UHF channels).
(3) shielding of the first IF circuitry.

This RFM receiver exhibited interference immunity better than 90% of the receivers tested by the FCC for the following taboos[6]:

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[5]L.A. Ash, An improved high-performance TV receiver, Proc. IEEE, 70, 1345, 1982.
[6]The measurement data on the RFM receiver design indicate that taboos related to the IF of conventional television receivers can be eliminated. These taboos are: the oscillator radiation (which ordinarily precludes assignment of channels n+7 and n-7 within 60 miles of a station assigned UHF channel n); the IF beat (n+8, n-8 within 20 miles); the sound image (n+14, n-14 within 60 miles), and the picture image (n+15, n-15 within 75 miles). Here "n" denotes the channel of interest amd "n+x", n-x" denote the associated taboo channels.
Separation distances are also set by the FCC - the socalled "UHF Taboos". They are:
(i) Co-channel interference: when any channel is assigned to a given city, that same channel cannot be reused within a prescribed cochannel separation distance.
(ii) Adjacent channel taboo (n±1): 55 miles based upon a ratio of desired to undesired signal required to produce an acceptable picture. This ratio was initially -6 dB, sometimes set at 0 dB, and dependent on receiver design.
(iii) Oscillation radiation taboo (n±7): conventional TV receiver local oscillator frequencies are always seven channels above the channel to which the receiver is tuned. This arrangement is necessary so that the oscillator frequency and the tuned channel frequency will beat together to produce the receiver's intermediate frequency.
(iv) Image frequency taboos (n±14 and n±15): the picture carrier of the 15th channel above the desired channel can produce an undesirable image frequency response. The sound carrier of the 14th channel above the desired channel can similarly cause interference. There is a 60 mile separation for the 14 channel and a 75 mile separation for the 15 channel taboo. For the 15 channel taboo, the image of the undesired visual carrier falls 1.5 MHz away from the desired visual carrier in the IF channel. For the 14 channel taboo, the image of the undesired sound carrier falls 3.0 MHz away from the desired visual carrier in the IF channel.
(v) IF Beat (n±8) taboo: the beat between an upper channel picture and the lower channel sound carrier can ride through into the IF amplifier. An FCC separation of 60 miles is required.
(vi) Third Order Modulation (n±2, n±3, n±4, n±5) taboos: this is due to nonlinearity in the receive and addresses twice the frequency of one station minus the frequency of the other. For stations less than six channels apart, FCC protects against intermodulation interference by requiring 20 miles of separation.

UHF TV Adjacent Channel
Conventional Receiver UHF Picture Image
Conventional Receiver UHF Sound Image
UHF TV Cross Modulation: n, n-2
UHF TV Cross Modulation: n, n+4
UHF TV Intermodulation: n, n+2, n+4
UHF TV Intermodulation: n, n-2, n-4

This RFM receiver also performed generally better than known existing receiver performance for the following taboos:

UHF TV Cross Modulation: n, n+2
UHF TV Cross Modulation: n, n-4
Conventional Receiver UHF IF Beat: n, n-8
Conventional Receiver UHF IF Beat: n, n+7
Conventional Recever UHF IF Beat: n, n-7

The following tests were conducted on the receiver:

(1) Interference tests for UHF taboo and adjacent channels.
(2) Noise figure measurements.
(3) Determination of the UHF signal level for TASO[7]-passable picture noise.
(4) Interference from Citizens Band and FM broadcasts.
(5) Interference from government radars operating within the first IF band.

0 dBm[8] is maximum undesired level.

The method of testing was as follows. The level of the desired signal on channel was set and then the interfering signal on another channel was raised until the observer reported just perceptible interference (Table I).

The RFM uses a much higher IF than conventional receivers, so for this receiver, the conventional taboos are eliminated: oscillator (n±7), IF beat (n±8), sound image (n±14), and picture image (n±15).

[7]Television Allocations Study Organization.

[8]dBm - decibels referred to one milliwatt.

Table I[9]

Tested "Taboo" Channel Combination	Level Ch. "n"	Undesired Channel Levels for "Just Perceptible" Interference	
		FCC (RFM)	Control
Adj. Ch. : n =34, n+1 = 35	-65 dBm	-22 dBm	
	-55[10]	-17	-38 dBm
	-45	-10	
	-35	- 4	-29
	-25	>0	
	-15	>0	-10
	- 5	>0	

The high selectivity and interference immunity is largely provided by the SAW filter. It is instructive, therefore, to analyze the functioning of this device. The SAW or acousto-optic (A-O) technologies provides the combined benefits of: (1) increased performance through instantaneous environment channelization in both the frequency and direction-of-arrival (DOA) domains, and (2) cost reduction through the use of hybrid, and eventually, monolithic integrated optics (I-O) implementation techniques.

Current A-O system concepts are based on narrow band channelization for high sensitivity, dense environment applications or wideband signal intercept for lower sensitivity systems operating in less dense environments. In addition, separate DOA and intercept receivers are employed where azimuthal signal data is required.

The SAW device functions as follows:

• Electrical signals are converted to longitudinal acoustic waves which propagate by alternatively compressing and expanding material in the interaction medium. The resultant refractivity modulation forms a diffraction grating which, when illuminated at a precise angle, (the Bragg angle), from the normal to the direction of acoustic propagation, deflects optical energy to an angle proportional to the acoustic frequency.

•The lateral acoustic column beamwidth is determined by the acoustic transducer aperture. Since the light source has a narrow beamwidth, the range of angles and corresponding electrical signal frequencies over which the conditions for Bragg angle deflection are met is determined solely by the acoustic beamwidth. However, a wider acoustic beamwidth results in decreased efficiency because the percentage of acoustic power at the precise angle for Bragg interaction is total beamwidth angle dependent.

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[9]H. Davis Advanced Technology UHF Receiver Study Part 1, Receiver Performance Measurements, OST Report FCC/OST R-83-1, February 1983, page 6.

[10]As an example: the level of the signal on the desired channel, n=34, was set at -55 dBm, and the level of the signal on the interfering channel, n+1 = 35, had to be set at -17 dBm for interference to be judged such on the RFM-modified Magnavox receiver and only at -38 dBm on the unmodified Magnavox receiver - indicating the effectiveness of the modifications.

•The laser source is expanded and collimated to achieve beam dimensions required for sufficient interaction time. The beam is apodized using a spatial filter to prevent scattered and defocused light from proceeding further into the system, which would limit the dynamic range. The laser light is deflected at twice the Bragg angle defined:

$\alpha = \sin^{-1} (\lambda/2L)$,

where α = Bragg angle (1/2 deflection angle); λ = light wave length; L = acoustic wave length.

•There is a beam steering diffraction tradeoff. The slope of the power flow angle determines the extent of both diffraction and beam steering. Losses occur with both diffraction and beam steering. Diffraction is a physical consequence of wave propagation and a fixed phenomenon for a given material. Beam steering occurs when transducers are misaligned from a pure mode axis. Any losses occuring, therefore, are due to both diffraction and beam steering.

•The state-of-the-art is in reflective array compressive filter (RAC) SAW devices. The RAC may be realized on either quartz or lithium niobate substrate with elementary transducers and obtains dispersion with two long oblique acoustic reflector arrays which are frequency selective due to their nonuniform period. The reflector arrays can be either deposited metal or ion milled grooves. Additionally, the RCA allows an "a posteriori" correction of phase errors by insertion of a metallic film between the arrays. SAW specifications are as follows:

Center Frequency: Minimum center frequency is 10 MHz, maximum center frequency is 1.3 GHz. Center frequencies below 300 MHz are considered highly reproducible.

Bandwidths: System bandwidths up to 500 MHz are available. (This requires a 1 GHz wide multiple RAC module.)

Resolution: Time dispersions up to 100 μsec permit a resolution of 10 kHz.

Sidelobe Suppression: Taylor weighting allows sidelobe suppression of better than 45 db. Sidelobe levels of 30 db and below are considered highly reproducible.

Dynamic Range: An 80 db dynamic range has been demonstrated. A 60 db dynamic range offers excellent performance/cost trade-offs.

Size, Weight, Power: A typical Sliding Transform Analyzer is housed in a 4.5x4.5x0.5 inch connectorized package. Total consumed power is 7 watts.

Trade-Offs are:

Time-Bandwidth Product: RACs are limited more to a total Time-Bandwidth product (TxB) than to an absolute limit on B or T. Time-Bandwidths of up to 1600 have been demonstrated using low cost photolithography.

Sidelobe Level versus Resolution: The spread factor associated with weighting causes a 50% decrease in resolution.

Center Frequency versus Manufacturability: As center frequency increases, transducer line widths decrease to sub-micron figures. Thus, the reproducibility of the manufacturing process degrades.

Resolution versus Bandwidth: This trade-off is related to the maximum Time-Bandwidth product. To optimize resolution, the time dispersion T is maximized. Bandwidth, however, is then limited.

Linearity versus Resolution: Delay linearity is determined by manufacturing precision. To achieve maximum time dispersion T, a longer substrate is used with a resulting complexity in manufacturability.

Dynamic Range versus Bandwidth: When bandwidth is maximized, the resulting increase in insertion loss must be compensated by amplifier stages. Thus, the dynamic range is adversely affected.

•Availability: Right now bandwidths of 1.2-1.3 GHz are available in SAW devices. Actually, this range is for 75% bandwidth not 100% which is probably 1 GHz or less. To achieve 2 GHz bandwidth would require changing the processing from a photolithographic process now used to a 1-2 μm resolution ion beam etcher. This is possible in principle, but no manufacturer appears to be doing this right now.

•Alternatives to SAW device to achieve 2 GHz bandwidth: Crystal Technology manufactures 1-2.5 GHz Bragg cell processors (A-O devices). Such devices can be used with a focusing lens configuration. For example, the Model 43000SN has a bandwidth of 2 GHz. The center frequency is 3 GHz and the time aperture is 0.5×10^{-6} sec. A focusing lens configuration could achieve 0.5×10^{-9} sec. compression of the time aperture.

This completes the analysis of the capabilities of the SAW devices which could be used in the IF filter.

Citizens Band (CB) Interference

CB interference can occur due to nonlinearities in the front-end RF amplifiers. High intensity CB signals drive a receiver into a nonlinear region of operation, producing harmonics or multiples of the fundamental CB frequency. In particular, the second harmonic of CB channels can interfere with channel 2. This second harmonic is at 54.81 MHz, which is only 0.44 MHz removed from the visual carrier frequency of the TV channel 2 at 55.25 MHz. The resulting interference is beat patterns. The following Table II shows the reasonable CB interference rejection from Channel 2 reception.

Table II[11]
Citizens Band Signal Levels for Just Perceptible
Interference to Television Signal Levels

TV Channel 2:	-65 dBm	-55 dBm	-52 dBm	-45 dBm	-35 dBm	-25 dBm
CB Channel 40:	-24 dBm	-18 dBm	-12 dBm	- 3 dBm	- 6 dBm	- 4 dBm

[11]H. Davis Advanced Technology UHF Receiver Study Part 1, Receiver Performance Measurements, OST Report FCC/OST R-83-1, February 1983, page 10.

FM Interference

The following Table III gives interference to TV channel 6 (82-88 MHz) from frequencies used by educational FM stations. The frequency modulation was at 75 KHz deviation with a 1 KHz tone.

Table III[12]
FM Signal Levels for Just Perceptible
Interference to TV Channel 6 Signal Levels

TV Channel 6: (82-88 MHz)	-65 dBm	-55 dBm	-45 dBm	-35 dBm
FM Channel 201, 88.1 MHz	-58 dBm	-49 dBm	-39 dBm	-29 dBm
FM Channel 203, 88.5 MHz	-46 dBm	-39 dBm	-30 dBm	-20 dBm
FM Channel 205, 88.9 MHz	-22 dBm	-14 dBm	- 4 dBm	> 0 dBm
FM Channel 209, 89.7 MHz	-24 dBm	-16 dBm	- 8 dBm	> 0 dBm
FM Channel 213, 90.5 MHz	-22 dBm	-14 dBm	- 5 dBm	> 0 dBm

Inland Waterways Communications Service (IWCS) Interference

IWCS is in the band 216-220 MHz which is adjacent to TV channel 13. Table IV shows the interference levels in that channel using the RFM receiver.

Table IV[13]
IWCS Signal Levels for Just Perceptible
Interference to TV Channel 13 Signal Levels

TV Channel 13	-65 dBm	-55 dBm	-45 dBm
216.1 MHz	-51 dBm	-45 dBm	-36 dBm
216.5 MHz	-44 dBm	-38 dBm	-26 dBm
216.9 MHz	-20 dBm	-12 dBm	- 3 dBm
217.7 MHz	-22 dBm	-18 dBm	-11 dBm
218.5 MHz	-18 dBm	-14 dBm	- 6 dBm

RFM IF Image Interference

[12]H. Davis Advanced Technology UHF Receiver Study Part 1, Receiver Performance Measurements, OST Report FCC/OST R-83-1, February 1983, page 10.

[13]H. Davis Advanced Technology UHF Receiver Study Part 1, Receiver Performance Measurements, OST Report FCC/OST R-83-1, February 1983, page 11.

The RFM IF image responses are due to the first IF of the RFM receiver: 444 MHz-450 MHz. Table V indicates the RFM receiver's interference levels on channels 3, 10 and 34.

Table V[14]
RFM IF Image Signal Levels for Just
Perceptible Interference to Television Signal Levels

TV Channel 3:	-65 dBm	-55 dBm	-45 dBm
955.7 MHz	-32 dBm	-33 dBm	-32 dBm
TV Channel 10:	-65 dBm	-55 dBm	-45 dBm
1087.7 MHz	-20 dBm	-17 dBm	-14 dBm
TV Channel 34:	-65 dBm	-55 dBm	-45 dBm
1485.7 MHz	-36 dBm	-32 dBm	-27 dBm

Radar Interference

The first IF band of the RFM receiver, 444-450 Mhz, is within the frequency band of some U.S. Government radar transmitters at 420-450 MHz. Despite tuner selectivity, radar frequency trap (UHF channels) and shielding of the first IF circuitry, the RFM receiver has IF vulnerability. Tests conducted showed that

"pulsed signals in the 420 to 450 Mhz band could be coupled into both conventional and 'high IF' television receivers by pulsed emission spectrum sideband energy occurring inband (cochannel or perhaps dependent on adjacent channel selectivity). Lower UHF channels were vulnerable, e.g., channels 14, 15, 16, etc."[15]

In addition, an IF beat response was also observed in conventional receivers when the difference between a signal frequency in the radar band and a desired TV signal frequency was at the conventional IF. UHF channels 14 and 18 were subject to such interference. Table VI shows the interference rejection levels of the RFM receiver in which a desired TV signal and interference signal are connected directly to the RFM receiver.

[14]H. Davis Advanced Technology UHF Receiver Study Part 1, Receiver Performance Measurements, OST Report FCC/OST R-83-1, February 1983, page 12.

[15]H. Davis Advanced Technology UHF Receiver Study Part 1, Receiver Performance Measurements, OST Report FCC/OST R-83-1, February 1983, page 12.

Table VI[16]
Radar Signal Levels for Just Perceptible
IF Interference to TV Signal Levels - Signals
Directly Connected to the RFM Receiver
(Pulse Center Frequency: 445.6 MHz)

Channel 14	-65 dBm	-55 dBm	-45 dBm
Pulse: 63 µsec, 300 pps	-17 dBm	-10 dBm	>-2 dBm
Channel 17	-65 dBm	-55 dBm	-45 dBm
Pulse: 63 µsec, 300 pps	- 8 dBm	- 2 dBm	>-2 dBm
Channel 18	-65 dBm	-55 dBm	-45 dBm
Pulse 63 µsec, 300 pps	- 5 dBm	>-2 dBm	>-2 dBm
Channel 25	-65 dBm	-55 dBm	-45 dBm
Pulse: 4 msec, 70 pps			
1.0 MHz chirp	- 6 dBm	0 dBm	+ 8 dBm
Channel 3	-65 dBm	-55 dBm	-45 dBm
Pulse: 63 µsec, 300 pps			
1.0 MHz chirp	+10 dBm	>+10 dBm	>+10 dBm
Channels 7, 13			
Pulse: 63 µsec, 300 pps			
1.0 MHz chirp	+10 dBm	+10 dBm	>+10 dBm

Table VII shows the vulnerability of the RFM receiver to radar signals simulated with signal generators. The receiver was most vulnerable with its back to the transmitting antenna.

Table VII[17]
Radiated Radar Signal Levels for Just Perceptible
IF Interference to TV Signal Levels - TV Signal
Directly Connected to the RFM Receiver
Pulse Center Frequency: 445.6 MHz

Channel 14	-65 dBm	-55 dBm	-45 dBm	-35 dBm
Pulse: 63 µsec, 300 pps	0.8 V/m	0.8 V/m	1.0 V/m	0.9 V/m
Pulse: 3 µsec, 300 pps	3.0 V/m	3.0 V/m	3.0 V/m	3.0 V/m
Channe 2	-65 dBm	-55 dBm	-45 dBm	-35 dBm
Pulse: 63 µsec, 300 pps	0.6 V/m	1.0 V/m	1.0 V/m	0.8 V/m
Pulse: 3 µsec, 300 pps	2.0 V/m	3.0 V/m	3.0 V/m	3.0 V/m

[16]H. Davis Advanced Technology UHF Receiver Study Part 1, Receiver Performance Measurements, OST Report FCC/OST R-83-1, February 1983, page 13.

[17]H. Davis Advanced Technology UHF Receiver Study Part 1, Receiver Performance Measurements, OST Report FCC/OST R-83-1, February 1983, page 14.

Oscillator Radiation

Measurements were made at a three-meter site using a half-wave dipole tuned to the oscillator frequency (instead of the antenna). Oscillator radiation measurements were converted to values at 100 feet using a factor of 18 dB (Table VIII). The RFM receiver's oscillator is reasonably protected from interference.

Table VIII[18]
Oscillator Radiation

Channel 4 Local Oscillator: 515.975 MHz
At 100 feet: 3.6 μV/m Horizontal
1.3 μV/m Vertical
Channel 7 Local Oscillator: 623.975 MHz
At 100 feet: 12 μV/m Horizontal
6 μV/m Vertical
Channel 6 Local Oscillator: 991.975 MHz
At 100 feet: 72 μV/m Horizontal
16 μV/m Vertical
Second Local Oscillator: 402.975 MHz
At 100 feet: 23 μV/m Horizontal
10 μV/m Vertical
Second Harmonic of
Second Local Oscillator: 805.95 MHz
At 100 feet: 21 μV/m Horizontal
9 μV/m Vertical

The operational characteristics of the RFM receiver are as follows:

(1) Receiver Selectivity

The receiver's passband were obtained by injecting a visual carrier frequency signal to stabilize the receiver and then injecting another test signal to measure the passband. It is not clear, therefore, what the receiver's passband characteristics are without that stabilization. The suspicion is that a 1 nsec. signal would not find the receiver stabilized.

(2) Phase Response

The phase characteristics of the SAW filter were measured and a 100 nsec. phase delay was found with some ringing at the end of the test pulse. This is less than the 170 nsec. delay assumed by the FCC is specifying the transmitted envelope delay[19]. Nonetheless, this is 100 times the pulse length (1 nsec.) of a time domain pulsed system. The likelihood is that such pulses are severely attenuated by the SAW filter.

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[18]H. Davis Advanced Technology UHF Receiver Study Part 1, Receiver Performance Measurements, OST Report FCC/OST R-83-1, February 1983, page 15.

[19]Report of the Television Allocations Study Organization (TASO) to the Federal Communications Commission, March, 1959, p. 506, 47 CFR Section 73.687(a).

The phase response is the crucial information for the present purposes. It shows the price paid for the superior frequency rejection characteristics of the SAW filter - 100 nsec. phase delay - a phase delay which is actually considered superior! This means that any signal which is on and off within, e.g., 1 nsec., would be very severely attenuated by such a filter. Due to this 10 MHz phase response, the conclusion here is that any receiver of this design which provides frequency selectivity and immunity from frequency interference, is also providing interference immunity from *individual* pulsed signals.

Appendix B.

Abstract: This appendix addresses time domain communications interference with frequency domain and interference from frequency domain communications with time domain. As a means to examining this interference, the historical origins of the design philosophy of conventional receivers are examined. Due to the restrictions of this design philosophy, particularly the onset response, the prediction is made that impulse signal interference to conventional reception is negligible.

If one takes an historical perspective, then, in the words of Yogi Berra, it is a case of "déjà vu, all over again", because in the early days - the 1890's - the transmitters were spark gaps, the signal was ultrawideband, and evidently the receiver was not resonant. Unfortunately, Tucker[20] reports that with multiple use of radio telegraphy, neighboring transmitters interfered. This interference was obviated by a system of "syntony" or tuning. That is, even although time domain signals were still used, transmitter and receiver were tuned in a frequency domain fashion. (This was before the appreciation of correlation techniques, which could have offered an alternative). The tuning was provided by adjustable inductors.

Next, even the transmitters become more "frequency domain"-like with the replacement of spark-generators by high-frequency alternators. This replacement introduced the era of *coherent transmissions*. Coherent transmissions themselves permitted the use of the heterodyne receiver invented by Fessenden in 1902.

Simply stated, the heterodyne principle permits a "beat signal" to be created by combining the received signal with a local, low-power RF alternator which is also of lower frequency than the signal. The alternator thus provided the ubiquitous *local oscillator* of conventional receiver design. The use of a local oscillator frequency downconversion permitted: (1) an increase in sensitivity because different coils were used for the entering signal and the local oscillator, and the detection was on the basis of the force *between* the coils; and (2) a further increase in sensitivity due to receiver performance at the lower frequencies and also to the frequency discrimination of the human ear.

The introduction of the thermionic triode (U.S.) or tube (U.K.) in its triode arrangement permitted major advances in reception. Placing a negative continuous bias voltage on the grid (*negative grid bias*), and no capacitative coupling to the external circuit, permitted the triode to be used as a linear amplifier between the extremes of positive grid current and negative cutoff. Furthermore, a large negative bias permitted the triode to be both a detector and amplifier.

The "frequency domain" nature of the receiver designs of this time is apparent in the inductive coupling of cascades of triodes. The general approach is known as *tuned radio frequency reception* or TRF. In essence, the couplings were frequency tuned. Multistage receivers involved the "ganging" of triodes with tuning capacitors. The accent on frequency tuning in many-staged amplification resulted in problems such as self-oscillation. Much activity went into obtaining reliable TRF with a single control.

The implementation of *positive feedback* was also crucial in vacuum tube receiver development. Positive feedback was first applied to generate RF waves. This resulted in a transmitter amplifier of high (frequency) selectivity as well as generating high frequency oscillations. The advantages of high amplification came about mainly because the frequency

[20] Tucker, D.G., Origins and types of radio receivers, pp. 1-20, in W. Gosling (ed) *Radio Receivers*, Peter Peregrinus, London, 1986.

selectivity and transmitter design were fully committed to the frequency domain approach. The use of positive feedback also permitted a very frequency-sensitive receiver. This type of receiver design was called the *feedback, or reaction, or regenerative, receiver.*

Important later designs were the *autodyne and the homodyne receivers*. The autodyne self-generated local oscillations. It was superceded by the homodyne receiver which produced a self-oscillation which synchronized to, or locked-on to, a transmitted wave. It is important to note that this relatively modern homodyne receiver is a frequency-domain receiver. However, the term, homodyne, is also also applicable to a time-domain receiver correlator, and should be. This cavalier approach to semantic definitions causes to this day much confusion. The IEEE definition is not to be trusted in this regard, as, in my opinion, they use the frequency domain corrupted definition.

The next major development was based on the exploitation of the extremely high gain in a feedback circuit at the point of oscillation. The receiver is kept at that point of oscillation by a circuit which alters the parameters of the main circuit when an oscillation builds up. This advance was called the *super regenerative receiver.*

The final major development we consider was motivated by a desire to (i) reduce the bandwidth of the receiver which increased with frequency; (ii) extend receivers to the high frequency (microwave) region; and (iii) improve selectivity at low frequencies. In order to reach these goals, high frequencies had to be downshifted by heterodyning to a supersonic beat frequency. This was achieved by the local oscillator method and the resulting difference frequency amplified by a fixed frequency amplifier called the *intermediate frequency* (IF) *amplifier*[21]. This overall design is called the *superheterodyne receiver*. The development of this receiver addresses the problems of proportioning the inductance of the oscillator circuit with capacitance coupling and also the tuned circuit of the oscillator. The receiver paradigm was, and still is, that of frequency selectivity. The superheterodyne receiver was an abandonment of feedback for multiple tube (now transistor) frequency downscaling for amplification. One should note that frequency selectivity remained common to all developments. Also common is that of a problem which arises when the frequencies of subcomponents are interactive and modulating. The problem is that of *sideband generation*. The handling, and exploitation, of sidebands is a complex and involved subject. The major point is that all of the sidelobe literature and technology is a biproduct of the frequency domain emphasis and approach.

The modern superheterodyne receiver consists of four basic building blocks: (i) RF amplifier, (ii) IF amplifier, (iii) demodulator/audio amplifier, and (iv) signal translation oscillator.

Some of the more important frequency components which arise from the mixing process are[22]:

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[21]According to den Brinker and Barrs (den Brinker, C.S. & Barrs, R.A. IF amplifiers, pp. 126-152 in W. Gosling (ed) *Radio Receivers*, Peter Peregrinus, London, 1986) the name, intermediate frequency (IF) amplifier is a misnomer. They favor the more appropriate term: "fixed center frequency, programmable active filter". The adjective, "intermediate", originally indicated that the center frequency of the amplifier was intermediate between the frequency at the receive antenna and the final human audio frequency.

[22]den Brinker, C.S. & Barrs, R.A. IF amplifiers, pp. 126-152 in W. Gosling (ed) *Radio Receivers*, Peter Peregrinus, London, 1986.

f_0
f_s
$f_0 \pm f_s$
$2f_0 \pm$, $f_0 \pm 2f_s$
$3f_0 \pm$, $f_0 \pm 3f_s$
$4f_0 \pm$ etc.

The $\pm$ notation refers to sideband pairs around the center frequency f_0. Let the two be labeled by the notation '1' and '2', then

$f_{s1} - f_0 = IF$
$f_{s2} - f_0 = -IF$,

so

$f_{s1} - f_{s2} = 2IF$.

The major consequences of the IF design approach are: (i) programmable gain which remains constant irrespective of the particular frequency of the received signal; (ii) a secondary selectivity due to the shape factor; and (iii) demodulation at a single frequency permitting coherent detection.

To prevent IF "breakthrough" by unwanted signals at the IF frequency, the input to a receiver is isolated from the IF amplifier, or filter, by 70-100 db. Therefore the front-end of the receiver, i.e., the RF amplification stage, is filtered through LC circuits or notched filters. The general rule follows that IF frequencies are chosen to be neither at, nor close to, the band of frequencies at the preceding mixer stage. In communications systems, IF frequencies are avoided which coincide with transmission frequencies of other locally used transmitters. Thus the question can be asked: if a time domain signal can create IF breakthrough, is it of sufficient amplitude to create interference? We return to the question below.

The level of signals to be mixed range over 120 db. Now time domain signals, being broadband, will approach the selective frequency of the IF amplifier. To take an example[23], suppose a wanted signal of 19.001 MHz is to be differentiated from a 100 db larger unwanted signal at 19 MHz. Then the mixer balance required must be 40 db and a linearity in the RF amplifier and mixer stages is also required - to avoid the production of harmonics - of about 60 db. These levels are rarely obtained, and so there is always the possibility of interference. The example is, of course, only plausible for time domain signals with respect to a receiver set near the average frequency of the pulse used, e.g., 1.001 GHz, for a pulse of average frequency 1 GHz. Only then might the pulse amplitude be 100 db above the wanted signal. As the FCC is likely to award a frequency allocation for time domain signals, this situation is unlikely to occur (except in the case of the Radio Astronomy bands).

Intermodulation products can cause interference due to unwanted signals at the mixer. This is a form of interference which might be investigated for time domain signals. Although each time domain signal might be of too low an amplitude, in itself, to cause

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[23]den Brinker, C.S. & Barrs, R.A. IF amplifiers, pp. 126-152 in W. Gosling (ed) *Radio Receivers*, Peter Peregrinus, London, 1986.